Reducing Exposure to Arsenic and Lead in Mining and Smelting Communities Alaverdi and Akhtala of Lori region, Armenia

Master of Public Health Integrating Experience Project

Problem Solving Framework

by

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Executive summary

Contamination of mining and smelting communities and, as a result, community members' exposure to toxicants remains a hot public health issue worldwide. The latter is particularly severe in low and middle income countries. Armenia is not an exception. There are 22 active metal mines in Armenia, mainly located in Lori and Syunik regions. Alaverdi and Akhtala in Lori region are prioritized mining and smelting communities for the current project due to significant contamination with toxic metals, particularly with lead and inorganic arsenic. The three main issues of concern in Alaverdi leading to significant spread of toxicants into the environment are smelter's smokestack, arsenic graveyard, and uncontrolled use of slag. The biggest sources of contamination in Akhtaka are abandoned "Nazik" tailing pond, the ore processing plant, and the local churchyard.

This paper aims to develop a comprehensive overview of factors leading to people's exposure to arsenic and lead in the mining and smelting communities Alaverdi and Akhtala in Lori region, analyze current prevention and intervention strategies, and suggest the most appropriate practice(s) to minimize the public health risk.

Social-ecological model of behavior change was used to categorize the key determinants of exposure of community members of Alaverdi and Akhtala to arsenic and lead into the societal, community, relationship and individual levels. The possible interventions to solve the public health problem could address all four level key determinants. The proposed interventions are continuous educational programs in Alaverdi and Akhtala, seismic stabilization and hermetisation of walls of arsenic graveyard in Alaverdi, clean-up of Akhtala churchyard, clean-up of children's play areas in Alaverdi and Akhtala, as well as capping, planting and isolation of "Nazik" tailings pond in Akhtala. Considering factors such as intervention's effectiveness,

political, technical, economical feasibility, intervention's cost and sustainability of the results, the following interventions were prioritized: 1. Continuous educational program in Alaverdi and Akhtala, 2. Capping, planting and isolation of "Nazik" tailing pond in Akhtala, 3. Clean-up of children's play areas in Alaverdi and Akhtala. The project team will develop an appropriate monitoring and evaluation plan for the recommended interventions.

1 Statement and magnitude of the problem

1.1 Introduction

The Oxford dictionary defines mining as "the process of getting coal or other minerals from under the ground" and smelting as "heating and melting the ore (rock that contains metal) in order to obtain the metal it contains."[1] The mining industry has an important role in modern economics, though it frequently is a topic of concern due to public health risks, mainly associated with toxic emissions into the environment throughout the mining process (see Appendix 1). This results in human exposures to toxicants in water, soil, food, and air via dermal contact, ingestion, and inhalation.[2]

This paper aims to develop a comprehensive overview of factors leading to people's exposure to toxicants in the mining communities of Alaverdi and Akhtala in Lori region, analyze current prevention and intervention strategies, and suggest the most appropriate practice to minimize the public health problem.

1.1.1 Health, social and environmental impacts of mining

The mineral ore contains only a small percent of desired mineral. After beneficiation, the waste which contains toxicants is stored at sites affecting the health of people living in the same geographic area.[3,4] The toxicity of an any compound depends on a variety of factors such as the type of toxicant, acute or chronic exposure, body mass and age, and exposure route.[5]

In terms of impact on human health, the most dangerous toxicants in mining wastes are metals, particularly lead, arsenic, cadmium, and mercury.[2] While four are naturally occurring metals in the environment, they are in the United States (US) Agency for Toxic Substances and Disease

Registry's (ATSDR) priority list because they are commonly found in mining sites and pose significant threat to human health.[6]

1.1.1.1 Health impacts

According to WHO estimates, lead poisoning resulted in approximately 500,000 deaths and loss of more than nine million disability-adjusted life years in 2015, most of which occurred in low- and middle-income countries (LMIC).[7] The International Agency for Research on Cancer (IARC) classifies lead as a probable human carcinogen.[8] Lead can enter human body through ingestion, which is the predominant route of exposure among the general population, and inhalation (breathing lead dust), which is the predominant route of exposure among the mining workers.[9] There is no safe amount of lead in the human organism,[7] and almost every organ can be affected by lead.[10] Lead affects the nervous system, causing degenerative disorder of the central nervous system among adults, and development/behavioral disorders among children such as decreased postnatal growth, delayed puberty, decreased cognitive performance and hearing, low intelligence quotient (IQ), attention related behavioral problems (attention deficit hyperactive disorder) and others.[10,11] Lead can also lead to decreased kidney function, cardiovascular and reproductive disorders, as well as death in case of high blood lead concentration.[11] Children are much more vulnerable to lead poisoning: children ingest 4-5 times more lead than adults, mainly due to hand to mouth behavior.[7] Moreover, the blood-brain barrier in young children is not fully developed, resulting in transfer of lead from blood to the brain and serious neurological disorders.[10] Lead is harmful for fetus too, as it crosses the placental barrier in-utero and harms the fetus, resulting in reduced development, decreased mental abilities, and premature birth.[10]

Inorganic arsenic is classified as a known human carcinogen.[8] The main source of inorganic arsenic is metal mining and smelting. People may be exposed to arsenic through inhalation or ingestion.[12] Exposure to inorganic arsenic leads to negatively affects the production of red and white blood cells, vomiting and nausea, and damaged blood vessels. Ingestion of inorganic arsenic may lead to liver, bladder, lung, and skin cancer. Long-term exposure in children may lead to low IQ scores.[12]

Cadmium is a probable human carcinogen,[8] and also is more dangerous for children due to their lower body mass.[13] Inhaled cadmium can damage the lungs, damaging epithelial cells and causing tracheobronchitis and pneumonitis.[14] Ingested cadmium can lead to stomach irritation, vomiting, and diarrhea. Some of the long-term effects of cadmium exposure include damage of kidneys and bones (fragile bones).[13]

Mercury is the only metal that exists in liquid form at room temperature. Mining wastes contain metallic and inorganic mercury.[15] Exposure to mercury can be through dermal absorption, ingestion, or inhalation. The most dangerous exposure to inorganic mercury is inhalation of vaporized form of it. Mercury poisoning can lead to kidney, brain, and lung damage, may cause coughing, vomiting, nausea, chest pain, increased blood pressure, coordination problems, tremors, hearing or vision disorders, and memory problems in case of chronic exposure.[16]

1.1.1.2 Social impacts

The social impacts of the mining industry on the well-being of the communities in different countries is quite controversial. Those countries that register economic growth from the mining industry have issues transferring the financial gains to the general public living in the mining communities. The latter is especially unjust since the LMIC communities bear the majority of the health, environmental, and social problems resulting from the mining.[17]

Frequently, mining workers have low salaries and no health insurance.[18] They do not voice their concerns due to fears of job loss.[18] There are continuous land conflicts between mining companies and local communities.[18,19] Noise, vibration, and dust resulting from mining and/or smelting processes, as well as lack of access to clear air, soil and water and low quality agricultural crop production negatively affect the quality of life of local communities.[18]

1.1.1.3 Environmental impact

The mining industry has significant impact on the environment.[3] The most significant consequences are contamination of water resources, which is difficult to mitigate. When sulfides from tailings, open pit walls, and underground mines contact the water and air, sulfuric acid is formed, which can dissolve toxic metals in the solution (Acid Mine Drainage-AMD). AMD can contaminate surface or ground water, impact aquatic life and result in the exposure of the local community members to contaminated water and food. Other pathways of impact are soil erosion and pollution, as well as air pollution by small, mobile dust particles. The whole geographic area around mining sites is being irreversibly harmed due to uncontrolled mining activity.[3] The destroyed environment leads to damage in such economic sectors as health, agriculture and tourism.

1.2 Situation in Armenia

Armenia is a lower middle-income country with the area of 29,743 km^2 and a population of about 3 million.[20] There are more than 670 mines in Armenia, of which 22 are active metal mines, including polymetallic, gold and gold-polymetallic, copper, copper-molybdenum, iron, and aluminum mines.[21]

The Lori region is located in northern Armenia with a population of 221,000 and area of approximately 3,800 km.[2] Lori is rich in mineral ores, such as lead-zinc-polymetallic ores, copper or copper-molybdenum ores, and iron ores.[22] Alaverdi and Akhtala are prioritized in terms of public health risk due to significant contamination with toxicants.[23]

Armenia's oldest and largest polymetallic smelter is located in Alaverdi. The smelter was established in the 18th century, had been paralyzed after the collapse of the Soviet Union, and reopened in late 1990s.[24] Currently, the smelter produces over 10,000 metric tons of copper blister annually.[25]

The three main issues of concern in Alaverdi leading to significant spread of toxicants into the environment are smelter's smokestack, arsenic graveyard, and uncontrolled use of slag.[24] The smelter's smokestack is a big source of contamination. Existing research showed an inverse association between lead contamination and distance from the smelter.[24] The smelting company tried to use filters preventing most of the emissions into the atmosphere, but stopped using it due to high cost.[26]

The arsenic graveyard is located less than 1 km north of Alaverdi, around the road leading to the "Madan" neighborhood.[27] The graveyard is located on the heal by Lalvar river.[28] The graveyard has 130 m width and 150 m length. It was built in 1980s and contains the arsenic waste from Soviet era metallurgical activities.[27] The biggest environmental and public health threat is the location of the graveyard in an active seismic zone, as possible earthquake might lead to uncontrolled spread of the buried hazardous waste.[28] According to the smelting company, the graveyard was fenced in the past, but the fences were stolen.[29] In 2009, when the issue of unregulated graveyard was raised, the smelting company added signboards and fenced the graveyard.[27] The walls of the graveyard are not hermetic, the cracks and holes give access to air and rain water, which results in the leakage of hazardous waste to the underground water and eventually to the riverbank.[27]

Another issue of concern in Alaverdi is uncontrolled use of slag, which is an operating byproduct of copper smelting, and has high concentrations of arsenic, lead, and other toxicants.[24] The slag is being sold by the smelting company and is used on the roads during winter months to melt the snow. For example, in the year 2005 alone, the company sold 29,062.35 tons of slag.[28] In February 2017, around 110,000 tons of slag was given to the Alaverdi municipality to spread on the roads, school-yards, and residential yards.[30]

One underground (operating since Soviet era) polymetallic mine and one open-pit mine (operating since 2001) are located near Akhtala.[31] The latter was recently closed, and the mining company obtained permission from the government to use it as a new tailing pond.[32] The main sources of contamination in Akhtala are "Nazik" tailing pond and the local church yard.[33] Nazik tailing (0.4-0.5 million square meters) is located in Akhtala, near the Akhtala church. It was conserved in 1988, then used for a short period in 2000.[34] The big amount of waste was taken from the Nazik tailing and moved to the Akhtala river coast.[35] In 2012, a part of Nazik tailing pond was covered with vegetation to stabilize the soil.[22] The most contaminated area in Akhtala is the churchyard, where in the 10th century a royal dynasty of Kurikian's had a fortress and smelter that produced copper coins.[24]

Both Alaverdi and Akhtala are significantly contaminated with toxicants. In 2001, a study observed the highest level of lead contamination of exterior dust and children's play areas in Alaverdi, which was higher in the areas surrounding the smelter.[36] The study conducted in 2014 showed increased levels of arsenic and lead in soil samples from Alaverdi and Akhtala: 100% and 22% of all soil samples in Alaverdi exceeded maximum allowable concentration (MAC) for arsenic of 12 mg/kg and for lead of 400 mg/kg, respectively.[23] More than ninety-three percent (93.6%) and 26.7% of all soil samples in Akhtala exceeded MAC for arsenic and for lead, respectively.[23] In addition to identifying the concentrations of toxic metals in soil, the study also included toxic metal detection at 10 cm and 20 cm depth to identify a maximum background metal concentration.[23] Forty-four percent (44%) of all arsenic measurements, 90% of all lead measurements, and 50% of all chromium measurements exceeded the highest background measurement for each toxic metal. The latter indicates contamination of the surface layer of soil.[33]

The blood lead survey among children 1 to 5 years old showed that 83.8% of children in Akhtala and 72.5% in Alaverdi had blood lead levels above 5 μg/dl, the reference value for children 1-5 years old in the US.[37] Another study on reproductive health of women living in Alaverdi reported a higher risk of perinatal mortality, stillbirths, and induced abortions due to medical indications, as compared with Artik, a comparable town that does not have a metal mining and smelting industry.[38] This literature suggests significant health risks for people living in Alaverdi and Akhtala as a result of exposures to toxic metals from the mining and smelting industries.

2 Key determinants of exposure to arsenic and lead among community members of Alaverdi and Akhtala

According to the social-ecological model of behavior change, all the key determinants of exposure of community members of Alaverdi and Akhtala to arsenic and lead can be categorized into individual, relationship, community, and societal levels (see Appendix 2).[39] These classifications can then be used to identify solutions targeted on specific levels.

The societal level key determinants include inappropriate regulation, legislation, and taxation of the mining sector, as well as contamination of the environment with toxic metals due to mining industry.[40] The mining industry in Armenia is mainly regulated by the Ministry of Nature Protection and the Ministry of Energy Infrastructures and Natural Resources. The main gap in the mining code of Armenia is in aspects related to waste management.[21] Specifically, the mine waste tailings are categorized as "man-made deposit," and due to the wording, they are being considered as the property of the Republic of Armenia. Thus, the mining company is exempt from the responsibility for the mining waste management.[21] Armenian law does not require tax on mining wastes, but 99% of all industrial waste in Armenia is formed by the mining industry.[21] This makes mining activities very cheap in Armenia and does not provide any motivation to the industry to use cleaner technologies that are more expensive. The environmental pollution by the mining industry, including contamination of soil and house dust, has a key role in people's exposure to toxic metals.[21,41] A study conducted in a former mining community showed that factors having the strongest association with high lead levels in children's blood were the mean lead concentration in soil and house floor dust.[41]

The community level key determinants include absence of proper remediation of abandoned tailing ponds, uncontrolled use of slag, lack of knowledge on toxic metals among community members, housing characteristics (concrete stone vs brick houses, distance from the source of contamination, and automobile traffic near home.[37,42] Lack of safety measures in the abandoned "Nazik" tailing pond in Akhtala is important factor leading to exposure of community members to toxic metals. Nazik Tailing pond is not fenced. There are no warning signs about hazardous substances. People and animals have free access to it. Lack of knowledge among community members about the health hazards caused by toxic metals and their exposure routes is another factor leading to toxic metal exposure.[33]

The relationship level key determinants include number of people in the family, presence of smoking family member, household's low income, household hygiene practices, caregiver's lower education (in case of children) and household member's employment in the mining industry.[37,41]

Individual level key determinants include male gender, younger age (before 1 year) among children, behavioral factors such as hand to mouth behavior among children, and child's poor hygiene.[41,43]

A study conducted in Alaverdi and Akhtala concluded that caregiver's lower education, low frequency of furniture dusting, and closer proximity of the house to the toxic source were statistically significantly associated with elevated levels of lead in blood among children in the mentioned communities.[37]

3 Prevention/ intervention strategies

3.1 Current prevention/intervention strategies

3.1.1 Nazik tailing pond's capping and planting with trees

In 2012, 0.7 hectares of abandoned tailing pond Nazik in Akhtala community was planted with 10 different species of 523 trees as a trial aimed to test if trees could survive. The five-month follow-up showed 96% survival rate, which was considered a successful outcome. This experience is an example of preventing the erosion of tailings and reducing the dust from the site.[22]

3.1.2 Akhtala community empowerment project

In 2013, a community empowerment pilot project was implemented in Akhtala. The project included the following four components: 1) thorough risk assessment, 2) blood lead level assessment in children, 3) community trainings, and 4) development of a local action plan.[33] Community trainings covered general information on mining industry worldwide and in Armenia, information on toxic metals (physical characteristics, origin, routs of exposure, way of transmission), health effects of toxic metals, ways of protection from exposure to toxic metals (clean home, self-hygiene, proper nutrition), and diagnostic measures for toxic metal poisoning. Trainings were conducted for the teachers of kindergartens and schools, mothers of children, workers in the Mayor's office, local NGO representatives, active community members, healthcare providers, and high school students. Training presentations and brochures were made based on a comprehensive literature review and were adapted for the specific audience groups. The evaluation of the intervention showed statistically significant improvement of the knowledge score from approximately 60% to 83% among the participants.[33] The project team collaborated with the Mayor's office and local NGO representatives to develop a local action plan that could help the community to reduce the environmental contamination with toxic metals and its consequences.

3.1.3 Strengthening regulations and their enforcement mechanisms in the mining sector in Armenia

In the recent years, Armenian mining sector has undergonereforms.[44] For example, the government of the Republic of Armenia approved the Natural Resources Management strategy in February 2018, which proposed to ensure sustainable management of natural resources processing.[45,46] The strategy pays a particular attention to waste management: for the first time in the Republic of Armenia, the law will force mining companies in the mining sector to comply with mandatory processing of waste.[46] One of the objectives of the strategy is to create an inventory of mining wastes disposals (active and closed sites) by the year 2025, implement a waste management system, and ensure a continuous monitoring of land pollution and other negative impacts of mining waste. This strategy prioritized biological remediation methods.

The new government of the Republic of Armenia highlighted the importance of mandatory inspections in all the mining companies of Armenia, minimizing any possibility of corruption via involving third party representatives from environmental NGOs. The inspections aim to explore and eliminate all the inconsistencies between the scope of actions of the mining companies and the current Armenian code of mining.

3.2 Proposed prevention/intervention strategies

3.2.1 Continuous educational program in Alaverdi and Akhtala

The lack of knowledge on toxic metals, their origins, routs of exposure and safe behavior practices is one of the key determinants of exposure to arsenic and lead among community members of Alaverdi and Akhtala to be addressed. The effectiveness of the conducted trainings in Akhtala is a justification for organization of a similar educational program, which could use the same training materials and presentations, adapting them to the local community

3.2.2 Seismic stabilization and hermetisation of walls of arsenic graveyard in Alaverdi

The iron-concrete construction of arsenic graveyard in Alaverdi is about 40 years old. The facility never went through renovations and it is totally abandoned. The walls of the three-floor construction are under the ground and are not visible and there is no information about their exact condition. Nevertheless, the decay of the walls above the ground is obvious.[47] The decay is happening because of chemically active substances inside the graveyard. The chemical activity could result from a contact with air and water with the arsenic waste through the damaged walls of the graveyard. The seismic stabilization and hermetisation of the arsenic graveyard aims to exclude possible environmental health hazard due to earthquakes and leakage of toxic waste out of the graveyard. The team performing the intervention should include environmental engineers, seismic engineers, and environmental health specialists. The US Environment Protection Agency standards on waste disposal could be used for the stabilization and hermetisation of graveyard.[48]

3.2.3 Clean-up of Akhtala churchyard

The Akhtala churchyard is an important public area both for the community members and visitors. The cleanup strategy should be based on the thorough assessment of depth, shape and expansion of the pollution in the churchyard.[33] After the thorough assessment, a churchyard clean-up proposal should be prepared and presented to the granting organizations. The working team should include environmental engineers and public health professionals.[33] One of the possible clean-up techniques is phytoremediation. Phytoremediation is a technique of contaminated soil remediation, which is used to immobilize, extract, contain, or degrade different contaminants, including toxic metals from soil or water.[49] This is the most aesthetically acceptable technique of soil remediation, though it can be used only for slightly to moderately contaminated soil and frequently is used as a final stage after traditional remediation.[50] Phytoremediation has been successfully completed in many countries, but it is an appropriate remediation technique only in case of low and moderate contamination.[50] Given that the Church yard is a historical monument and excavations might not be permitted by the Ministry of Culture of Armenia, phytoremediation might be one of the best solutions. It can also be an option for residential areas and gardens in Alaverdi and Akhtala.

3.2.4 Clean-up of children's play areas in Alaverdi and Akhtala

"Environmental oasis" could be offered to at least children, who live in Alaverdi and Akhtala, the most vulnerable population group in terms of toxic metal exposure. The contaminated hotspots are kindergarten yards, schoolyards, and children's play areas. The clean-up should include the removal of all the contaminated soil and replacement with soils verified to be well below soil action levels for all metals.

3.2.5 Capping, planting and isolation of "Nazik" tailing pond

The survival rate of trees planted on the part of "Nazik" tailing is the basis for considering phytoremediation of the whole tailing pond, which will stabilize the soil and minimize the spread of toxicants. The intervention includes capping (coverage with clean soil), planting (planting with trees) and isolation (fencing).

4 Policy Priority setting

All the suggested strategies are categorized using the following criteria: 1) effectiveness, 2) political, technical and economic feasibility, 3) cost, and 4) sustainability of proposed interventions (Table 1).

4.1 Continuous educational program in Alaverdi and Akhtala

The Akhtala community empowerment program was proven to be effective in raising the awareness of community members about the existing contamination in the community and ways to minimize the community members' exposure to toxic metals.[33] The advantages of the proposed program include the availability of training materials developed for the Akhtala pilot project. The intervention is politically, economically and technically feasible to conduct. The cost of intervention will be relatively high due to continuous element of the program. On the other hand, the continuous element gives sustainability to the program. Main disadvantage of continuous educational program is, that it does not solve the core problem of metal contamination in Alaverdi and Akhtala, so the advantage is mainly in individual, and partly community level, but not for the society level. Nevertheless, awareness raising on the health risks of toxic metals and safe behavior practices is crucial for local communities.

4.2 Seismic stabilization and hermetisation of walls of arsenic graveyard in Alaverdi

The seismic stabilization could effectively prevent a huge environmental hazard in case of possible earthquake, and hermetisation would eliminate the problem of leakage of hazardous waste into the ground water, which is extremely difficult to mitigate. It would be politically feasible, though technically and economically difficulties would arise due to extremely high cost and required human resources. However, if implemented, the project would have quite high sustainability and despite all the challenges, the seismic stabilization and hermetisation of arsenic graveyard is one of the first interventions to be done in Alaverdi.

4.3 Clean-up of Akhtala churchyard

The Akhtala churchyard is a contamination hot spot that is widely popular both for the community members and for the tourists visiting Lori region, hence, its clean-up should be prioritized among other interventions. The main challenge of Akhtala churchyard clean-up is the fact, that this area cannot be isolated because it is a historical monument and a working church. It might not be politically feasible to conduct excavations there, at least to eliminate the superficial contaminated layer of soil and replace it with clean one. Hence, the best solution could be phytoremediation, remediation with the help of specific plants to stabilize metals in soil near their roots.[50] The project could have short-term and long-term effectiveness in terms of reducing the exposure levels. The sustainability of the intervention might be moderate, as it might need repetitive efforts of phytoremediation.

4.4 Clean-up of children's play areas in Alaverdi and Akhtala

The main advantage of clean-up of children's play areas is protection of the group most vulnerable to metals poisoning. The intervention is politically, economically, and technically feasible. The cost of intervention depends on total area and volume of soil under replacement. It might be challenging to find an adequate quantity of clean soil. The clean soil than should be covered by grass, in order to stabilize it.

4.5 Capping, planting and isolation of "Nazik" tailing pond

The advantage of capping, planting and isolation of the "Nazik" tailing ponds includes that fact that it would limit the availability of the most contaminated hazardous waste to both humans and animals. Capping only is the most cost effective, but the least sustainable and effective soil remediation technique. Nevertheless, the planting and isolation of capped area makes the intervention politically, technically, and economically acceptable.

5 Specific recommendations

Based on the available human and financial resources, as well as feasibility and effectiveness analyses, three strategies are prioritized:

- Continuous educational program in Alaverdi and Akhtala
- Capping, planting and isolation of "Nazik" tailing pond
- Creation of safe play areas in Alaverdi and Akhtala

6 Implementation and practice

6.1 Continuous educational program in Alaverdi and Akhtala

Community trainings will be implemented to raise the awareness about the health hazards caused by arsenic and lead, as well as their routes of exposure and safe behavior practices. The trainings will be conducted for different population groups, particularly parents of children of kindergarten age and attending primary schools, teachers and healthcare providers of kindergartens and schools, local NGOs, high school students, and active community members. The recruitment of training participants will be conducted in the following basis: The Lori municipality will electronically inform all the heads of kindergartens and schools as well as NGOs of Alaverdi and Akhtala regarding the continuous educational program, sending the preliminary scheduled timeframe of the trainings to specific population groups, and contacts of educational program representative. After that, the program representative will contact all the informed officials, and ask them to send the employees list (schools, kindergartens, and NGOs) as well as contacts of all the parents (schools, kindergartens). The participants will be randomly selected from each list provided by officials, then contacted and invited to the trainings. The total number of trainings and number of participants for each training depends on the budget of the program.

The availability of educational materials will save time and financial resources during the project proposal preparation process. The training manual used for Akhtala community empowerment project will be adapted to local needs, followed by adding the slag related information in the presentations and slag related questions to the pre-test and post- test.[33] The trainers should be trained prior to the start of the project and should have a health degree. Technical resources such as projector and computer, transportation resources, and stationery will be required to organize and conduct the trainings.

6.2 Capping, planting and isolation of "Nazik" tailing pond

The intervention will start with preparation of comprehensive capping and clean-up proposal with the help of environmental engineers. Barriers for implementation can be the lack of financial, human, and technical resources. The whole area should be covered by clean soil. The clean soil layer height should be based on the best international practice. After the coverage, the same species of plants will be planted in non-covered part of "Nazik" tailing pond, as were used before. After the capping and planting, the whole area of tailing should be fenced in order to prevent the free entry for humans and animals. The signboards should be placed in order to warn people about the contamination.

6.3 Clean-up of children's play areas in Alaverdi and Akhtala

Considering the vulnerability of children to arsenic and lead poisoning, and their propensity towards hand-to-mouth behavior, it is crucial to ensure safe play areas for them. The project team will identify all kindergarten and school play areas, requesting the information from Lori Municipality, as well as most popular places for children's daily activities, using observation techniques. The registry of all play areas will be created and a comprehensive clean-up proposal will be developed. The contaminated soil should then be removed from those areas using heavy machinery, replaced with clean soil and then covered with grass. Thorough assessment of arsenic and lead contamination depth will help to understand the level of contamination, the depth of soil to be removed, and the quantity of clean (low-lead and arsenic) soil for replacement.

7 Evaluation

7.1 Continuous educational program in Alaverdi and Akhtala

The approval by Institutional Review Board will be required prior to the program evaluation. The evaluation of the intervention hypothesize that the average percent score of all training participants will be 23% (absolutely) higher in the follow-up survey at the end of each training, as compared with the average score of the baseline survey, at the beginning of each training.[33] The trainings evaluation will be carried out separately in Alaverdi and Akhtala.

The evaluation of the trainings will be conducted by independent evaluators, through baseline (before each training) and follow-up (after each training) surveys using pre-post-test pre-experimental panel design. The evaluation instrument will be adapted from the Akhtala community empowerment project, and pretested prior to the baseline and follow-up survey.[33]

The evaluation team will enter the data into a previously created SPSS database, clean the data, and proceed with the data analyses. The dependent variable will be the knowledge percent score. The independent variable will be the presence or absence of the intervention. The intervening variables for the outcome variable of knowledge score will be the age, gender, education, employment status, belonging to certain targeted population group, perceived socio-economic status, smoking status, family size, monthly spending of the family, and having mine worker in the family.[33,37,41]

7.2 Capping, planting and isolation of “Nazik” tailing pond

The evaluation of effectiveness of capping, planting and isolation of “Nazik” tailing pond will be carried out by baseline and follow-up soil samples from the pond, using US EPA operating procedures on soil sampling as a guideline.[51] Baseline soil sampling of tailing pond before the intervention, and follow up soil sampling of tailing pond after the intervention, as well as sampling of capped and planted pond once per every six months continuously, will be conducted using US EPA suggestions on soil sampling: one soil sample per each 84 square meters of capped soil is required in superficial 1 inch (~2.5 cm) depth.[51] A database will be created containing data of all soil sample results. The evaluation will hypothesize that after the intervention, during all the follow-up soil samplings, the concentration of arsenic and lead in all soil samples will not exceed the MAC levels for each metal.

7.3 Clean-up of children's play areas in Alaverdi and Akhtala

Evaluation of creation of safe play areas for children will be conducted by sampling superficial 1 inch depth soil, in terms of arsenic and lead concentration at least twice a year.[52] The sampling technique should be consistent with guidelines developed by the Blacksmith Institute for child play areas. The independent trained investigator will divide the whole area into 9-12 equal subareas, then take 3-5 soil samples from the center of each subarea, for measuring the mean concentration from each subarea.[53] In case of detecting arsenic and lead concentrations exceeding the MAC level, the superficial contaminated layer should be removed replaced, and covered with grass again.

8 Conclusion

Exposure to arsenic and lead in mining and smelting communities of Alaverdi and Akhtala is one of the hot public health issues in Armenia. The international practice shows, that tremendous amount of financial resources, appropriate human and technical resources, as well as contribution from the government is required for proper remediation of contaminated environment and assurance of clean soil, water, and air for the community members living in Alaverdi and Akhtala. Nevertheless, isolation of contaminated hotspots, assurance of clean playing areas for children, and continuous educational programs to raise the awareness on toxic metals are important immediate interventions needed to reduce the community members' exposure to toxicants.

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Tables

Table 1: Intervention strategies

Eligibility criteria	Continuous Educational Program in Alaverdi and Akhtala	Seismic stabilization and hermetisation of walls of arsenic graveyard in Alaverdi	Clean-up of Akhtala churchyard	Clean-up of children's play areas in Alaverdi and Akhtala	Capping, planting and isolation of "Nazik" tailing pond ion Akhtala
Intervention's effectiveness	+++	++++	++++	+++	+++
Intervention political, technical and economic feasibility	++++	+	+	+++	+++
Intervention's cost	+++	++++	++++	++	+++
Intervention's sustainability	+++	++++	++++	++	+++
Priority setting	++++	+	++	++++	++++

\+ Very low ++ Low +++Medium ++++High

Appendix 1:

The process of mining:

Mining techniques were developed in ancient times.[54] During the Roman Empire, due to mining, people could extract and use metals such as copper (Cu), lead (Pb), zinc (Zn) and mercury (Hg).[54] The mining process starts with extraction of mineral ore, the part of the earth containing different elements. Even rich ores have only a small percent of the desired mineral. Frequently, the mineral ore is located under the layer of ordinary rock or soil[3] Different methods are used for accessing mineral ore, including placer mining, underground mining, and open-pit mining. Frequently, removal or burning of vegetation growing in the area of interest is required in order to access the ore. The extraction of ore is being done using heavy machinery. The process of ore extraction leads to a significant amount of fugitive dust emissions.[3]

The ore extraction is followed by beneficiation, which evolves the ore milling to separate desirable elements from undesirable particles. The result of milling is transformation of the ore into very small, mobile particles. The desired ore is then separated from other particles using different technologies, such as gravity concentration, magnetic separation (metals), leaching with cyanide, and others.[3]

Leaching with cyanide needs to be highlighted due to serious environmental and public health impacts. Leaching is usually used with silver, gold, and copper ores. After creation of a large leach pile above an impermeable pad, cyanide containing solution is sprayed on the leach pile, which dissolves the metals. The solution with metals then is collected with the help of pipes.[3] Then, tailings, the amount of ore remaining after the beneficiation, should be disposed of. Tailing disposal could be via (a) creation of tailing ponds (wet tailings), (b) dewatering and burying of dry tailings as backfill (the most environmentally preferable option), and (3) tailing disposal in the sea.[3]

Appendix 2:

Social-ecological model[39] of exposure of community members of Alaverdi and Akhtala to arsenic and lead.