**Heavy metal pollution from mining activities**

**Practical**; Assessing the impact of heavy metal pollution from mining operations



Your task is to evaluate the risk of chronic toxicity due metal exposure by the local population (part 1) and to assess the impact of heavy metal pollution from mining activities for causing these risks (part 2).

The main river has a small tributary, which drains a mining area (lead-zinc mine). The water in this tributary is an orange colour. Downstream from the tributary is a town that uses the river for drinking water and to irrigate rice fields. People from the town also eat fish caught from the river.

Further upstream on the main river, local people mine the river sediments for gold (artisanal mining) – red box. They use the mercury amalgamation technique to process the gold from the sediment.

**Part 1:** Exposure of local people to heavy metals

The people living in the local town use the river for drinking water and to irrigate their rice fields. They also eat fish caught from the river.

In this part of the practical we will assess the risk of chronic toxicity posed by exposure of local people to heavy metals via drinking water and food.

Instructions

Step 1

Using the following equation calculate the average daily intake (ADI) of each metal (Pb, Cd and Hg) for 3 different exposure activities;

1. drinking river water,
2. eating rice and
3. eating fish.

ADI = (C × IR × EF × ED) ÷ (BW × AT)

Where;

|  |  |  |
| --- | --- | --- |
| ADI | Average daily intake | Average amount of metal, consumed per day, per body mass (μg/day/kg) |
| C | Metal concentration | Concentration of metal in water (μg/L) or food (μg/kg) |
| IR | Ingestion rate | Amount of water (L/day) or food (kg/day) consumed per day |
| EF | Exposure frequency | Number of days per year that exposure activity (i.e. consumption of contaminated food or water) occurs |
| ED | Exposure duration | Number of years exposure occurs over |
| BW | Body weight | Average body weight (kg) |
| AT | Averaging time | Total time period considered (days) – often the lifetime of an individual (same length of time as ED, but in days not years) |

Step 2

Calculate the hazard quotients (HQ) for these different metals and exposure activities using:

Hazard Quotient (HQ) = ADI/Recommended daily intakes

Step 3

Assess the chronic toxicity risks posed by exposure to these 3 metals by the 3 different activities

HQ > 1 risk of chronic toxicity

HQ < 1 no risk of chronic toxicity

(1) Drinking water

Assume the following;

Ingestion rate (IR) = 2L/day

Exposure frequency (EF) = 365 days/year (i.e. people drink water everyday)

Exposure duration (ED) = 70years (over the lifetime of an individual)

Averaging time (AT) = 25550 days (70 years in days)

Body weight (BW) = 70kg (average weight of person)

Calculate ADI and HQ for the following metals;

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Metal** | **Concentration**  **(μg/L)** | **Average daily intake**  **(μg/day/kg)** | **Recommended daily intake** **(μg/day/kg)** | **Hazard Quotient** |
| Pb | 15 | **0.43** | 0.14 | **3.1** |
| Cd | 2 | **0.06** | 1 | **0.06** |
| Hg | 0.01 | **0.0003** | 0.16 | **0.002** |

(2) Eating rice

Assume the following;

Ingestion rate (IR) = 0.5kg/day

Exposure frequency (EF) = 365 days/year (i.e. people eat rice everyday)

Exposure duration (ED) = 70years (over the lifetime of an individual)

Averaging time (AT) = 25550 days (70 years in days)

Body weight (BW) = 70kg (average weight of person)

Calculate ADI and HQ for the following metals;

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Metal** | **Concentration**  **(μg/kg)** | **Average daily intake**  **(μg/day/kg)** | **Recommended daily intake** **(μg/day/kg)** | **Hazard Quotient** |
| Pb | 15 | **0.1** | 0.14 | **0.77** |
| Cd | 200 | **1.43** | 1 | **1.43** |
| Hg | 6 | **0.04** | 0.16 | **0.27** |

(3) Eating Fish

Assume the following;

Ingestion rate (IR) = 0.1kg/day

Exposure frequency (EF) = 52 days/year (i.e. people eat fish once a week)

Exposure duration (ED) = 70years (over the lifetime of an individual)

Averaging time (AT) = 25550 days (70 years in days)

Body weight (BW) = 70kg (average weight of person)

Calculate ADI and HQ for the following metals;

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Metal** | **Concentration**  **(μg/kg)** | **Average daily intake**  **(μg/day/kg)** | **Recommended daily intake** **(μg/day/kg)** | **Hazard Quotient** |
| Pb | 30 | **0.006** | 0.14 | **0.04** |
| Cd | 3 | **0.0006** | 1 | **0.0006** |
| Hg | 1000 | **0.2** | 0.16 | **1.3** |

**Group discussion**

Based on the hazard quotients (HQ), which metals (Pb. Cd, Hg) and which exposure activities (drinking, eating rice and fish) represent a chronic toxicity risk?

(i.e. which HQ’s are greater than 1?)

**Should be pretty straight forward; Pb drinking water (HQ = 3.1), Cd eating rice (HQ = 1.43), Hg eating fish (HQ = 1.3)**

**Out of these Pb in drinking water presents the highest risk for chronic toxicity health problems (has the highest HQ). Get them to note that HQs are a useful tools for ranking relative risks exposure to different metals via different routes in populations, which in turn is useful for prioritizing which issues to tackle given a limited amount of resources and time.**

This risk assessment was for adults. How might these hazard quotients (HQ) differ for children? Hint; consider that children have less body weight

**Discuss how body weight would need to be set to lower values for children, which would raise the HQs (i.e. risks of chronic toxicity), however children will also eat and drink less per day than adults, lowering the ingestion rate which in turn will lower HQ’s. Will also need to change the average time and exposure duration, as people are children for only a limited amount of time. May also need to change the exposure frequency depending on the lifestyle habits of children compared to adults in the population being assessed, for example children may eat rice or fish, more or less frequently than adults.**

What are the assumptions and sources of uncertainty in these assessments of toxicity risk?

**Recognize that all of the variables in the ADI equations will vary in a given population generating uncertainty in the calculated HQs. Concentrations of metals in water and food can vary considerably, and ideally require measurement of a large number of samples to characterize the average value and degree of variance. Likewise, BW, IR, and EF will all vary between individuals in the population. These variables may also change over the average time (and exposure duration). Need to consider these potential sources of uncertainties when interpreting HQs. Can try to assess the likely variance in each of these variables and propagation through the calculation to give a sense of the likely range of HQ given these sources of uncertainty.**

**Part 2:** Are the mining activities upstream from the town the cause of the identified toxicity risks?

To help identify the sources of the heavy metals to the river water near the town, environmental scientists also measured river water pH, and heavy metal concentrations at a location on the tributary upstream from the town (Site 2) and upstream of the gold mining activities on the main river (Site 3).

**Heavy metal concentrations and pH of river water from Sites 1, 2 and 3**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | pH | Iron (μg/L) | Lead (μg/L) | Arsenic (μg/L) | Copper (μg/L) | Cadmium  (μg/L) | Mercury (μg/L) |
| Site 1 | 7.6 | 60 | 15 | 30 | 2 | 2 | 0.01 |
| Site 2 | 4 | 23000 | 650 | 1000 | 200 | 50 | 0.005 |
| Site 3 | 7 | 10 | 0.5 | 5 | 1 | 0.05 | 0.005 |

1. Which site has the highest concentrations of heavy metals and which site has the lowest?

**Site 2 >> Site 1 > Site 3**

1. Do any of the sites show evidence for being affected by acid mine drainage? If so what is the evidence?

**Site 2; low pH, and heavy metal concentrations are very high. This sample is from the tributary draining the lead-zinc mine, which features waste material with abundant metal sulfides.**

1. Upstream from site 3, there are no other mining or industrial activities in the river catchment area. The heavy metal concentrations at this site are believed to represent natural ‘background’ values.

We can use these natural ‘background’ values to estimate the proportion of the heavy metals at Site 1 that are derived from mine pollution compared to natural sources

For example, the natural ‘background’ iron concentration at Site 3 = 10 μg/L,

and total iron at Site 1 = 60 μg/L

Iron from mine pollution = Total – background = 60 – 10 = 50 μg/L

Percentage of iron from mine pollution = (Pollution ÷ Total) × 100

= (50 ÷ 60) × 100 = 83%

**Repeat this calculation for the other heavy metals and record the results in the table below**

Assessment of heavy metals derived from mine pollution at Site 1

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Natural ‘background’** concentration  from Site 3 | **Total** heavy metal concentration Site 1 | Heavy metal concentration from **pollution**  *Total - Background* | Percentage of pollution derived heavy metal  *(Pollution/Total) × 100* |
| Iron | 10 μg/L | 60 μg/L | 50 μg/L | 83% |
| Lead | 0.5 μg/L | 12 μg/L | **11.5 μg/L** | **96%** |
| Arsenic | 5 μg/L | 30 μg/L | **25 μg/L** | **83%** |
| Copper | 1 μg/L | 2 μg/L | **1 μg/L** | **50%** |
| Cadmium | 0.05 μg/L | 2 μg/L | **1.95 μg/L** | **98%** |
| Mercury | 0.005 μg/L | 0.01 μg/L | **0.005 μg/L** | **50%** |

1. In the first practical session, Pb intake by drinking water was identified as a significant chronic toxicity risk (HQ = 3.1).

Assuming the river water used for drinking near the town was not affected by heavy metal pollution from the mines further upstream, would this toxicity risk still exist?

To answer this, re-calculate the average daily intake of Pb by drinking water using the background river water Pb concentration of 0.5 μg/L measured a site 3. Use this to re-calculate the hazard quotient.

**ADI = 0.014**

**HQ = 0.1**

**Much lower than 1. This suggests that pollution from the mining activities is to blame for the chronic toxicity threats posed by lead in the drinking water.**

**Group discussion**

What are the important mining related processes (acid mine drainage, smelting and Hg amalgamation) for contaminating the river with different metals?

**For Pb, As, Cu, Cd and Fe, the metal pollution (elevated over background values of site 3) is derived from acid mine drainage generated from the Pb-Zn mine. Evidence being that they are highly concentrated in the tributary draining this area (site 2), which has a low pH and an orange colour, both of which are characteristics of waters impacted by acid mine drainage. The latter due to the precipitation of secondary Fe-oxyhydroxide minerals. For Hg, the metal pollution at site 1 is instead derived from the use of the mercury amalgamation technique in the artisanal gold mining area upstream of the town on the main river channel. Hg is not significantly added from acid mine drainage from the Pb-Zn mine, because waters from site 2 are not enriched in Hg.**

Would closing the lead-zinc mine result in a decrease in heavy metal pollution?

**Closing the Pb-Zn mine would not result in a decrease in metal pollution. As established this pollution is derived from acid mine drainage, which will be continued to be generated even once this mine is closed. This is because metal sulfide rich mine tailings will continue to react with water and oxygen for many decades to centuries. Reducing the metal pollution derived from acid mine drainage will require implementation of remediation techniques – as we will learn about in part 3**

Would stopping the artisanal gold mining result in a decrease in heavy metal pollution, and if so which metal(s)?

**Stopping the artisanal gold mining on the other hand should result in a decrease in Hg pollution, due to the cessation of the Hg amalgamation technique in this area.**