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Estimation of excess lifetime cancer risk due to heavy metals: A case study of Dana steel limited dumpsite, Kastina, Nigeria

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ABSTRACT/RESUME

Abstract: *This study was carried out to assess the excess lifetime cancer risk of the exposure of children and adults population living in the vicinity of Dana steel limited dumpsite, Katsina state Nigeria to heavy metal contamination through ingestion, inhalation and dermal pathways. Soil samples were analyzed for Chromium (Cr), Arsenic (As) and Lead (Pb) by atomic absorption spectrophotometry. The total cancer risk values due to ingestion and inhalation pathways in both adults and children were found to be above the requirement and were majorly contributed by Chromium (Cr). The excess lifetime cancer risk was found to have mean value of 9.66E-03(9660 out of 1 million) and 4.85E-05(49 out of 1 million) for adults and children respectively. These carcinogenic risk values were higher than acceptable value of 1.00E-06 (1 out of 1 million) for all population ages indicating significant risk to the populace.*

I. Introduction

Heavy metals are a group of widespread pollutants in the environment that mostly originate from traffic industrial activities, domestic emission and weathering of buildings and pavements [10, 35]. Although some natural sources result in heavy metals emissions, human activities contribute most of their emissions in urban systems [33, 27]. The potential of continuous exposure to toxic atmospheres makes it necessary for rigorous monitoring of the chemical agents in the environment. In order to prevent damage to health it is necessary to gather information on the levels of heavy metals in soils of industrial dumpsites and evaluate exposure to the members of public due to these chemical agents. Soil is prone to contamination both from industrial and natural sources. When soil is the receptor of industrial tailings originating from extracting of iron from metal scraps for steel production, this waste disposal causes a major impact, and poses serious environmental concerns [9]. As a direct result of this industrial activity, soil is generally, affected over a considerable area. The soil fine fraction is usually enriched in metals, due to the relative large surface area of fine particles that facilitate adsorption and metal binding to iron and manganese oxides and to organic matter [25, 36]. Wind-blown dust originating from polluted soil is responsible for the aerial dispersion of trace metals [11]. Exposure to these hazardous elements may have different pathways, e.g., through the direct ingestion of soils and dust, ingestion of vegetables grown on contaminated soil or dust adhering to plants or dust inhalation. According to several authors [11, 8, 13, 25, 18, 14]. the studies dealing with the bioavailability and bio-accessibility of metal(loid) contaminants in highly-polluted soil are extremely useful to understand the possible effect on biota, and particularly on human health due to the exposure to these contaminants [25,3]. Exposure to increasing amounts of metal(loid)s in environmental and occupational settings is a reality worldwide, affecting a significant number of individuals. Most metal(loid)s are very toxic to living organisms and even those considered as essential can be toxic when in excess. They can disturb important biochemical processes, constituting an important threat for human health. Major health effects include development retardation, endocrine disruption, kidney damage, immunological and neurological effects, and several types of cancer [20]. The identification of potential threats to human health and natural ecosystems is useful information [24].The quantification of all the types of risks and the determination of the total risk of metal(loid)s to the exposed population through oral intake, inhalation and dermal contact is also very important [28].Risk assessment is typically a multistep process of identifying, defining, and characterizing potentially adverse consequences of exposure to hazardous materials. According [28] As, Cr and Pb are known to be toxic to humans and were classified as carcinogens. In today's industrial society, there is no escaping exposure to toxic chemicals and metals. This is so because somehow, our society is dependent upon metallurgy for proper functioning. It is therefore not surprising that human exposure to heavy metals has risen dramatically in the last 50 years as a result of an exponential increase in the use of heavy metals and/or their compounds in industrial and agricultural processes. In the United States for instance, tons of toxic industrial wastes are reportedly mixed with liquid agricultural fertilizers and dispersed across America's farmlands [32].Mining, manufacturing and the use of synthetic products (for example, pesticides, paints, batteries, industrial waste, and land application of industrial or domestic sludge) can result in heavy metal contamination of urban and agricultural soils. Potentially contaminated soils may occur at old landfill sites (particularly those that accepted industrial wastes), old orchards that used insecticides containing arsenic as an active ingredient, fields that had past applications of waste water or municipal sludge, industrial areas where chemicals may have been dumped on the ground, or in areas downwind from industrial sites [32]. Environmental contamination and exposure to heavy metals is a serious growing problem throughout the world, as both natural sources and anthropogenic processes emit heavy metals into various environmental media. The rapid industrialization and urbanization of the world have dramatically heightened these emissions, thus increasing the overall environmental load of heavy metals and consequent human exposures to them. Arsenic and its compounds is also possessing great human exposure scenario as they are used in pesticides, insecticides, herbicides, and some kinds of alloys and their containers can be found everywhere in steel rolling dumpsites. Contaminated food, water, air and cigarette smoking are part of the sources of exposure to arsenic [2, 21]. As for lead, human exposure also occurs through food, water, air and soil. People can be exposed to lead contamination from industrial sources such as lead smelting and manufacturing industries [16].Though the risk of lead contamination from motor vehicle exhaust of leaded gasoline has decreased in the last couple of decades as a consequence of reduction of lead addition to petrol [26], because lead is a cumulative metal, it still remains a major hazard for human health. Same is the case for many metals because of the problem of non-degradability and accumulation. Occupational activities are part of the environmental factors responsible for environmental distributions and human exposures to metals. Workers that produce or use various metals (for example, arsenic) and their compounds are also at the risk of their exposure. Indeed, many occupations involve daily heavy metal exposures. It is therefore not quite surprising that despite the efforts of the regulatory agencies, many studies have demonstrated variable concentrations of various heavy metals in various environmental media, thus indicating that the problem of environmental metal pollution is very much around us. Toxic heavy metals have no function in the body and can be highly toxic. The metals are taken into the body through inhalation, ingestion and skin absorption. If heavy metals enter and accumulate in body tissue faster than the body's detoxification pathways can dispose of them, a gradual build-up of these toxins will occur. High concentration exposure is not necessary to produce a state of toxicity in the body tissues and over time, toxic concentration levels may be reached. Heavy metals are dangerous not only because of their inherent nature but also because of their bioaccumulate tendency and problem of bio magnifications with increasing trophic levels, and therefore can cause permanent damage to health. While the inorganic form of the metal may not be easily taken up, the organic (alkylated) forms are readily taken up by body tissues and can be retained for a considerable length of time [6, 15]. Excess heavy metal accumulation in soils is toxic to humans and other animals. Exposure to heavy metals is normally chronic (exposure over a longer period of time) due to food chain transfer. Acute (immediate) poisoning from heavy metals is through ingestion or dermal contact. Chronic problems associated with long-term heavy metal exposures are: lead, mental lapse; cadmium, affects kidney, liver, and gastrointestinal tract; arsenic, skin poisoning, affects kidneys and central nervous system. Heavy metal toxicity can result in damaged or reduced mental and central nervous function, lower energy levels, and damage to blood composition, lungs, kidneys, liver, and other vital organs. Long-term exposure may result in slowly progressing physical, muscular, and neurological degenerative processes that mimic Alzheimer's disease, Parkinson's disease, muscular dystrophy, and multiple sclerosis. Allergies are not uncommon and repeated long-term contact with some metals or their compounds may even cause cancer [17]. Most human load of toxic metals is acquired from the ambient concentrations of these metals through inhalation of dust and fumes,

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ingestion of food and drink and/or absorption through skin in extreme cases [1, 22]. However the most classical toxicities associated with these metals have come through massive pollution of the environment through industrial activities. Apart from the raw materials or process chemicals, production of wastes is an integral part of industrial activities that can increase the metal load of the ambient environment through pollution of the environment with metal-bearing wastes in the form of solids, liquids, gases and air-borne particulate matter; and quite often, facilities needed for their proper disposal are not adequate. This underscores the need for investigation into the toxic metal load of our immediate environment, given the massive degradation suffered by most of our cities from various forms of wastes. This work therefore hopes to estimate the carcinogenic potential of soils from Dana steel limited dumpsite located in Katsina state of Nigeria due to exposure from As, Pb and Cr concentrations using models provided by the United States environmental protection agency.

II. Materials and methods

II.1 Study area

Dana steel limited dumpsite is located in latitude 12º 57¹ 43¹¹N to 12º 58¹ 7¹¹N, Longitude 7º 37¹11¹¹E to 7º 37¹ 16¹¹E and altitude 522.5m to 616.6m in Katsina state of Nigeria. The dumpsite was partitioned into nine (9) grid points labeled A-I. Soil samples were collected randomly from each grid at varying depths of 0-<80cm using hand auger. Nine soil samples were collected from each depth making a total of 36 samples. After removal of stones and some metal scraps, each soil sample was packed into its own secure water tight polythene bag to prevent cross contamination.

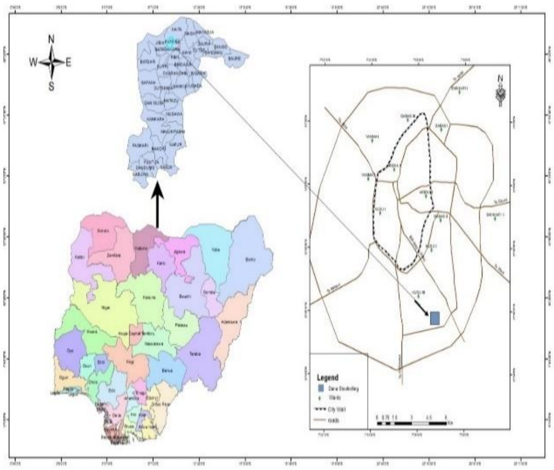

Figure 1. *Map of the Study Area.*

II.2 Sample preparation and analysis

All soil samples were air-dried at ambient laboratory temperature. Soil samples were grounded using mortar and pestle and sieved to pass through 2 mm sieve and stored for chemical analysis. With the aid of spatula and weighing bottle, 0.5g of each soil sample was obtained. This was placed in a Teflon beaker and transferred to a fume-cupboard for digestion. The digestion was carried out using concentrated nitric (10 mL) and concentrated perchloric (5 mL) acids in the ratio of 2:1 and the oven was maintained at 200^{oC}. After one hour, the mixture was allowed to cool before leaching the residue with 5 cm3 of 20% HNO3. Digested samples were then filtered and made up to 100 mL with deionized water. A blank determination was treated in the Atomic Absorption Spectrometer but without sample. Solution of samples were then taken and aspirated into Atomic Adsorption Spectrophotometer (Unicam Solar A.A.S 969 model) for analyzing metals. Blank determination was also carried out as in a similar way as described above except for the omission of the sample. A calibration graph was plotted for each element using measured absorbance and the corresponding concentration. The calibration curve was used to determine the concentration of the metal [4, 5].

II.3 Theory of Risk Assessment

Human health risk assessment is a process used to estimate the health effects that might result from exposure to carcinogenic and non-carcinogenic chemicals [29]. The risk assessment process is made up of four basic steps: hazard identification, exposure assessment, toxicity (dose-response) assessment, and risk characterization [21]. Hazard Identification basically aims to investigate chemicals that are present at any given location, their concentrations, and spatial distribution. In the study area, As, Pb, Cd and Cr were identified as possible hazards for the community. The purpose of exposure assessment is to measure or estimate the intensity, frequency, and duration of human exposures to an environmental contaminant. In the study, exposure assessment was carried out by measuring the average daily intake (ADI) of heavy metals earlier identified through ingestion, inhalation and dermal contact by adults and children from the study area. Adults and children are separated because of their behavioral and physiological differences [34].for carcinogenic risk assessment the cancer slope factors estimates the toxicity due to exposure levels of chemicals and hence is the important toxicity index used. Risk characterization predicts the potential cancerous health risk of children and adults in the study area by integrating all the information gathered to arrive at quantitative estimates of excess lifetime cancer risk [31].The potential exposure pathways for heavy metals in contaminated soils are calculated based on recommendations by several American publications. ADI (mg/kg-day) for the different pathways were calculated using the following exposure Eqs. 1–3 as prescribed by [30].

II.3.1 Ingestion of Heavy Metals through Soil

$$ADIing = C * IR * EF * ED * \frac{CF}{BW*AT} \quad (1)$$

Where ADIing is the average daily intake of heavy metals ingested from soil in mg/kg-day,

C = concentration of heavy metal in mg/kg for soil. IR in mg/day is the ingestion rate, EF in days/year is the exposure frequency, ED is the exposure duration in years, BW is the body weight of the exposed individual in kg, AT is the time period over which the dose is averaged in days. CF is the conversion factor in kg/mg.

II.3.2 Inhalation of Heavy Metals via Soil Particulates

$$ADIinh = Cs * IRair * EF * ED * \frac{CF}{BW * AT * PEF} \quad (2)$$

Where ADIinh is the average daily intake of heavy metals inhaled from soil in mg/kg-day, CS is the concentration of heavy metal in soil in mg/kg, IRair is the inhalation rate in m^3/day, PEF, is the particulate emission factor in m^3/kg. EF, ED, BW and AT are as defined earlier in Eq. 1.

II.3.3 Dermal Contact with Soil

$$ADIderm = Cs * SA * FE * AF * ABS * EF * ED * \frac{CF}{BW*AT} \quad (3)$$

Where ADIderm is the exposure dose via dermal contact in mg/kg/day. CS is the concentration of heavy metal in soil in mg/kg, SA is exposed skin area in cm^2, FE is the fraction of the dermal exposure ratio to soil, AF is the soil adherence factor in mg/cm2, ABS is the fraction of the applied dose absorbed across the skin. EF, ED, BW, CF and AT are as defined earlier in Eq. 1 before. Table 1 shows the exposure parameters used for the health risk assessment for standard residential exposure scenario through different exposure pathways.

***Table1**: Exposure parameters used for the assessment of carcinogenic health risk through different exposure pathways for soil*

Parameter	Unit	Child	Adult
Body weight (BW)	Kg	15	70
Exposure frequency (EF)	days/year	350	350
Exposure duration (ED)	Years	6	30
Ingestion rate (IR)	mg/day	200	100
Inhalation rate (IRair)	m^3/day	10	20
Skin surface area (SA)	cm^2	2100	5800

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Soil adherence factor (AF)	mg/cm^2	0.2	0.07
Dermal absorption factor (ABS)	None	0.1	0.1
Dermal exposure ratio (FE)	None	0.61	0.61
Particulate emission facor (PEF)	m^3/kg	1.3E+09	1.3E+09
Conversion factor (CF)	kg/mg	E-06	E-06
Averaging time (AT)	Days	365*70	365*70

Source: [12, 31]

II.3.4 Carcinogenic risk assessment

For carcinogens, the risks are estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen. Eq. 4 shows the excess life time cancer risk.

$$Risk_{pathway} = \sum_{k=1}^{n} ADI_k CSF_k \quad (4)$$

Where, Risk is a unit less probability of an individual developing cancer over a lifetime. ADIk (mg/kg/day) and CSFk are the average daily intake and the cancer slope factor respectively for the Kth heavy metal, for n number of heavy metals. The slope factor converts the estimated daily intake of the heavy metal averaged over a lifetime of exposure directly to incremental risk of an individual developing cancer (USEPA,1989).the total excess lifetime cancer risk for an individual is finally calculated from the average contribution of the individual heavy metals for all the pathways using the Eq. 5

$$Risk_{total} = Risk_{ing} + Risk_{inh} + Risk_{dermal} \quad (5$$

Where Risk(ing), Risk(inh) and Risk(derm) are risks contributions through ingestion, inhalation and dermal pathways. The carcinogenic risk assessment is calculated using cancer slope factors provided in Table 2

***Table 2**: Cancer slope factors (CSF) in (mg/kg/day) for the different heavy metals*

Heavy Metals	Oral CSF	Dermal CSF	Inhalation CSF
As	1.50E+00	1.50E+00	1.50E+01
Pb	8.50E-03	-	4.20E-02
Cd	-	-	6.30E+00
Cr (VI)	5.00E-01	-	4.10E+01
Co	-	-	9.80E+00

Source: [12, 31].

III. Results and discussion

Toxic metals were detected at varying concentrations in the samples except for Pb and Cr which were not detected in some samples due to the detection limit of the machine used.Table3 Summarizes the concentrations (mg/kg) of the heavy metals studied. The mean and standard deviations of the concentrations of Cr, As and Pb in the dumpsite soil samples were 1096.296±912.090, 0.564±0.081, 202.100±208.116mg/kg respectively. The Highest concentration corresponds to Cr and the lowest corresponds to As. The increasing trend was in the order: As <Pb <Cr. The obtained Average concentrations were compared with the results obtained by other researchers on similar Sites. [23] Analyzed heavy metal contents in steel rolling industrial Area of Ikirun, Osun State Nigeria and [24] studied heavy metals contaminations of soil and water at scrap market in Accra. the obtained average concentration (mg/kg) in this work corroborates with the results of those researchers. The High Cr and Pb

concentrations observed in this study corroborates with that obtained by [23].

Table3. *Univariate descriptive Statistics of the concentration of the toxic metals (mg/kg) (n=36)*

Toxic metal	Mean	Minimum	Maximum
Cr	1096.296	800.000	4800.00
As	0.564	0.430	0.740
Pb	202.100	91.000	818.200

III.2 Carcinogenic health risk of heavy metals for adults and children

The concentrations of heavy metals (mg/kg) in the analyzed soil samples from Dana steel limited dumpsite were used for the computation of annual daily intake values (mg/kg/day) using the models provided by equation1,2 and 3 for oral ,inhalation and dermal pathways respectively. The exposure parameters provided by Environmental protection agency were used for the computation. The obtained annual daily intake values were subjected to descriptive statistics using MS Excel 2010 and the Mean, minimum and maximum values corresponding to each heavy metal for a particular receptor (adult and children) via a particular pathway were presented in table 4.the obtained annual daily intake values were further used for the computation of cancer risk using equation 4 and 5 and the cancer slope factors provided by [29] in table2**.**the total excess lifetime cancer risk in adults and children for each pathway due to exposure from all the studied heavy metals was also calculated and the results were also subjected to descriptive statistics with the mean, minimum and maximum presented in table 5**.**The calculated risk indices were compared with the united states environmental protection guidelines for maximum cancer risk of 1E-06 .based on this guideline, it was found that the values of cancer risks for Cr were seriously above the limits for all the exposure pathways (ingestion, inhalation, dermal) in both adults and children implying that both population ages are at serious risk of developing cancer in their lifetime due to Cr exposure. The mean cancer risk values of Cr were found to be 9.654E-03 and 3.045E-06 in adults via ingestion and inhalation pathways respectively with maximum values of 5.63E-02 and 1.778E-05 respectively. For children the mean cancer risk values were estimated to be 4.51E-05 and 1.421E-06 for ingestion and inhalation pathways respectively with maximum values of 2.63E-04 and 8.295E-06 .for Pb some cancer risk values were too high for both adults and children in ingestion pathway with maximum values of 4.08E-06 and 7.62E-06 for adults and children respectively. For As the cancer risk values were found to be too high in some samples for ingestion in children with maximum values of 1.22E-06.the cancer risk due to Cd and Co were found to be within the requirement for all the samples in all the exposure pathways. The total cancer risk values due to ingestion pathway in adults and children were found to be above the requirement and were majorly contributed by Cr, Pb and As in both adults and children. For the inhalation pathway, the total cancer risk values were found to be above the requirement with major contribution mainly from Cr. for dermal, the cancer risk values due to As were all within the requirement indicating no risk to members of population. From table5 it could be seen that the total excess lifetime cancer risk was found to have maximum and minimum values of 2.73E-04 and 9.23E-07 for children, 5.64E-02 and 6.07E-07 for adults.

Table 4. *Summary statistics of average daily intake (ADI) values in mg/kg/day for adults and children in soils from Dana Steel Limited Dumpsite for carcinogenic risk calculations*

Parameters	Receptor	Statistical parameter	Average daily intake values (ADI) for heavy metals in (mg/kg/day)			
			Pb	As	Cr	Cd
ADI_{ing} (mg/kg/day)	Adult	Mean	5.93E-05	3.31E-07	4.83E-04	8.82E-06
		Minimum	N/D	2.52E-07	N/D	2.35E-07
		Maximum	4.80E-04	4.34E-07	2.82E-03	1.84E-05
	Children	Mean	1.11E-04	6.18E-07	9.01E-04	1.65E-05

		Minimum	N/D	4.71E-07	N/D	4.38E-07
		Maximum	8.97E-04	8.11E-07	5.26E-03	3.44E-05
ADI_{inh} (mg/kg/day)	Adult	Mean	9.13E-09	5.09E-11	7.43E-08	1.35E-09
		Minimum	N/D	3.88E-11	N/D	3.61E-11
		Maximum	7.39E-08	6.68E-11	4.34E-07	2.83E-09
	Children	Mean	4.26E-09	2.38E-04	3.47E-08	6.33E-10
		Minimum	N/D	1.81E-11	N/D	1.69E-11
		Maximum	3.45E-08	3.12E-11	2.02E-07	1.32E-09
ADI_{derm} (mg/kg/day)	Adult	Mean	1.40E-05	8.20E-08	1.20E-04	2.18E-06
		Minimum	N/D	6.25E-08	N/D	5.82E-08
		Maximum	1.19E-04	1.08E-07	6.98E-04	4.57E-06
	Children	Mean	1.42E-05	7.92E-08	1.15E-04	2.11E-06
		Minimum	N/D	6.04E-08	N/D	5.62E-08
		Maximum	1.15E-04	1.04E-07	6.74E-04	4.41E-06

N/D: not detected

Table 5. *Summary statistics of calculated cancer risk values for adults and children in soils from Dana steel limited dumpsite*

Parameter	Receptor	Statistical parameter	Cancer Risk values				Total cancer risk
			Pb	As	Cd	Cr	
Risk (Ingestion)	Adult	Mean	5.04E-07	4.97E-07	-	9.65E-03	9.66E-03
		Minimum	N/D	3.79E-07	-	N/D	4.23E-07
		Maximum	4.08E-06	6.52E-07	-	5.63E-02	5.63E-02
	Children	Mean	9.41E-07	9.27E-07	-	4.51E-05	4.69E-05
		Minimum	N/D	7.07E-07	-	N/D	7.89E-07

		Maximum	7.62E-06	1.22E-06	-	2.63E-04	2.650E-04
Risk (Inhalation)	Adult	Mean	3.83E-10	7.64E-10	8.55E-09	3.05E-06	3.11E-06
		Minimum	N/D	7.83E-10	2.28E-10	N/D	6.571E-08
		Maximum	3.10E-09	1.00E-09	1.79E-08	1.78E-05	1.78E-05
	Children	Mean	1.79E-10	3.57E-10	2.66E-11	1.42E-06	1.45E-06
		Minimum	N/D	2.72E-10	7.08E-13	N/D	2.54E-08
		Maximum	1.45E-09	4.68E-10	5.56E-11	8.30E-06	8.32E-06
Risk (Dermal)	Adult	Mean	-	1.23E-07	-	-	1.23E-07
		Minimum	-	9.39E-08	-	-	9.39E-08
		Maximum	-	1.61E-07	-	-	1.61E-07
	Children	Mean	-	1.19E-07	-	-	1.19E-07
		Minimum	-	9.05E-08	-	-	9.05E-08
		Maximum	-	1.56E-07	-	-	1.56E-07

N/D: not detected.

Table 6. *Summary statistics of calculated excess lifetime cancer risk (ELCR) values for adults and children in soils from Dana steel limited dumpsite.*

Statistical parameter	Mean	Maximum	Minimum
ELCR (Adult)	9.66E-03	5.64E-02	6.07E-07
ELCR (Children)	4.85E-05	2.73E-04	9.23E-07

IV. Conclusion

Soils samples have been collected from the Dana steel limited dumpsite in Katsina state and were analyzed for toxic metals' (As, Pb and Cr) composition and concentration using flame atomic absorption spectrophotometry. The obtained concentrations (mg/kg) were used in computations of annual daily intake values through ingestion, inhalation and dermal pathways. The obtained annual daily intake values were further used for computations of carcinogenic risk hazards using united state environmental protection agency models for risk assessment. On the basis of these computations, it has been established that the soils of Dana steel limited are capable of causing cancer in the lifetime of the inhabitants. Soils samples have been collected from the Dana steel limited dumpsite in Katsina state and were analyzed for toxic metals' (As, Pb and Cr) composition and concentration using flame atomic absorption spectrophotometry. These toxic metals can cause environmental problems in ecosystem of the area due to the release of toxic metals from the contaminated soil to the ground water system and also in the plants grown in the soil. This alarming situation should be regularly monitored for health related problems in the inhabitants of the area. It is therefore strongly recommended that Phyto and bio-remedial measures be considered by appropriate authorities in order to minimize the extent of accumulated pollutant loads.

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