Human Health Risk Assessment (HHRA) for Communities in Kadamjai Rayon, Batken Oblast, Kyrgyz Republic

Final Report

Project Partners:
Kyrgyz Ministry of Health (MOH), Sanitary and Hygienic Laboratory (SHL) of the Interdistrict Kadamjai Center for Disease Prevention and State Sanitary and Epidemiological Surveillance, Médecins Sans Frontières (MSF), TerraGraphics International Foundation (TIFO)

2 April 2022

1 Executive Summary

1.1 Work Accomplished

SHL, MOH, TIFO, and MSF have collaborated since 2018 on an environmental health project in Kadamjai Rayon, Batken Province, Kyrgyzstan. Project partners have worked closely with local stakeholders throughout the project, with the goal of identifying pathways of heavy metal exposure with potential health impacts and developing programs to reduce those exposures and thus improve health in the communities. The project has included several milestones, including:

- Seismic Risk Assessment in Aidarken and Kadamjai towns (2018)
- Data Gaps Analysis and Work Plans (2019)
- Environmental Assessment in Aidarken, Chauvai, and Birlik (villages surrounding Aidarken) (2019)
- Draft Human Health Risk Assessment for Aidarken, Chauvai, and Birlik (2020)
- Kadamjai Area Biomonitoring (Aidarken, Chauvai, and Birlik) and meat/dairy sampling (in Aidarken) (2021)

This report presents final results of the human health risk assessment (HHRA) for residential areas in Aidarken, Chauvai, and Birlik, updating the 2020 HHRA with new information from biomonitoring, meat/dairy sampling, and a cancer risk analysis. Like the 2020 HHRA, this updated 2022 HHRA relies on information from previous investigations.

The 2019 environmental assessment found that contamination levels in soil, water, sediment, and fruit/vegetables throughout the communities exceed Kyrgyz and US health and environmental norms. These exceedances are related to contamination from past mining and mineral processing industry operations. A detailed summary of the environmental assessment is presented in the 2020 Data Summary Report. Excerpts from that report relevant to the HHRA are included in this document for convenience as they are relevant to development of characteristic exposure concentrations. At stakeholders' requests, meat and dairy sources have been sampled and results from that analysis are included in this 2022 HHRA. The results from the 2021 meat/dairy sampling effort are also presented in a February 2022 memo to stakeholders and project partners

1.2 Vulnerable Populations and Associated Health Risks

The HHRA identifies potentially hazardous exposures for children and women living or visiting the most contaminated areas of the communities. Contaminated soils and home-grown vegetables are likely the largest sources of metals intake. There are concerns for oral, chronic and sub-chronic, non-carcinogenic health risks with arsenic (As), antimony (Sb) and mercury (Hg); and lifetime cancer risks associated with oral arsenic (As) exposures. Airborne exposures were not evaluated, although these likely substantially increase cancer risk in the community.

Adult non-carcinogenic risks are generally low, with the exception of potential food-related intakes for pregnant women in the most contaminated areas. Some forms of these toxins can cross the placenta in humans, exposing the fetus to the chemical. Risks for children are significantly higher than adults. Chronic oral exposure to these metals has been associated with gastrointestinal effects, anemia, peripheral neuropathy, skin lesions, hyperpigmentation, and liver or kidney damage. Long-term exposures to arsenic are a carcinogenic risk for both children and adults. Fetal, infant, and childhood risks are of greatest concern. Children tend to have higher contaminant intake rates for behavioral reasons, have a lower body weight, and are in critical developmental periods that are sensitive to metal exposures. Oral ingestion of inorganic arsenic can increase risk of skin, bladder, liver and lung cancer.

1.3 Relevant findings from the Kadamjai Area Biomonitoring (KAB) Study

The Kadamjai Area Biomonitoring (KAB) study conducted in the summer of 2021also indicates significant exposures to arsenic and antimony are ongoing among reproductive-aged women and children in the most contaminated areas. Ninety-two percent (92%) of survey participants exhibited urine or blood metals concentrations exceeding reference levels. About 20% of participants showed clinically significant levels and were referred for medical evaluation. This is an important finding as it aligns with the environmental pathways identified in the HHRA, which appear to be complete. This suggests a substantial portion of the population is experiencing absorption of toxic metals.

1.4 Significant sources of exposure for vulnerable groups

The HHRA evaluated risks associated with heavy metals in water, soil, sediment, vegetables/fruits, and meat/dairy. The assessment focused on ingestion risks only; inhalation-related exposures are likely significant and add to the overall risk of health impacts in the population. These were not evaluated because there is no air data available to use in risk calculations.

In general, adult noncancer risks are low, but there are significant noncancer risks for children related to the concentration of metals in vegetables and soils for Chauvai and Aidarken (see Figure 1-1 and Figure 1-2). At *Typical* (average) concentrations in soil and vegetables, this results in Risk Levels of 2-3 on a 5-point scale. At *Reasonable Maximum Exposures (RME,* worst case scenario), this results in Risk Levels of 3-5 on a 5-point scale.

Figure 1-1. Relative arsenic and antimony intakes at typical exposures for an Aidarken 6-year-old.

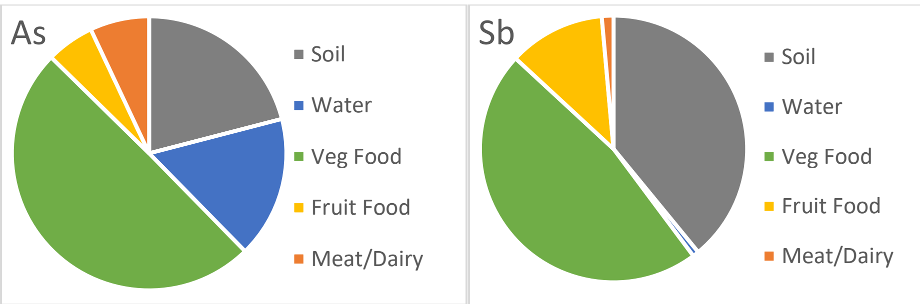
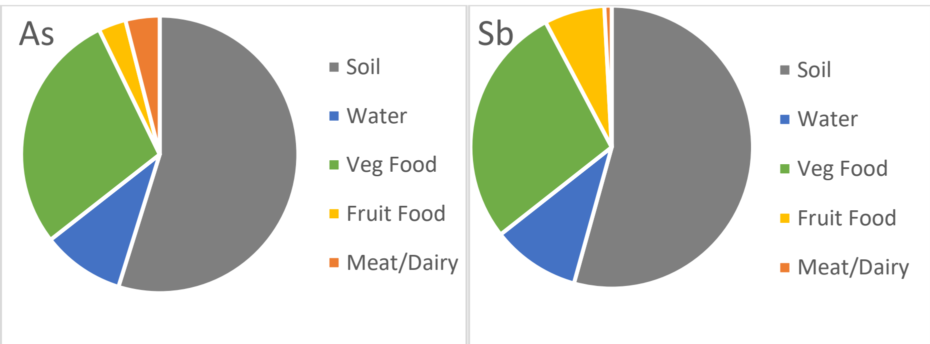


Figure 1-2. Relative arsenic and antimony intakes at typical exposures for a Chauvai 6-year-old.



1.5 Percent of Population at Risk

Understanding the approximate percentage of people in each noncancer risk category is important. For typical adults, 25-45% of the adult populations are in the lowest risk category (Level 1 on 5-point scale) and 0% are in category 4 or greater. Risk levels for children are significantly higher due to higher soil ingestion and food consumptions rates relative to lower body weights. Risk calculations were done for four ages (30-year-old, 20-year-old female, 6-year-old, 2-year-old) and two exposure scenarios (typical environmental media concentrations and reasonable maximum exposure (RME) environmental media concentrations) in all three areas (Aidarken, Chauvai, Birlik).

Table 1-1. Distribution of each community's sub-group in the five noncancer risk categories (based on typical exposure scenarios).

		Negligible Concern (Level 1)	Minimal Concern (Level 2)	Some Concern (Level 3)	Concern (Level 4)	Serious Concern (Level 5)	Total
Aidarken	30-year-old	40%	50%	10%	.	.	100%
	20-year-old female	35%	55%	10%	.	.	100%
	6-year-old	.	25%	30%	35%	10%	100%
	2-year-old	.	15%	20%	45%	20%	100%
Chauvai	30-year-old	35%	50%	15%	.	.	100%
	20-year-old female	25%	60%	15%	.	.	100%
	6-year-old	.	15%	25%	35%	25%	100%
	2-year-old	.	10%	15%	35%	40%	100%
Birlik Villages	30-year-old	50%	40%	10%	.	.	100%
	20-year-old female	45%	45%	10%	.	.	100%
	6-year-old	.	40%	25%	25%	10%	100%
	2-year-old	.	30%	25%	30%	15%	100%

For **Aidarken children at typical exposures**, 75% of 6-year-old and 85% of 2-year-old children are at or above Some (Level 3) Concern. Ten percent (10%) of 6-year-old and 20% of 2-year-old children are at Serious (Level 5) Concern. The principal risk drivers for children in Aidarken are mercury in soil and arsenic and mercury in vegetables.

For **Chauvai children at typical exposures**, 85% of 6-year-old and 90% of 2-year-old children are at or above Some (Level 3) Concern. Twenty-five percent (25%) of 6-year-old and 40% of 2-year-old children are at Serious (Level 5) Concern. The principal risk drivers for children in Chauvai are arsenic and antimony in soil and arsenic and mercury in vegetables.

For **Birlik children at typical exposures**, 60% of 6-year-old and 70% of 2-year-old children are at or above Some (Level 3) Concern for overall risk. Ten percent (10%) of 6-year-old and 15% of 2-year-old children are at Serious (Level 5) Concern. The principal risk drivers for children in Birlik are arsenic and mercury in vegetables.

1.6 Cancer Risks

Carcinogenic risks are assessed differently than non-carcinogenic risks. The 2021 HHRA Summary Memo identified arsenic as a major contaminant of concern risk driver for potential oral non-carcinogenic health effects but did not assess potential cancer risk associated with contaminant exposures. The international Agency for Research on Cancer (IARC) and the US Environmental Protection Agency (USEPA) have classified inorganic arsenic as a human carcinogen. Cancer risk is given in the probability of cancer occurring in a population: i.e., a cancer risk of 10^{-6} would mean the probability of excess cancer occurring is 1 of 1,000,000 people, whereas a cancer risk of 10^{-3} would mean the probability of excess cancer occurring is 1 of 1,000 people.

As stated previously, this study did not include assessment of inhalation-related health risks. Exposure to arsenic via inhalation would greatly increase overall cancer risks. This exposure is likely ongoing along contaminated haul-roads in Chauvai and to a certain extent, Aidarken, and should be considered for future assessments. These roads have both high arsenic and silt content that likely results in suspension of fine particulate arsenic during operations. A school is located nearby and children were observed crossing the roads.

Table 1-2 summarizes lifetime risks for the Typical and RME Scenarios for each of the communities. Total risk ranges from Total risk for 10^{-3} in the Villages Typical Scenario to 10^{-2} in the Chauvai RME scenario. All communities exceed the recommended US health criteria of 10^{-4} to 10^{-7} (1 in 10,000 to 1 in 10,000,000) range of probability of excess cancers from oral exposure alone.

Table 1-2. Lifetime cancer risks associated with oral arsenic exposures.

Exposure Source	**Aidarken**		**Chauvai**		**Birlik**	
	Typical	RME	Typical	RME	Typical	RME
Soil	2.1E-04	4.4E-04	9.8E-04	3.3E-03	1.4E-04	2.9E-04
Water	6.3E-04	8.3E-04	6.4E-04	1.2E-03	9.2E-05	1.9E-04
Veg Food	7.5E-04	5.4E-03	7.5E-04	5.4E-03	7.5E-04	5.4E-03
Fruit Food	6.1E-05	1.4E-04	6.1E-05	1.4E-04	6.1E-05	1.4E-04
Total	1.7E-03	6.8E-03	2.4E-03	1.0E-02	1.0E-03	6.0E-03

Figure 1-3 shows contribution of each Life Stage to Total Lifetime Risk for the Chauvai RME Scenario. Although the childhood stages represent a shorter number of years, the first 16 years of life are responsible for the majority total lifetime risk, with a substantial portion occurring in the first two years. Figure 1-4 shows the by Exposure Source contribution to Total Lifetime Risk for the Chauvai RME Scenario. The most significant exposures are due to arsenic in vegetables and soil. This figure illustrates the significance of highly contaminated home-grown vegetables to overall arsenic exposure and risk.

Figure 1-3. Contribution of exposure during each life stage to lifetime total cancer risk (TCR) in Chauvai RME scenario.

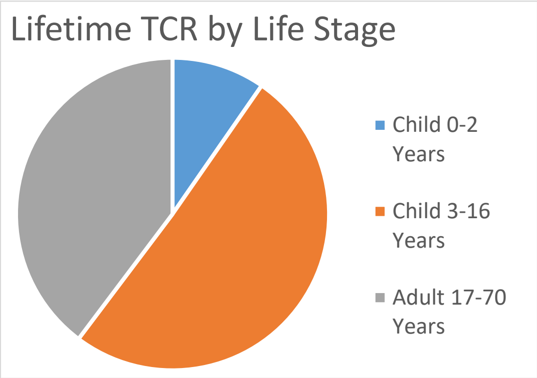
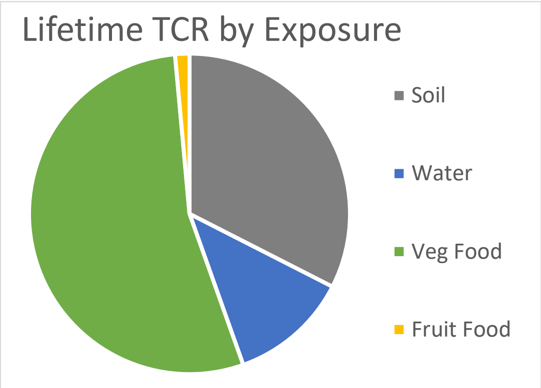


Figure 1-4. Contribution to lifetime total cancer risk (TCR) for different environmental media in Chauvai RME Scenario.



In summary, lifetime oral arsenic carcinogenic risks are excessive throughout all three communities and are largely related to arsenic contamination of food sources throughout the lifetime, and by ingestion of contaminated soils for younger children. The childhood exposures disproportionately contribute to overall lifetime risk.

1.7 Risk Summary

The inclusion of three additional activities completed in 2021-2022 noted above (KAB, animal testing, and cancer risk analyses) did not significantly alter the conclusions of the preliminary 2021 HHRA memo regarding risks presented to Stakeholders in April 2021. Rather, the findings of these activities tend to confirm and enhance the earlier analyses.

Collectively, these results emphasize the significance of incidental soil ingestion and locally-grown food sources in the risk analyses. Arsenic levels in food, particularly from high risk areas, are principal determinants of carcinogenic and non-carcinogenic risk for both children and adults. It is important to note that the RME (high risk) are based on relatively few samples from home gardens exhibiting high soil contamination levels. Although the food samples were washed prior to analyses, it was not determined whether the contaminants were inherent in the plant tissue or in dust in soil attached to the surface of the vegetable.

Any intervention strategy aimed at reducing exposure to contaminated vegetables should be balanced against any potential adverse nutritional aspects of restricting the food source. Proper nutritional and vitamin status is important to children's health and can influence absorption rate of metals in the gut. Encouraging thorough washing and peeling of locally-grown produce and, when possible, avoiding growing produce in highly-contaminated areas, should be promoted.

Behavioral related risks: Risks related to individual or group behaviors or practices in a family or community can include consumption of contaminated vegetables and soils, especially for children. Food-related risk is amplified if vegetables are not washed and peeled prior to consumption. Exposure to contaminated soil is also a significant risk for children in Aidarken and Chauvai, and any time spent in industrial areas (e.g., sludge ponds in Aidarken, tailings pipe field in Eshme, former Kombinot site and mining haul roads in Chauvai) can significantly increase risk.

Infrastructure related risks: Risks related to the structure and function of the general community can include industrial activities that can transport highly contaminated soils, dust, gases, or wastes from current or former industrial areas into the community by wind, water or carried on vehicles or by workers can increase risk. Risks can also include use of mine water for irrigation or watering livestock in agricultural areas. Use of irrigation water for drinking consumption would increase risk to adults and children. Other potentially significant risk associated with industrial releases of pollutants include mercury emissions from the operating Kombinot in Aidarken and arsenic emissions from contaminated haul roads at the mining operation roads in Chauvai. These pathways were not evaluated in this risk assessment because air data are not available. Inhalation exposure to As and Hg are typically higher risk than ingestion exposures. While the KAB study did not find significant levels of Hg, that could be due to the low production from the Kombinot at the time of sampling.

Due to time, budget, and resource constraints, there are limitations to the scope of every HHRA. These limitations result in some uncertainty regarding total risk. An uncertainty analysis is included in this report and should be taken into consideration when making regulatory or public health policy decisions related to heavy metal exposures. A major uncertainty relates to Kombinot operations – significant pollutant levels, exposures, risks, absorption rates and adverse health were documented during the peak of Aidarken Kombinot operations years 20-40 years ago. The SHL/MOH/TIFO/MSF collaboration focused on public health risks related to environmental exposures; no samples were collected from Kombinot property. Further, the studies were conducted while mining and mineral refining were curtailed in comparison to historical operations. Exposures related to mining and mineral operations would likely exceed those identified in these recent efforts should processing operations increase. Renewed operations of the mercury Kombinot in Aidarken and haul roads from mining operations in Chauvai are examples of activities that, potentially, could result in greater exposures than those assessed in this investigation.

1.8 Risk Reduction through Exposure Reduction

The potential health risks associated with these exposures should be addressed through a comprehensive public health response that includes access to medical care, public health advisories and health promotion activities, community-wide measures to reduce exposures through remediation or access controls, parental and child counseling to modify behavioral co-factors, environmental testing to identify sources of contamination, and advice and assistance in reducing exposures in the home environment.

The most effective overall interventions benefiting the greatest percentage of the population are exposure reduction strategies that reduce intake. These environmental intervention strategies are aimed at severing the active exposure pathways. The ultimate success in implementing environmental interventions is determined by the reduction in or elimination of the need for medical intervention.

A significant challenge in implementing an effective health intervention program is to reduce metals intake rates and exposure without compromising the nutritional and socio-economic well-being of the child and family. This is particularly important with respect to food sources and behavioral constraints.

The interventions proposed in the 2021 HHRA Memo to reduce exposures in the Kadamjai Rayon mining communities remain valid and are repeated below for emphasis. They include categories of behavioral interventions, short-term institutional interventions, larger-scale institutional interventions, monitoring recommendations, and medical interventions.

Behavioral Interventions

- Consistent, thorough washing and peeling of fruits and vegetables
- Developing a program where residents can have produce tested for metals by SHL
- Consistent dust abatement measures indoors (frequent cleaning)
- Designating "safe" outdoor play areas with barriers from contaminated soils
- Discouraging/preventing children from visiting industrial sites
- When possible, avoiding the cultivation of crops in soil with high heavy metal concentrations

Short-term Institutional Interventions

- Fencing off contaminated areas (sludge ponds, Chauvai Kombinot site)
- Providing safe play areas with spot remediation
- Re-routing mine-site water to prevent residential use
- Separating mine water discharge from Kombinot wastewater discharge; wastewater should be piped directly to tailings pond

Larger-scale interventions

- Mine wastewater filtration/treatment prior to discharge
- Remediation of Aidarken sludge ponds, Chauvai Kombinot area, and Eshme field with broken tailings pond pipe
- Remediation of residential, public, and agricultural areas with high contamination

Monitoring recommendations

- Conduct regular monitoring of soil (especially residential), water (drinking and irrigation), food, and air in the territories of Aidarken and Chauvai. Monitoring should be conducted for Hg, As, and Sb in all of these media.

Medical interventions

- Train local doctors and nurses in environmental health intervention priorities, with a focus on exposure reduction
- Develop Environmental awareness message for reducing the exposure of heavy metals to the general population and especially children
- Strengthen the clinical toxicology capacity in Kyrgyzstan
- Continue to assess and analyze medical needs

2 Introduction

2.1 Background

This report updates the 15 April 2021 Human Health Risk Assessment (HHRA) Summary Report, specifically updating the analyses related to the 2021-2022 activities undertaken after the HHRA Summary Report was published.

The following reports contain important information relevant to this 2022 HHRA Report and should be referenced for more detailed information related to previous studies, environmental sampling plans, environmental results, and HHRA analysis methodologies and assumptions:

- *Seismic Hazard Assessment Report* (2018) and *Addendum* (2019)
    - Background information on extent and stability of mining wastes in Aidarken and Kadamjai towns
- *Data Gaps Analysis Memo* (2019)
    - Background information on previous studies and information needed to characterize public health risk in communities
- *Scope of Work* and *Work Plan* for HHRA and associated environmental sampling (2019)
    - Sampling plan for collection of environmental data
- *Data Summary Reports* (*Technical* and *Stakeholder* Versions, 2020)
    - Extensive summary of environmental media concentrations from SHL/MOH/TIFO/MSF 2019 sampling activities
- *HHRA Summary Results Memo* (2021)
    - Detailed descriptions of how risk assessment calculations where performed, which health-based standards were used, and underlying assumptions in quantifying overall risks within the populations of Aidarken, Chauvai, and Birlik
- *Intervention Program Development Memo* and *Remediation Memo* (2021)
    - Summaries of options for reducing heavy metal exposures based on information gathered in HHRA and other assessments.

The 2021 HHRA Summary Memo evaluated health risks associated with environmental sampling undertaken in 2019. The preliminary HHRA addressed Aidarken, Chauvai, and Birlik. The results of these analyses concluded that non-carcinogenic adult exposures, contaminant intake rates, and risks were relatively low in all three communities. Conversely, overall risk levels for children are significantly greater in all communities, due to higher soil ingestion and food consumption rates relative to body weight. Additionally, children are more susceptible to adverse health outcomes during early stages of development. The preliminary HHRA results were presented to Stakeholders in April of 2021 by SHL. The meetings were used to solicit comments and concerns from the public and to introduce the proposed Biomonitoring Study to be conducted in the summer of 2021. Stakeholders indicated concerns with potential risks associated with contaminated meat, dairy, and poultry food sources, and cancer risks. In response to these concerns, three important activities related to the health assessment were completed in 2021-2022:

Biomonitoring Study (*detailed results forthcoming in separate report*)	(See Section 4)
Animal Food Product Testing	(See Section 3.2)
Carcinogenic Risk Assessment	(See Section 8)

2.2 Summary of HHRA Process

HHRA is a scientific methodology that allows for estimates of risk related to exposure. It requires an understanding of contaminant concentration (e.g., concentration of Sb in vegetables) and knowledge of how often a person or population is exposed to that media (e.g., how many servings of vegetables per day). From this, an intake is calculated, usually in mg of contaminant consumed per kg body weight of the individual per day, and compared to a health-based standard. In this document, the characteristic contaminant concentrations are presented in Section 5 and contaminant intakes are detailed in Section 6.

Risk is estimated separately for noncarcinogens and for carcinogens. For noncarcinogens, risk is quantified by comparing total intake to a Reference Dose (RfD). The RfD is an estimate of daily exposure in a population (including sensitive subgroups) that is likely to be without an appreciable risk during a lifetime of exposure. The ratio of Intake/RfD is called a Hazard Quotient (HQ). The sum of Hazard Quotients is a Hazard Index. A HQ or HI greater than 1 indicates that there are significant risks of noncancer health impacts related to exposure. A summary of noncarcinogenic risks for the communities in this study is presented in Section 7.

For carcinogens, intakes are calculated over the course of a lifetime. These intakes are then multiplied by a Slope Factor (SF), which is the risk of cancer per dose of the chemical, to give a Cancer Risk (CR). CRs can be summed to estimate Total Cancer Risk (TCR). Because cancer risk has no threshold, the CR or TCR are often compared to an 'acceptable cancer risk' value ranging from 1 in 100,000 to 1 in 10,000,000 (10^{-5} to 10^{-7}). If a TCR exceeds the acceptable cancer risk value, it means there is significant lifetime risk of excess cancer developing in a population. A summary of carcinogenic risks is presented in Section 8.

The underlying assumptions and resulting uncertainties associated with an HHRA are given in Section 10 of this document.

The results of the HHRA are used to identify the most significant sources of exposure in a population so that exposure reduction efforts can specifically target those issues and prevent or reduce health impacts. For example, if an HHRA identifies an HQ > 1 for pesticides in drinking water, but HQ < 1 for all other media, the intervention can focus on reducing exposure via water. Proposed risk reduction strategies are detailed in Section 11.

3 Supporting Database

3.1 Data Summary Report

The data used in the April 2021 HHRA Summary Memo is from the 2019 environmental survey conducted jointly by Center for Disease Prevention and State Sanitary and Epidemiological Surveillance of Kadamjai (SHL), TIFO, and MSF. These data were detailed in the Data Summary Report (DSR) entitled: AUGUST-SEPTEMBER 2019 ASSESSMENT OF THE ENVIRONMENTAL STATE OF AIDARKEN AND CHAUVAI AREAS OF KADAMJAI RAYON, BATKEN OBLAST and presented to Health Authorities and Stakeholders in April 2021. This cooperative study developed a representative database of metals in soils, water, sediments, and food in the Aidarken and Chauvai regions of Kadamjai Rayon. The database was used to:

i) characterize baseline contamination levels in residential and public areas near the former mercury Kombinats,
ii) assess potential risks to public health,
iii) target follow-up human biological monitoring surveys among area residents, and
iv) develop interventions to reduce health risks.

That database was supplemented by the results of the biomonitoring and animal food product testing for this 2022 HHRA report. Section **Error! Reference source not found.** Appendix contains a summary from the DSR for reference.

3.2 Animal Sampling Results

No animal protein samples were collected during the 2019 Environmental Survey. During the release of HHRA results to the stakeholder committee in 2021, several residents requested that health authorities investigate potential heavy metal contamination of meat, dairy, and eggs raised in contaminated areas. A limited investigation was undertaken in the fall of 2021 and results and subsequent risk analyses were presented in a 14 February 2022 Memorandum *Animal Sampling Results and Risk Analysis*, by TIFO to MSF, MOH, and SHL. Detailed information about sampling and laboratory methodology can be found in the February 2022 Memo. A summary of tissue results is provided in Table 3-1. These values, along with estimates of meat and dairy intake developed by Kyrgyz researchers, were used to estimate risks related to consumption of these products. Those estimates are included in total risk calculations in Sections 5-8.

Because the sampling protocol targeted animals that foraged in the most contaminated areas of the community, the results of the assessment should not be interpreted to represent all meat/dairy sources in the region.

Table 3-1. Summary of wet weight arsenic, antimony, mercury, and cadmium results from Joseph Stephan Institute (JSI) by sample type (mg/kg); liver and muscle results are combined across species.

		Arsenic (As)		Antimony (Sb)		Mercury (Hg)		Cadmium (Cd)	
Sample Type	Count (N)	Average	Max	Average	Max	Average	Max	Average	Max
Egg	6	0.017	0.030	0.010	0.027	0.046	0.081	0.0001	0.0002
Liver	6	0.028	0.061	0.071	0.187	0.133	0.507	0.0525	0.1013
Milk	6	0.004	0.009	0.002	0.006	0.000	0.001	0.0001	0.0001
Muscle	12	0.032	0.110	0.011	0.037	0.009	0.021	0.0039	0.0229

4 Biomonitoring Study

4.1 KAB Overview

The preliminary results of the HHRA summarized in April of 2021 were used to identify target areas to recruit participants in the Kadamjai Area Biomonitoring Study (KAB Study). The 2021 risk analyses concluded that children and women of reproductive age living in the most contaminated areas are the most likely to experience excessive risk related to arsenic, mercury, and antimony exposures. The most significant sources are locally grown vegetables and contaminated soils at the home, schools, playgrounds, and daycare locations.

The KAB study was a targeted, cross-sectional study to assess the level of heavy metal exposure in the most sensitive individuals (children and reproductive-aged women) in the most contaminated regions of the Kadamjai district. It included collection of blood and urine samples from 255 participants (131 women and 124 children) from 116 households. The KAB study thus provides an estimate of exposure for the highest risk subgroups in the highest risk areas. Children < 5 years were not solicited in the study due to lack of available population-based reference levels.

4.2 KAB Results

This study established that there are complete pathways of exposure to the heavy metals identified in the environmental assessment. The KAB results suggest that levels of exposure in this targeted area are much higher than levels in other population-based studies globally. The majority (92%) of participants had a value for at least one analyte in either matrix that exceeded an established reference value. Nearly 20% were offered a clinical assessment as they had levels above an established action level.

The Biomonitoring Study Results indicated significant levels of absorption in most of the population for multiple contaminants.

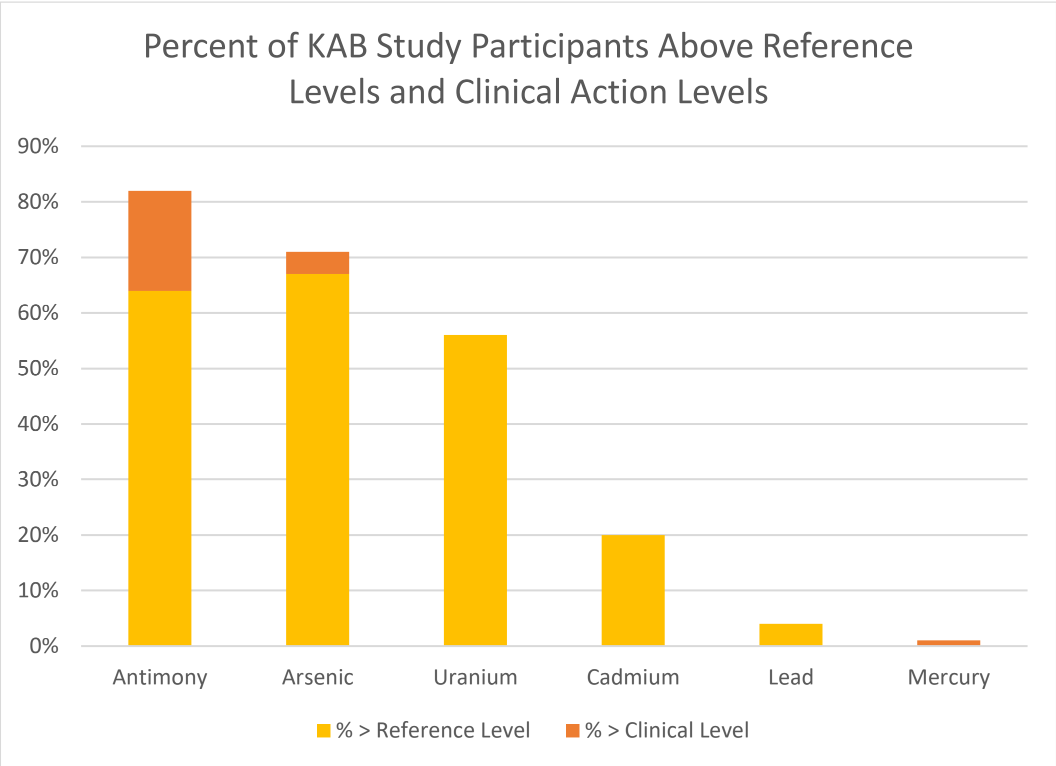
The number of participants with levels in blood or urine above a reference value were (also see Figure 4-1):

- 209 (82%) for antimony (18% of these individuals had values warranting clinical follow-up)
- 176 (69%) for arsenic (2% of these individuals had values warranting clinical follow-up)
- 143 (56%) for uranium
- 51 (20%) for cadmium
- 11 (4%) for lead
- 3 (1%) for mercury (1% of these individuals had values warranting clinical follow-up)

The levels of all metals appear to be highest in the youngest children (5-10 years old). For example, the levels of blood antimony in children under 10 is almost 3 times higher than levels in adults older than 45.

Both the HHRA and the KAB indicate that there are active pathways of exposure to heavy metals. These results will help inform targeted public health measures to mitigate ongoing exposures, identify health effects, and implement primary prevention activities.

Figure 4-1. Percent of biomonitoring study participants above reference (yellow) and clinical (orange) action levels.



Some of the KAB findings are discussed in the next two subsections because they were not anticipated at the beginning of the Project.

4.2.1 Mercury absorption

Previous health and environmental assessments by other investigators focused on mercury contamination associated with the long history of mercury production in Aidarken and Chauvai. The HHRA found lower levels of mercury and exposure than earlier studies and low levels of MeHg, except near the former sludge pond areas of Aidarken. Mercury hazards are most likely related to vapor emissions from the operation of the

Mercury Kombinot and were not evident at the time of HHRA and Biomonitoring field surveys. Despite the presence of a large primary mercury mine and smelter, average mercury blood and urine values were below established reference levels. In general, levels of urine mercury were highest in Aidarken.

4.2.2 Antimony absorption

Literature reviews and the results of limited *in vitro* bioavailability tests of soil samples (Appendix Section **Error! Reference source not found.**) suggested that uptake or absorption rates for antimony would be low. However, the biomonitoring study shows significant antimony absorption is occurring. Both the absorption mechanisms and clinical significance of antimony uptake are poorly understood. The apparent high bioavailability of antimony may be associated with the food pathway in the gut, or to the air pathway that was not characterized, or to other unknown factors. Additional investigation of antimony intake and potential health effects in these communities is warranted.

5 Estimating Characteristic Exposure Concentrations

HHRA is a process that quantitatively evaluates the potential for adverse health effects associated with exposures to contaminated environmental media (air, soil, water, food) by different pathways (e.g., inhalation, ingestion). This HHRA quantifies carcinogenic risk due to oral ingestion of arsenic and non-carcinogenic risk associated with oral ingestion of four contaminants of concern (COC): antimony (Sb), arsenic (As), total mercury (Hg) and methylmercury (MeHg). These risks are calculated for adults (30 and 20-years old) and children (2 and 6 years old) from ingestion of soils, food, and water in Aidarken, Chauvai, and the villages surrounding Aidarken (Birlik).

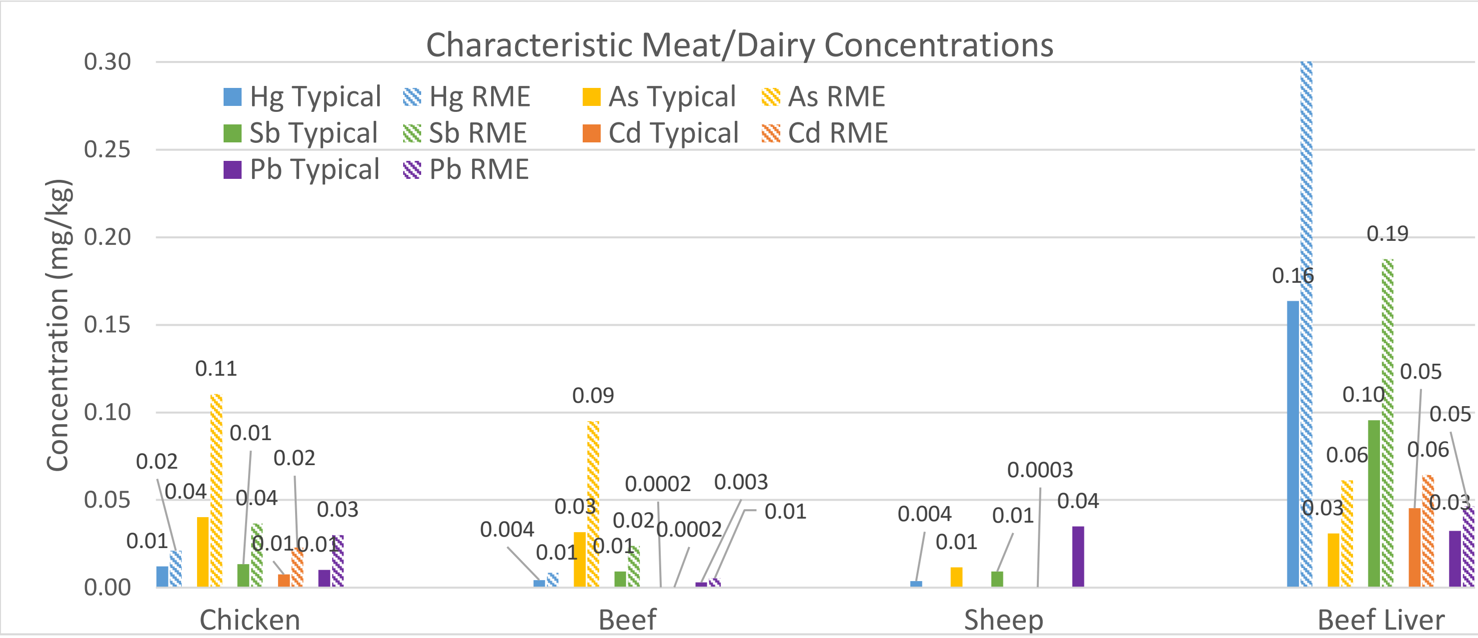
Health risks are quantified by combining exposure concentrations with exposure frequency to determine estimated daily intakes (EDI) of each contaminant. Environmental results from the August-September 2019 sampling and 2021 animal testing were used to estimate contamination levels in soil, water and food. Exposure Frequency was calculated using exposure factors derived from Kyrgyz Ministry of Health guidance documents in consideration of practices and characteristics of the local population. Contaminant intake estimates are then compared to acceptable levels and Reference Doses determined by international health criteria.

5.1 Characteristic Contaminant Concentrations

Characteristic contamination values were developed for soil, water, and food using data from the 2019 environmental sampling. These are detailed in the 2021 HHRA Report and shown in **Error! Reference source not found.** through **Error! Reference source not found.** in Appendix Section **Error! Reference source not found.** for convenience.

Food protein sources (meat, milk, eggs, liver) were sampled in 2021 from the most contaminated areas. As a result, the animal protein contaminant concentrations are assumed to represent “worst case” exposures. Typical (average) and Reasonable Maximum Exposures (95^{th} percentile, RME) concentrations were developed for meat and dairy. RME values may be considered the “worse-case scenario” values. Although the RME characteristic concentrations and intake estimates developed below are appropriate, the typical concentrations for the communities may be biased high because the sampling was biased towards the most contaminated areas.

Figure 5-1. Characteristic meat/dairy concentrations by sample type for mercury (Hg), arsenic (As), antimony (Sb), cadmium (Cd), and lead (Pb) in mg/kg.



6 Estimating Contaminant Intakes

6.1 Exposure factors (EFs):

EFs are variables specific to the local population. These are important for understanding the rate or frequency at which people come into contact with the contaminated media (soil, water, food). Exposure factors include physical characteristics such as body weight, and behavioral factors such as consumption of locally-grown produce, soil ingestion rate, etc.

This HHRA focused on four age groups and utilized the exposure factors described in Table 6-1.

Table 6-1. Exposure factors used in calculating intakes. Red values indicate culturally specific exposure factor estimates based on Kyrgyz standard values and/or literature review. NC=noncancer, C=cancer.

Exposure Factor	Adult Age 30 Years	Child Age 6 Years	Adult Female Age 20 years	Child Age 2 Years
Age (yr)	30	6	20	2
Body weight (kg)	64	18.6	58	11.4
Duration-Food, Soil, Water (yr)	1	1	1	1
Frequency- Soil, Water (day/yr)	365	365	365	365
Frequency- Food (day/yr)	365	365	365	365
Frequency- Air (day/yr)	260	260	260	260
Ingestion Rate-Soil (mg/day)	50	200	50	200
Ingestion Rate-Water (L/day)	2	0.69	2	0.69
Ingestion Rate-Fruit (g/day)	280	297	280	325
Ingestion Rate- Vegetable (g/day)	542	509	542	320
Ingestion Rate-Meat (g/day)	69	46	69	32
Ingestion Rate-Milk/milk products (g/day)	140	333	140	365
Average Time- Food, Water, Soil-NC (days)	365	365	365	365
Average Time- Food, Water, Soil-C (days)	25550	25550	25550	25550

6.2 Exposure Scenarios:

An Estimated Daily Intake (EDI) was developed for each of the four age groups listed in Table 6-1. An EDI is calculated by combining the concentration in media with the rate at which people ingest that media. For example, an EDI can be calculated for vegetables by combining the concentration in vegetables with the average amount of potatoes and other vegetables consumed each day. The EDI is then compared to recognized health criteria for each contaminant of concern. Health criteria are available from United States, European Union and World Health Organization sources. The health criteria used in this analysis are based on a Provisional Tolerable Weekly Intake (PTWI) from the World Health Organization (WHO) or the European Food Safety Association converted to a Tolerable Daily Intake (TDI).

Table 6-2. Health criteria used in comparison to the contaminant EDIs.

Criteria	Units	Arsenic	Methylmercury	Total Mercury	Antimony
PTWI[1]	µg/kg*week	15	1.3[2]	4	NA
TDI[3]	µg/kg*day	2.1	0.2	0.6	6.0
TDI[3]	mg/kg*day	0.0021	0.000186	0.00057	0.006

6.3 Updated Intake Calculations

The following intakes have been updated from 2021 to include exposures related to meat and dairy. Note that the methyl mercury intakes have not changed since the 2021 HHRA Summary Memo because the animal tissue analysis did not include mercury speciation.

[1] Provisional Tolerable Weekly Intake (PTWI) is the WHO health-based criteria for minimal risk. Available at https://apps.who.int/iris/handle/10665/40675

[2] EFSA 2012. Scientific Opinion on the risk for public health related to the presence of mercury and methylmercury in food. European Food Safety Authority, Parma, Italy

[3] Tolerable Daily Intake (TDI) is derived from the PTWI by dividing by 7 days/1 week.

Figure 6-1. Arsenic intakes (mg As per kg body weight per day) for the three communities, by risk group and exposure scenario (typical and reasonable maximum exposure (RME)). The WHO tolerable daily intake (TDI) and the US EPA Reference Dose (RfD) are indicated by solid and dashed orange lines, respectively.

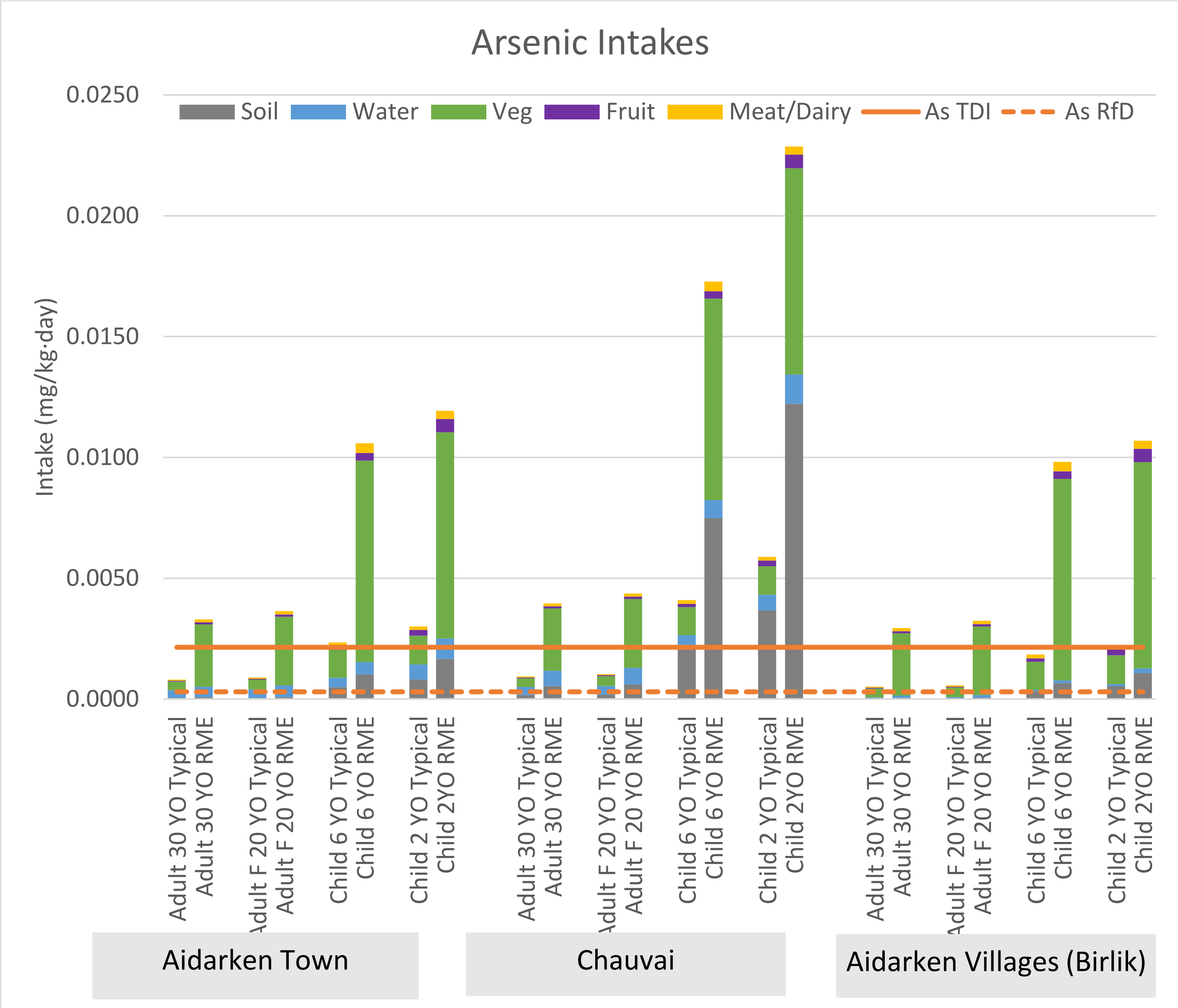


Figure 6-2. Methylmercury intakes (mg MeHg per kg body weight per day) for the three communities, by risk group and exposure scenario (typical and reasonable maximum exposure (RME)). The WHO tolerable daily intake (TDI) and the US EPA Reference Dose (RfD) are indicated by solid and dashed orange lines, respectively. Note that there is no MeHg data available for meat/dairy samples.

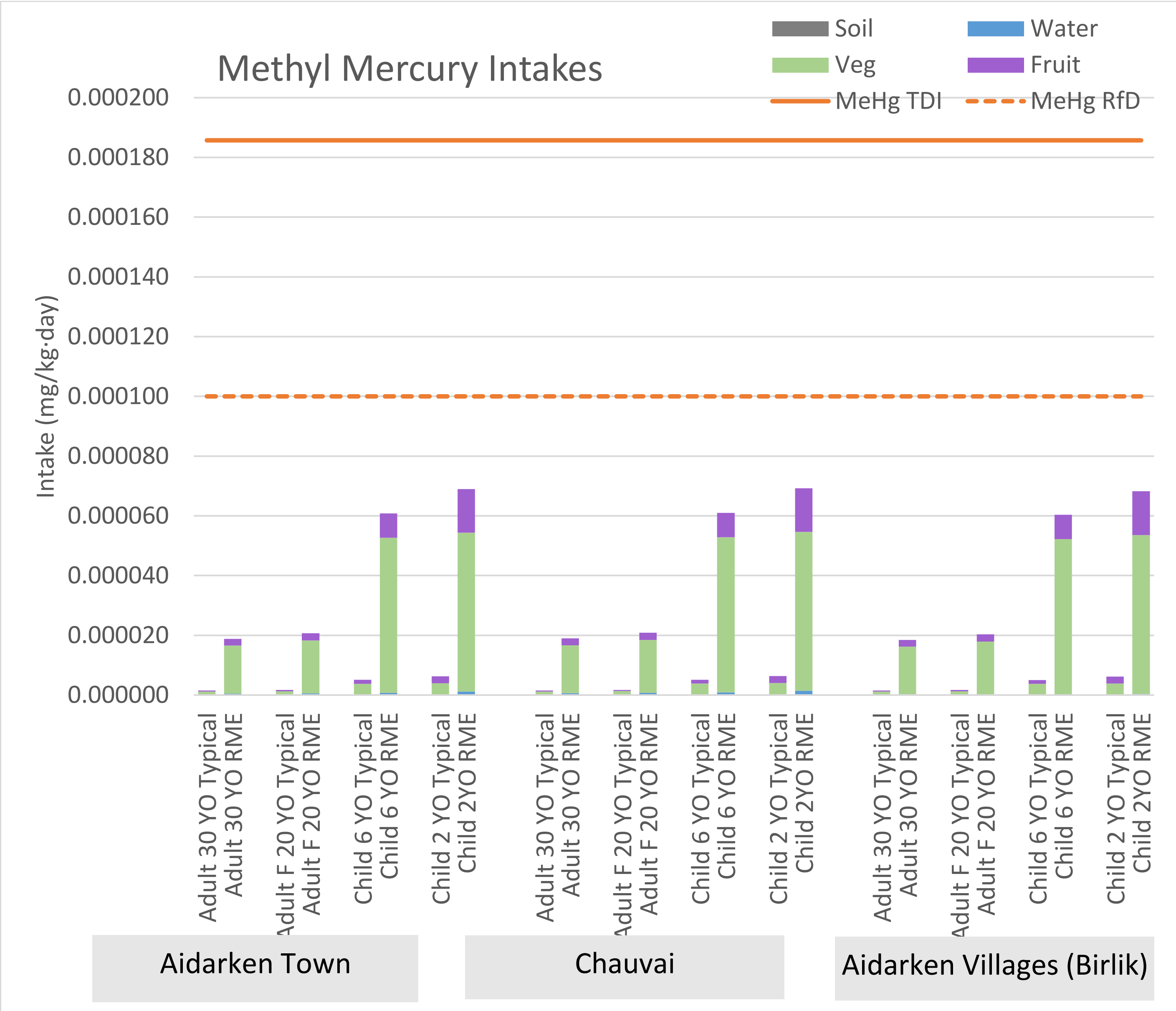


Figure 6-3. Mercury intakes (mg Hg per kg body weight per day) for the three communities, by risk group and exposure scenario (typical and reasonable maximum exposure (RME)). The WHO tolerable daily intake (TDI) and the US EPA Reference Dose (RfD) are indicated by solid and dashed orange lines, respectively.

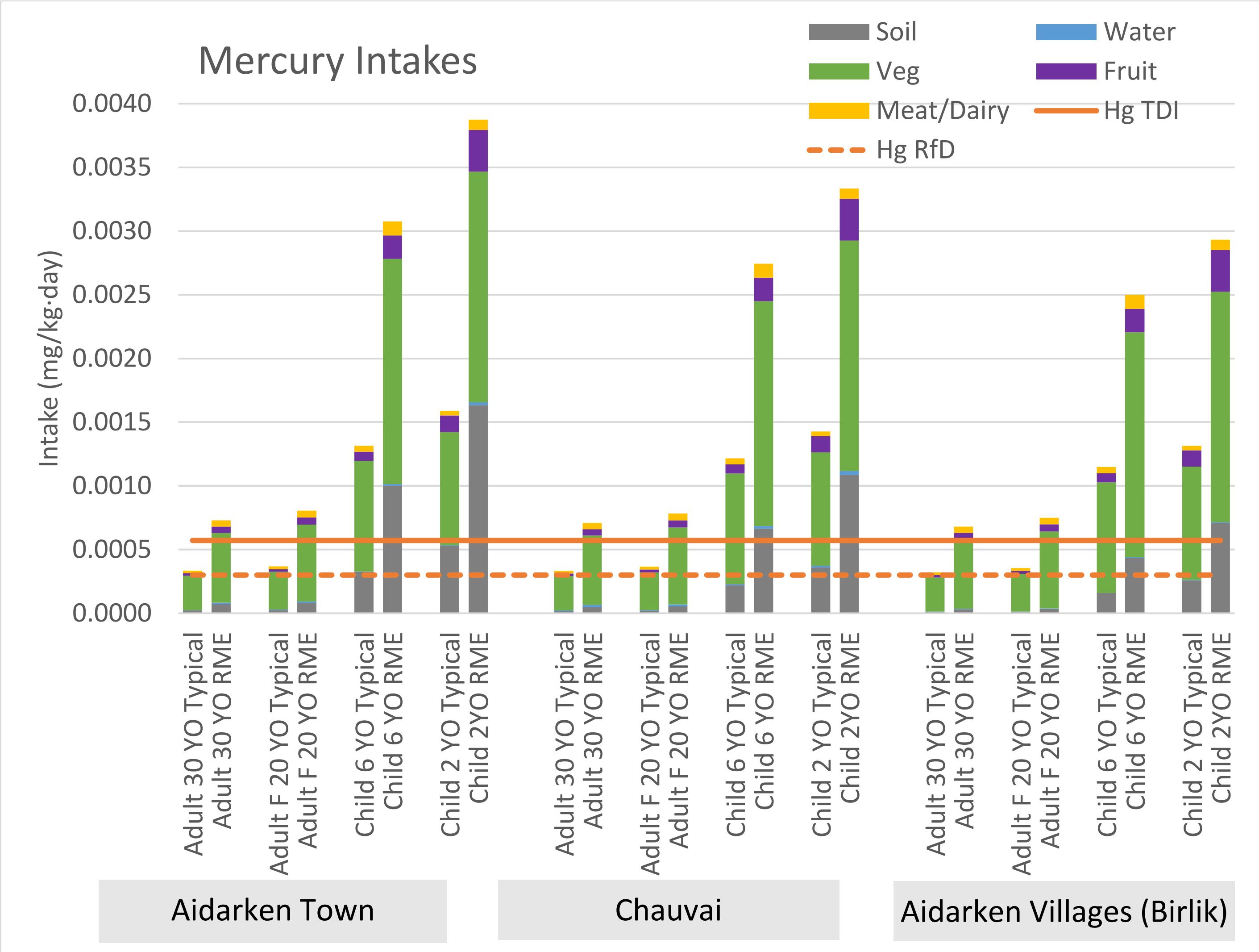
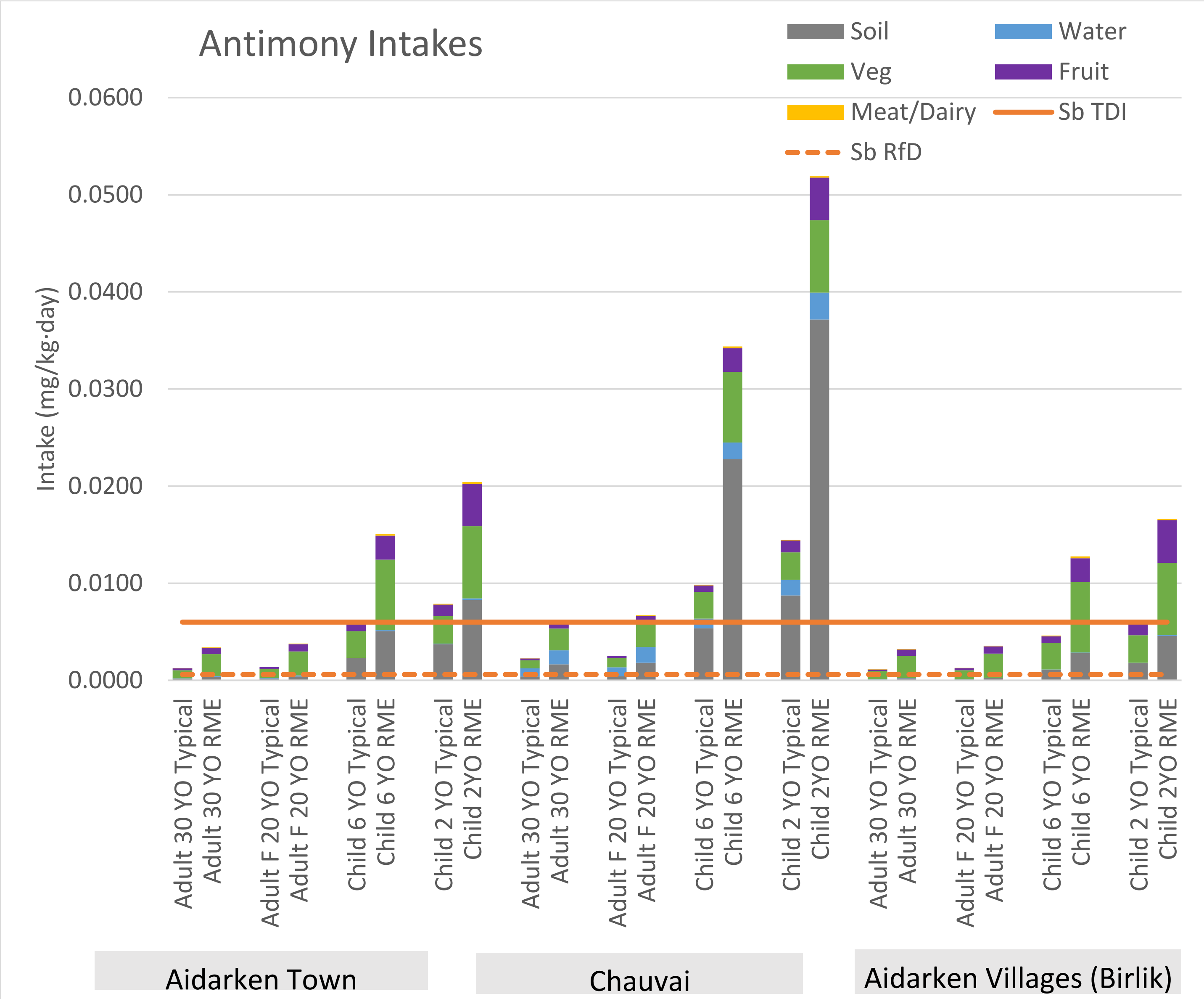


Figure 6-4. Antimony intakes (mg Sb per kg body weight per day) for the three communities, by risk group and exposure scenario (typical and reasonable maximum exposure (RME)). The WHO tolerable daily intake (TDI) and the US EPA Reference Dose (RfD) are indicated by solid and dashed orange lines, respectively.



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In general, adult noncancer risks are low, but there are significant risks for children related to the concentration of metals in vegetables and soils for Chauvai and Aidarken. At *Typical* (average) concentrations in soil and vegetables, this results in Risk Levels of 2-3 on a 5-point scale. At *Reasonable Maximum Exposures (RME,* worst case scenario), this results in Risk Levels of 3-5 on a 5-point scale.

Figure 6-5. Relative arsenic and antimony intakes (percent of total intake) at typical exposures for an Aidarken 6-year-old.

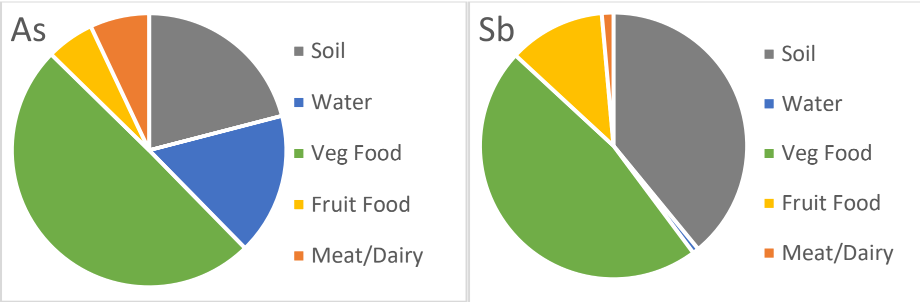
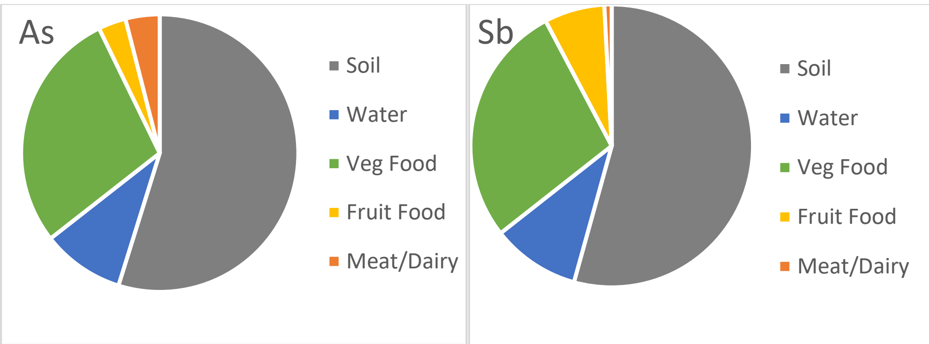


Figure 6-6. Relative arsenic and antimony intakes (percent of total intake) at typical exposures for a Chauvai 6-year-old.



7 Quantifying Non-Carcinogenic Health Risks

7.1 Risk Calculations:

A Hazard Quotient (HQ) is a ratio of an EDI to a health criterion. HQs are calculated for each metal and media. Hazard Indices (HI)s are developed by summing HQs by media and contaminant, or both, provided the contaminants have common toxic mechanisms and health effect endpoints (target organs). These calculations have been updated from the 2021 HHRA Memo to include heavy metal intakes related to meat/dairy consumption.

Table 7-1 summarizes potential health effects and target organs for the four contaminants. Mercury, arsenic, and antimony have common target neurologic effects and target organs. Non-cancer HI tables are color-coded (see Table 7-2) to identify exposure routes with potential health concern.

Table 7-1. Summary of potential health effects for contaminants of concern. Blank values indicate that the health effect has not been evaluated for the metal.

Systemic Effects	Arsenic	Antimony	Total Mercury	Methyl Mercury
Neurological	YES	YES	YES	YES
Hematological	YES	YES	YES	NO DATA
Cardiovascular	YES	YES	YES	.
Renal	NO	NO	YES	LIMITED DATA
Dermal	YES	YES	YES	NO DATA
Respiratory	YES	YES	YES	.
Cancer	YES	YES	NO	POSSIBLE
Genotoxicity	NO	NO	YES	YES
Hepatic	YES	YES	YES	YES
Bone	NO	NO	.	.
Developmental	YES	YES	YES	YES
GI	YES	YES	YES	YES
Musculoskeletal	.	.	YES	YES
Endocrine	.	.	YES	NO DATA

Table 7-2. Color-coding system for Hazard Quotients (HQ) and Hazard Indices (HI).

Level of Concern	Risk Scale	HQ	HI
Serious Concern	5	>5	>10
Concern	4	3-<5	>5-10
Some Concern	3	1.5-<3	>3-5
Minimal Concern	2	.5-<1.5	1-<3
Negligible Concern	1	<.5	<1

Levels 1 and 2 indicate low risk and are not of concern for most members of the population. Level 3 indicates some concern and the need to further investigate to determine whether exposure mitigation efforts are appropriate. Levels 4 and 5 indicate that the populations should be made aware of the excessive risk and measures to reduce risk should be identified and implemented where appropriate.

Table 7-3 shows summary HIs calculated by the WHO health criteria (TDI). **Error! Reference source not found.** through **Error! Reference source not found.** in Appendix Section **Error! Reference source not found.** show the HQ values for each metal and media, HI values for each media and contaminant, and a total HI for all media and contaminants combined. Both HQ and HI are unitless.

Table 7-3 below gives these values for the updated meat/dairy analysis.

Table 7-3. Hazard Indices (HI) across metals for each media, based on WHO Tolerable Daily Intake (TDI) health-based criteria. These are calculated for 4 risk groups at typical and reasonable maximum exposure (RME) concentrations.

		Hazard Indices for Typical Exposure						Hazard Indices for RME					
		Soil	Veg	Fruit	Meat/ Dairy	Water	HQ	Soil	Veg	Fruit	Meat/ Dairy	Water	HQ
Scenario 1, Aidarken, Typical EF	30-year-Old	0.1	0.8	0.1	0.1	0.2	1.2	0.2	2.6	0.3	0.2	0.2	3.5
	20-year-Old Female	0.1	0.9	0.1	0.1	0.2	1.3	0.2	2.9	0.3	0.1	0.3	3.8
	6-year-old	1.2	2.5	0.3	0.2	0.2	4.4	3.1	8.5	0.9	0.4	0.3	13.1
	2-year-old	1.9	2.6	0.6	0.1	0.3	5.5	5.0	8.7	1.6	0.3	0.5	16.1
Scenario 1, Chauvai, Typical EF	30-year-Old	0.2	0.8	0.1	0.1	0.3	1.4	0.6	2.6	0.3	0.4	0.6	4.4
	20-year-Old Female	0.2	0.9	0.1	0.1	0.3	1.6	0.7	2.9	0.3	0.1	0.6	4.6
	6-year-old	2.3	2.5	0.3	0.2	0.4	5.7	8.5	8.5	0.9	0.4	0.7	18.9
	2-year-old	3.8	2.6	0.6	0.1	0.6	7.7	13.8	8.7	1.6	0.3	1.1	25.5
Scenario 1, Birlik, Typical EF	30-year-Old	0.0	0.8	0.1	0.1	0.0	1.0	0.1	2.6	0.3	0.2	0.1	3.2
	20-year-Old Female	0.0	0.9	0.1	0.1	0.0	1.1	0.1	2.9	0.3	0.1	0.1	3.5
	6-year-old	0.6	2.5	0.3	0.2	0.0	3.7	1.5	8.5	0.9	0.4	0.1	11.3
	2-year-old	1.0	2.6	0.6	0.1	0.1	4.3	2.5	8.7	1.6	0.3	0.1	13.3

7.2 Risk Interpretation Summary

Elevated HQs and HIs identify exposures that merit additional consideration for environmental remediation, and health intervention and monitoring activities. HQs and HI are not indicators of disease or ongoing health effects.

7.2.1 Adult Risks

In general, adult risks are low (

Table 7-3), but there are significant risks for children related to the concentration of metals in vegetables and in soils for Chauvai and Aidarken. Younger children are at significantly higher risk due to higher vegetable and soil consumption rates relative to body weight. There is Negligible (Level 1) to Minimal (Level 2) Concern for all media in all communities under a typical exposure scenario. Vegetables pose Minimal (Level 2) Concern and Cumulative HIs are (Level 4) Concern under the RME scenario.

7.2.2 Risks at Typical (average) Exposures for Children

- Washed/peeled fruit and drinking water are Negligible (Level 1) Concern in all communities.
- Hazard indices indicate Minimal (Level 2) Concern for As and Some (Level 3) Concern for Hg in vegetables, with a total HI of Minimal (Level 2) concern.
- Soil Hazard Indices indicate:
    - Minimal (Level 2) Concern for soil in Aidarken due to Hg and As
    - Minimal (Level 2) to Some (Level 3) Concern in Chauvai due to As and Sb
    - Negligible (Level 1) to Minimal (Level 2) Concern in Birlik
- Total HIs across all media are:
    - Some Concern (Level 3) to Concern (Level 4) for children in Aidarken
    - Concern (Level 4) for children in Chauvai
    - Some Concern (Level 3) for children in Birlik, largely attributed to vegetable concentrations

7.2.3 Risks at RME (worst-case scenario) Exposures for Children

- Washed and peeled fruit and drinking water are of Negligible (Level 1) Concern in all communities.
- Vegetable HIs range from Some (Level 3) Concern to Concern (Level 4).
- Soil exposures indicate:
    - Some (Level 3) Concern for Hg and Minimal (Level 2) Concern for As and Sb in Aidarken
    - Concern (Level 4) to Serious (Level 5) Concern for As and Sb and Negligible (Level 1) Concern for Hg in Chauvai
    - Minimal (Level 2) Concern in Birlik
- Total HIs for RME exposures for all contaminants and media are:
    - Concern (Level 4) to Serious (Level 5) Concern in Aidarken, largely due to As and Hg in vegetables and Hg in soil.
    - Serious (Level 5) Concern in Chauvai, largely due to As and Hg in vegetables and As and Sb in soil.
    - Serious (Level 5) concern in Birlik Villages, largely due to metal concentrations in vegetables.

7.2.4 Population Distribution of Overall Risk

Approximately half of the population in each community would have exposures less than the Typical value and most of the other one-half would have exposures between the Typical and RME values. Approximately 5% of each population sub-group is expected to have risk levels greater than the RME. The >95th percentile individuals are often subject to uncommon exposures or behaviors that result in extraordinary risk levels. Special consideration is often given to identifying and intervening with these individuals in health response programs.

Understanding the approximate percentage of people in each risk category is important. Table 7-4 estimates the percentage of each sub-population group's overall combined risk for each sub-group and community (to the nearest 5%).

Table 7-4. Distribution of each community's sub-group in the five risk categories.

		Negligible Concern (Level 1)	Minimal Concern (Level 2)	Some Concern (Level 3)	Concern (Level 4)	Serious Concern (Level 5)	Total
Scenario 1, Aidarken	30-year-old	40%	50%	10%	.	.	100%
	20-year-old female	35%	55%	10%	.	.	100%
	6-year-old	.	25%	30%	35%	10%	100%
	2-year-old	.	15%	20%	45%	20%	100%
Scenario 1, Chauvai	30-year-old	35%	50%	15%	.	.	100%
	20-year-old female	25%	60%	15%	.	.	100%
	6-year-old	.	15%	25%	35%	25%	100%
	2-year-old	.	10%	15%	35%	40%	100%
Scenario 1, Birlik	30-year-old	50%	40%	10%	.	.	100%
	20-year-old female	45%	45%	10%	.	.	100%
	6-year-old	.	40%	25%	25%	10%	100%
	2-year-old	.	30%	25%	30%	15%	100%

Adult Risks: The results suggest relatively low exposures, contaminant intake rates, and risk for adults in all three communities. Twenty-five percent (25%) to 45% of the adult populations are in the lowest category (Level 1).

Children's Risks: Risk levels for children are significantly higher due to higher soil ingestion and food consumption rates relative to lower body weights. Additionally, children are more susceptible to adverse health outcomes during early stages of development.

For **Aidarken children**, 75% of 6-year-old and 85% of 2-year-old children are above Some (Level 3) Concern. Ten percent (10%) of 6-year-old and 20% of 2-year-old children are at Serious (Level 5) Concern. The principal risk drivers for children in Aidarken are mercury in soil and arsenic and mercury in vegetables.

For **Chauvai children**, 85% of 6-year-old and 90% of 2-year-old children are above Some (Level 3) Concern. Twenty-five percent (25%) of 6-year-old and 40% of 2-year-old children are at Serious (Level 5) Concern. The principal risk drivers for children in Chauvai are arsenic and antimony in soil and arsenic and mercury in vegetables.

For **Birlik children**, 60% of 6-year-old and 70% of 2-year-old children are above Some (Level 3) Concern for overall risk. Ten percent (10%) of 6-year-old and 15% of 2-year-old children are at Serious (Level 5) Concern. The principal risk drivers for children in Birlik are arsenic and mercury in vegetables.

8 Quantifying Carcinogenic Health Risks

The 2021 HHRA Summary Memo identified arsenic as a major contaminant of concern risk driver for potential oral non-carcinogenic health effects, but did not assess potential cancer risk associated with contaminant exposures. The International Agency for Research on Cancer (IARC) and the US Environmental Protection Agency (USEPA) have classified inorganic arsenic as a human carcinogen and IARC has classified antimony as a possible human carcinogen. Several epidemiological studies suggest that prolonged inhalation exposure to inorganic arsenic increases the risk of lung cancer. Oral ingestion of inorganic arsenic can increase risk of skin, bladder, liver and lung cancer. Because inhalation exposures to As increase cancer risk more than ingestion exposures, the most significant cancer risks in these communities are respiratory or lung cancers due to airborne arsenic. Because of the lack of reliable data regarding air contaminant data, it is not possible to effectively assess lung cancer risk without extensive air pollution monitoring.

The biomonitoring study suggests that there is significant arsenic absorption ongoing among adults and children in, at least, the high risk areas. There are significant carcinogenic risks associated with oral intake of arsenic. Cancer risk is separated from noncancer risk in this report because it is calculated differently – it relies on different assumptions and is presented as a risk of excessive cancer occurring within the population. Because carcinogens do not have a threshold (there is no reference dose, RfD), acceptable cancer risks are set at the lowest practical value and can vary within a country and region.

8.1 Calculating Intakes for Cancer Risk (CR)

In assessing cancer risk, the biological response is described as a lifetime probability of experiencing an excess tumor. Although the exposure may not occur over the entire lifetime, doses are calculated differently than for noncancer risk; they are presented as lifetime average daily doses (LADDs), using the following formula:

$$LADD = [C * IR * ED] / [BW * LT]$$

Where:

LADD = Lifetime Average Daily Dose (mg/(kg*day) (70 year-average))
C = Media Contaminant Concentration (mg/kg)
IR = Media Intake Rate (mg/day)
ED = Exposure Duration (1 year (365 days))
BW = Body Weight (kg)
LT = Lifetime (70 years (25550 days))

8.2 Cancer Risk Estimates for Aidarken, Chauvai, and Birlik

Cancer risk is estimated by multiplying the LADD by the oral cancer slope factor (SF). The USEPA has calculated an oral cancer slope factor of 1.5 (mg/(kg*d)) -1 for inorganic arsenic.

$$\text{Cancer Risk} = LADD * SF$$

Cancer risk is given in the probability of cancer occurring in a population: i.e., a cancer risk of 10^{-6} would mean the probability of excess cancer occurring is 1 of 1,000,000 people.

USEPA[4] recommends calculating risk for the children at younger life stages during childhood, when low body weight results in a higher dose rate than would be calculated using the lifetime average exposure. In this case, it is appropriate to apply these risks to different segments, labelled "i", of life and average the dose rate over the 70 year lifetime.[5]

Error! Reference source not found. through **Error! Reference source not found.** in Appendix **Error! Reference source not found.** show the estimated oral arsenic cancer risks. The left three columns of those tables show the estimated lifetime probability cancer risk for one year of exposure for 2-year-old and 6-year-old children and for adults. The next three columns show risk for three lifetime segments: 0-2 years, 3-16 years, and 17-70 years. The final (rightmost) column adds the life stage segment risks for the total lifetime cancer risk.

Table 8-1 presents the risk scale associated with different cancer risks. Table 8-2 summarizes lifetime risks for the Typical and RME Scenarios for each of the communities. Total risk ranges from total risk for 10^{-3} in the

[4] USEPA Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens[4] (EPA/630/R-03/003F March 2005)

[5] LADDi is the lifetime average daily dose rate (intake rate/body weight), EDi is the exposure duration (time over which the contact actually takes place), is the average exposure concentration during period of calendar time EDi, IRi is the average ingestion rate during EDi, BWi is body weight during exposure duration EDi, and LT is the averaging time, in this case, a lifetime (converted to days).

Villages Typical Scenario to 10^{-2} in the Chauvai RME scenario. All communities exceed the recommended US health criteria of 10^{-4} to 10^{-7} (1 in 10,000 to 1 in 10,000,000) range of probability of excess cancers.

Table 8-1. Ranking system for Carcinogenic Risk. For example, 10^{-3} is a risk of excess cancer occurring in 1 of 1,000 people, 10^{-4} is a risk of excess cancer occurring in 1 of 10,000 people, etc.

Level of Concern	Risk Scale	Risk	
Serious Concern	5	$>10^{-3}$	
Concern	4	$>10^{-4}$	and $<10^{-3}$
Some Concern	3	$>10^{-5}$	and $<10^{-4}$
Minimal Concern	2	$>10^{-6}$	and $<10^{-5}$
Negligible Concern	1	$<10^{-6}$	

Table 8-2. Lifetime cancer risks associated with oral arsenic exposures.

Lifetime Cancer Risks

Exposure Source	**Aidarken Typical**	**Aidarken RME**	**Chauvai Typical**	**Chauvai RME**	**Villages Typical**	**Birlik RME**
Soil	2.1E-04	4.4E-04	9.8E-04	3.3E-03	1.4E-04	2.9E-04
Water	6.3E-04	8.3E-04	6.4E-04	1.2E-03	9.2E-05	1.9E-04
Veg Food	7.5E-04	5.4E-03	7.5E-04	5.4E-03	7.5E-04	5.4E-03
Fruit Food	6.1E-05	1.4E-04	6.1E-05	1.4E-04	6.1E-05	1.4E-04
Total	1.7E-03	6.8E-03	2.4E-03	1.0E-02	1.0E-03	6.0E-03

Figure 8-1 shows contribution of each Life Stage to Total Lifetime Risk for the Chauvai RME Scenario. Although the childhood stages represent a shorter number of years, the first 16 years of life are responsible for the majority total lifetime risk, with a substantial portion occurring in the first two years. Figure 8-2 shows the Exposure Source contribution to Total Lifetime Risk for the Chauvai RME Scenario. The most significant exposures are due to arsenic in vegetables and soil. This figure illustrates the significance of highly contaminated home-grown vegetables to overall arsenic exposure and risk. Figure 8-3 illustrates the relative importance of contaminated soils to children's exposures, and the evolving dominance of food exposures with age into adulthood.

Figure 8-1. Relative (%) contribution of exposure during each life stage to total lifetime cancer risk in Chauvai RME scenario.

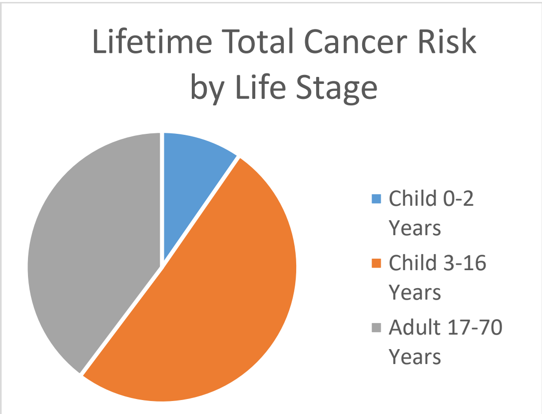


Figure 8-2. Relative (%) contribution to total lifetime cancer risk for different environmental media in Chauvai RME Scenario.

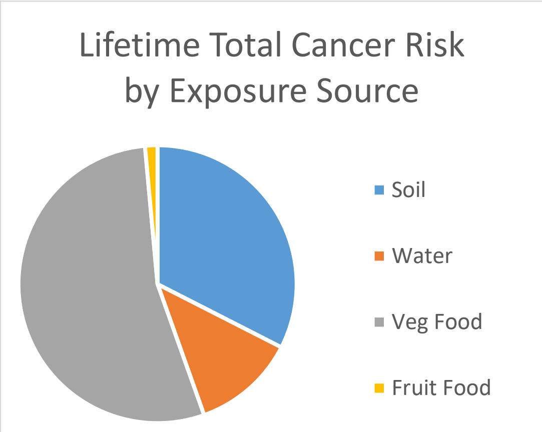
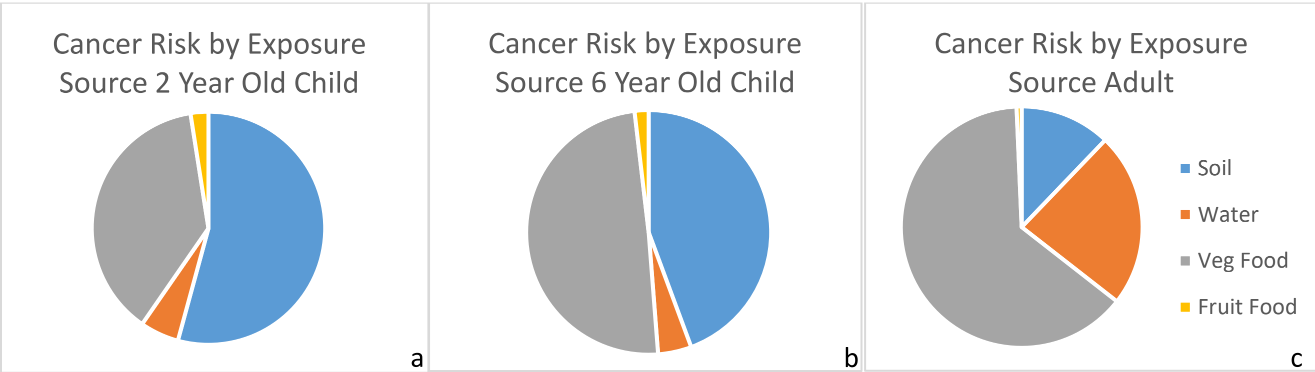


Figure 8-3. Relative (%) cancer risk by environmental media for a 2-year-old child (a), a 6-year-old child (b), and for an adult (c).



In summary, lifetime oral arsenic carcinogenic risks are excessive throughout all three communities and are largely related to arsenic contamination of food sources throughout the lifetime, and by contaminated soils for younger children. The childhood exposures disproportionately contribute to overall lifetime risk.

9 Risk Discussion

9.1 Additional information from 2021-2022 efforts

The inclusion of three additional activities completed in 2021-2022 noted above, (i.e., biomonitoring, animal testing, and cancer risk analyses) did not significantly alter the conclusions of the preliminary report regarding non-carcinogenic risks presented in Section 7 and provided to Stakeholders prior to the Biomonitoring Study in April 2021. Rather, the findings of these activities tend to confirm and enhance the earlier analyses

Biomonitoring Study: With respect to non-carcinogenic risk, the HHRA suggests about 10% to 15% of the adult population, and 60% to 90% of children show non-carcinogenic risk levels of some concern, with 10% to 40% of 6 year-old and 15% to 40% of 2 year-old children at the most serious concern levels. The biomonitoring study indicates about 90% of both children and adult women have absorption of arsenic and antimony concentrations greater than reference levels; and about 20% are above clinical levels. This suggests that a majority of the population may be experiencing significant absorption in all communities.

Overall risk levels for children are significantly greater than adults in all communities, due to higher soil ingestion and food consumption rates relative to lower body weights. Additionally, children are more susceptible to adverse health outcomes during early stages of development.

Animal Food Product Testing: The animal tissue tests indicate observable metals levels in meat, offal and dairy products collected from highly exposed animals. In general, concentrations were similar to those in vegetables and fruits. These data suggest that metals in the high risk areas are bioavailable to forage agricultural animals. However, consumption of these animal proteins did not appreciably increase non-carcinogenic risks for adults and children due to relatively low intake rates compared to vegetables.

Carcinogenic Risk Assessment: The HHRA found excessive carcinogenic risk in all three communities. This is largely related to arsenic contamination of food sources throughout the lifetime, and by contaminated soils for younger children. The childhood exposures disproportionately contribute to overall lifetime risk, due to higher soil ingestion and food consumption rates relative to lower body weights. It should be noted that the food exposures are the same for all communities. As a result, any differences in oral arsenic carcinogenic risk among communities are likely due to childhood soil exposures. This might suggest that the similarities in arsenic absorption rates between adults in children noted in the biomonitoring study are related to food sources.

The enhanced uptake implications of the biomonitoring study may indicate that arsenic and antimony are, perhaps, more bioavailable than anticipated from *in vitro* bioaccessibility tests conducted on soil and waste samples from the site (see Appendix, Section **Error! Reference source not found.**. The HHRA results in Appendix Section **Error! Reference source not found.** suggest that soils and vegetables grown in contaminated soils are the risk-drivers for arsenic sources for children. However, adult risk is more related to food and antimony risk indices point to soils as the primary contaminant intake source.

Collectively, these results emphasize the significance of food sources in the risk analyses. Arsenic levels in food, particularly from high risk areas, are principal determinants of carcinogenic and non-carcinogenic risk for both children and adults. It is important to note, that the RME (high risk) are based on relatively few samples from home gardens exhibiting high soil contamination levels. Although the food samples were washed prior to analyses, it is not clear whether the contaminants were inherent in the plant tissue or in dust in soil attached to the surface of the vegetable.

Any intervention strategy aimed at reducing the consumption of fruits and vegetables should be balanced against any potential adverse nutritional aspects of restricting the food source. Proper nutritional and vitamin status is important to children's health and can influence absorption rate of metals in the gut. Additional investigation of the relative significance of food and soil exposures is warranted.

9.2 Risk Categories

In considering the exposure sources and mechanisms, as these might influence intervention strategies, risks can be discussed as behavioral, infrastructure, and chemically related.

Behavioral related risks: Risks related to individual or group behaviors or practices in a family or community can include consumption of contaminated vegetables and soils, especially for children. Food-related risk is amplified if vegetables are not washed and peeled prior to consumption. Exposure to contaminated soil is also a significant risk for children in Aidarken and Chauvai, and any time spent in industrial areas (e.g., sludge ponds in Aidarken, tailings pipe field in Eshme, former Kombinot site and mining haul roads in Chauvai) can significantly increase risk.

Infrastructure related risks: Risks related to the structure and function of the general community can include industrial activities that can transport highly contaminated soils, dust, gases, or wastes from current or former industrial areas into the community by wind, water or carried on vehicles or by workers can increase risk. These include use of mine water for irrigation or watering livestock in agricultural areas. Use of irrigation water for drinking consumption would increase risk to adults and children. Other potentially significant risk associated with industrial releases of pollutants include mercury emissions from the operating Kombinot in Aidarken and arsenic emissions from contaminated haul roads at the mining operation roads in Chauvai. These pathways were not evaluated in this risk assessment.

Chemically related risks consider the contribution of total risk by the different metals (As, Hg, MeHg, Sb). HQ and HI summaries for individual and combined metals intakes are shown in **Error! Reference source not found.**, **Error! Reference source not found.**, and **Error! Reference source not found.**. Specific concerns for each metal are discussed below.

Methylmercury is a potential concern because of the relatively high toxicity and bioavailability. MeHg levels were low in most of the media sampled for this study, except for the abandoned sludge ponds near Aidarken. MeHg concentrations in the sludge ponds are of potential concern to humans and livestock that access the area.

Arsenic is a primary risk driver for oral non-carcinogenic risks in vegetables and soils in Chauvai. Arsenic is not fully characterized with respect to cancer risk in this 2022 HHRA. Arsenic is classified as a human carcinogen by both oral and inhalation routes. Cancer risk was not evaluated because of insufficient air quality data. The highest cancer risks are likely associated with arsenic concentrations in air near the mining operation haul roads in Chauvai. These roads have both high arsenic and silt content that likely results in suspension of fine particulate arsenic during operations. A school is located nearby and children were observed crossing the roads. Samples from the roadsides and sediment from adjacent streams were analyzed for bioavailability at a US laboratory and the results are summarized in **Error! Reference source not found.**. Arsenic bioavailability is extremely high for these samples indicating enhanced toxicity. Arsenic bioavailability was elevated throughout the study area indicating that arsenic risks may be greater than the estimated results.

Antimony is a primary risk driver in soils in Chauvai and for combined media pathways in Aidarken and Chauvai. Although the antimony bioavailability results from *in vitro* were low as shown in Appendix Section 17, the biomonitoring study results suggest that antimony-related risk may be greater than estimated in the 2021 HHRA results.

Mercury is a primary risk driver in vegetables and soils in Aidarken**.** Mercury bioavailability and chemical speciation results were low, except for one sample from a garden area bordering the Kombinot in Aidarken. In general, this would suggest mercury risks may be less than estimated in the HHRA.

10 Uncertainty Analysis

Due to time, budget, and resource constraints, there are limitations to the scope of every HHRA. These limitations result in some uncertainty regarding total risk. The following summarizes the uncertainties and limitations of this assessment. These uncertainties may result in an over- or under-estimation of total risk.

- This assessment focuses on ingestion risks; inhalation of the metals of concern could be significant for both non-cancer and cancer risks.
- Due to lack of air data, the assessment does not address inhalation carcinogenic risks, which may be significant and should be considered for future assessments. Total carcinogenic risk analysis requires reliable air arsenic data.
- Airborne mercury vapor exposures could be significant, but are dependent on Kombinot operations which were not monitored for this investigation.

- Sample collection and exposure estimates are limited to residential and public areas in the communities and exclude active mining sites.
- Although this report addresses the most comprehensive food contamination survey conducted in these communities, the results rely on relatively few samples and the data should be interpreted with care.
- Food exposures are assessed separately for vegetables, fruit and meat/dairy sources because consumption rates and contamination levels differ significantly.
- Because few fruit and vegetable samples from Chauvai and Birlik were analyzed, results from Aidarken were aggregated across communities and applied for all locations. This may result in an over- or under-estimation of risk in Chauvai, and likely results in an over-estimation of risk in Birlik (because of lower soil heavy metal concentrations in those villages).
- Animal protein sources (meat, dairy, poultry) were sampled in an animal testing survey conducted in 2021. This study targeted animals foraging in the most contaminated areas of the communities. Estimated meat/dairy contamination levels are likely over-estimated for the general population.
- No pulse or legumes plant protein sources were sampled.
- Water exposures are limited to designated drinking and irrigation water sources reported by survey participants.
- Water risks assumed that irrigation water is never consumed (ingested); this may result in an under-estimation of total risk if surface waters are consumed.
- No recreational, occupational, or background exposures are considered.
- Bioavailability and speciation should also be considered when interpreting data. **Error! Reference source not found.** through **Error! Reference source not found.** in the Appendix provide bioavailability and chemical speciation results.
- The bioavailability of As is elevated at industrial sites, likely increasing total risks. While investigations at other sites indicate the bioavailability of Sb and Hg in soil is low, the elevated levels of As and Sb in urine and blood samples indicate absorption is ongoing.
- Relatively few individuals were included in the biomonitoring study. It is likely that substantial percentage of the population in high risk areas and considerable numbers of residents in other portions of the community are also experiencing significant health risks due to heavy metal exposures.

11 Risk Intervention Strategies

Figure 11-1 taken from the USEPA Exposure Factors Handbook[6] illustrates the exposure continuum from release of pollutants from industrial activities, incorporation of the contaminants into the environmental media, human intake through ingestion, inhalation and dermal contact with the contaminated media, absorption of the toxins into human tissues, and eventual adverse health effects in target organ systems.

[6] Exposure Factors Handbook 2011 Edition (Final Report) | Environmental Assessment | US EPA

Figure 11-1. Exposure-Dose-Effect Continuum from the USEPA Exposure Factors Handbook.

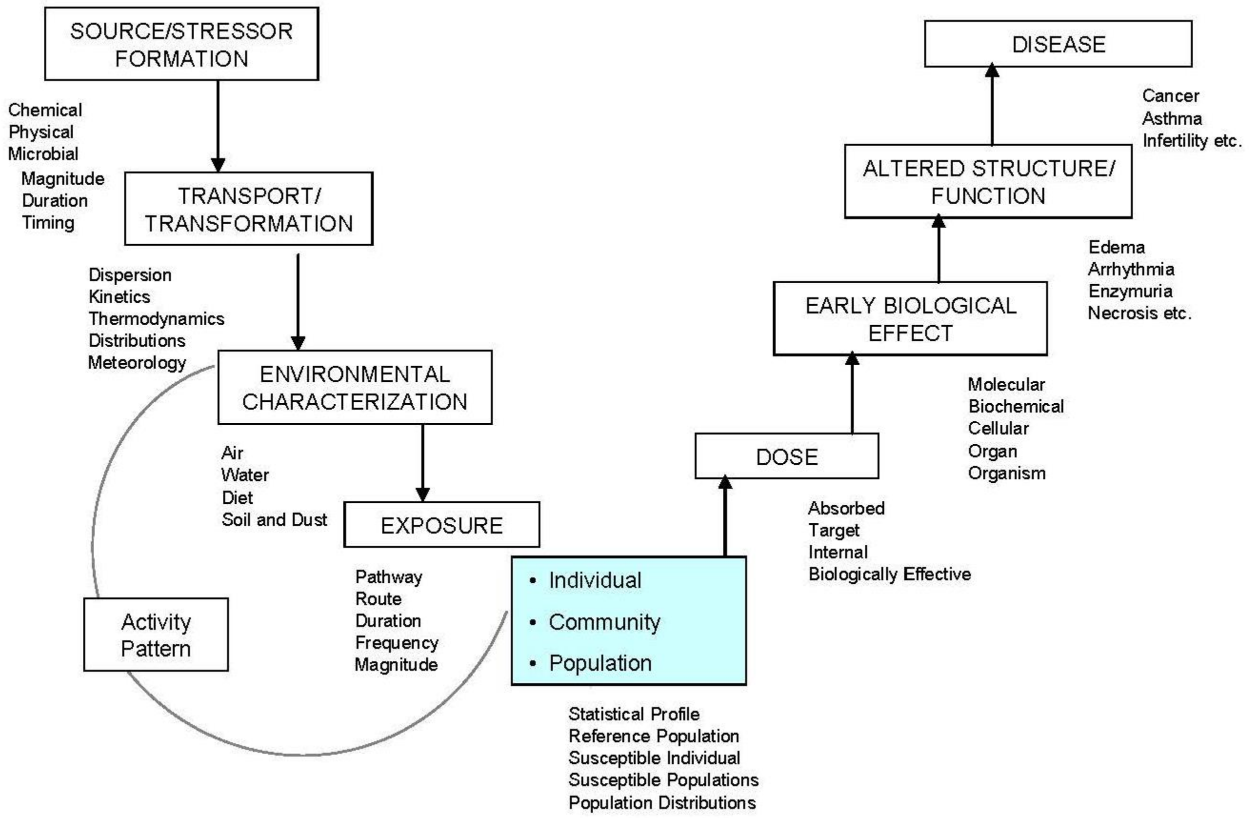


Figure 1-2. Exposure-Dose-Effect Continuum.

Source: Redrawn from U.S. EPA (2003c); WHO (2006); Ott (2007).

The exposure-dose-effect continuum depicts the trajectory of an agent from its source to an effect. The agent can be transformed and transported through the environment via air, water, soil, dust, and diet. Individuals can become in contact with the agent through inhalation, ingestion, or skin/eye contact. The individual's physiology, behavior, and activity patterns as well as the concentration of the agent will determine the magnitude, frequency, and duration of the exposure. The exposure becomes an absorbed dose once the agent crosses the absorption barrier (i.e., skin, lungs, eyes, gastrointestinal tract, placenta). Interactions of the chemical or its metabolites with a target tissue may lead to an adverse health outcome. The text under the boxes indicates the specific information that may be needed to characterize each step in the exposure-dose-effect continuum.

This risk assessment addresses the left side of Figure 11-1 by characterizing the contamination levels in environmental media, estimating human intake and external dose, and assessing the probability of adverse health risks. The biomonitoring study identifies absorption on the right side of Figure 11-1, confirming that absorption is ongoing in as much as 90% of the population in the most contaminated high risk areas with 20% of participants being advised to seek clinical follow-up.

Interventions can be applied at any stage in this continuum. For those experiencing clinical absorption levels on the right side of Figure 11-1, medical interventions are warranted; MOH and MSF are working to develop clinical toxicology capacity.

However, the most effective overall interventions benefiting the greatest percentage of the population are exposure reduction strategies that reduce intake. These environmental intervention strategies are aimed at severing the continuum pathways on the left side of Figure 11-1. The ultimate success in implementing environmental interventions is determined by the reduction in or elimination of the need for medical intervention.

As the center box in Figure 11-1 indicates, these interventions can be implemented at the individual, community, or population level. Potential environmental risk intervention strategies have been suggested in previous reports and meetings with partners and stakeholders. These are detailed below. These are technical recommendations based on the HHRA results and will reduce exposure to contaminants and overall health risks. However, it is important that:

- Stakeholders and other community members provide input and comments regarding the feasibility and public acceptance of these interventions to identify the most appropriate methods.
- The interventions do not compromise the nutritional and socio-economic wellbeing of the individual or family.
- The interventions are implemented by trusted local institutions in the course of typical public/environmental health services.
- The interventions don't impose extraordinary cost or burden on the residents or implementing institutions

Behavioral Interventions

- Consistent, thorough washing and peeling of fruits and vegetables
- Developing a program where residents can have produce tested for metals by SHL
- Implementing dust abatement measures indoors (frequent cleaning)
- Designating "safe" outdoor play areas with barriers from contaminated soils
- Discouraging / preventing children from visiting industrial sites
- When possible, avoiding cultivation of crops in soil with high heavy metal concentrations

Short-term Institutional Interventions

- Fencing off contaminated areas (sludge ponds, Chauvai Kombinot site)
- Providing safe play areas with spot remediation
- Re-routing mine-site water to prevent residential use
- Separating mine water discharge from Kombinot wastewater discharge; wastewater should be piped directly to tailings pond

Larger-scale interventions

- Mine wastewater filtration/treatment prior to discharge
- Remediation of Aidarken sludge ponds, Chauvai Kombinot area, and Eshme field with broken tailing pond pipe
- Remediation of residential, public, and agricultural areas with high contamination

Monitoring recommendations

- Conduct regular monitoring of soil (especially residential), water (drinking and irrigation), food, and air in the territories of Aidarken and Chauvai. Monitoring should be conducted for Hg, As, and Sb in all of these media.

Medical interventions

- Train local doctors and nurses in environmental health intervention priorities, with a focus on exposure reduction.
- Develop Environmental awareness message for reducing the exposure of heavy metals to the general population and especially children
- Strengthen the clinical toxicology capacity in Kyrgyzstan
- Continue to assess and analyze medical needs