


Predicting children's blood lead levels from exposure to school drinking water in Addis Ababa, Ethiopia

Dawit Debebe , Fiseha Behulu and Zerihun Getaneh

ABSTRACT

Human beings could be exposed to impacts associated with heavy metals such as lead (Pb) through drinking water. The objective of this study was to evaluate quality of water consumed by kindergarten school children in Addis Ababa city, who are highly susceptible to issues related to heavy metals in water. Through conducting chemical analysis, using microwave plasma atomic emission spectrophotometry (MP-AES), the level of lead (Pb) was measured at 38 selected schools in the city. Drinking water samples were taken from three water supply sub-systems: Akaki, Legedadi, and Gefersa. Results revealed the average Pb concentration in the city was 62.37 µg/L which is significantly higher than the World Health Organization (WHO) recommended threshold value of 10 µg/L. The children's blood lead levels and exposure to Pb were also calculated using the integrated exposure uptake bio-kinetic (IEUBK) model as per USEPA guidelines. Estimated geometric mean blood lead levels (BLLs) for each school ranged from 4.4 to 13.2 µg/dL. On average, the model predicted that 20% of children in the city will have blood lead levels above the WHO recommended 10 µg/dL. The study can be considered as an unprecedented piece of work as it addresses critical issues and methods to mitigate problems caused by high concentration of Pb in water supply distribution infrastructure.

Key words | blood lead levels, lead contamination, MP-AES, school drinking water

Dawit Debebe  (corresponding author)
 Fiseha Behulu
 Zerihun Getaneh
 School of Civil and Environmental Engineering,
 Addis Ababa Institute of Technology (AAIT), Addis
 Ababa University,
 Addis Ababa,
 Ethiopia
 E-mail: dawit6619@gmail.com

INTRODUCTION

Lead (Pb) is a toxic metal whose widespread use has caused extensive environmental contamination and health problems in many parts of the world (Cañas *et al.* 2014). Exposure to lead is associated with a wide range of effects, including various neurodevelopmental effects, mortality (mainly due to cardiovascular diseases), impaired renal function, hypertension, impaired fertility, and adverse pregnancy outcomes. The presence of Pb in human organs is unwanted as it disturbs metabolic processes (WHO 2017).

The accumulation of Pb in humans occurs through ingestion of food, drinking water, soil, and the inhalation of atmospheric Pb dust (Haider *et al.* 2002; Ahmed *et al.*

2008; Winther & Slentø 2010; Yalemsew *et al.* 2012). It can be taken into the body as a result of the corrosion of drinking water supply systems covered with lead, and may also result in health problems in the form of learning and behavioral disorders, such as mental retardation (Bakir *et al.* 2015). When exposed to high doses of lead, damage occurs in the brain, the red blood cells, and the kidney (USEPA 2018). Lead in drinking water may come from contamination at the source, but it can also be present in tap water as a result of its dissolution from natural sources; rather, its presence is primarily from household plumbing systems containing lead in pipes, joints, fittings, or the service connections to homes (WHO 2017).

Children may be more exposed to lead than adults due to their behavior, diet, and metabolic and physiologic characteristics (Albalak *et al.* 2003). They take in more air, water, and

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food per unit of body weight per day than adults (Wigle et al. 2007). In addition, school-aged children spend many hours in and around school facilities that may expose them to potentially contaminated sources of water by lead. Further, schools are high-risk environments due to both the complex nature of their drinking water systems and the vulnerability of the users (WHO 2017). For these reasons assessing lead contamination in schools' water is very important.

Non-occupational exposure of the general population to lead is most likely to occur in developing countries like Ethiopia through the ingestion of contaminated drinking water because of the old water distribution systems (Haider et al. 2002). In the present study, the oldest water supply system in the country (almost back-dated to 100 years) was evaluated in view of Pb concentration. However, one of the key observations is that the authority mandated for the water delivery and administration in the metropolitan city, Addis Ababa Water and Sewerage Authority (AAWSA), does not monitor the level of any heavy metals in its drinking water system. On the other hand, unlike the industrialized countries, there are very limited studies conducted on the status of Pb, and therefore, it has been a major challenge to find data (Getaneh et al. 2014).

The intensity of lead exposure is mainly measured by blood lead levels. The USEPA has recommended the integrated exposure uptake bio-kinetic (IEUBK) model as a predictor of potential long-term blood lead levels for children (USEPA 2018). Child health risk assessment and blood lead levels in children were conducted using this model. The model has been widely used by several countries to estimate pediatric blood lead levels and its predictions have demonstrated close agreement with the measured blood lead level (USEPA 2007). The main objective of this study is to assess the levels of lead in drinking water at kindergarten schools and to assess the children's health risk through predicting blood lead levels.

MATERIALS AND METHODS

The study was conducted in Addis Ababa, the capital city of Ethiopia, which has a population of more than four million in an area of 540 km² (CSA 2007). The city gets its treated water from three sub-systems:

- A. Akaki subsystem has a ground water source and its treatment system is only disinfection (chlorination).
- B. Legedadi subsystem has both ground and surface water sources.
 - Its surface water source has a conventional water treatment system. This system includes pre-chlorination, coagulation, sedimentation, filtration, and post-chlorination (AAWSA 2014).
 - The ground water source has a treatment system of disinfection (chlorination). These two systems then join at a reservoir.
- C. Gefersa subsystem has a surface water source and it has a conventional water treatment system. This system is the same as Legedadi and includes pre-chlorination, coagulation, sedimentation, filtration, and post-chlorination (AAWSA 2014).

According to Addis Ababa Education Bureau, there are 164,072 kindergarten children in the city. Fifteen kindergarten schools from the Akaki sub-system, fifteen from Legedadi, and eight schools from Gefersa sub-systems were selected according to the sub-systems' coverage areas. Samples were randomly chosen to make the schools dispersed and representative of the catchments, as shown in Figure 1. The sampling was carried out based on the standardized sampling techniques as outlined in USEPA guidelines for water testing (USEPA 1991).

One water sample was taken from each school giving a total of 38 samples. However, from the sources, two water samples were taken from each treatment plant, before and after the water is treated, which means six samples have been taken from the three treatment plants. The total number of samples taken is 44. Flushed water samples were taken and each sample had a volume of 500–1,000 mL, collected using pre-labeled 500–1,000 mL sterile plastic bottles. The bottles were initially cleaned using standard detergents and distilled water. The water samples were transported to the Addis Ababa University Faculty of Science, Department of Chemistry laboratory, and acidified and digested to a pH < 2 with 69% HNO₃ immediately and stored at 4 °C in a refrigerator before analysis. Digestion and examining lead levels of the water samples were made based on the standard analytical method of the water quality (APHA 2005).

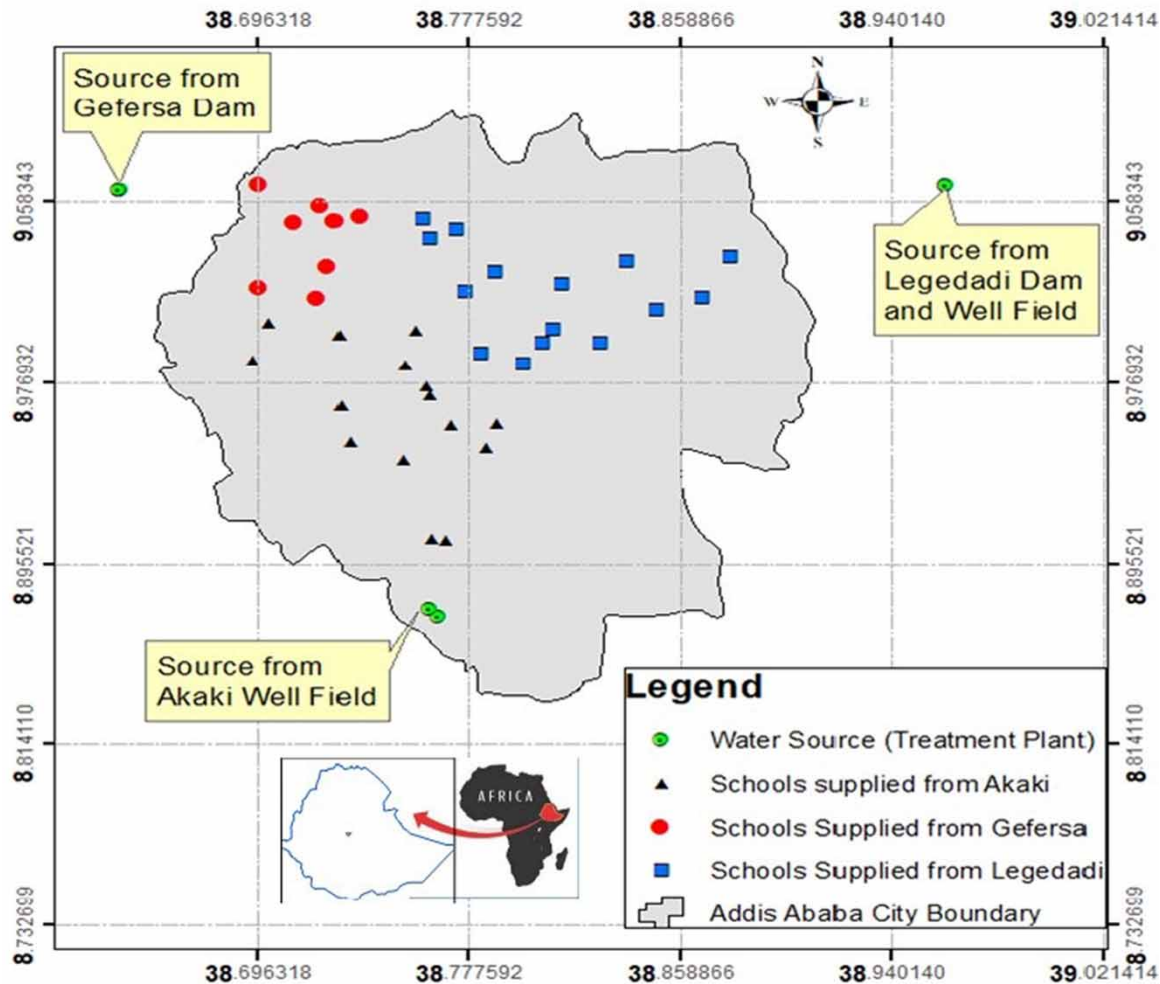


Figure 1 | Sampling sites in Addis Ababa city.

The lead concentration in the samples was measured using Agilent 4200 MP-AES (microwave plasma atomic emission spectroscopy). The Agilent 4200 MP-AES was calibrated initially using four different known lead concentrations of 2.5, 5, 7.5, and 10 ppm. Triplicate readings for each concentration and average values were taken. The correlation coefficient was 0.9994.

The child health risk assessment from lead exposure was conducted using the USEPA recommended integrated exposure uptake bio-kinetic (IEUBK) model as a predictor of potential long-term blood lead levels for children (USEPA 2005). The IEUBK model combines estimates of lead intake from air, water, soil, dust, and diet with an absorption module for the uptake of lead from the lung

and gastro-intestinal tract, and a bio-kinetic model of lead distribution and elimination from a child's body. This allows the IEUBK model to predict plausible distributions of blood lead levels in children six months to seven years of age. It assumes three months of consistent exposure through these pathways. The three-month period of exposure is based on the premise that if a child is exposed to the same environment over time, he or she will have a steady-state BLL (USEPA 2007). The model estimates the risk (i.e., probability) that a child or a population of children will have their BLL concentrations exceed a certain level of concern (typically 10 µg/dL) set by the WHO. The default values represent averages or plausible central values that were developed based on many years of research. (EPA

user's guide for IEUBK model for lead in children 2007). Lead concentration in water, air, soil, and dietary are the main input windows for the model. But for this study, only water lead concentration was entered as $\mu\text{g/L}$ and EPA specified default values for air ($0.1 \mu\text{g}/\text{m}^3$), soil ($200 \mu\text{g}/\text{g}$), and dietary (ranging from 1.95 to $2.26 \mu\text{g}/\text{day}$ for different age groups) were selected. Default parameters are recommended unless there are sufficient data to characterize site-specific conditions (IEUBK guidance manual USEPA 2007). These values were set since environmental lead data for air, soil, and dietary are unavailable for Addis Ababa city. Therefore, the city's mean water lead concentration and each sub-system's water lead concentration was used to estimate the blood lead levels and the probability of a child having BLLs above $10 \mu\text{g}/\text{L}$.

Data analysis was done using SPSS version 23.0. Tukey's multiple comparison tests were computed to compare lead concentrations between groups. The value was set at 0.05 with $p < 0.05$ considered significant in the analysis.

RESULTS AND DISCUSSION

Lead concentration in raw and schools' drinking water

The findings revealed that all raw water samples taken from the three treatment plants had lead concentrations above the WHO recommended $10 \mu\text{g}/\text{L}$ (WHO 2017). The raw water from Akaki well field, Legedadi dam, and Gefersa dam were $50 \mu\text{g}/\text{L}$, $50 \mu\text{g}/\text{L}$, and $40 \mu\text{g}/\text{L}$, respectively. These findings are similar to a study conducted by Duressa (2008), regardless of the time of sampling. In that study, raw water samples taken from Legedadi and Gefersa treatment plants had lead concentrations of $30.18 \pm 3.44 \mu\text{g}/\text{L}$ and $14.98 \pm 1.55 \mu\text{g}/\text{L}$, respectively. Water samples taken from Akaki boreholes also contained 11.24 ± 2.1 to $19.66 \pm 0.09 \mu\text{g}/\text{L}$. The above-mentioned study was conducted more than ten years ago. The trend clearly shows that the problem had been increasing when we compare the results with the current study. For the past decade no countermeasures have been taken and there is no lead monitoring system set by Addis Ababa Water and Sewerage Authority (AAWSA), therefore the lead concentration in the raw water samples increased.

The water supply from the three sub-systems shows different catchment dynamism. The catchment supplying Legedadi dam is surrounded by intense agricultural activities with significant deforestation. Therefore, the high levels of Pb in the raw samples are presumably attributed to the natural occurrences of Pb in the area and the uses of lead compounds in the agricultural activities. The leachates of Pb from cement-mortar lining of the dams may also contribute to the elevated levels of lead in the raw water samples (Guo 1997). In Gefersa sub-system, there is less agricultural practice in that area with better forest cover and the supplying catchment is also smaller in size as compared to Legedadi. For these reasons raw water samples from Legedadi show a higher lead concentration.

The lead concentrations of the samples from Akaki, Legedadi, and Gefersa after treatment were 40, 30, and $30 \mu\text{g}/\text{L}$, respectively, which are still above the WHO recommended value of $10 \mu\text{g}/\text{L}$ (WHO 2017). This shows that these treatment plants are not efficient in heavy metal removal. These results also agree with the findings by Duressa (2008). Treated water samples from Legedadi and Gefersa dams in that study had lead concentrations of 13.85 ± 2.23 and 15.66 ± 2.31 , respectively, which are still above the WHO set threshold of ten years ago.

The findings revealed that all water samples taken from the three sub-systems had lead concentrations above the WHO (WHO 2017) recommended value of $10 \mu\text{g}/\text{L}$. Mean lead concentration of all 38 schools was $62.37 \pm 24.8 \mu\text{g}/\text{L}$ (Table 1). These results showed that the lead concentrations between the three sources significantly differed from each

Table 1 | Mean lead concentration (mg/L) of school drinking water supplied by the three sub-systems

Sampling sites	No. of samples	Minimum	Maximum	Mean	SD
Schools supplied from Akaki well field (AWF)	15	40	50	48.6	3.52
School supplied from Legedadi dam and well field (LD)	15	30	170	80	32.07
School supplied from Gefersa dam (GD)	8	50	70	55	7.56

other ($p < 0.01$). From Tukey's multiple comparison tests, the Legedadi sub-system was significantly greater than the other two. These findings are similar to a study conducted by Duressa (2008), where the water samples collected from households in different parts of the city ranged as high as $53.71 \pm 4.2 \mu\text{g/L}$ and about 89.29%, 80.65%, and 86.49% of households had water supplied from Akaki, Gefersa, and Legedadi, respectively, which were observed to receive mean Pb concentrations higher than the permissible level of $10 \mu\text{g/L}$. Since there were no measures taken and the awareness about lead contamination is still very low, the problem has increased in the past ten years.

In comparison, in Washington DC (USA), a study was conducted to evaluate the levels of lead in drinking water in 2003–2004. The results showed that of the 6,170 homes, 68% had lead concentrations of $59 \mu\text{g/L}$. During this period, the lead concentration for some homes exceeded $300 \mu\text{g/L}$, which is unprecedented in the history of recent water management (Guidotti et al. 2007). Furthermore, lead concentration was measured in Nairobi, Kenya, which is a neighboring country to Ethiopia. In this study, water samples were taken from river, boreholes, tap, and rain water. The lead concentration in these water bodies was 19.1, 13.4, 5.5, and $5.8 \mu\text{g/L}$, respectively (Duressa 2008). Furthermore, lead content was analyzed in raw water from the Nile River and treated drinking water at four treatment plants in Greater Cairo, Egypt. The concentration of lead in the raw and treated waters was, respectively, $22.6 \pm 8.74 \mu\text{g/L}$ and $9.93 \pm 0.5 \mu\text{g/L}$, mean \pm SD (Mohammed et al. 1995). Addis Ababa being a less developed city compared to the above cities mentioned, has relatively the lowest industrial activities. However, Table 2 shows that the lead concentration in Addis Ababa's tap water is higher than the other cities. Therefore, countermeasures should be taken to handle this high amount of lead in the water distribution system.

Table 2 | Comparison of mean lead concentration in four cities

Cities	Pb mean conc. ($\mu\text{g/L}$)	Source
Nairobi	5.5	Duressa (2008)
Cairo	9.93	Mohammed et al. (1995)
Washington DC	59	Guidotti et al. (2007)
This study	62.7	

Blood lead levels (BLLs)

The blood lead level was predicted for each school and for the three catchments using their average lead concentrations. Three schools from Legedadi catchment had estimated BLLs $\geq 10 \mu\text{g/dL}$. The schools had BLLs of $13.2 \mu\text{g/dL}$, $10 \mu\text{g/dL}$, and $10 \mu\text{g/dL}$ with respective lead concentrations of $170 \mu\text{g/L}$, $110 \mu\text{g/L}$, and $110 \mu\text{g/L}$. Such levels of Pb can seriously harm children's health in numerous ways, including reduction in intelligence quotient (IQ) development, hyperactivity, learning difficulties, behavioral problems such as inattentiveness and aggressiveness, hearing loss, and impaired growth (Meyer et al. 2003).

Figure 2 shows average BLLs and probability of exceeding $10 \mu\text{g/dL}$ based on the average water lead concentration. As shown in the figure, the probability exceeding $10 \mu\text{g/dL}$ of children's BLL for Akaki, Gefersa, and Legedadi sub-systems were 12.25%, 15.80%, and 31.09%, respectively, with the city average of 20.37%. Legedadi sub-system, having the biggest lead concentration, has the highest estimated BLL. The children in Legedadi sub-system will have 31.09% probability of having BLLs above $10 \mu\text{g/dL}$. The USEPA recommends these percentages to be less than 5%, therefore, taking countermeasures for these problems is critical. There was also significant difference of average BLLs between the sub-systems ($p < 0.001$). From Tukey's multiple comparison test, the average BLLs of Legedadi sub-system were greater than the others ($p < 0.001$).

The average water lead concentration in Addis Ababa city being $62.7 \mu\text{g/L}$, the average BLL and percentage of a child's probability of having BLL above $10 \mu\text{g/dL}$ was $6.75 \mu\text{g/dL}$ and 20.17%, respectively (Figure 2). For the present study, if soil and air lead concentrations were measured, more children in the city would have BLLs above $10 \mu\text{g/dL}$. The study conducted in Jimma by Getaneh et al. (2014) showed the mean lead concentration of the soil from the four quadrants of the town was $220.08 \pm 135.95 \mu\text{g}$ and the average air lead concentration was $1.01 \pm 0.41 \mu\text{g/m}^3$. As was justified by the same study, the high air lead content may be related to pollutants emitted from cars, buses, and trucks (Getaneh et al. 2014). Since Addis Ababa is densely populated and has heavy traffic movement, air lead concentrations would be greater than or equal to that of Jimma town. This, in turn, causes more children in the city to have BLLs above $10 \mu\text{g/dL}$.

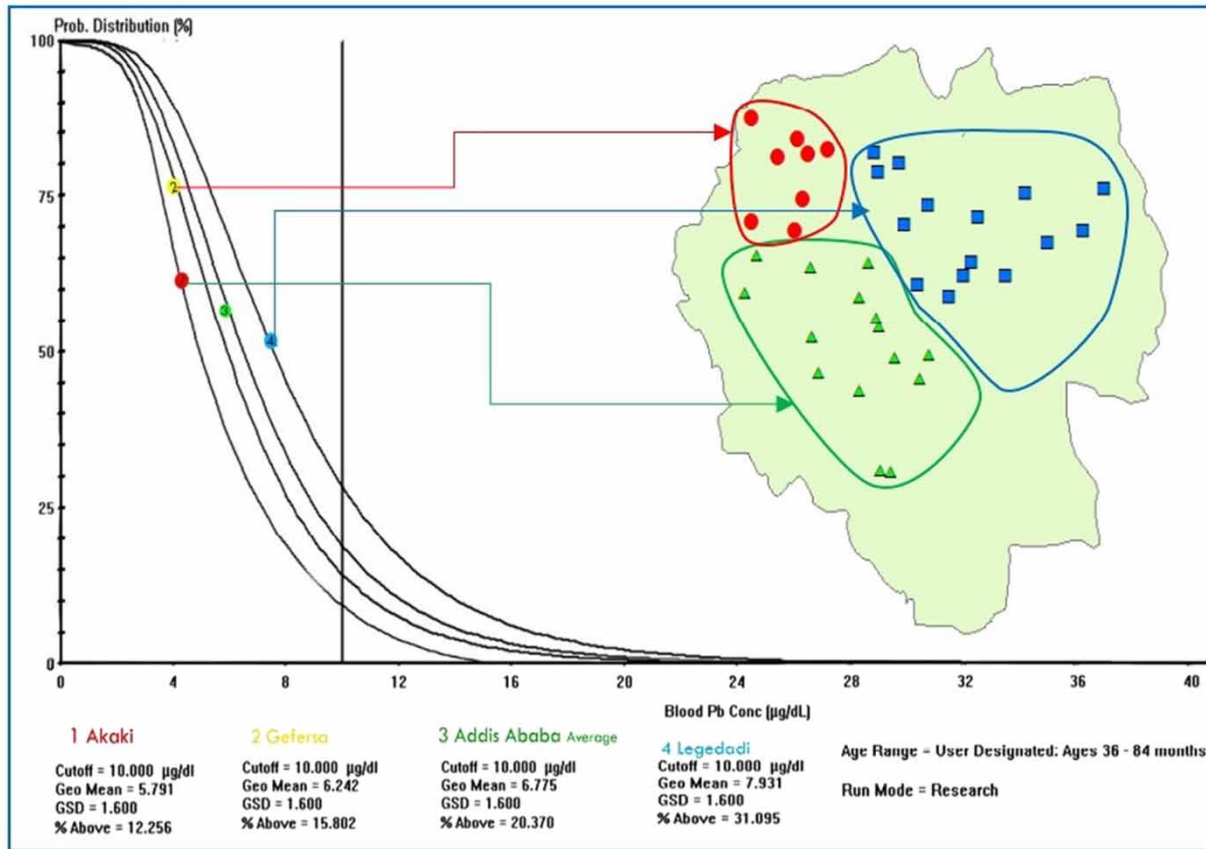


Figure 2 | Average BLLs and probability of exceeding 10 µg/dl.

Similarly, a study conducted by Teju *et al.* (2012) on Addis Ababa roadside soils showed the mean soil lead concentration of 418.6 ± 3.4 µg/g. In most of the sampling sites, the concentration of lead observed was directly correlated with the traffic density of the roads (Teju *et al.* 2012). The study showed that soil lead level would also be higher than the default selected values in the model and more children would be exposed to lead contamination in Addis Ababa.

CONCLUSION

In general, the content of mean lead in water from the selected sub-systems is above the acceptable level set by the WHO, 10 µg/L. Children could also be affected by exposure to lead (Pb); many different organs and physiological functions (neurological, hematological, cardiovascular, renal, immune, and other functions) are affected even at very low

exposure levels of lead. According to different studies carried out on dose–response association between blood lead levels and IQ, revealed failure is stronger at blood lead levels lower than 10 µg/dL. The American Control for Disease Center (CDC) also sets a lead poisoning reference of 5 µg/dL. If we take this value as a benchmark, the exposure would be even higher than the results in this study.

Conducting research to identify the exact sources of Pb in the piped drinking water and at the source is crucial. Standard environmental safeguard implementation practices should be followed by the government. Some of these practices include reduced or limited use of agricultural inputs that may lead to excess production of heavy metals including lead, catchment protection through afforestation practices and reduction of sediment yield by building check dams in the upstream part, monitoring, evaluation and periodic review of lead levels in drinking water, soils, and air (environment) at regular intervals and maintaining a database either by Regional or Federal EPA

of Ethiopia is mandatory. Also, monitoring of lead-composed insecticides, rodenticides, and herbicides in agricultural sectors is necessary since it could be the source of lead in the raw water samples.

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