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Levels of Lead in Potable Water Sources of Artisanal Gold Mining Town of Bagega, in Northern Nigeria

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Abstract: *In March 2010 Medecins Sans Frontieres (MSF) discovered an epidemic of lead poisoning in Zamfara state in northern Nigeria, with at least 10, 000 people estimated to be affected; out of which 1, 500 are children under the age of 5 (with 153 mortalities). The source of the outbreak was associated with artisanal gold ore processing that occurs in the villages. For several months, grinding operations were conducted at numerous sites in villages and crushing, washing, and gold recovery were undertaken within residential compounds after the ore is transported from the nearby mines. Of particular concern is the town of Bagega (Lat 11.86°N; Long 6.004°E) in Anka Local Government Area, which is a regional hub for the ore processing and the informal gold trade. Many family compounds in the town have soil lead concentrations above 1 000 ppm. Studies conducted by the Centre for Disease and Control (CDC) in the town tested several hundred children and adults, identified the principal exposure routes, and quantified contamination levels in soils in the village. However, water sources were not investigated. Thus, this study reports the levels of lead in all drinking water sources of the town, which was found to range from 0.057-2.558 Mg/l, higher than the WHO permissible limit of 0.01Mg/l of lead in drinking water.*

Keywords*: Lead, Gold, Mining and Water.*

1. INTRODUCTION

The mining region of northern Nigeria is known since the colonial era. The most popular among the mining sites is Jos, known for its tin mines, followed by the Zamfara mining belt in the late 70's. The Zamfara mining region has deposits of precious metals like tantalite and gold among others [1]. In 2010, Medecins Sans Frontieres *(MSF)* discovered an epidemic of lead poisoning in Zamfara state as a result of gold mining. Subsequent investigations by the Centers for Disease Control (CDC), the World Health Organization (WHO) and the Zamfara State Ministry of Health (ZMoH) confirmed that hundreds of children under age five years were at risk of death or serious acute and long-term irreversible health effects due to extremely high levels of lead and mercury. At least 10, 000 people were estimated to be affected overall. The source of the outbreak was associated with artisanal gold ore processing that occurs in the villages. For several months grinding operations were conducted at numerous sites in villages and crushing, washing, and gold recovery were undertaken within the residential compounds.

A particularly dangerous ore, of high lead content sometimes exceeding 10% lead, was introduced into the processing stream in early 2010. In early April 2010, when death and illnesses became prevalent, these operations were moved outside the residential areas away from the villages. Extremely hazardous exposures associated with residual wastes and contaminated soils remained in the home compounds and exterior processing areas. In May, at the request of the Zamfara State government, the United States (US) and Nigerian CDC conducted an assessment of the extent of the epidemic. At the request of the CDC, the USA firm TerraGraphics Environmental Engineering (TG) and the international NGO Blacksmith Institute (BI) assisted with and provided equipment and expertise in this survey. The assessment confirmed the lead poisoning diagnosis and 163 deaths among children less than five years of age in two villages, tested several hundred children and adults, identified the principal exposure routes, and quantified contamination levels in environmental media in the villages.

While the full scale of the problem is still not fully determined, the survey has revealed at least 43 villages in the State where there are confirmed cases of lead poisoning (blood lead concentration >10 μg/dL). In at least seven of these villages there are children who need chelation therapy (with blood lead concentration >45 μg/dL). This is in addition to the seven villages that have already been remediated, including Abare, Tungar Guru, Tungar Daji, Sunke and Duza [2].

However, of particular concern is the town of Bagega in Anka Local Government Area, which is a regional hub for ore processing and the informal gold trade. The town is situated in Anka, Zamfara state, Nigeria, with geographical coordinates 11° 51' 47" North, 6° 0' 15" East. Many family compounds and communal areas in the town have soil lead concentrations above 1 000 ppm (400 ppm is the limit in the USA for areas where there are children), and it is estimated that 1 500 young children may be poisoned with lead. Before these children can be treated they must have a clean environment to live in.

Jane Cohen, a researcher with New York-based Human Rights Watch who visited the area said the situation was worse than anticipated with "a large number of children exposed to high lead contamination well above the WHO (World Health Organisation) accepted limit.

Most of the victims are from Bagega village, a 9, 000-strong farming and herding community where all 1, 500 children suffer from lead poisoning and one of the devastated communities was Bagega. The community, Bagega provides the worst challenge because it is more than the size of all the other seven villages combined and all the over 1, 500 children in the village suffer from lead poisoning, " Cohen said.

1.1 MINING AND WATER POLLUTION

According to Safe Drinking Water Foundation, SDWF (2014), there are four main types of mining impacts on water quality which includes; Acid Rock Drainage (ARD) is a natural process whereby sulphuric acid is produced when sulphides in rocks are exposed to air and water. Acid Mine Drainage (AMD) is essentially the same process, greatly magnified. When large quantities of rock containing sulphide minerals are excavated from an open pit or opened up in an underground mine, it reacts with water and oxygen to create sulphuric acid. When the water reaches a certain level of acidity, a naturally occurring type of bacteria called *Thiobacillus ferroxidans* may kick in, accelerating the oxidation and acidification processes, leaching even more trace metals from the wastes. The acid will leach from the rock as long as its source rock is exposed to air and water and until the sulphides are leached out – a process that can last hundreds, even thousands of years. Acid is carried off the mine site by rainwater or surface drainage and deposited into nearby streams, rivers, lakes and groundwater. AMD severely degrades water quality, and can kill aquatic life and make water virtually unusable.

Heavy Metal Contamination & Leaching; which is caused when such metals as arsenic, cobalt, copper, cadmium, lead, silver and zinc contained in excavated rock or exposed in an underground mine come in contact with water. Metals are leached out and carried downstream as water washes over the rock surface. Although metals can become mobile in neutral pH conditions, leaching is particularly accelerated in the low pH conditions such as are created by acid mine drainage.

Fig. 1. Community members' interaction with gold mining activities in the lead affected areas.

Processing Chemicals Pollution; which occurs when chemical agents (such as cyanide or sulphuric acid used by mining companies to separate the target mineral from the ore) spill, leak, or leach from the mine site into nearby water bodies. These chemicals can be highly toxic to human and wildlife.

Erosion and Sedimentation; Mineral development disturbs soil and rock in the course of constructing and maintaining roads, open pits, and waste impoundments. In the absence of adequate prevention and control strategies, erosion of the exposed earth may carry substantial amounts of sediment into streams, rivers and lakes. Excessive sediment can clog riverbeds and smother watershed vegetation, wildlife habitat and aquatic organisms. Fig. 1 shows the activities of artisan miners in the lead affected areas.

1.2 LEAD AS A POISON

Lead is a cumulative poison; infants, children up to 6years of age, the fetus and pregnant women being the most susceptible to its adverse health effects. Its effects on the central nervous system can be particularly serious [3]. Overt sign of acute intoxication include dullness, restlessness, irritability, poor attention span, headaches, muscle tremor, abdominal cramps, kidney damage, hallucinations, and loss of memory, encephalopathy occurring at blood lead levels of 100-120µg/dl in adults and 80-100µg/dl in children. Signs of chronic lead toxicity, including tiredness, sleeplessness, irritability, headaches, joint pains and gastrointestinal symptoms, may appear in adults at blood lead levels of 50-80µg/dl.

After 1-2 years of exposure, muscle weakness, gastro intestinal symptoms, lower scores on psychometric tests, disturbances in mood, and symptoms of peripheral neuropathy were observed in occupationally exposed populations at blood lead levels of 40-60 µg/dl [4]. Renal disease has been associated with lead poisoning. Damage to the kidneys includes acute proximal tubular dysfunction at blood lead concentration of 40-80 µg/dl [5]. Also there are indications of increased hypersensitivity at blood lead levels greater than 37 µg/dl. It also interferes with the activity of several of the major enzymes involved in the biosynthesis of heam [4]. The only clinically defined symptom associated with the inhibition of heam biosynthesis is anemia [6]. Lead has been shown to interfere with calcium metabolism, both directly and by interfering with the haem-mediated generation of the vitamin-D precursor 1, 25-Dyhydroxycholecalciferol. Several lines of evidence demonstrate that both the central and peripheral nervous system are the principal targets for lead toxicity. The effects include subencephalopathic neurological and behavioral effects in adults. There is also the electrophysiological evidence of effects on the nervous system of children at blood lead levels below 30 µg/dl [7]. Children as a risk group for central nervous system (CNS) effects have received particular attention in studies dealing with lead-induced neuropsychological defects at blood lead levels between 0.15-0.7 $\mu g/cm^3$. The earlier work describing cognitive dysfunctions, namely IQ deficit, impairment of eye-hand coordination and attention deficits as well as behavioral abnormalities such as hyperactivity has been reviewed [8]. The review concluded that these earlier studies presented no convincing evidence of cognitive deficits associated with blood lead levels below 0.4 $\mu g/cm^3$ in children.

Gonadal dysfunction in men, including decreased sperm counts, has been associated with blood lead levels of 40-50 µg/dl [9]. Reproductive dysfunction may also occur in females occupationally exposed to lead [4]. Epidemiological studies have shown that exposure of pregnant women to lead increases the risk of preterm delivery at blood lead levels above 14 µg/dl [10]. Lead can cause gene mutations and cell transformation in mammalian cells in culture. Lead also interferes with DNA synthesis in mammalian cell in culture. Many studies have shown that feeding lead compounds to rodents induces kidney tumors. Available epidemiologic studies of people occupationally exposed to lead give some indication that occupational exposure to lead may cause cancer. However, in these studies, lead was only one of several known or putative carcinogens present in the occupation environment.

The International Agency for Research on Cancer (IARC) has placed lead in class 2B, possibly carcinogenic to humans, based on sufficient evidence of carcinogenicity from oral exposure studies in animals and inadequate evidence of carcinogenicity in humans. Likewise, the U.S. EPA has placed lead in Group B2, probable human carcinogen, based on sufficient evidence of carcinogenicity from oral exposure studies in animals. The map of zamfara state is presented in fig. 2.

Fig. 2. Map Showing Zamfara State of Nigeria

2. MATERIALS AND METHODS

2.1 COLLECTION OF WATER SAMPLES

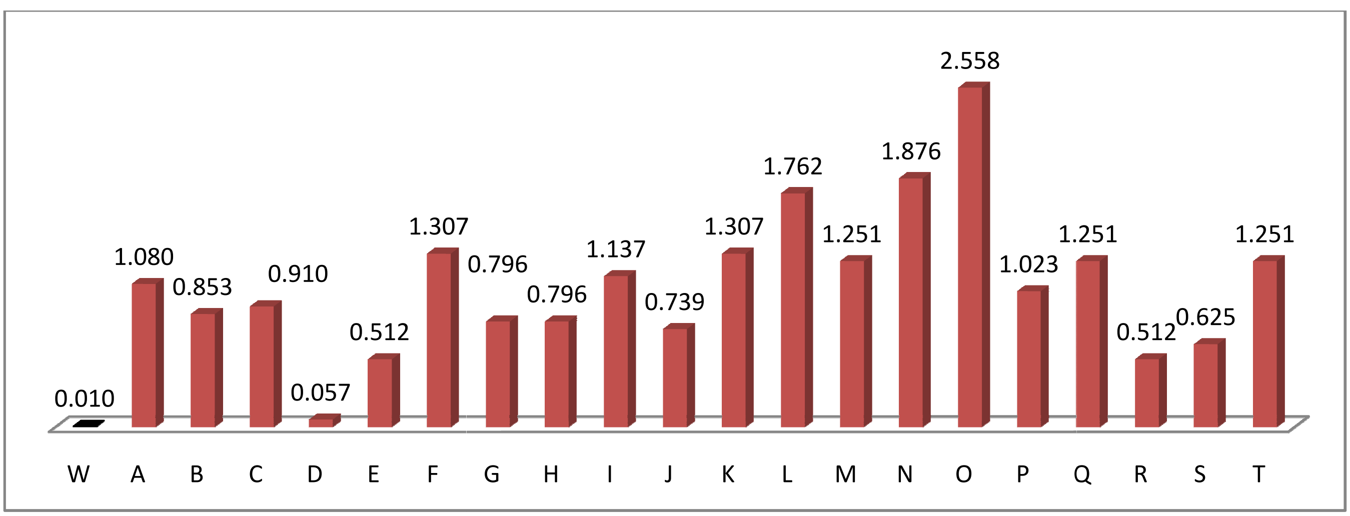
Water Samples were collected in clean plastic containers from all the sources of potable water in the village which includes ordinary wells, concrete reinforced wells and boreholes (both solar powered and hand pumped). The containers were previously cleansed by washing in detergent, rinsed with tap water and later soaked in 10% HNO_3 for 24 hours and finally rinsed with deionized distilled water prior to use. The samples were stored at 4^0C. The sampling locations were coded as follows: **A=** *Turmuzawa {Ordinary Well}*: **B=** *Tudun Wada (Concrete reinforced well)*: **C=** *Garka (Solar Borehole)*: **D=** *Dankaka Borehole (Hand Pumped)*: **E=** *Dam*: **F=** *Shiyyar Marafa (Concrete reinforced well)*: **G=** *Rijiyar Mayana (Concrete reinforced well)*: **H=** *Rijiyar Gwagwi (Concrete reinforced well)*: **I=** *Rijiyar Yamma (Concrete reinforced well)*: **J=** *Kuranmota Gidan Sani Chibi (Ordinary Well)*: **K=** *Rijiyar Kasuwar Gida (Concrete reinforced well)*: **L=** *Rijiyar Saulawa (Concrete reinforced well):* **M=** *Rijiyar Yar Kurna (Concrete reinforced well)*: **N=** *Rijiyar Makaranta (Concrete reinforced well)*: **O=** *Sabonfegi Gidan Mal Abdullahi (Ordinary Well)*: **P=** *Rijiyar Rawayya (Concrete reinforced well)*: **Q=** *Sabonfegi Gidan Dankwanchami (Ordinary Well)*: **R=** *Rijiyar Madalma Tasha (Ordinary Well)*: **S=** *Kara Zube Masallacin Izala (Ordinary Well)*: **T=** *Rijiyar Kasuwar Daji (Concrete reinforced well).*

2.2 WATER DIGESTION AND ANALYSIS

The sample bottle was shaken thoroughly before measuring 50 mL into a beaker. 5 mL of concentrated HNO_3 was added and boiled slowly on a hot plate until the volume is reduced to about 20 mL. Concentrated HNO_3 was further added, covered with a watch glass, and heated. Addition of HNO_3 and heating was continued slowly until the solution appears light coloured and clear. This indicates that digestion is complete. Do not allow to dry during digestion. The beaker walls and watch glass were washed down with water. The filtrate was transferred to a 50 mL volumetric flask, cooled and made up to the mark with deionised distilled water [11]. The analysis was conducted using an Atomic Absorption Spectrophotometer (AA 6500) and the result was posted in milligram of lead per litre of water (Mg/l).

3. RESULTS AND DISCUSSION

Water quality standards vary from one country to the other. In most developing countries like Nigeria, the standards are not strictly adhered to due to accessibility issues related to water sanitation. Physico-chemical properties of water like temperature and pH are important properties that determine the mobility of metals in solution and consequently the water quality. The average temperature of samples in this study (19.10 ± 0.01) was higher than the average water temperature of 7.22 for Itaogbolu area of Ondo state reported by Adefemi and Awokunmi [12], while the average pH recorded in this study (5.30 ± 0.15) was slightly low compared to the WHO value. Fig. 3, presented the average concentration of lead in the water samples collected across Bagega, while table 1 presented the two-tailed analysis of the results.



Note: W=World Health Organisation limit:

Fig. 3. Average lead concentration (mg/l) in water samples across Bagega town.

Considering the fact that the WHO guideline value for lead in drinking water is 0.01 mg/l, it can be seen that none of the water sources can be considered safe for domestic utilities. In fact it is scary to see some of the samples with lead levels above 2 mg/l. All the samples have water lead levels far above all known standards. For instance the European Union (EU) maximum admissible concentration of lead in drinking water is 0.05 mg/l while the US Environmental

Protection Agency (EPA) maximum contamination level of lead in drinking water is 0.015 mg/l. Canada has maximum acceptable concentration of 0.01 mg/l. Other similar but past studies have also reported varying lead concentrations in drinking water. Table 1 suggested the correlation within of lead presence with the different samples studied. This was found to be closely related to previous studied conducted and reported elsewhere. For instance, Levei et al [13] have reported a lead level of up to 0.4 mg/l. Matsusha et al [14] reported a range of 28-142 in a gold mine tailings dam. WHO 2011 [15] recorded a maximum of 3.15 mg/l for samples collected over four seasons. However, none of these studies reported a value higher than this unbelievable amount of lead recorded in this study.

4. CONCLUSIONS

High level of lead was found in almost all the water samples collected in Bagega community, one of the lead poisoned areas of Zamfara state in northern Nigeria. The study revealed the presence of additional potentially toxic heavy metals high needs to be monitored as well.

5. RECOMMENDATIONS

The situation needs to be given an utmost attention to avert a catastrophe and further studies on all toxic metals/metalloids should be conducted on the soil, water and plants available in the town. Boreholes should be dug in farther and safer areas, which can now be piped to the town and also chemical treatment of the existing boreholes water should commence immediately. Then chelation therapy for the inhabitants should be done vigorously. The inhabitants should also be made aware of the dangers as well as alternative sources of cleaner water and finally, a new settlement should be constructed for them in a safer place.

TABLE 1: Pearson correlation (2-tailed ANOVA) of lead in various water samples in Bagega town

		A	B	C	D	E	F	G	H	I	J	K	L	M	N
A	Pearson Correlation	1	.487	.458	.216	-.950	.589	-.824	-.434	.873	.275	-.578	-.347	-.631	.489
	Sig. (2-tailed)		.677	.697	.862	.201	.599	.383	.714	.325	.823	.608	.774	.565	.675
	N	3	3	3	3	3	3	3	3	3	3	3	3	3	3
B	Pearson Correlation	.487	1	.999*	.958	-.191	-.419	.094	-.998*	.851	-.706	-.994	-.988	-.985	1.000**
	Sig. (2-tailed)	.677		.021	.185	.878	.725	.940	.038	.352	.501	.069	.098	.111	.002
	N	3	3	3	3	3	3	3	3	3	3	3	3	3	3
C	Pearson Correlation	.458	.999*	1	.967	-.158	-.449	.126	-1.000*	.834	-.729	-.990	-.993	-.979	.999*
	Sig. (2-tailed)	.697	.021		.164	.899	.704	.919	.017	.373	.480	.090	.077	.132	.023
	N	3	3	3	3	3	3	3	3	3	3	3	3	3	3
D	Pearson Correlation	.216	.958	.967	1	.099	-.662	.375	-.973	.665	-.880	-.921	-.991	-.894	.957
	Sig. (2-tailed)	.862	.185	.164		.937	.539	.755	.148	.537	.315	.254	.088	.296	.187
	N	3	3	3	3	3	3	3	3	3	3	3	3	3	3
E	Pearson Correlation	-.950	-.191	-.158	.099	1	-.811	.959	.132	-.677	-.560	.295	.038	.358	-.194
	Sig. (2-tailed)	.201	.878	.899	.937		.398	.182	.916	.526	.622	.809	.976	.767	.876
	N	3	3	3	3	3	3	3	3	3	3	3	3	3	3
F	Pearson Correlation	.589	-.419	-.449	-.662	-.811	1	-.943	.472	.120	.939	.319	.553	.255	-.416
	Sig. (2-tailed)	.599	.725	.704	.539	.398		.216	.687	.924	.224	.793	.627	.836	.727
	N	3	3	3	3	3	3	3	3	3	3	3	3	3	3
G	Pearson Correlation	-.824	.094	.126	.375	.959	-.943	1	-.152	-.443	-.771	.014	-.245	.081	.091
	Sig. (2-tailed)	.383	.940	.919	.755	.182	.216		.903	.708	.440	.991	.843	.949	.942
	N	3	3	3	3	3	3	3	3	3	3	3	3	3	3
H	Pearson Correlation	-.434	-.998*	-1.000*	-.973	.132	.472	-.152	1	-.819	.747	.986	.996	.973	-.998*
	Sig. (2-tailed)	.714	.038	.017	.148	.916	.687	.903		.389	.463	.106	.060	.149	.040
	N	3	3	3	3	3	3	3	3	3	3	3	3	3	3
I	Pearson Correlation	.873	.851	.834	.665	-.677	.120	-.443	-.819	1	-.230	-.903	-.761	-.929	.853
	Sig. (2-tailed)	.325	.352	.373	.537	.526	.924	.708	.389		.852	.283	.449	.241	.350

	N	3	3	3	3	3	3	3	3	3	3	3	3	3	3
J	Pearson Correlation	.275	-.706	-.729	-.880	-.560	.939	-.771	.747	-.230	1	.626	.806	.573	-.704
	Sig. (2-tailed)	.823	.501	.480	.315	.622	.224	.440	.463	.852		.569	.403	.612	.503
	N	3	3	3	3	3	3	3	3	3	3	3	3	3	3
K	Pearson Correlation	-.578	-.994	-.990	-.921	.295	.319	.014	.986	-.903	.626	1	.966	.998*	-.994
	Sig. (2-tailed)	.608	.069	.090	.254	.809	.793	.991	.106	.283	.569		.167	.042	.067
	N	3	3	3	3	3	3	3	3	3	3	3	3	3	3
L	Pearson Correlation	-.347	-.988	-.993	-.991	.038	.553	-.245	.996	-.761	.806	.966	1	.947	-.988
	Sig. (2-tailed)	.774	.098	.077	.088	.976	.627	.843	.060	.449	.403	.167		.209	.100
	N	3	3	3	3	3	3	3	3	3	3	3	3	3	3
M	Pearson Correlation	-.631	-.985	-.979	-.894	.358	.255	.081	.973	-.929	.573	.998*	.947	1	-.985
	Sig. (2-tailed)	.565	.111	.132	.296	.767	.836	.949	.149	.241	.612	.042	.209		.109
	N	3	3	3	3	3	3	3	3	3	3	3	3	3	3
N	Pearson Correlation	.489	1.000**	.999*	.957	-.194	-.416	.091	-.998*	.853	-.704	-.994	-.988	-.985	1
	Sig. (2-tailed)	.675	.002	.023	.187	.876	.727	.942	.040	.350	.503	.067	.100	.109	
	N	3	3	3	3	3	3	3	3	3	3	3	3	3	3

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

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