Lead Pollution and Poisoning Crisis

Environmental Emergency Response Mission

Zamfara State, Nigeria

September/October 2010

UNEP

JOINT
UNEP/OCHA
ENVIRONMENT UNIT

Mobilizing and coordinating
the international response to
environmental emergencies

OCHA

Published in Switzerland in June 2010 by the Joint UNEP/OCHA Environment Unit.

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Cover photo: Gathering sediment sample from drinking water well in a village of Anka Local Government Area, Zamfara State, northern Nigeria (credit Joint UNEP/OCHA Environment Unit).

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Executive summary

In March 2010, an unusually high number of deaths, primarily among children under age five in Bukkuyum and Anka Local Government Areas (LGAs) of Zamfara State, northern Nigeria, was reported by Médecins Sans Frontières (MSF-Holland) to state health authorities. Further study[1] on blood samples taken by MSF-Holland revealed that the increased mortality was the result of acute lead poisoning, determined to be caused by massive environmental contamination from artisanal mining and processing of gold found in lead-rich ore. The grinding of the ore into fine particles resulted in extensive dispersal of lead dust in the villages concerned, including within family compounds. Ingestion and inhalation of the fine lead particles was determined to be the major reason for high blood lead levels (BLLs) in victims' bodies.[2] BLLs were "unprecedented" for human beings, according to the US Centers for Disease Control and Prevention (CDC).

From 20 September through 7 October 2010, the United Nations Environment Programme (UNEP) and the Office for the Coordination of Humanitarian Affairs (OCHA), through the Joint Environment Unit (JEU), led a sampling and analysis mission to investigate the lead pollution emergency in Zamfara State, following requests for assistance from the Federal Ministry of Health of Nigeria (FMOH) and the United Nations Resident Coordinator (UN RC). Specifically, the mission focused on determining quantities of lead in ground and surface water, building on investigations already conducted by the CDC, the World Health Organization (WHO), and the National Water Resources Institute of Nigeria (NWRI), and a team from TerraGraphics Environmental Engineering/The Blacksmith Institute, as it was determined that there was insufficient information in these domains. The mission also took the opportunity to look at lead levels in soil and mercury levels in air.

Field work focused on five villages in Anka LGA, two of which had been confirmed as lead-contaminated (Abare and Sunke); two of which were newly suspected of contamination (Kirsa and Bagega); and one of which had been remediated (Dareta).

Findings

Water: The mission found that drinking water from wells did not meet WHO and Nigerian standards (10 micrograms per litre (µg/l)) for lead limits – in at least one case, exceeding this by more than tenfold. Water in ponds was often highly contaminated (frequently reaching 200 µg/l). However, no boreholes were found to have been contaminated, indicating that lead pollution most likely remains confined to areas where processing has taken place,[3] and has not, as yet, spread throughout the groundwater aquifer. The lead found in wells and ponds was likely to have come from external sources – such as processing – rather than to be naturally occurring.[4]

[1] Conducted by Professor Ruddiger Arndt Haus, Labor Lademannbogen, Hamburg, Germany (www.labor-lademannbougen.de)
[2] The determination was made by a joint CDC/WHO/MSF-Holland investigation team based on epidemiological, clinical and laboratory research conducted in some of the villages where ore processing activities occurred.
[3] In other words, contamination did not spread to other areas such as farmlands because most of the processing has been done in compounds or near water sources like rivers, ponds or wells.
[4] In most cases, exceeding of the WHO guideline was coupled with high concentrations of lead in the soil around the well. Therefore, the mission suspects that the contamination of the wells has been caused by run-off from sites where lead-contaminated ore has been/is being processed. This is consistent the mission's findings that drinking water from boreholes was never found to be contaminated.

Soil: In the four as-yet unremediated villages visited, the soil was often highly polluted with lead. While, for example, the US standard is 400 parts per million (ppm), readings were sometimes as high as 60,000 ppm. Since young children readily ingest soil as part of normal hand-to-mouth behaviour, such high concentrations expose children to potentially harmful amounts of lead. WHO has recently withdrawn the Provisional Tolerable Weekly Intake value for lead on the grounds that it is not possible to set an intake value that is protective for health.[5]

Air: As for concentrations of mercury in air, for which 50 nanograms per cubic metre (ng/m^3) is the maximum exposure for non-industrial workers in the Netherlands,[6] for example, readings of up to 24 micrograms per cubic metre – nearly 500 times the acceptable limit – were measured. This is cause for particular concern. Toxic effects cannot be ruled out, especially as the exposure is more or less chronic.[7]

Dareta village: Perhaps most troubling of all, the mission found high lead and mercury levels in a number of home compounds in the remediated village of Dareta, which could be an indication that processing activities have been continued by some individuals.

Conclusions

- The mission believes that contaminated water is less of a concern than contaminated soil due to the levels and extent of contamination, meaning that priority should be given to soil in remediation efforts.

- Contamination is coming from "above," meaning that lead has been introduced into the wells from the top during processing of ore and from run-off during the rainy season.

- Lead pollution remains confined to areas (wells and ponds) where processing has taken place, and has not spread though the groundwater aquifer.

- High concentrations of lead (up to more than 1,000 μg/l – ten times higher than the exposure limit suggested by the Food and Agriculture Organization of the United Nations (FAO) for livestock) were often found in ponds, rivers and lakes sampled by the mission. It was not in the mission's terms of reference to assess the risk of consuming animal products. However, as it is common practice to use most or all of the animal after it has been slaughtered, including using bones for soup, it is reasonable to suspect that the consumption of such meat might also be an important exposure route for humans.

- Further study of food pathways (livestock, crops) should be undertaken by federal and state experts, with support from international partners, as livestock was seen to be drinking from contaminated ponds, and crops were found to be growing in contaminated soil near affected wells.

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[5] www.who.int/foodsafety/publications/chem/summary73.pdf

[6] WHO cites a tolerable exposure of 200 ng/m^3 (www.who.int/phe/news/Mercury-flyer.pdf)

[7] Studies among occupationally exposed persons have shown that chronic exposure to concentrations of 15-30 micrograms/m^3 of mercury may lead to neurotoxicological and renal effects. This is in the same range as the concentration of 25 ug/m^3 as measured in the affected area in Zamfara State. The measurements, however, only cover a limited time period. It remains unclear if the people in the affected area have been chronically exposed to concentrations as high as measured. The precise extent of their exposure cannot be evaluated without long-term study or bio-monitoring activities.

- Until complete remediation of polluted villages takes place, and as long as ore processing continues in sensitive areas – home compounds and villages, wells and ponds used for drinking water by humans and livestock – there remains an alarming, continuing health risk.

Recommendations

- Drinking water from boreholes should be a safe alternative for people in the villages. As lead is very immobile in soil, leaching of lead into ground water is not expected to be a problem.

- In cases where lead concentrations in wells were significantly (2-3 times) higher than the WHO guideline, remedial measures (i.e. closing the well) should be taken immediately by federal, state and local authorities, after the installation of an alternative drinking water supply system (i.e. boreholes). The remediation of these wells should be integrated into an overall remediation plan.

- Measures should be taken by federal, state and local authorities to prevent further ore processing activities from taking place at sensitive sites – such as water sources from which humans and livestock drink – and polluted villages must be remediated in the nearest possible future, thereby enabling lead-intoxicated children to return to their villages for recovery and follow-up care.

- For all wells without them, walls should be constructed to prevent the possible run-off of potentially lead-contaminated soil into these sources of drinking water.

- Any villages in Zamfara State not yet assessed where suspected and/or confirmed mining and/or ore processing activities have taken/are taking place should be assessed immediately for possible lead pollution and poisoning.

Finally, messages such as the following should be emphasized by federal and state authorities, as well as by the United Nations Children's Fund (UNICEF) and its implementing partners, in public information efforts:

- Ore processing should only occur outside of the village, as directed by local Emirs in May 2010.

- Children should not be allowed to play on former ore processing sites. They should wash their hands in unaffected water before eating to avoid contaminating food with lead soil.

- Grinders used for the processing of ore should not be used for the processing of food. Similarly, sacks used for transporting ore, and mortar and pestles used for crushing ore, should not be used for the transport and processing of food.

- Grains and any other food items should not be dried or stored on the ground where lead dust may be present.

- Information on safer mining practices needs to be disseminated to the miners. Those working with ore could consider forming associations to facilitate dissemination of information, and should include a self-regulatory component.

The **Joint UNEP/OCHA Environment Unit (JEU)** is the United Nations (UN) mechanism that mobilizes and coordinates international assistance to countries affected by environmental emergencies and natural disasters with significant environmental impact. It is a 16 year-old partnership between UNEP and OCHA, combining the technical expertise of UNEP with the rapid humanitarian response and coordination mechanisms of OCHA. It serves as the UN mechanism to respond to environmental emergencies, which can be defined as a sudden onset disaster or accident resulting from natural, technological or human-induced factors, or a combination of these, that cause or threaten to cause severe environmental damage as well as harm to human health and/or livelihoods. The Unit is integrated into the Emergency Services Branch of OCHA.

List of acronyms and glossary of terms

Acronyms

CDC	United States Centers for Disease Control and Prevention
CERF	Central Emergency Response Fund
EAM	Environmental Assessment Module
FAO	United States Food and Agriculture Organization
FMOH	Federal Ministry of Health, Nigeria
JEU	Joint Environment Unit (UNEP/OCHA)
LGA	Local Government Area
MSF-Holland	Médecins Sans Frontières/Doctors Without Borders
NWRI	National Water Resources Institute, Nigeria
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
RIVM	National Institute for Public Health and the Environment
US EPA	United States Environmental Protection Agency
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNICEF	United Nations Children's Fund
UNOSAT	United Nations Institute for Training and Research (UNITAR) Operational Satellite Applications Programme
UN RC	United Nations Resident Coordinator
WHO	World Health Organization
XRF	X-Ray Fluorescence

Technical terms and symbols

BLL	Blood lead level
DVB/CAR/PDMS	Divinylbenzene/carboxen/polydimethylsiloxane
GC-MS	Gas Chromatography-Mass Spectrometry
Mg	Milligram
mg/L	Milligrams per litre
mL	Millilitre
ng/m^3	Nanograms per cubic metre
ppm	Parts per million
SPME	Solid phase microextraction
µg/l	Micrograms per litre
µL	Microlitre

1 Introduction

This section provides the mission's context, including a brief introduction to Nigeria and Zamfara State, the lead pollution emergency in Zamfara State, and the scope of the JEU mission.

Figure I: ReliefWeb overview.

1.1 Nigeria

Nigeria is 923,768 km^2, with a population estimated at 154,729,000 in 2009.[8] It is located on the western coast of Africa, bordered to the west by Benin, to the north by Niger, to the east by Chad and Cameroon, and to the south by the Gulf of Guinea of the Atlantic Ocean. It is Africa's most populous country.

Nigeria has a diverse geography, with climates ranging from arid to humid equatorial. The country has abundant natural resources, notably large deposits of petroleum and natural gas.

Minerals mined in Nigeria include barite, coal, columbite (an iron-bearing mineral that accompanies tin), gold, gypsum, kaolin, lead, phosphates, rock salt, sapphires, tin, and topazes. Uranium deposits discovered in the north-eastern part of the country have not yet been exploited.

About two-thirds of all Nigerians earn a living from small-scale subsistence farming.

Nigeria consists of 36 states and the Federal Capital Territory of Abuja. There are two tiers of government – state and local – below the federal level.

1.2 Zamfara State

Zamfara State is situated in the north-western part of Nigeria and occupies 39,762 kilometres squared.[9] Its capital is Gusau. It shares borders with Kebbi, Kaduna, Sokoto, Niger and Katsina states. It also shares an international boundary with Niger Republic to the north. The State has 14 LGAs, 62 districts and 147 political wards. Its major towns and villages are Gusau, Kaura Namoda, Anka, Talata Mafara and Zugu. The total population of Zamfara State is estimated to be 3,582,912 out of which 716,582 are estimated to be children under the age of five years and 143,316 constitute children under the age of one year. The population is predominantly Muslim, and the State was the first in the country to establish Sharia (Islamic holy law).

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[8] Encyclopedia Britannica and the Economist Intelligence Unit
[9] Zamfara State Government

The predominant occupation of the people of Zamfara State is farming, with over 80 per cent of its people engaged in various forms of agriculture. Major agricultural produce includes millet, guinea-corn, maize, rice, groundnuts, cotton, tobacco and beans. Some industrial infrastructure exists within the state for the processing of these raw materials into finished products.

The average number of people per household in Zamfara State is 5.4, compared to 4.8 as an average for Nigeria, according to the National Population Census of 2006. Meanwhile, 18.8 per cent of households have access to electricity, 27.6 per cent have access to an improved source of water, and 27.5 per cent have improved sanitation facilities (not shared), according to the National Demographic and Health Survey of 2008.

Zamfara State is populated primarily by Hausa and Fulani peoples. Other ethnic groups in the State include the Bade, Kanuri, Karekare, Nupe and Tivs.

The climate of Zamfara is warm tropical, with temperatures rising up to 38^{o} C between March and June. The rainy season typically lasts from July to September, while the cold season, known as Harmattan, lasts from December to February.

1.3 Mass acute lead poisoning

Lead poisoning is most commonly caused by ingestion and inhalation of lead and lead compounds. Lead causes damage to multiple body systems, and the nervous system is particularly vulnerable, especially in young children. Chronic lead poisoning occurs when small amounts of lead are taken in over a longer period. The CDC defines childhood lead poisoning as a whole-blood lead concentration equal to or greater than 10 micrograms/dL. Acute lead poisoning, while less common, shows up more quickly and can be fatal, when a relatively large amount of lead is taken into the body over a short period of time. Children constitute the vast majority of such cases. Symptoms can include severe abdominal pain, diarrhoea, nausea and vomiting, weakness of the limbs, seizures, and coma.[10]

In March 2010, an unusually high number of deaths, primarily among children under age five in Bukkuyum and Anka LGAs of Zamfara State was reported by MSF-Holland to state health authorities. Further study[11] of blood samples taken by MSF-Holland revealed that the increased mortality was the result of acute lead poisoning, determined to be caused by massive environmental contamination from artisanal mining and processing of gold found in lead-rich ore. The grinding of the ore into fine particles resulted in extensive dispersal of lead dust in the villages concerned, including within family compounds. Ingestion and inhalation of the fine lead particles was determined to be the major reason for high BLLs in victims' bodies.[12] BLLs were "unprecedented" for human beings, according to the CDC.

Following the identification of the mass acute lead poisoning situation in Zamfara State, an immediate, two-pronged response approach was developed, consisting of a medical component and an environmental component.

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[10] http://medical-dictionary.thefreedictionary.com/Lead+neuropathy
[11] Conducted by Professor Ruddiger Arndt Haus, Labor Lademannbogen, Hamburg, Germany (www.labor-lademannbougen.de)
[12] The determination was made by a joint CDC/WHO/MSF investigation team based on epidemiological, clinical and laboratory research conducted in some of the villages where ore processing activities occurred.

Medical treatment, led by MSF-Holland and in collaboration with WHO, includes use of chelating agents to reduce BLLs. The Zamfara State Government is leading environmental remediation efforts, with technical advice provided by the Blacksmith Institute and its implementing partner, TerraGraphics Environmental Engineering. Initial remediation of two villages (Dareta and Yargalma) was funded by the State Government. Phase two of remediation of five additional villages is funded under the auspices of UNICEF. The environmental remediation process involves removal of contaminated soil from home compounds and village common areas where processing has taken place, followed by burial in landfills.

It is essential that medical treatment and environmental remediation are carefully coordinated. Crucial extended care (chelation therapy) cannot be provided for children who come from, and are to return to, polluted villages, since villages must be remediated for their safe return and continued treatment.

Meanwhile, several advisory and coordination bodies were established by the federal and state authorities to address the lead poisoning crisis, namely the Inter-Ministerial Committee, created by the President and chaired by the Minister of Mines and Steel Development; the Inter-Ministerial Task Force, established and chaired by the FMOH; and the Zamfara State Rapid Response Team, inaugurated and chaired by the State Commissioner of Health following approval by the State Governor.

At the time of this mission, only two villages had been remediated, and the list of villages suspected to be contaminated continued to grow. Efforts to temporarily settle children in "clean" villages that are not their own have had limited success.

2 Response activities

2.1 Joint Environment Unit sampling and analysis mission

Upon the request for assistance received by the JEU from the UN RC in Nigeria and the FMOH, and following extensive consultations with key stakeholders involved in the response to the lead pollution and poisoning situation, it was thus agreed that the JEU would focus primarily on determining lead contamination of ground and surface water, thereby providing analytical support for decision-making and priority-setting by authorities and other actors.

From 20 September through 7 October 2010, the JEU led a sampling and analysis mission to investigate the lead pollution and poisoning situation in Zamfara State, northern Nigeria, resulting from the informal processing of lead-rich ore to extract gold. Specifically, the mission focused on determining quantities of lead in ground and surface water, building on studies already done by the CDC (May-June 2010), WHO (June 2010), and the NWRI (June 2010). The mission also took the opportunity to look at lead levels in soil, and mercury levels in the air. However, a number of remediation and broader development issues related to the situation were outside the scope of the mission and therefore of this report. A number of these issues may well need to be explored further by the responsible organizations. It should also be borne in mind that this report is intended for non-technical audiences, with the purpose of conveying the overall contours of the challenges in Zamfara State such that action can be taken to protect lives. It is not the purpose to offer an exhaustive or definitive scientific evaluation of all contamination issues in the state.

The mission was supported by the Government of the Netherlands with four technical experts and equipment from the Environmental Assessment Module (EAM), a mobile laboratory designed and assembled specifically for international deployment. Mapping support was provided by UNOSAT, which is the Operational Satellite Applications Programme of the United Nations Institute for Training and Research (UNITAR).

Figure II: The mission was supported by the Government of the Netherlands which provided four technical experts and equipment from the Environmental Assessment Module (EAM), a mobile laboratory designed and assembled specifically for international deployment. The above photo displays part of the EAM at the team's base in Anka village.

Field work focused on five villages in Anka LGA, two of which had been confirmed as lead-contaminated (Abare and Sunke); two of which were newly suspected of contamination (Kirsa and Bagega); and one of which had been remediated in June-July 2010 (Dareta). The number and selection of villages studied varies from that set out in the mission's original terms of reference for two reasons: one, access to all villages proved extremely difficult (if not impossible) and time-consuming due to the non-existence of paved roads and the damage done to these roads by a particularly abundant rainy season; and two, actors on the ground involved in the response to the emergency requested that the mission give special attention to the large village of Bagega in light of worrisome information emerging on the possible lead intoxication situation there.

The JEU mission worked on the basis of the Central Emergency Response Fund (CERF)[13] application, which had identified seven affected villages, impacting an estimated 18,350 individuals.[14] The number of people needing immediate emergency medical treatment was estimated to be 2,400, representing the number of children under age five, who are the most vulnerable to acute lead poisoning.[15] However, it should be noted that since the CERF application was submitted, additional villages have been confirmed as being contaminated with lead, while still more remain unconfirmed but suspected. The full scale of this problem is still unknown, although efforts are underway by a variety of actors to gain a clearer understanding of the scope of the crisis.

The **Environmental Assessment Module (EAM)** is a fully equipped mobile laboratory that can be deployed together with a small flexible team of experts quickly after a disaster involving hazardous substances in countries that lack the specialist knowledge or capacity needed to deal with environmental disasters. The module is equipped with technology for taking samples, performing environmental measurements and analyses and for communication and navigation purposes. With the equipment and personnel expertize, the EAM team can identify a large number of chemical substances in polluted material, and advise on the nature of the pollution, and the threat it poses. The EAM is an initiative of the Government of the Netherlands, in particular the Ministry of Foreign Affairs (MinBuza) and the Ministry of Infrastructure and the Environment (IenM). The aim of this initiative is to support international humanitarian missions, with a focus on health and the environment. The EAM is accommodated by the Dutch National Institute for Public Health and the Environment (RIVM).

2.2 Assessments and findings

2.2.1 Sampling and analytical strategy

In all the villages assessed, samples were taken and indicatively analysed from all communal and private wells of Abare, Bagega, Kirsa and Sunke, while limited, representative sampling was done in the remediated village of Dareta.[16] When possible, depending on the structure of the wells, sediment samples from the bottom of the wells were also taken. Additionally, samples were taken from ponds and rivers from which livestock drink, and from ponds where processing of ore takes, or has taken, place. Since livestock in northern Nigeria roam freely around and through the villages, it is expected that the animals drink wherever they find surface water. This means that drinking from specific processing places cannot be ruled out, particularly as the mission observed firsthand several instances of this.

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[13] The CERF is a humanitarian fund established by the UN to enable more timely and reliable humanitarian assistance to those affected by natural disasters and armed conflicts. The CERF was approved by consensus by the UN General Assembly on 15 December 2005 to promote early action and response to reduce loss of life; enhance response to time-critical requirements; and strengthen core elements of humanitarian response in underfunded crises. It is notable that this was the first time the CERF was used for an environmental emergency.

[14] See application summary at http://ochaonline.un.org/CERFaroundtheWorld/Nigeria2010/tabid/6915/language/en-US/Default.aspx

[15] For more on the particular vulnerability of young children to lead poisoning, see www.cdc.gov/nceh/lead/publications/books/plpyc/chapter1.htm

[16] The water samples were first tested for lead with a commercially available water testing kit. This kit is accurate for concentrations above 100 µg/l. If the concentration of lead in the water sample tested below 100 µg/l, then a more sensitive analytical method using a GC-MS was performed. This was done to ensure that the analytical data would meet the WHO guideline for lead in drinking water for humans, which is 10 µg/l.

The sediment samples could not be analysed with the lead water testing kit or Gas Chromatography-Mass Spectrometry apparatus (GC-MS), and were measured with a hand-held X-Ray Fluorescence (XRF) analyser instead. In addition, the lead concentration of the top soil (maximum 5 cm) was also measured with this hand-held XRF analyser at several sample locations (e.g. near wells). These XRF measurements of the soil were performed in collaboration with Blacksmith/TerraGraphics. The XRF analyser is a screening device and gives only an indication of the lead content in top soil and wet sediment. There are no WHO guidelines for lead concentration in soil and sediment. However, during prior screening of the soil with a hand-held XRF analyser, Blacksmith/TerraGraphics used the United States Environmental Protection Agency (US EPA) guidelines of 400 ppm in soil (dry) to indicate a potential health risk. In this report, the US EPA guideline will also be used to indicate the potential health risk of lead in soil and sediment. Please note that sediment samples were not dried before testing.

Figure III: The Gas Chromatography-Mass Spectrometry apparatus (GC-MS) used for the detection of lead in water.

Figure IV: The X-Ray Fluorescence analyser (XRF) used as a lead screening device. The XRF gave an indication of the lead content in top soil and wet sediment.

Figure V: The mercury analyser used to measure the presence of mercury in the air.

In Annex VI of this report, the analytical methods and the specifications of the equipment are presented in greater detail.

2.2.2 Results of the measurements

In total, 76 well water samples, 31 surface water samples and 21 sediment samples were taken**.** In addition, at 35 locations, the soil was analysed, and at 49 locations, air measurements were performed. An overview of the number of samples per village is given in Table I.

Table I: An overview of the five villages assessed

In this table, the number of samples per village and some additional information is presented.

Village	additional information on village	date of sampling	number of samples				
			well water	surface water	sediment	soil[1]	air[2]
Abare	suspected lead contamination	24 september 2010	12	7	8	5	6
Kirsa	suspected lead contamination	25 september 2010	4	5	5	4	15
Sunke	suspected lead contamination	26 september 2010	16	10	3	5	7
Bagega	suspected lead contamination	28 and 29 september 2010	40	5	3	15	13
Dareta	cleaned before rain season 2010 (june)	29 and 30 september 2010	4	4	2	6	8

1: The top soil was monitored for lead concentration. No soil samples taken

2: The air was monitored for mercury concentration. No air samples taken

In the following five tables, the results of the measurements for each village are listed, including lead concentration in water and sediment. In addition, at some locations, the air was monitored for the presence of mercury, and lead concentration in the top soil was measured. As lead measurement with the water testing kit is not accurate enough for concentrations below 100 µg/l, in these cases an additional GC-MS measurement was performed.

In the tables, the results that are above a given guideline concentration are highlighted in gray. This could indicate a potential health risk.

In Annex VII of this report, all coordinates of the samples are given. The pH, conductivity and turbidity of the water samples (well water samples only) were measured directly after sampling as part of a standard operating procedure (in the Netherlands) for sampling water. These results are also presented in Annex VII.

Map I: Overview of area

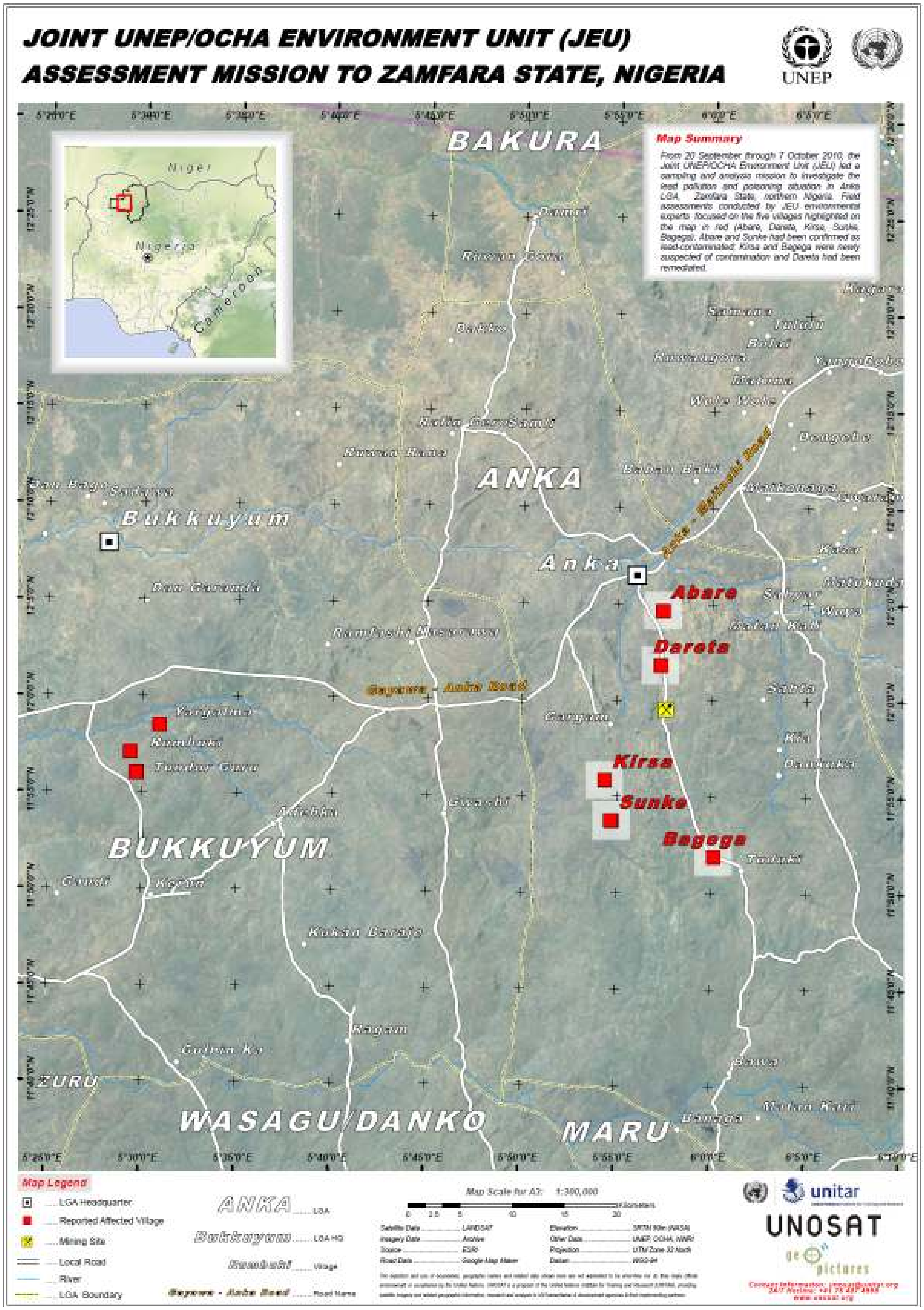


Table II: Results of measurements in Abare village

Note: The Sample ID coordinates differ on Map II from the table and text below (e.g. ABA001 is cited on the map as AB1).

Sample ID	*Sample Type*	*Location description*	*Lead[1] in water* µg/l	*Lead[2] in sediment XRF* mg/kg	*Lead[2] in top soil XRF (max)* mg/kg	*Mercury[3] in air (max)* ng/m³
ABA001	well water	Well A, communal well near mosque	10		1210	
ABA003	well water	Private well, chiefs compound	<10		<100	
ABA008	well water	Communal well near palmtrees, south of compound 52	51			1100
ABA009	well water	Private well with no lip; processing place	14		7000	
ABA012	well water	Communal well with 3 ex grinding sites	13			6500
ABA014	well water	Communal well near compound 79	27			24000
ABA015	well water	Welll pump near compound 56	<10			
ABA016	well water	Communal well near path from compound 35 and 56	11			
ABA018	well water	Communal well between compound 16 and 28	<10			
ABA024	well water	Private well	<10		26000	
ABA026	well water	Private well	57		27000	
ABA029	well water	Well pump next to compound 4	<10			
ABA004	surface water	Pond	258			
ABA005	surface water	River	128			
ABA020	surface water	Pond east of compound 85 and 90	129			
ABA021	surface water	Pond south of compound 63	20			
ABA022	surface water	Pond east of compound compound 1	320			
ABA023	surface water	Pond east of compound 59 and 60	164			
ABA028	surface water	Pond north east of town	138			
ABA002	sediment	Well A, communal well near mosque		580		
ABA006	sediment	River		<100		
ABA007	sediment	Communal well near palmtrees, south of compound 52		<100		1100
ABA013	sediment	Communal well with 3 ex grinding sites		2360		6500
ABA017	sediment	Communal well near path from compound 35 and 56		480		
ABA019	sediment	Communal well between compound 16 and 28		110		
ABA025	sediment	Private well; too much water with sediment		not measured		
ABA027	sediment	Private well		450		
no sample	air	Village square near shelter				350

1: WHO guideline lead in drinking water: 10 µg/L
2: US-EPA guideline lead in soil: 400 mg/kg
3: WHO guideline mercury in air: 200 ng/m^3

The results of the assessment of Abare village are presented in Table II. As can be seen, six of 12 wells did not meet the WHO guideline, and three of them exceeded the guideline by a factor of two or more. Concentrations in other surface water samples were often higher: in six sampled surface water sources, the lead concentration was above 100 µg/l, which is the FAO guideline for drinking water for livestock.[17] During the mission, livestock were seen drinking from surface water sources.

The sediment samples, measured with the XRF analyser, indicate that four of the eight samples were above the US EPA guideline for lead in soil. In addition, the lead concentration measured in the topsoil of four out of five locations in the village revealed concentrations above the US EPA guideline for lead in soil. No result was available for sample ABA025 because it contained too much water.

The mercury concentration of the air was monitored at six locations in the village. In all six cases, the mercury concentration in the air was above the WHO guideline.

[17] www.fao.org/docrep/003/t0234e/T0234E07.htm

Map II: Abare village

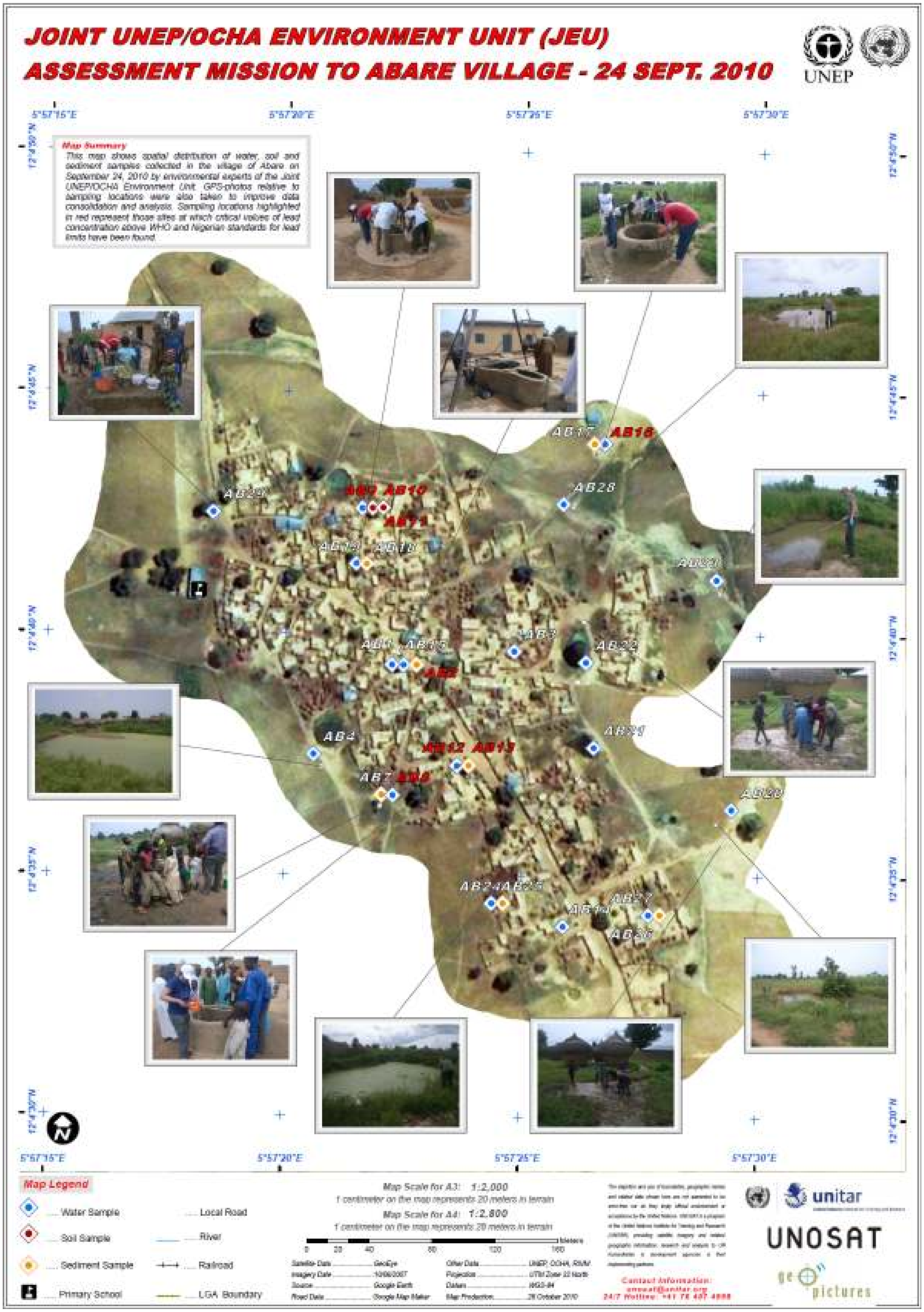


Table III: Results of measurements of Kirsa village

Note: The Sample ID coordinates differ on Map III from the table and text below (e.g. KIR001 is cited on the map as KR1).

Sample ID	*Sample Type*	*Location description*	*Lead[1] in water* *µg/l*	*Lead[2] in sediment XRF* *mg/kg*	*Lead[2] in top soil XRF (max)* *mg/kg*	*Mercury[3] in air (max)* *ng/m[3]*
KIR001	well water	Communal well with no lip, larger opening	<10		120	<50
KIR003	well water	Communal well with no lip, small opening	<10		<100	<50
KIR005	well water	Communal well with lip (approx. 0.5 m)	<10		<100	<50
KIR007	well water	Private well with low lip (approx. 0.1m) near KIR005	<10		<100	<50
KIR009	surface water	River/Stream; used for washing/processing	<10			<50
KIR011	surface water	Pond, swamp like on the way back from river/stream	322			<50
KIR012	surface water	Pond	<10			<50
KIR013	surface water	Pond on the way the separate western village part	131			<50
KIR014	surface water	Pond next to KIR014	<10			<50
KIR002	sediment	Communal well with no lip, larger opening		<100		<50
KIR004	sediment	Communal well with no lip, small opening		<100		<50
KIR006	sediment	Communal well with lip (approx. 0.5 m)		<100		<50
KIR008	sediment	Private well with low lip (approx. 0.1m) near KIR005		<100		<50
KIR010	sediment	River/Stream		<100		<50
no sample	air	broken pump well at village entrance				60

1: WHO guideline lead in drinking water: 10 µg/L
2: US-EPA guideline lead in soil: 400 mg/kg
3: WHO guideline mercury in air: 200 ng/m^3

The results of the assessment of Kirsa are presented in Table III. As can be seen, all drinking water samples meet the WHO guideline. However, two of five sampled ponds contain concentrations higher than 100 µg/l.

The sediment samples, measured with the XRF analyser, indicate that the lead concentrations of the five samples were below the US EPA guideline for lead in soil. In addition, the lead concentrations measured in the topsoil at four locations in the village were also below the US EPA guideline.

At 15 locations in the village, the mercury concentration of the air was monitored. All concentrations of mercury in air were below the WHO guideline.

Map III: Kirsa village

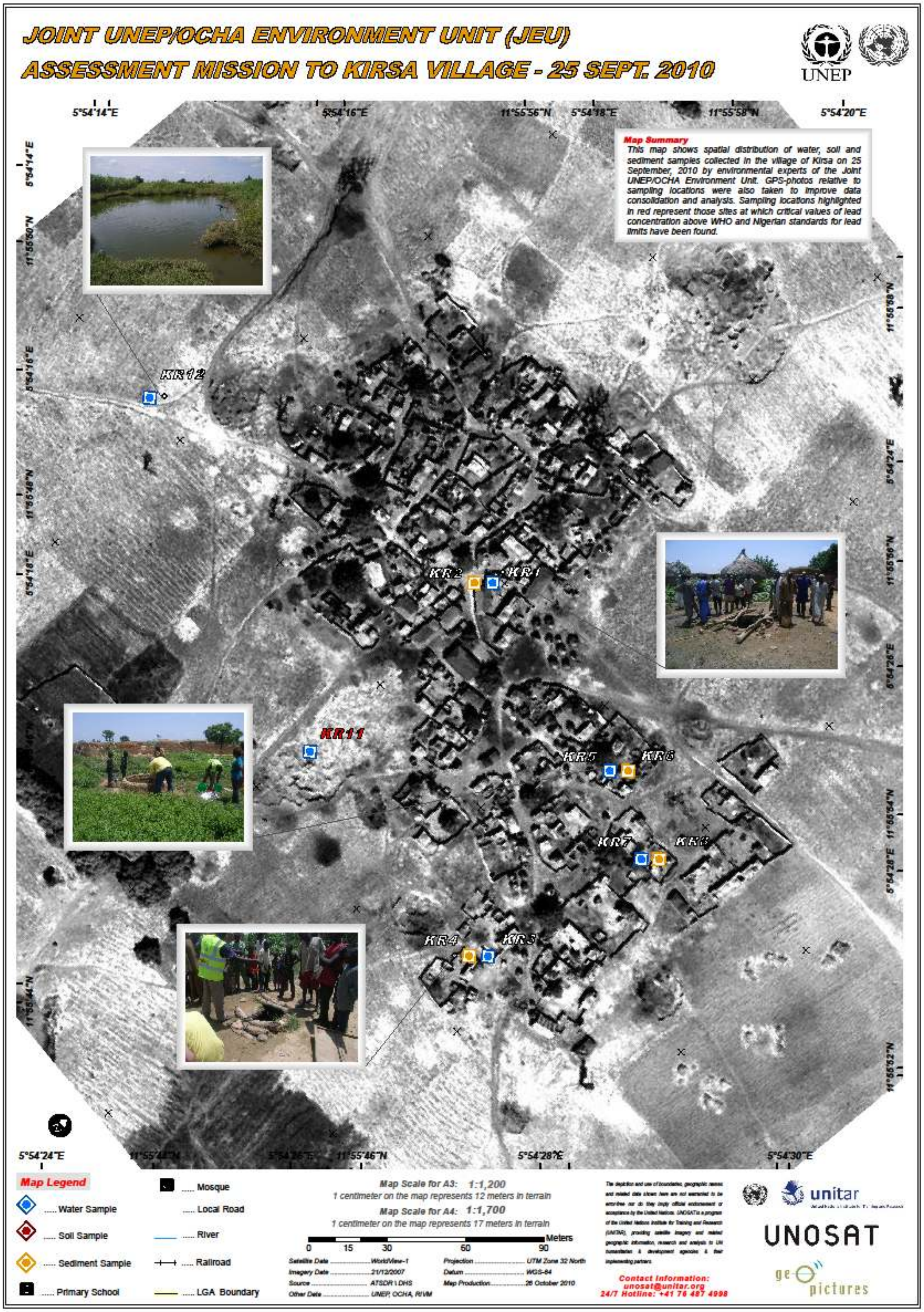


Table IV: Results of measurements of Sunke village

Note: The Sample ID coordinates differ on Map IV from the table and text below (e.g. SUN001 is cited on the map as SN1).

Sample ID	Sample Type	Location description	Lead[1] in water µg/l	Lead[2] in sediment XRF mg/kg	Lead[2] in top soil XRF (max) mg/kg	Mercury[3] in air (max) ng/m^3
SUN001	well water	Communal well; open	<10		1080	
SUN002	well water	Communal well, open	<10		1810	60
SUN004	well water	Communal well, near pond	<10		2060	5000
SUN006	well water	Communal well	165		2750	100
SUN008	well water	Communal hand pump	<10		34800	250
SUN009	well water	Private well; chief's compound	<10			38
SUN010	well water	Private well	16			300
SUN011	well water	Private well	23			
SUN012	well water	Private well; cavety well: ore in compound visible	<10			
SUN013	well water	Private well	12			
SUN014	well water	Private well	<10			
SUN015	well water	Private well	<10			
SUN016	well water	Private well	<10			
SUN017	well water	Private well	19			
SUN018	well water	Private well	138			
SUN019	well water	Private well	<10			
SUN020	surface water	Pond	475			
SUN021	surface water	Pond	176			
SUN022	surface water	Pond	454			
SUN023	surface water	Pond	<10			
SUN025	surface water	Pond near hand pump	151			
SUN026	surface water	Pond	11			
SUN027	surface water	Pond	307			
SUN028	surface water	Pond near well SUN006/007; sluicing place	160			
SUN029	surface water	Pond; southern of the two; sluicing place	418			
SUN030	surface water	Pond near well SUN004/005; sluicing place	387			
SUN003	sediment	Communal well, open		<100		
SUN005	sediment	Communal well, near pond		<100		
SUN007	sediment	Communal well		<100		
no sample	air	Tree near chief's compound				60

1: WHO guideline lead in drinking water: 10 µg/L
2: US-EPA guideline lead in soil: 400 mg/kg
3: WHO guideline mercury in air: 200 ng/m^3

The results of the assessment of Sunke are presented in Table IV. As can be seen, six of 16 wells did not meet the WHO guideline. Of these six wells above the guideline, three exceeded the guideline by a factor of two or more. In addition, eight out of ten of the sampled ponds contained lead levels higher than 100 µg/l.

The sediment samples, measured with XRF the analyser, indicated that the lead concentrations of all samples were below the US EPA guideline for lead in soil. However, the measured lead concentration in the topsoil at five locations in the village revealed concentrations above the US EPA guideline for lead in soil. In the well in the north of Sunke (samples SUN006 and SUN007) the water was found to contain a relatively high concentration of lead, while the sediment appeared to be clean. It should be noted that this well was very shallow (less than one metre of water) with much sediment in it.

At seven locations in the village, the mercury concentration of the air was monitored. At three locations, the concentration was above the WHO guideline.

Map IV: Sunke village

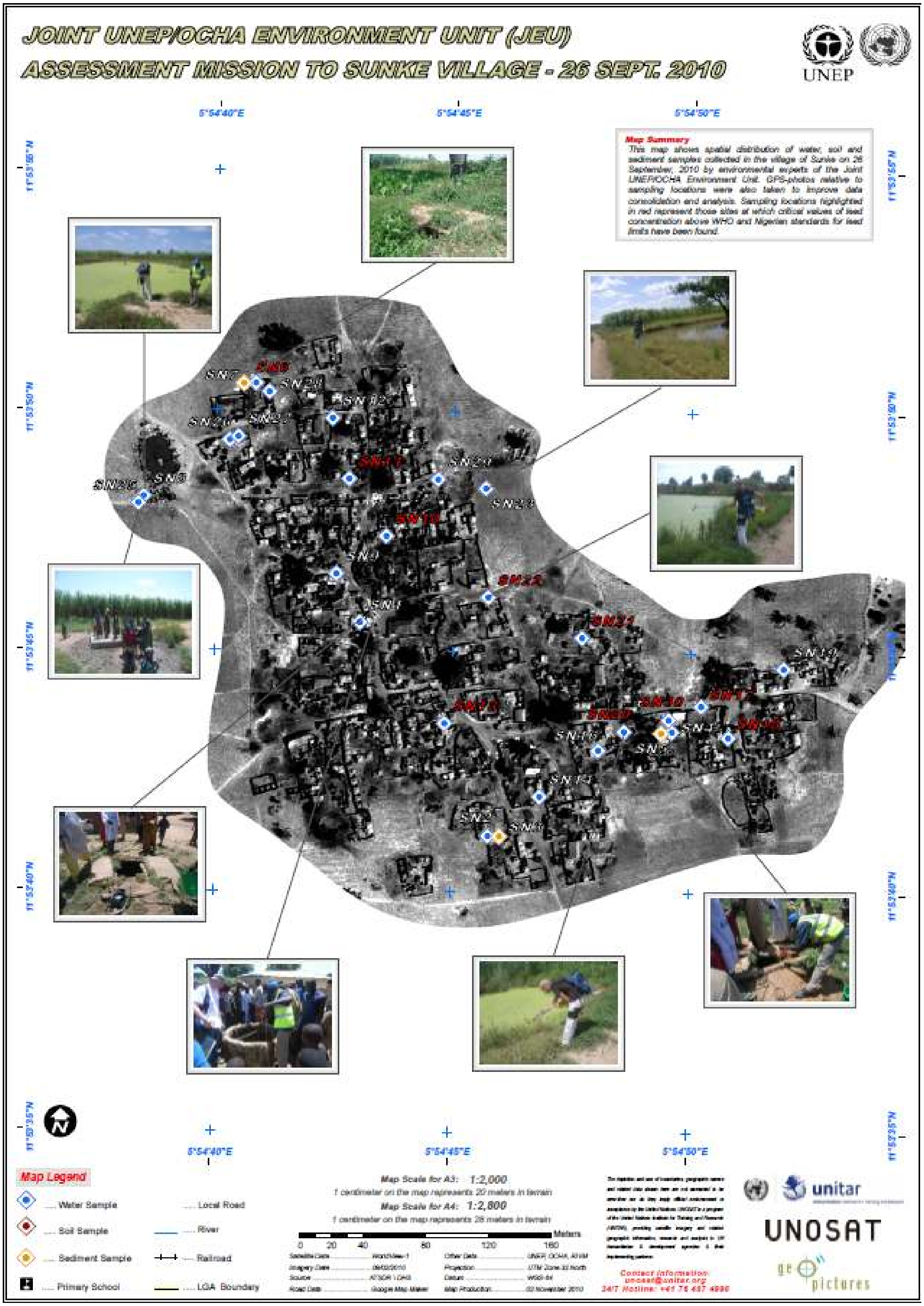


Table V: Results of measurements of Dareta village

Note: The Sample ID coordinates differ on Map V from the table and text below (e.g. DAR001 is cited on the map as DR1).

Sample ID	Sample Type	Location description	Lead[1] in water µg/l	Lead[2] in sediment XRF mg/kg	Lead[2] in top soil XRF (max) mg/kg	Mercury[3] in air (max) ng/m^3
DAR003	well water	Communal well	<10			15
DAR005	well water	Communal well	13			
DAR007	well water	Private well chief	<10		<100	13
DAR010	well water	Private well; high mercury level in air	<10		37500	6500
DAR001	surface water	Dareta landfill	198			
DAR002	surface water	Pond at processing site at landfill	605			1100
DAR006	surface water	Pond at south east entrance	<10		<100	10
DAR009	surface water	Old sluicing pond/ near processing well	<10		130	92
DAR004	sediment	Communal well (market)		not measured	240	15
DAR008	sediment	Private well chief		not measured	<100	13

1: WHO guideline lead in drinking water: 10 µg/L
2: US-EPA guideline lead in soil: 400 mg/kg
3: WHO guideline mercury in air: 200 ng/m^3

The results of the assessment of Dareta are presented in Table V. Dareta village was remediated by the Zamfara State Government with technical supervision provided by Blacksmith/TerraGraphics in June-July 2010. The topsoil was removed and transported to a landfill. Samples DAR001 and DAR002 were taken from ponds filled with rainwater at this landfill site. As can be seen in Table V, only one of four sampled wells did not meet the guideline. This well was used for processing before the remediation of the village, and was not cleaned. The open landfill and the processing place that is still in use show high concentrations of lead. Drinking of this water by livestock can not be excluded.

The two sediment samples (DAR004 and DAR008) were not tested for lead due to technical problems with the XRF analyser. The lead concentration in the top soil layer at six locations was measured with the XRF analyser and revealed that at one location, the lead concentration measured in soil was above the US EPA guideline for lead in soil. An interview with the family revealed that processing of ore continued in the compound after remediation was complete.

At eight locations in the village, the mercury concentration of the air was monitored. At two locations, the mercury concentration in the air was above the WHO guideline.

Map V: Dareta village

Table VI: Results of measurements of Bagega village

Note: The Sample ID coordinates differ on Map VI from the table and text below (e.g. BAG001 is cited on the map as BG1).

Sample ID	*Sample Type*	*Location description*	*Lead[1] in water µg/l*	*Lead[2] in sediment XRF mg/kg*	*Lead[2] in top soil XRF (max) mg/kg*	*Mercury[3] in air (max) ng/m³*
BAG001	well water	Handpump near hospital	<10		380	400
BAG003	well water	Communal well with wall (0,5 m)	<10		800	100
BAG005	well water	Private well	<10			
BAG006	well water	Private well	<10			
BAG008	well water	Private well	<10			
BAG009	well water	Private well	12		15300	
BAG011	well water	Communal well	56		11400	
BAG012	well water	Private well	<10			
BAG013	well water	Private well	130			
BAG014	well water	Private well	12			
BAG015	well water	Private well	10			
BAG016	well water	Private well	12			
BAG017	well water	Private well	<10			
BAG018	well water	Private well	<10			
BAG019	well water	Private well	<10			
BAG020	well water	Private well				
BAG021	well water	Private well	<10			
BAG022	well water	Communal well near mosque				120
BAG023	well water	Private well	12			
BAG024	well water	Private well	<10			
BAG025	well water	Private well	<10			
BAG026	well water	Private well	<10			1500
BAG027	well water	Private well	<10			
BAG028	well water	Communal well	28			1100
BAG029	well water	Communal well	13			
BAG030	well water	Communal well	<10			440
BAG031	well water	Private well	<10			133
BAG032	well water	Communal well	<10			1400
BAG033	well water	Communal well	42			2700
BAG034	well water	Private well	18			
BAG037	well water	Communal well	<10			
BAG038	well water	Private well	<10			
BAG066	well water	Communal well near edge of town	<10		680	
BAG067	well water	Communal well at market	<10		170	
BAG068	well water	Private well	<10		12500	
BAG069	well water	Private well	<10		330	
BAG070	well water	Private well	<10		1700	
BAG071	well water	Communal well	<10		4500	
BAG072	well water	Communal well	<10		200	
BAG074	well water	Private well	111		<100	
BAG002	surface water	Stream (processing + animal drinking place)	<100		890	170
BAG035	surface water	lake sluicing place	1100			500
BAG036	surface water	lake sluicing place	423			500
BAG073	surface water	Pond near butcher	<100		560	
BAG075	surface water	Pond near pink mosque	269			
BAG004	sediment	Communal well with wall (0,5 m)		840	800	100
BAG007	sediment	Private well		<100		
BAG010	sediment	Private well		540		

1: WHO guideline lead in drinking water: 10 µg/L
2: US-EPA guideline lead in soil: 400 mg/kg
3: WHO guideline mercury in air: 200 ng/m³

The results of the assessment of Bagega are presented in Table VI. Of the 40 wells tested in Bagega, 11 did not meet the WHO guideline for lead in drinking water. Of these 11 wells, five contained lead concentrations higher than 20 µg/l. For two of the wells that were sampled, results were inconclusive.

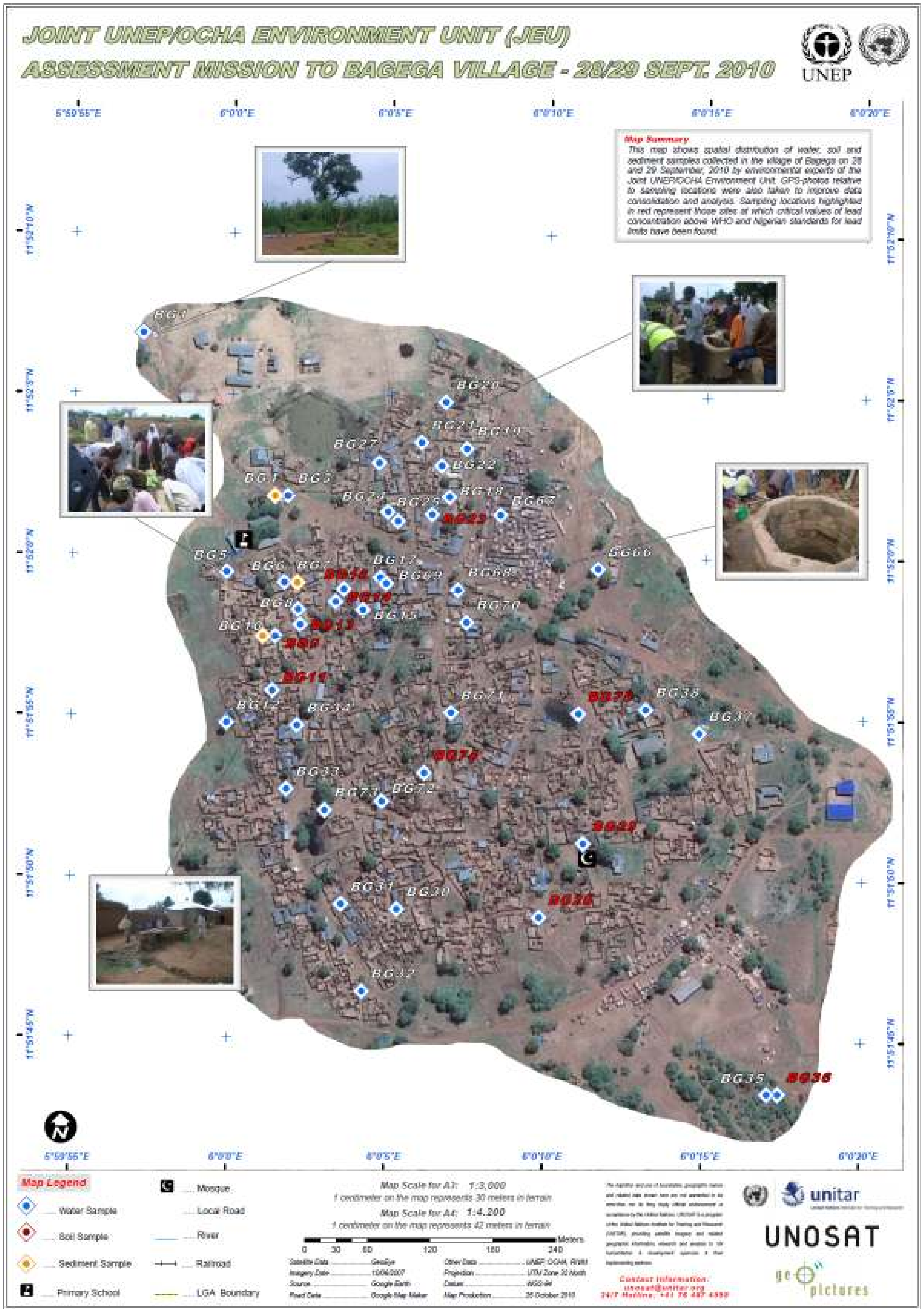
In addition, five sources of surface water were sampled. Three contained lead in concentrations above 100 µg/l. Two had a lower concentration, but were only analysed with the water kit due to safety concerns.[18]

The sediment samples, measured with the XRF analyser, indicated that two of the three samples were above the US EPA guideline for lead in soil. In addition, the lead concentration measured in the top soil at ten out of 15 locations in the village was above the US EPA guideline for lead in soil.

At 13 locations in the village, the mercury concentration of the air was measured. At nine of these locations, the mercury concentration was above the WHO guideline.

[18] Samples BAG002 and BAG073 were possibly contaminated with high concentrations of biological waste (visual offal was floating in the water). For safety reasons, these samples were only analysed using the water kit.

Map VI: Bagega village



3 Conclusions

3.1 Lead in drinking water

Measurements showed that 25-30 per cent of wells in the villages assessed did not meet the WHO guideline for lead in drinking water, although in most wells, the limit of 10 µg/l was exceeded by no more than several µg/l. However, in some wells, concentrations of up to 10-15 times the guideline were found. In most cases, exceeding of the guideline was coupled with high concentrations of lead in the soil around the well. Therefore, the mission suspects that the contamination of the wells has been caused by dust deposition and soil run-off from sites where lead-contaminated ore has been/is being processed. This is consistent the mission's findings that drinking water from boreholes was never contaminated.

Lead concentrations found by the mission are consistent with earlier (pre-rainy season) measurements taken by the NWRI, suggesting that concentrations were not significantly affected by the particularly abundant rainy season.

Recently, scientists have suggested that all exposure to lead should be avoided and that there is no safe exposure concentration.[19] This would imply that even the relatively low concentrations found in most wells by the mission might be a risk, especially for young children.[20] To see this in perspective, the following should be considered: when children who drink contaminated water are also exposed to lead-contaminated dust or soil, the latter probably has a bigger impact on lead body burden than the intake of water that contains lead just above the guidelines. This means that it can be expected that in a contaminated environment, exposure through drinking water is low compared to exposure through hand-to-mouth behaviour.

A notable aspect of the mission's investigations is that no contamination was found in boreholes. This suggests three likely conclusions:

- Contamination is coming from "above," meaning that lead has been introduced into the wells from the top during processing of ore and from soil run-off during the rainy season.
- Lead pollution remains confined to areas (wells and ponds) where processing has taken place, and has not spread though the groundwater aquifer.
- Drinking water from boreholes might be a safe alternative for people in the villages.

3.2 Lead in surface water

High concentrations of lead (up to more than 1,000 µg/l – ten times higher than the exposure limit suggested by FAO for livestock) were often found in ponds, rivers and lakes sampled by the mission. This is not surprising since surface water sources are often used for processing ore. The mission could not determine if the concentrations found were representative for the dry season as well. However, in the sampling period (towards the end of the rainy season), the concentrations reflect concentrations to which livestock were exposed.

[19] www.efsa.europa.eu/en/scdocs/scdoc/1570.htm
[20] For more on the particular vulnerability of young children to lead poisoning, see www.cdc.gov/nceh/lead/publications/books/plpyc/chapter1.htm

It was not in the mission's terms of reference to assess the risk of consuming animal products. However, it is common practice to use most or all of the animal after it has been slaughtered, including using bones for soup. Since people in the villages report illness and death among livestock, it is reasonable to suspect that the consumption of such meat might also be an important exposure route for humans.

3.3 Lead in soil

The concentrations of lead in soil in the villages varied significantly within villages, suggesting a human factor in the dispersion of lead. Higher concentrations (up to 8 per cent) were seen close to drinking water wells and to other surface water sources. At other locations, concentrations were often much lower. At ore processing locations, incidental ingestion of soil (*via* hand-to-mouth behaviour and eating food with dirty hands) by young children could be a substantial exposure route. Since processing is often done within the walls of home compounds, infants and toddlers would be particularly exposed.

3.4 Mercury in air

Concentrations of mercury in air were found to be elevated close to processing sites, suggesting that emissions were coming from human activities, resulting from the injudicious discarding of mercury waste. In the villages, concentrations were often between 100 and 400 ng/m^3, with peak concentrations up to 25,000 ng/m^3. As mercury is very toxic, this could easily damage the health of exposed persons, especially children, who tend to play on the ground where mercury may have been spilled.

3.5 Mercury in water and soil

The mission was not able to assess the concentration of mercury in (drinking) water. While some research was possible on the amount of mercury in soil, the information found was very limited. Mercury was found in only one analysis, and the concentration was not very high. Mercury in soil would not be expected to emanate from a natural source. During processing, hotspots emerge which are difficult to detect with the measuring method used, i.e. spilled mercury does not mix with soil very well, leading to a heterogeneous dispersion in the soil, resulting in inconsistent detection.

3.6 Possible resumption of processing activities in remediated villages

High lead and mercury levels were found by the mission in a number of home compounds in the remediated village of Dareta, which could be an indication that ore processing activities have been continued by some individuals.

3.7 Further study of food pathways needed

Further study of food pathways (livestock, crops) should be undertaken by federal and state experts, with support from international partners, as livestock was seen to be drinking from contaminated ponds, and crops were found to be growing in contaminated soil near affected wells.

3.8 Further study needed to determine extent of lead pollution

Further study of the lead pollution emergency in Zamfara State is clearly needed. The geographic extent of this crisis and the number of people potentially affected are still not known. The CDC's recently concluded two-month assessment in conjunction with the Nigerian Field Epidemiology and Laboratory Training Program is a most welcome initiative on this front, as it should provide a detailed map of the affected area and delineate the complete scope of the situation. Similarly, a full environmental assessment of communities that have not yet been evaluated should be undertaken, as should an in-depth geological study of the region in order to ascertain the potential geographic extent of the occurrence of lead.

3.9 Wholistic approach to further study

A more wholistic study of the environment and health situations in Zamfara State should be undertaken, as the approach has thus far been rather piecemeal, i.e. one mission looking at water in certain villages, another mission looking at soil in other villages, yet another mission taking blood samples in other villages. Many factors are having an important influence on the gravity of the situation in Zamfara State, such as, for example, the poor baseline nutritional status of children of the region, which is a major contributing factor to how severely they are affected by lead poisoning.

4 Recommendations

Within the scope of its terms of reference, the mission makes the following recommendations.

4.1 Remediation of highly contaminated wells

In cases where lead concentrations in wells were significantly (2-3 times) higher than the WHO guideline, remedial measures (i.e. closing the well) should be taken immediately by the appropriate authorities, after the installation of an alternative drinking water supply system (i.e. boreholes). The remediation of these wells should be integrated into an overall remediation plan.

4.2 Protect sensitive areas and remediate villages

Measures should be taken by federal, state and local authorities to prevent further ore processing activities from taking place at sensitive sites – such as water sources from which humans and livestock drink – and polluted villages must be remediated in the nearest possible future, thereby enabling lead-intoxicated children to be treated and returned to their villages for recovery and follow-up care.

4.3 Erect safety walls around wells

For all wells without them, walls should be constructed to prevent the possible run-off of potentially lead-contaminated soil into these sources of drinking water.

4.4 Assess other villages for possible contamination

Any villages in Zamfara State not yet assessed where suspected and/or confirmed mining and/or ore processing activities have taken/are taking place should be assessed immediately for possible lead pollution and poisoning.

4.5 Key messages for inclusion in public education efforts

Finally, messages such as the following should be emphasized by federal and state authorities, as well as by UNICEF and its implementing partners, in public information efforts:

- Children should not be allowed to play on former ore processing sites. They should wash their hands before eating to avoid contaminating the food with lead soil.

- Grinders used for the processing of ore should not be used for the processing of food. Similarly, sacks used for transporting ore, and mortar and pestles used for crushing ore, should not be used for the transport and processing of food.

- Grains and any other food items should not be dried or stored on the ground where lead dust may be present.

5 Further considerations

Although beyond the scope of the mission's terms of reference, owing to the complex nature of the lead pollution emergency in Zamfara State, there are a variety of observations and considerations to be made.

Lead poisoning, while treatable to some degree, does irreparable damage to young children's neurological systems (learning disabilities, reduced IQ, behavioural disorders, loss of control of muscles), threatens unborn children (lead passes directly through placenta, resulting in stillbirths, birth defects) and breastfeeding babies (lead passes freely through mothers' breasts, the human body "mistakes" lead for much-needed calcium). Zamfara State is seeing the health and well-being of its children put in grave danger by this acute and ongoing disaster. More rapid and coordinated intervention is imperative by federal and state authorities, with the support of the international community, in making mining safer, cleaning up polluted villages, and treating those affected by lead poisoning. Hundreds of lives have been lost already, and thousands more are at risk.

Although some US $2 million was provided by the CERF, such funding is not intended to cover all costs of a humanitarian operation. No donors are matching funds thus far provided through the CERF, turning this into a neglected, underfunded emergency. Already, actors have been forced to scale back activities at a moment when they should instead be expanding them, and in some cases finances for key activities related to remediation and coordination will be exhausted by year-end. Government authorities and the UN should consider what additional steps might be taken to access national and international resources needed to respond to this crisis.

Most stakeholders familiar with the situation in Zamfara State are of the strong opinion that bans on mining should be lifted, as they often result in illegal continuation of such activities, thereby rendering them even more risky. Given the reality of extreme poverty in Zamfara State, stopping mining operations without an alternative source of income is not realistic. Focus should instead be placed on informing about and implementing safer practices; enacting stronger regulation; and establishing areas outside of villages where ore could be securely stored and safely processed without posing significant threats to human health and the environment. National and international experience and expertize in safer mining practices should be drawn upon.

Given the scope and complexity of the lead pollution crisis in Zamfara State, and the need for many actors to be working together closely and sharing information regularly, the importance of coordination for the response to this emergency can not be understated. The signing of a Memorandum of Understanding between UN agencies and Government authorities to better define roles and responsibilities, and the establishment of a simple web-based platform to facilitate information sharing and activity coordination, could be considered.

6 Acknowledgements

The mission benefitted from a generous contribution from the Government of the Netherlands in the form of four technical experts and equipment from the EAM, a mobile laboratory designed and assembled specifically for international deployment. The JEU therefore extends its special thanks and appreciation to the Dutch Ministry of Infrastructure and the Environment (IenM), the Ministry of Foreign Affairs (MinBuza), and the National Institute for Public Health and the Environment (RIVM).

The JEU also extends its thanks and appreciation to the following persons and organizations, without whose support this mission would not have been possible:

- His Royal Highness, The Emir of Anka, Alhaji Attahiru Muhammad Ahmad
- Blacksmith Institute and TerraGraphics Environmental Engineering, Inc.
- MSF-Holland
- Federal Government of Nigeria
- State Government of Zamfara
- UNICEF – Nigeria
- UN Development Programme (UNDP) – Nigeria
- UNOSAT
- CDC
- WHO – Nigeria and HQ/Geneva

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8 Annexes

Tables

Annex I: Composition of the mission team

Matthew Conway (Team Leader)
Programme Officer
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Geneva, Switzerland

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Edith van Putten
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National Institute for Public Health and the Environment (RIVM)
Bilthoven, the Netherlands

Ramon Ramlal
Senior Laboratory Researcher
National Institute for Public Health and the Environment (RIVM)
Bilthoven, the Netherlands

Annex II: Mission itinerary

19 September
Arrival of Mr. Conway and Mr. van Belle in Abuja for preliminary consultation.

20 September
Meetings in Abuja with:
WHO Country Representative Dr. Peter Eriki;
UNDP Resident Representative and UN RC in Nigeria Mr. Daouda Touré; and
Federal Task Force.
Arrival of Ms. van Putten, Mr. Knetsch, Mr. Ramlal.

21 September
Travel to Gusau, Zamfara State.
Meeting in Kaduna with NWRI.
Meeting with Zamfara State Rapid Response Committee.

22 September
Meeting in Gusau with Zamfara State Commissioner of Health and Permanent Secretary.
Travel to Anka Town, Anka LGA, Zamfara State.
Meeting with His Royal Highness, The Emir of Anka, Alhaji Attahiru Muhammad Ahmad.
Abare village introduction of JEU team.

23 September
Visit to Anka clinic, Dareta mines, Dareta village.

24 September
Abare village sampling/analysis.

25 September
Kirsa village sampling/analysis.

26 September
Sunke village sampling/analysis.

27 September
Analysis day in Anka.

28 September
Bagega village, Day One.

29 September
Bagega village, Day Two.
Dareta village.

30 September
Analysis day in Anka.
Dareta village.

1 October
Analysis day in Anka.
Meeting with Governor of Zamfara.

2 October
Pack-up day.

3 October
Travel of team from Anka Town to Gusau Town, Zamfara State.
Debriefing with Zamfara State Rapid Response Team.
Travel of team from Gusau Town, Zamfara State to Abuja.

4 October
Debriefings in Abuja with:
WHO Country Representative Dr. Peter Eriki; and
Federal Task Force and Federal Minister of State for Health.
Depature of Mr. van Belle, Ms. van Putten, Mr. Knetsch, Mr. Ramlal.

5 October
Meeting with Masayoshi Matsuhita, UN Industrial Development Organization (UNIDO) Representative in Nigeria.
Meeting with CDC and WHO to discuss follow-up actions.

6 October
Meeting with UNICEF (Mr Vinod Alkari) and WHO (Dr. Emmanuel Musa) to discuss follow-up actions.
Meeting with UN RC Daouda Touré.

7 October
Meeting with Mohamed Sani Sidi, Director General, National Emergency Management Agency (NEMA).
Meeting with Ministry of Mines and Steel Development, Sustainable Management of Mineral Resources Project, CDC, UNICEF, US Embassy.
Meeting with Ministry of Mines and Steel Development, Artisanal & Small Scale Mining Department (ASM).

Annex III: Mission terms of reference

Environmental Sampling and Analysis, Mass Lead Poisoning, Zamfara State, Nigeria, 15 September 2010

1. Occurrence and initial response

Excess childhood death and illness were recorded since the beginning of 2010 in the LGA of Bukkuyum and Anka in Zamfara State of northern Nigeria. Further investigations revealed that the cause was acute lead poisoning from the artisanal processing activities of lead-rich ore for gold extraction, taking place inside houses and compounds.

Figure VI: Zamfara State highlighted in red

An immediate two-pronged response approach was developed, consisting of (a) a medical component: provision of chelation therapy to most severe cases of children under five; and (b) an environment component: decontamination of houses and villages.

It is imperative that both activities take place concurrently as treatment is ineffective if children return and are re-exposed to lead pollution. This two-pronged approach requires a strong coordination and sufficient resources on both sides to be fully effective.

The main international actor for the provision of chelation therapy is MSF-Holland, together with WHO and the UNICEF in Nigeria, supporting local authorities and the Nigerian Ministry of Health.

The decontamination is undertaken by the Blacksmith Institute and TerraGraphics Environmental Engineering Inc., supporting local authorities and the Ministry of Environment.

Scope of the problem

As of beginning of September 2010, the scope of the lead pollution and poisoning was believed to be as follows:

Table VII: Lead pollution and poisoning as of September 2010

	Village	Poisoning	Pollution	Treatment	Decontamination
1	Yarmalga	Confirmed	Confirmed	Ongoing (<5yrs)	Finished
2	Dareta	Confirmed	Confirmed	Ongoing (<5yrs)	Finished
3	Abare	Confirmed	Confirmed	Emergency only	*Anticipated*
4	Kasunke	Confirmed	Confirmed	Emergency only	*Anticipated*
5	Tudjun/Tungar Daji	?	Confirmed	*Anticipated*	*Anticipated*
6	Duza	?	Confirmed	*Anticipated*	*Anticipated*
7	Tudun Guru/Tungar Garu/Gidan Gurua	?	Confirmed	Emergency only	*Anticipated*
8	WHO has reported that, based on a hospital registry survey conducted across all 14 Zamfara State LGA's, additional villages may be at risk. However, it is not known how many, and their location. Furthermore, the villages of Bagega and Kersa have since been identified as contaminated.				

The funding request to the CERF puts the number of affected people at 18,350 individuals. The number of people needing immediate emergency medical treatment is estimated to be

2,400 – this represents the estimated number of children under five. It must be noted that, to date, any children over five and adults tested from these communities also have extremely high BLLs that will likely require treatment and follow-up. Funding of approximately US $2 million has been agreed upon by the Emergency Relief Coordinator.

The now-concluding rainy season may still pose some logistical challenges to response activities (in particular to decontamination activities due to the remoteness of the villages, poor access and need for moving of heavy equipment). According to MSF in Anka/Bukkuyum, access to five out of seven villages is possible by 4x4 on an intermittent basis.

Due to the rainy season, there is a risk of lead contamination having spread farther and into deeper soil layers, while for standing/open sources of water, the rainy might have a further diluting and spreading effect.

Request for assistance

The Chief of OCHA's Emergency Services Branch has offered the services of the JEU to the UN RC in Nigeria which was subsequently welcomed. A request for assistance from the JEU was later received from the Nigerian Ministry of Health.

The JEU contacted all international actors (WHO Health Action in Crises (HAC)-Nigeria/International Programme on Chemical Safety (IPCS), MSF, UNICEF Nigeria, Blacksmith Institute, TerraGraphics, the UNEP Post-Conflict and Disaster Management Branch and OCHA Regional Office, CERF and the Coordination and Response Division) currently involved in response activities and, based on consultations with them, the following mission is proposed to support ongoing activities.

2. Scope of mission

The assistance that would be provided by this mission is not covered by any other stakeholder and/or financing mechanism, and would feed into planned activities of all stakeholders.

The focus of the mission is to provide analytical support for decision-making and priority-setting by the authorities and other actors for the decontamination activities of villages. As such, it is not directly aimed at the medical treatment component of the response activities, but due to the inter-linkages between the two, fully part of the overall response strategy.

The mission will be an independent and impartial assessment mission. It will focus on identifying concentrations of heavy metals (in particular, lead) in well water and surface water and provide recommendations for the decontamination of polluted sources, taking into consideration the means available locally.

Based on the findings, recommendations will be made for remediation and/or decontamination activities that can be undertaken by local authorities and their partners.

Specific objectives include:

- Representative samples of well and surface water (ponds) for drinking water analysis for lead will be taken in the aforementioned villages of: Yarmalga, Dareta, Abare, Kasunke, Tudjun/Tungar Daji, Duza, and Tudun Guru/Tungar Garu/Gidan Guru; Bagega, Kersa, and Rumbuki shall also be considered, time permitting, as shall one or more “control sites” (villages not suspected of contamination) to establish baselines.

- In addition to the water samples, sampling of soil and sludge/sediment might be necessary.

- The samples will be analysed for lead. Drinking water samples will be analysed to meet with the WHO drinking water limit of 10 $\mu g\ l^{-1}$.

- Indicative samples of surface water will be collected to be checked on contamination levels of mercury and copper.

Sampling Strategy and Underlying Assumptions

Drinking water
Depending on the amount of wells/open water, about 50 water samples per village should be taken. A rough estimation shows that the total amount of water samples might be 400.

Sludge/sediment
Depending on the structure of the wells and ponds, sludge/sediment and soil sampling and analysis might also be necessary. This leads to an estimated amount of 300 extra samples.

Surface water
Surface water near sluicing places will be indicatively checked on lead, copper and mercury.

Soil
If soil sampling is needed, we estimate that this will require an extra 100 samples.

The villages are located in an area roughly estimated to be 45 km x 60 km. This means that under normal circumstances, only one village per day can be visited. It should be possible to access all villages from the LGA capital (Bukkuyum/Anka) for day trips.

Therefore, with a total amount of 800 samples and an area of 2700 km^2, a gender-balanced four-member team (two sampling experts, an analysis expert and a team leader/additional sampler) would be required for a minimum deployment time of 14 days.

Mapping support

Currently, no mapping support exists for the ongoing response activities. UNOSAT has generously agreed to provide remote mapping support to assist in the documentation and visualization of all ongoing response activities.

3. Output

Key outputs from the assessment mission will be a consolidated, easy-to-read summary report, which will be made available in English within two weeks of completion of the mission.

4. Mission team members

The team will consist of five persons: a mission team leader (from the JEU) and four staff of the EAM, consisting of two sampling experts, an analysis expert and a team leader/addition sampler.

Equipment

The mission team would bring the following pieces of equipment:

- Hand-held XRF-device with supplies for 400 solid samples
- Water kit and disposables for 400 aqueous samples (analysis for lead, Hg and Cu)
- Sampling equipment for soil
- Sampling equipment for surface water
- Sampling equipment for drinking water
- Sampling equipment for sludge
- 400 containers for liquid samples
- 400 containers for solid samples
- If necessary, vaporized Hg can be checked in hotspots with contaminated water or soil
- Transport (sampling and analysis equipment)
- Personal protective equipment

5. Mission itinerary

The mission will begin in Abuja on Monday 20 September for initial briefings and conclude on Thursday 7 October, comprising 13 full days spent in the field, and time for debriefings in Abuja at the end of the mission.

Logistical support

It is anticipated that in-country support would be required in the domains of:

- Customs clearance of equipment
- Transport in country of team and equipment
- Accommodation

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Table VIII: Overview measurements, sampling and analysis as of September 2010

	Village or Mining Site	Soil	Water	Population estimate		Current remediation status
1	Yargalma village	Yes	5 (NWRI) 3 (MSF)	3000 (NWRI)		"clean"
2	Dareta village	Yes	4 (NWRI) 2 (MSF)	2000 (NWRI)		"clean"
3	Rumbuki village (not affected)	Yes	1 (NWRI) 1 (MSF)			Follow-up recommended
4	Abare village	40 (WHO)	6 (NWRI) 2 (WHO) 3 (MSF)	5000 (NWRI)		Remediation needed
5	Kasunke village	Yes	No			Remediation needed
6	Tudjun Daji village	Yes	No			Remediation needed
7	Duza village	Yes (WHO)	No			Remediation needed
8	Tudun Guru/Gidan Guru/Tungar Garu village	29 (WHO)	2 (NWRI) 4 (WHO) 2 (MSF)	2100 (NWRI)		Remediation needed
9	Tungar Ravk		1 (MSF)			
10	Sunke Mining Site	Yes (WHO) 2 rock samples (NWRI)				Remediation needed
11	"additional villages" (on state health survey)	No	No			Possibly remediation needed
12	Nagaku Mining Site	1 rock sample (NWRI)				
13	Kwali Mining Site	1 rock sample (NWRI)				
14	Gwashi Mining Site	1 rock sample (NWRI)				
15	Lambargudu Mining Site	2 rock samples (NWRI)				
16	+ Bagega					
17	+ Kersa					

Annex IV: Mercury fact sheet

Source: CDC/Agency for Toxic Substances and Disease Registry (www.atsdr.cdc.gov/toxfaqs/TF.asp?id=113&tid=24)

What is mercury?

Mercury is a naturally occurring metal which has several forms. The metallic mercury is a shiny, silver-white, odourless liquid. If heated, it is a colourless, odourless gas.

Mercury combines with other elements, such as chlorine, sulphur, or oxygen, to form inorganic mercury compounds or "salts," which are usually white powders or crystals. Mercury also combines with carbon to make organic mercury compounds. The most common one, methylmercury, is produced mainly by microscopic organisms in the water and soil. More mercury in the environment can increase the amounts of methylmercury that these small organisms make.

Metallic mercury is used to produce chlorine gas and caustic soda, and is also used in thermometers, dental fillings, and batteries. Mercury salts are sometimes used in skin lightening creams and as antiseptic creams and ointments.

Exposure to mercury occurs from breathing contaminated air, ingesting contaminated water and food, and having dental and medical treatments. Mercury, at high levels, may damage the brain, kidneys, and developing fetus.

What happens to mercury when it enters the environment?

- Inorganic mercury (metallic mercury and inorganic mercury compounds) enters the air from mining ore deposits, burning coal and waste, and from manufacturing plants.
- It enters the water or soil from natural deposits, disposal of wastes, and volcanic activity.
- Methylmercury may be formed in water and soil by small organisms called bacteria.
- Methylmercury builds up in the tissues of fish. Larger and older fish tend to have the highest levels of mercury.

How can mercury affect my health?

The nervous system is very sensitive to all forms of mercury. Methylmercury and metallic mercury vapours are more harmful than other forms, because more mercury in these forms reaches the brain. Exposure to high levels of metallic, inorganic, or organic mercury can permanently damage the brain, kidneys, and developing fetus. Effects on brain functioning may result in irritability, shyness, tremors, changes in vision or hearing, and memory problems.

Short-term exposure to high levels of metallic mercury vapours may cause effects including lung damage, nausea, vomiting, diarrhoea, increases in blood pressure or heart rate, skin rashes, and eye irritation.

How does mercury affect children?

Very young children are more sensitive to mercury than adults. Mercury in the mother's body passes to the fetus and may accumulate there. It can also pass to a nursing infant through breast milk. However, the benefits of breast feeding may be greater than the possible adverse effects of mercury in breast milk.

Mercury's harmful effects that may be passed from the mother to the fetus include brain damage, mental retardation, coordination, blindness, seizures, and inability to speak. Children poisoned by mercury may develop problems of their nervous and digestive systems, and kidney damage.

Annex V: Lead fact sheet

Sources: US EPA (www.epa.gov/opptintr/lead/pubs/leadinfo.htm) and CDC/Agency for Toxic Substances and Disease Registry (www.atsdr.cdc.gov/toxfaqs/TF.asp?id=93&tid=22)

What is lead?

Lead is a naturally occurring bluish-gray metal found in small amounts in the earth's crust. Lead can be found in all parts of our environment. Much of it comes from human activities including burning fossil fuels, mining, and manufacturing. Lead has many different uses. It is used in the production of batteries, ammunition, metal products (solder and pipes), and devices to shield X-rays. Due to health concerns, lead from paints and ceramic products, caulking, and pipe solder has been dramatically reduced in recent years.

How can lead affect one's health?

The effects of lead are the same whether it enters the body through breathing or swallowing. Lead can affect almost every organ and system in your body. The main target for lead toxicity is the nervous system, both in adults and children. Long-term exposure of adults can result in decreased performance in some tests that measure functions of the nervous system. It may also cause weakness in fingers, wrists, or ankles. Lead exposure also causes small increases in blood pressure, particularly in middle-aged and older people and can cause anaemia. Exposure to high lead levels can severely damage the brain and kidneys in adults or children and ultimately cause death. In pregnant women, high levels of exposure to lead may cause miscarriage. High level exposure in men can damage the organs responsible for sperm production.

How does lead affect children?

Children are more vulnerable to lead poisoning than adults. A child who swallows large amounts of lead may develop blood anaemia, severe stomach ache, muscle weakness, and brain damage. If a child swallows smaller amounts of lead, much less severe effects on blood and brain function may occur. Even at much lower levels of exposure, lead can affect a child's mental and physical growth. Exposure to lead is more dangerous for young and unborn children. Unborn children can be exposed to lead through their mothers. Harmful effects include premature births, smaller babies, decreased mental ability in the infant, learning difficulties, and reduced growth in young children. These effects are more common if the mother or baby was exposed to high levels of lead. Some of these effects may persist beyond childhood. It is important to note that even children who seem healthy can have high levels of lead in their bodies.

What happens to lead when it enters the environment?

- Lead itself does not break down, but lead compounds are changed by sunlight, air, and water.
- When lead is released to the air, it may travel long distances before settling to the ground.
- Once lead falls onto soil, it usually sticks to soil particles.
- Movement of lead from soil into groundwater will depend on the type of lead compound and the characteristics of the soil.

Lead may cause a range of health effects, from behavioural problems and learning disabilities, to seizures and death. Children six years old and under are most at risk.

Health effects of lead

Childhood lead poisoning remains a major environmental health problem in the United States.

People can get lead in their body if they:

- Put their hands or other objects covered with lead dust in their mouths
- Eat paint chips or soil that contains lead
- Breathe in lead dust, especially during renovations that disturb painted surfaces

Lead is more dangerous to children because:

- Babies and young children often put their hands and other objects in their mouths. These objects can have lead dust on them
- Children's growing bodies absorb more lead
- Children's brains and nervous systems are more sensitive to the damaging effects of lead

If not detected early, children with high levels of lead in their bodies can suffer from:

- Damage to the brain and nervous system
- Behaviour and learning problems, such as hyperactivity
- Slowed growth
- Hearing problems
- Headaches

Lead is also harmful to adults. Adults can suffer from:

- Reproductive problems (in both men and women)
- High blood pressure and hypertension
- Nerve disorders
- Memory and concentration problems
- Muscle and joint pain

Annex VI: Background information on analysis

Lead detection in water with water testing kit method

The Hach Lange GMBH (Düsseldorf, Germany) water test kit is a field portable measuring system for several physical and chemical parameters in water. For lead measurement in water, the Hach Lange portable DR2800 spectrophotometer (Hach Lange GMBH) with the LCK 306 cuvette test (Hach Lange GMBH) was used. The principle of the test is that the available soluble lead will be captured by specific chemicals to form a colourimetric agglomerate. The test was performed according to the manufacturer's description. This lead cuvette test is suitable in the range from 100 µg/l to 2000 µg/l. Therefore, in this report, results below 100 µg/l are reported as <100 µg/l. Note that this test can only measure the dissolved lead in a water sample.

Lead detection in water with GC-MS method

If the results of the lead water testing kit were below 100 µg/l, additional measurements with the GC-MS method were performed. This analytical method is based on the ethylation of lead with tetraethylborate and simultaneous headspace-solid-phase-micro-extraction of the derivative compounds (tetraethyl lead) followed by GC-MS.

The limit of quantification of lead in water is 10 µg/l (with a dynamic range of 10 – 100µg/l).

Chemicals and reagents

Lead nitrate
Acetic acid buffer, 0.2 Molarity, pH = 5.3
Sodium hydroxide, 0.1 Molarity
Nitric Acid, 10 per cent (rinse solution)
Tin standard (2 milligrams per millilitre with pH 1)
Three lead standards (0.2 milligrams per litre (mg/L); 2 mg/L; 20 mg/L with pH 1)
Water blank (with pH 1)

Instruments

The GC-MS apparatus (Agilent 6850 GC and 5975C MSD; Agilent Technologies, Little Falls, DE, USA) with a 0.75 mm (ID empty) liner was used (Injector Temperature was 250° C). The HP-5MS (Agilent Technologies) GC column was a 30 m, x 0.25 mm ID, 0.25 mm film thickness with a constant column pressure of 70 kilo pascals.

GC temperature program: 50° C (1 minute) followed by a 10° C increase per minute for 7 minutes leading to an end temperature of 120° C and finishing with a fast temperature increase of 30° C per minute to an end temperature of 250° C.

Sample preparation

Analyses were performed by adding a 4 millilitre (mL) water sample in a 10 mL headspace vial with a Teflon-coated stir bar (5 mm), 60 microlitre (µL) internal standard (2 mg/L tin solution), 1 mL acetate buffer (pH = 5.3). The sample vial was vigorously shaken and placed in an ultrasonic bath for 10 minutes. The vial was placed in a sand bath (100 mL glass beaker with 50 mL quartz sand placed on a hot plate/stirrer) at 80 °C and stirring rate of 500 revolutions per minute (1 minute incubation time at 80° C). Headspace extraction with solid phase microextraction (SPME) (divinylbenzene/carboxen/polydimethylsiloxane (DVB/CAR/PDMS)) was performed for 15 minutes (see following schematic representation).

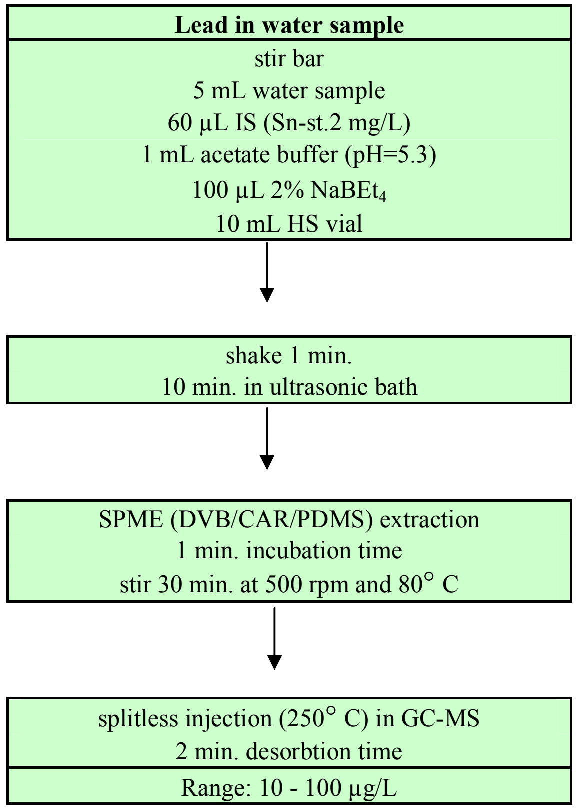

Figure VII: Schematic representation of lead detection in water with the GC-MS method.

Lead detection in sediment and soil with XRF method

The Thermo Scientific NITON® XL3 (Thermo Fisher Scientific, Billerica, USA) is a miniaturized handheld X-ray tube-sourced XRF analyser (Figure VIII). This XRF apparatus can detect the emission of X-rays from a material (such as soil) that has been beamed on with a primary X-ray source. The absorption of radiation and the fluorescence gives information on the elementary content of materials, particularly in the investigation of metals.

The lowest detection limit in (dry) soil for lead is 50 ppm (= 50 mg lead/kg soil). When measuring with the instrument on the ground without any sample preparations, the measured sample might be wet. This might affect the lowest detection limit. Therefore, in this report, results below 100 ppm (100 mg lead/kg soil) are reported as < 100 mg/kg.

The lowest detection limit of lead in water is 2 ppm. This implies that only concentrations above 2000 µg/l can be detected (200 times above the WHO water guideline concentration of 10 µg/l). This detection limit is too high for purposes of this mission. For the detection of lead in water, the water testing kit (range 100µg/l to 2000 µg/l) or the GC-MS (range starting from 5µg/l) techniques can be used.

Figure VIII: Lead measurements were taken on location with the X-Ray Fluorescence analyser (XRF). The apparatus gives direct readings without taking samples.

Mercury detection in air with mercury analyser

The LUMEX RA-915+ portable mercury analyser (Ohio Lumex Co, Twinsburg, OH, USA) employs a differential atomic absorption spectrometry technique (using the direct Zeeman effect) with a mercury lamp (254 nanometres). According to the manufacturer, the limit of detection for mercury in air is 2 ng/m^3. The sample volume is 20 litres of air per minute. This analyser samples in real-time, meaning that the mercury analyser gives instant readings of the sampled air.

Annex VII: Background information on samples

Table IX: The location coordinates of Abare village and additional pH, conductivity and turbidity measurements of the wells.

Note: The Sample ID coordinates differ on Map II on page 19 from the table below (e.g. ABA001 is cited on the map as AB1).

Sample ID	*Sample Type*	*Location coordinates*		*pH*	*Conductivity*	*Turbidity*
		Lat. (N)	*Long. (E)*		*(µS/cm)*	*(NTU)*
ABA001	well water	12,07760	5,95633	6.66	566	8.42
ABA002	sediment	12,07760	5,95633	-	-	-
ABA003	well water	12,07768	5,95700	5.83	1369	3.36
ABA004	surface water	12,07708	5,95583	-	-	-
ABA005	surface water	12,07742	5,95255	-	-	-
ABA006	sediment	12,07742	5,95255	-	-	-
ABA007	sediment	12,07685	5,95623	-	-	-
ABA008	well water	12,07685	5,95623	6.89	761	60.9
ABA009	well water	12,07850	5,95617	6.69	824	13.2
ABA012	well water	12,07702	5,95667	6.49	523	14.7
ABA013	sediment	12,07702	5,95667	-	-	-
ABA014	well water	12,07610	5,95730	6.43	452	27.5
ABA015	well water	12,07760	5,95633	6.71	293	14.5
ABA016	well water	12,07888	5,95752	7.80	278	54.8
ABA017	sediment	12,07888	5,95752	-	-	-
ABA018	well water	12,07818	5,95607	6.70	818	2.53
ABA019	sediment	12,07818	5,95607	-	-	-
ABA020	surface water	12,07678	5,95828	-	-	-
ABA021	surface water	12,07713	5,95747	-	-	-
ABA022	surface water	12,07762	5,95742	-	-	-
ABA023	surface water	12,07810	5,95818	-	-	-
ABA024	well water	12,07623	5,95688	6.85	328	16.8
ABA025	sediment	12,07623	5,95688	-	-	-
ABA026	well water	12,07617	5,95780	6.97	384	79.0
ABA027	sediment	12,07617	5,95780	-	-	-
ABA028	surface water	12,07853	5,95728	-	-	-
ABA029	well water	12,07847	5,95523	6.61	489	1.99

Table X: The location coordinates of Kirsa village and additional pH, conductivity and turbidity measurements of the wells.

Note: The Sample ID coordinates differ on Map III on page 21 from the table below (e.g. KIR001 is cited on the map as KR1).

Sample ID	*Sample Type*	*Location coordinates*		*pH*	*Conductivity*	*Turbidity*
		Lat. (N)	*Long. (E)*		*(µS/cm)*	*(NTU)*
KIR001	well water	11,93108	5,9062	6.63	2230	16.7
KIR002	sediment	11,93108	5,9062	-	-	-
KIR003	well water	11,93015	5,90713	6.80	1385	7.09
KIR004	sediment	11,93015	5,90713	-	-	-
KIR005	well water	11,93098	5,90697	6.85	1377	2.30
KIR006	sediment	11,93098	5,90697	-	-	-
KIR007	well water	11,93087	5,90728	7.01	1226	6.77
KIR008	sediment	11,93087	5,90728	-	-	-
KIR009	surface water	11,9288	5,90605	-	-	-
KIR010	sediment	11,9288	5,90605	-	-	-
KIR011	surface water	11,93022	5,90625	-	-	-
KIR012	surface water	11,93058	5,90492	-	-	-
KIR013	surface water	11,93142	5,90435	-	-	-
KIR014	surface water	11,9314	5,90422	-	-	-

Table XI: The location coordinates of Sunke village and additional pH, conductivity and turbidity measurements of the wells.

Note: The Sample ID coordinates differ on Map IV on page 23 from the table below (e.g. SUN001 is cited on the map as SN1).

Sample ID	Sample Type	Location coordinates		pH	Conductivity (μS/cm)	Turbidity (NTU)
		Lat. (N)	Long. (E)			
SUN001	well water	11,896	5,91207	7.30	1136	1.80
SUN002	well water	11,89477	5,91283	6.83	843	4.51
SUN003	sediment	11,89477	5,91283			
SUN004	well water	11,89538	5,9139	6.87	377	8.25
SUN005	sediment	11,89538	5,9139			
SUN006	well water	11,89738	5,91145	7.16	357	280
SUN007	sediment	11,89738	5,91145			
SUN008	well water	11,89672	5,9108	7.18	424	0.72
SUN009	well water	11,89628	5,91193	6.86	1447	19.6
SUN010	well water	11,8965	5,91222	6.85	1390	1.24
SUN011	well water	11,89683	5,912	7.25	1008	1.70
SUN012	well water	11,89718	5,9119	6.62	1602	24.0
SUN013	well water	11,89542	5,91257	6.84	834	3.15
SUN014	well water	11,895	5,91313	7.35	731	15.4
SUN015	well water	not logged	not logged	6.85	1252	7.69
SUN016	well water	11,89527	5,91347	6.58	1468	1.90
SUN017	well water	11,89553	5,91407	6.73	721	4.65
SUN018	well water	11,89535	5,91423	6.57	677	5.51
SUN019	well water	11,89575	5,91455	6.89	1147	3.04
SUN020	surface water	11,89538	5,91362			
SUN021	surface water	11,89592	5,91337			
SUN022	surface water	11,89615	5,91282			
SUN023	surface water	11,89678	5,9128			
SUN025	surface water	11,89668	5,91077			
SUN026	surface water	11,89705	5,9113			
SUN027	surface water	11,89707	5,91135			
SUN028	surface water	11,89733	5,91153			
SUN029	surface water	11,89683	5,91252			
SUN030	surface water	11,89545	5,91388			

Table XII: The location coordinates of Dareta village and additional pH, conductivity and turbidity measurements of the wells.

Note: The Sample ID coordinates differ on Map V on page 25 from the table below (e.g. DAR001 is cited on the map as DR1).

Sample ID	*Sample Type*	*Location coordinates*		*pH*	*Conductivity*	*Turbidity*
		Lat. (N)	*Long. (E)*		*(µS/cm)*	*(NTU)*
DAR001	surface water	12,01937	5,96042	7.29	33.6	188
DAR002	surface water	12,01997	5,95924	7.09	134.3	7.44
DAR003	well water	12,03005	5,95507	7.21	600	2.28
DAR004	sediment	12,03005	5,95507	-	-	-
DAR005	well water	12,03143	5,95511	7.40	959	0.89
DAR006	surface water	12,02907	5,95443	7.28	164.3	39.6
DAR007	well water	12,03035	5,95375	7.15	525	2.94
DAR008	sediment	12,03035	5,95375	-	-	-
DAR009	surface water	12,03123	5,95448	6.85	176.2	6.30
DAR010	well water	12,03075	5,95388	7.23	814	1.53

Table XIII: The location coordinates of Bagega village and additional pH, conductivity and turbidity measurements of the wells.

Note: The Sample ID coordinates differ on Map VI on page 28 from the table below (e.g. BAG001 is cited on the map as BG1).

Sample ID	Sample Type	Location coordinates		pH	Conductivity	Turbidity
		Lat. (N)	Long. (E)		(μS/cm)	(NTU)
BAG001	well water	11,86858	5,99932	7.38	418	4.91
BAG002	surface water	11,87167	5,99852	7.46	167	27.2
BAG003	well water	11,86718	6,0006	7.30	545	1.01
BAG004	sediment	11,86718	6,0006	-	-	-
BAG005	well water	11,86652	6,00007	7.41	1104	2.66
BAG006	well water	11,86643	6,0006	7.74	602	160
BAG007	sediment	11,86643	6,0006	-	-	-
BAG008	well water	11,8662	6,0007	7.54	692	1.26
BAG009	well water	11,86597	6,0005	7.35	705	1.22
BAG010	sediment	11,86597	6,0005	-	-	-
BAG011	well water	11,8655	6,00048	7.34	903	0.90
BAG012	well water	11,86522	6,00008	7.65	870	2.65
BAG013	well water	11,86607	6,00072	7.53	767	3.41
BAG014	well water	11,86627	6,00103	7.69	581	3.25
BAG015	well water	11,8662	6,00127	7.33	1097	2.11
BAG016	well water	11,86638	6,0011	7.54	724	1.02
BAG017	well water	11,86648	6,00142	7.45	934	1.22
BAG018	well water	11,86718	6,00202	7.41	911	1.72
BAG019	well water	11,8676	6,00217	7.31	805	4.12
BAG020	well water	11,868	6,00198	7.37	912	7.50
BAG021	well water	11,86765	6,00177	7.13	1048	0.69
BAG022	well water	11,86745	6,00195	7.45	900	1.65
BAG023	well water	11,86703	6,00187	7.56	909	1.63
BAG024	well water	11,86705	6,00148	7.31	840	1.11
BAG025	well water	11,86697	6,00157	7.58	773	0.80
BAG026	well water	not logged	not logged	7.32	978	4.11
BAG027	well water	11,86747	6,0014	7.39	1604	1.12
BAG028	well water	11,86356	6,00284	7.31	969	0.89
BAG029	well water	11,8642	6,00322	7.26	473	1.60
BAG030	well water	11,86362	6,00159	7.36	610	1.29
BAG031	well water	11,86366	6,0011	6.97	1066	0.72
BAG032	well water	11,86291	6,00129	7.31	310	1.19
BAG033	well water	11,86465	6,00061	7.27	857	5.55
BAG034	well water	11,8652	6,0007	7.35	1056	1.00
BAG035	surface water	11,86205	6,00495	7.34	55.9	65.5
BAG036	surface water	11,86205	6,00495	7.39	55.7	57.7
BAG037	well water	11,86516	6,00423	7.05	602	1.21
BAG038	well water	11,86536	6,00376	7.35	774	1.38
BAG066	well water	11,86657	6,00333	6.88	410	1.61
BAG067	well water	11,86703	6,00247	7.10	681	0.58
BAG068	well water	11,86638	6,0021	7.41	825	1.24
BAG069	well water	11,86643	6,00147	7.36	932	1.79
BAG070	well water	11,8661	6,00218	7.37	1322	0.92
BAG071	well water	11,86532	6,00205	7.21	923	2.69
BAG072	well water	11,86455	6,00145	7.02	695	1.29
BAG073	surface water	11,86447	6,00095			
BAG074	well water	11,8648	6,00182	7.20	1375	1.80
BAG075	surface water	11,86532	6,00317	6.84	399	36.5