Tutor instructions: Course split into three 1.5 hour sessions. Each involves a lecture follow by a practical session.

Structure and rough timings for part 1.
Lecture (slides 1 to 28): 30-40minutes
Break: 5minutes
Introduce practical (slides 29 to 39): 5-10minutes
Completion of practical questions by participants: 30minutes
Wrap up and group discussion of summary practical questions (slide 41): 10 minutes

Tutor introduction

TIDE

Dr. Luke Bridgestock

- MSci Geology and PhD Isotope Geochemistry, Imperial College London
- Postdoctoral Research Associate, University of Oxford (2015 to 2020)
- Leverhulme Early Career Research Fellow, University of Cambridge (May, 2020 to present)
- Research interests in metal cycling in the environment
- More details at https://www.earth.ox.ac.uk/people/luke-bridgestock/

Tutor instruction: Introduce yourself and give a brief outline of your career background. Ask each of the participants to introduce themselves and their academic backgrounds in turn (e.g. geology, botany, physics etc.). Comment on the diversity of the different areas of expertise present and state that the subject of this course requires expertise from a wide variety of disciplines

Activity Outline

This activity will focus on the exposure of local populations to heavy metal pollution from mining operations

Part 1; the impact of heavy metal pollution from mines on water quality and the health of local populations

Part 2; the release of heavy metals to surface waters (rivers and lakes) from mining activities

Part 3; remediation techniques for acid mine drainage

Practical; a case study to assess the exposure routes of local people to heavy metals and the sources of heavy metals to a river system impacted by mine pollution.

This activity is split into 3 parts.

In the first part we will learn about the different routes by which people can be exposed to heavy metals, and how we can identify and assess the risks of metal exposure by these different routes

In part 2 we will learn about the processes related to mining activities that release metals to surface waters (rivers and lakes)

Finally in part 3 we will build on this understanding to learn about different techniques to remediate metal release by acid mine drainage (the dominant mining process for releasing metals to the surrounding environment).

Each part involves a short lecture of about 3o to 40 minutes followed by a practical session where you will put the skills and knowledge you have learnt into action.

Heavy metal pollution from mining activities

TIDE

Part 1: Heavy metal toxicity and exposure of local populations to metal pollution from mines

Luke Bridgestock
Department of Earth Sciences,
University of Oxford

UNIVERSITY OF OXFORD

In this course we are going to learn about the release of heavy metals to surface environments (soils, rivers, lakes) from mining activities and the impact of the health of local populations.

Introduction

Exposure to heavy metals can result in harmful effects for wildlife and humans.

To be able to implement successful strategies to protect populations from the toxic effects of heavy metals, it is important to understand;

1. How people are exposed to these metals (i.e. the exposure route)
2. The sources of these metals to the environment

Human activities, in particular mining have been a major source of heavy metals to the environment during recent history

Exposure to heavy metals can result in harmful effects for wildlife and humans. To be able to protect human populations from health problems resulting from heavy metal exposure we must first understand 2 things.

1. How people are exposed to these metals (the exposure route, for example through eating certain foods or from drinking water), and
2. Where these metals have come from in the environment, and their transport pathway to the point of human exposure

Understanding these 2 things then allows for the development of strategies to protect human populations, by addressing metal exposure routes, for example changing the source of drinking water, or by reducing the release and transport of metals within the environment.

Heavy metals occur naturally in environment, but human activities, in particular mining have released huge amounts of these elements to the environment during the past century, which has increased the risk of human populations developing heath problems due to metal exposure.

Part 1; Key learning objectives

1. What are ‘heavy metals’ and why are they important water quality parameters?
2. What are the routes by which people can be exposed to heavy metals?
3. How can the toxicity risks of chronic metal exposure be evaluated?

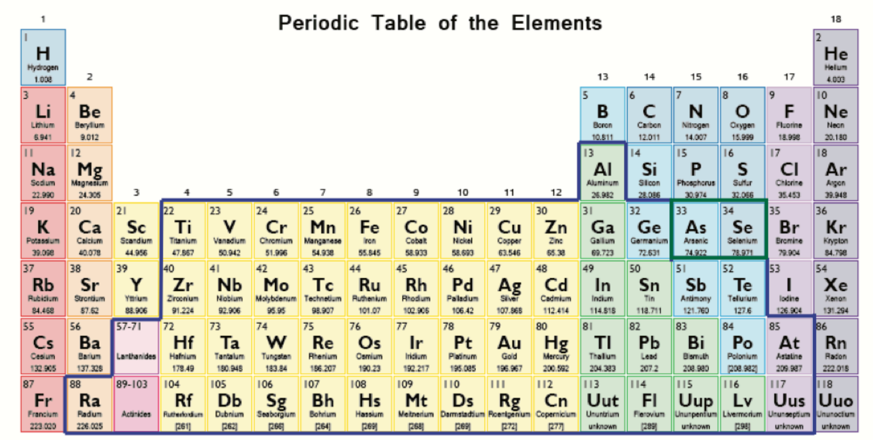
The learning goals of this first part are to be able to answer these 3 questions.

1. What are ‘heavy metals’ and why are they important water quality parameters?
2. What are the routes by which people can be exposed to heavy metals?
3. How can the toxicity risks of chronic metal exposure be evaluated?

We will return to these at the end of this lecture, by which hopefully you will all be able to confidently answer these questions.

What are ‘heavy metals’?

Loose definition, but generally refer to metal elements with a high density or atomic number.
These elements can also be referred to as ‘trace metals’ or ‘trace elements’



The elements within the blue outline are considered heavy metals

The elements arsenic and selenium are often called ‘metalloids’

So firstly, what are heavy metals?

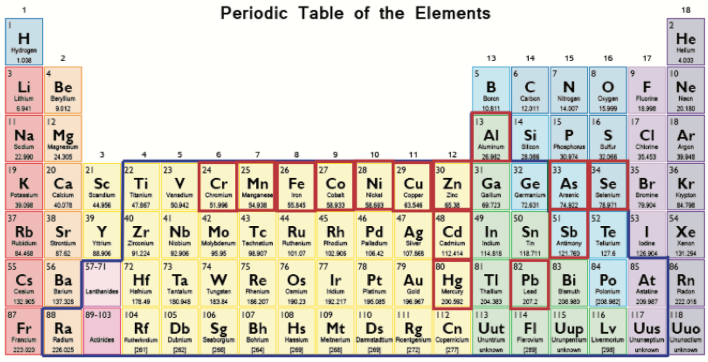
This is a term used throughout the literature in environmental science, but is poorly defined.
Generally, refers to metal elements with a high density or atomic number, but different studies often use ‘heavy metals’ to refer to different groups of elements.
Trace element and trace metal are other commonly used terms.

Note that the elements arsenic and selenium are technically non-metals, but show similar chemical behavior to metal elements, and are often referred to as ‘metalloids’. These elements can also be toxic and are often including in studies of heavy metal pollution.

Why are heavy metals important?

TIDE

- Some heavy metals are important nutrients for living organisms
  e.g. iron, zinc
- Most of these elements are toxic to living organisms at high concentrations
- Heavy metal concentrations are therefore an important ***water quality parameter***



Elements highlighted in **red** are considered important for assessing water quality

Why are heavy metals important?

Many heavy metals are important nutrients, essential to life − e.g. Fe, Zn, Cu. We need at least some of these in our diets to remain healthy.

However, at high enough exposure most elements are toxic to life.

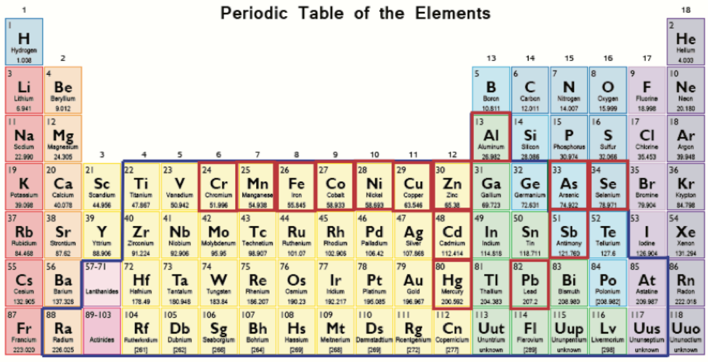
Both the nutrient and toxic roles of metals, in particular those highlighted in red, make them a key water quality parameter

Why are heavy metals important?

- The concentrations of these elements in water can vary due to natural processes

  For example, arsenic in groundwater can naturally occur at high concentrations that are toxic to life

- However, human activities have released large amounts of these elements into the environment as pollution



Elements highlighted in **red** are considered important for assessing water quality

It is important to note that while human activities (including mining) have released large amounts of metals to the environment, high concentrations of the elements in water sources and food can occur due to natural processes.

A particularly important example of this are concentrations of arsenic in groundwater, which can be well above levels deemed safe for drinking water due to natural processes. This is a major concern for public health in the delta regions of large south east Asian rivers, including the Irrawaddy in Myanmar. This issue will not be covered here, but is considered in the courses designed by Laura Richards and Gianfranco Pincetti Zuniga.

Distinguishing between the different human and natural sources these elements to the environment is a major challenge (as considered in part 2 of this course). It is a common misconception that high heavy metal concentrations in environmental systems must be linked to human inputs. This is not necessarily the case, and rigorous assessment of both natural and human metal sources is required before any solid conclusions regarding metal sources can be made.

Nutrient or toxin?

Some elements are required nutrients essential for life

- e.g. Selenium (Se), Zinc (Zn), Iron (Fe)

Others have no known nutritional value

- e.g. Mercury (Hg), Lead (Pb), Arsenic (As)

Most elements can be toxic in high enough quantities and certain chemical forms

It is therefore important to consume the right amount of certain heavy metals to remain healthy

Another common misconception is that all heavy metals are toxic, and that we should reduce our exposure to all heavy metals as much as possible to be healthy

This is not true. As mentioned, some elements classified as heavy metals are in fact key nutrients. Not having enough in our diet (being deficient in that element) can result in health problems (e.g. Se, Zn, Fe)
E.g. Se intake should be 40-400ug/day according to WHO– lower can result in health problems due to Se deficiency, higher can result in health problems sue to Se toxicity.

Others have no known nutritional value (Hg, Pb, As). In this case it is desirable to have lowest exposure to these elements as possible.

In detail the nutritional value and potential toxicity of an element depends on both the intake amount, and the chemical form (speciation) of the element.

Exposure to metals

TIDE

People can be exposed to metals by different routes;

1. Inhalation (breathing into lungs)
   - This is important for gold mine workers using the mercury amalgamation technique (covered in part 2)

2. Ingestion
   - Drinking water
   - Eating food

   → Important metal exposure routes for general populations living in mining areas

3. Dermal exposure (absorbed through skin)
   - Generally only important for people working with hazardous chemicals (e.g. gold miners using mercury, see part 2)

How are people exposed to heavy metals?

Heavy metals (and other toxic chemicals, such as various organic compounds) can enter human bodies through a variety of pathways
1. Inhalation – breathing small metal bearing particles (or in the case of Hg – vapor) into the lungs where they can dissolve and be transferred into the blood stream
2. Ingestion – eating food and drinking water containing metals, which can then enter the body through the digestive system
3. Dermal – metals being absorbed directly through the skin.

Note that inhalation and dermal exposure only likely to be a problem in very specific circumstances (i.e. people who work in hazardous conditions, handling materials containing very high metal contents). In part 2 we will discuss an example of this related to the use of mercury in artisanal gold mining operations (which is an important issue in Myanmar).

Ingestion is typically the most important route by people are exposed to heavy metals, so we will focus on this exposure route further in this lecture.

Drinking and eating likely most important route for the vast majority of population, so these are the exposure routes that we will now consider in more detail.

Acute versus chronic toxicity

Acute toxicity: harmful effects of short term exposure to a high concentration of a substance

Chronic toxicity: harmful effects due to long term exposure to low concentrations of a substance

If exposed to high amounts of a heavy metal, people may experience adverse health effects due to metal toxicity - as these metals disrupt important biological processes.

Many metals species are also carcinogens, and can exposure to them increases the risk of cancer in populations.
The non-cancer toxicity effects due to metal exposure can be split into 2 categories

Acute toxicity refers to harmful effects on health due to the short term exposure to a toxic substance. The symptoms are quite quickly apparent.

However, most cases of heavy metal toxicity are more subtle, and involve the exposure to lower amounts of heavy metals over long periods of time (years to decades). This is known as chronic toxicity and the symptoms of the metal toxicity develop slowly, often over the lifetime of the individual.

In this case, it is often hard to diagnose heavy metal toxicity as the cause of the resulting health problems, so that many people can develop chronic toxicity due to heavy metal exposure without realizing it. Identifying groups of people that are at risk of chronic metal toxicity represents an important first step towards addressing these issues. In the latter part of the lecture and in the practical section we will focus how this can be done (specifically for exposure via ingestion).

Summary
True or false?

1. Certain heavy metals are important nutrients but exposure to too much of a heavy metal can result in harmful effects
2. Inhalation, ingestion and dermal are all exposure routes for heavy metals
3. To remain healthy, we should try to minimize our exposure to all heavy metals

Tutor instruction: These summary 'True or False' sections are inserted throughout the lectures in this course. They are intended to encourage the participates to actively think about the lecture material. Ask them to read through these statements and decide, based on the material presented so far, if they think they are true or false. Give them 3-5mins to to this and discuss among themselves. Then ask them to shout out what they think, before revealing the answers on the next page.

Summary
True or false?

1. Certain heavy metals are important nutrients but exposure to too much of a heavy metal can result in harmful effects **TRUE ✔**

2. Inhalation, ingestion and dermal are all exposure routes for heavy metals **TRUE ✔**

3. To remain healthy, we should try to minimize our exposure to all metals/metalloids **FALSE ✗** We need small amounts of some elements to remain healthy (e.g. Se, Zn, Fe)

Tutor instruction: Spend a moment to briefly explain any incorrect answers.

Ingestion: Drinking Water

World Health Organization's (WHO) guidelines for drinking water metal concentrations

Element	Maximum concentration (µg/L)
Arsenic (As)	10
Cadmium (Cd)	3
Chromium (Cr)	50
Copper (Cu)	2000
Lead (Pb)	10
Mercury (Hg)	6
Nickel (Ni)	70
Selenium (Se)	40

To limit heavy metal exposure in drinking waters to levels deemed safe, various government bodies and organizations have set legal limits/guidelines of the concentrations of heavy metals and metalloids in water – here are the ones given by the WHO for some important heavy metals and the metalloids, arsenic and selenium.

If the concentration of these elements in drinking water is higher than these guideline values, then there is a risk that people will develop chronic metal toxicity problems due to being exposed to too much of these metals over time.

Many of these levels have been set to lower and lower values over the past few decades, as the harmful effects of long term exposure has become more apparent. For example the UK recently lower the legal limit of Pb in drinking water from 25 to 10 µg/L in 2013.

Due the accumulation of lead in cells of the lifetime of individuals, UN states that there is no agreed upon 'safe' level of lead intake, and it should be reduced as much as possible
Ideally, intake of As, Hg etc should also be as close to zero as possible. Legal/recommended limits of these elements are often influenced by both what is considered safe and what can be practically achieved

Ingestion: Food

For many metals, intake by food is typically much more important than drinking water.

Metal pollution from mines and other human activities to water sources can affect food supplies

1. Contaminated waters may be use to irrigate crops

2. Fish and seafood can accumulate large amounts of some metals

Photos; pexels.com

Generally ingestion of food however is the most important exposure route for most heavy metals.

Heavy metals enter food chains via uptake from water and soils into plants. Certain life forms can accumulate large amounts of certain metals, so that if eaten by people they represent an important exposure route into humans.

Ingestion: Food

1. Contamination of irrigation waters

Contaminated waters may be use to irrigate crops, resulting in metals entering the food chain

<u>Cadmium poisoning – *Itai-Itai disease*</u>

A prominent example of metal poisoning occurred in Toyama Prefecture, Japan in the early 20th century.

Mining operations contaminated rivers used for irrigation of rice fields. This caused high levels of cadmium (Cd) to accumulate in the rice.

The local population became sick with 'itai-itai' disease (cadmium poisoning) after eating the contaminated rice

Photo; pexels.com

Rice in particular is prone to accumulating Cd and As, with rice consumption an important exposure route for these metals to many people around the world.

An prominent example of Cd toxicity due to rice consumption occurred in Japan in the early 20th century. Mining operations released Cd into rivers which then accumulated in soils downstream. Rice grown in these soils accumulated large amounts of this Cd and many people became sick from eating this rice.

Ingestion: Food

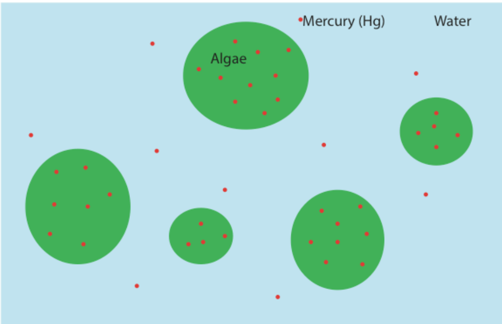
2. Bioaccumulation and biomagnification

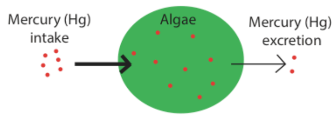
Some metals can be concentrated by living organisms, a process known as **bioaccumulation**

This happens because the organisms take in metals faster than they excrete them as waste

Over their lifetime, the concentration of these metals in their tissues increases

For example, algae living in rivers can take in mercury (Hg) faster than they excrete it. This means the concentration of mercury in the algae can be 2 – 3 times higher than the river water.





Metal exposure via eating food is a dominant exposure route because organisms can accumulate metals in there cells to much higher concentrations than in the surrounding environment – known as bioaccumulation.

This occurs because organisms uptake metals dissolved in the water they live in faster than they excrete them as waste, so that over time the concentration of these metals increases.

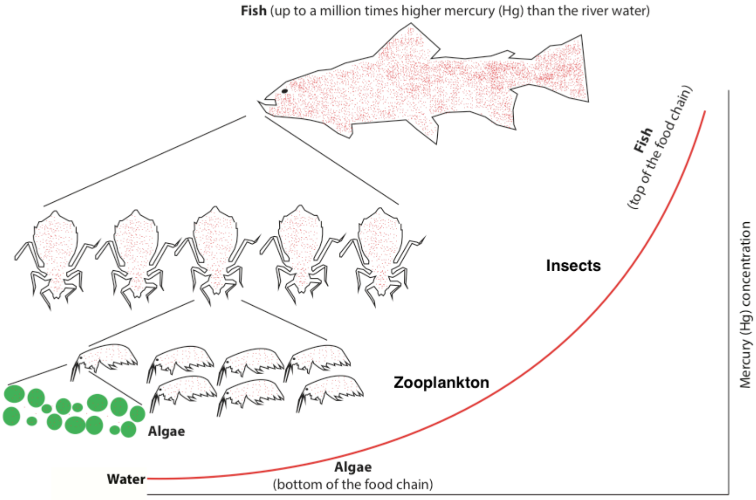
Mercury (Hg) is very toxic heavy metal that prone to bioaccumulation. Photosynthesizing algae (living at the bottom of the food web) can feature Hg concentrations 2 to 3 times higher than the waters they live in due to this process.

Ingestion: Food

2. Bioaccumulation and biomagnification

This process (bioaccumulation) can continue up the food chain

Zooplankton eat lots of algae over their lifetime, accumulating mercury (Hg) from the algae to higher concentrations.



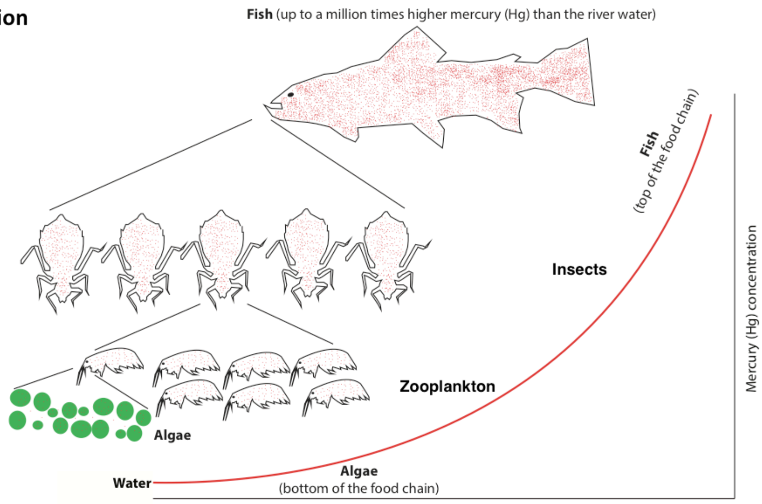
Bioaccumulation of heavy metals continues up the food chain. For example, zooplankton will eat a large amount of algae over their lifetime, and due to will accumulation a large fraction of of the Hg in all this algae. This increases this Hg concentration in the zooplankton to even higher levels than the algae

Ingestion: Food

2. Bioaccumulation and biomagnification

This process is repeated up the food chain, so that fish at the top of the food chain can have up to 1 million times higher concentrations of mercury (Hg) in their tissues than the river water they live in.

This process is known as **biomagnifcation**



This process is repeated in many steps up the food chain, so that fish at the top of the food chain can have Hg concentrations in their tissues of up to 1 milliion times higher than the water they live in − collectively this is known as biomagnification.

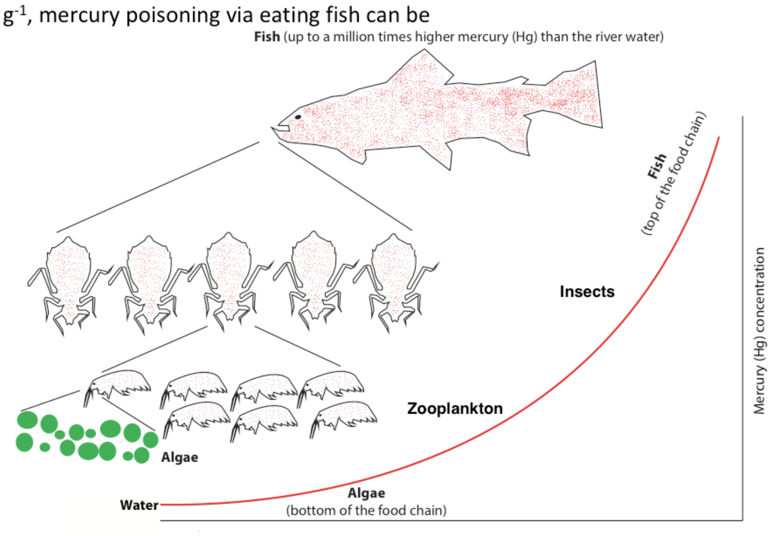
Ingestion: Food

2. Bioaccumulation and biomagnification

TIDE

Local populations who eat these fish can then be exposed to large amounts of mercury

Even though the mercury (Hg) concentration of water may be much lower than the WHO drinking water guideline of 6 µg g^{-1}, mercury poisoning via eating fish can be important.



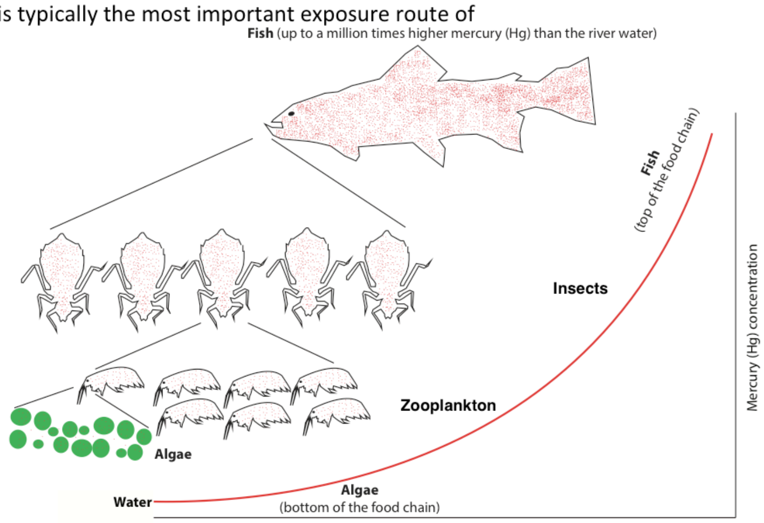
People who eat this fish can then be exposed to large amounts of Hg − and because of this fish and shell fish consumption is an important exposure route for Hg (and other toxic metals including Cd). Concentrations of Hg (and Cd) in water bodies (rivers, lakes, groundwater) are typically much lower than WHO drinking water guideline values.

Ingestion: Food

2. Bioaccumulation and biomagnification

Contamination of water with mercury (Hg) by mining and other human activities can cause high levels of this element to accumulate in fish and shell fish

The consumption of fish and shell fish is typically the most important exposure route of mercury (Hg)



Even in areas influenced by pollution, concentrations of Hg dissolved in water bodies are typically very low, presenting little toxicity risk due to exposure via drinking this water. Fish and shell fish living in these waters however can accumulate huge amounts of these metals, and eating these animals can result in exposure to toxic amounts of these elements. Due to the metal accumulation by these animals, measurements of metal in their tissues can often be a more useful way of assessing levels of contamination by pollutions sources, than direct measurements of the water.

Summary
True or false?

1. Different government bodies and organizations (such as WHO) have set limits for the maximum concentrations of certain heavy metals in drinking water

2. It is only important to consider heavy metal concentrations in water used for drinking to assess the toxicity risk to local populations

3. Biomagnification is a process by which certain metals increase in concentration in living organisms higher up the food chain

Tutor instruction: Ask participants to read through these statements and decide, based on the material presented so far, if they think they are true or false. Give them 3-5mins to to this and discuss among themselves. Then ask them to shout out what they think, before revealing the answers on the next page.

Summary
True or false?

1. Different government bodies and organizations (such as WHO) have set limits for the maximum concentrations of certain heavy metals in drinking water **TRUE ✔**

2. It is only important to consider heavy metal concentrations in water used for drinking to assess the toxicity risk to local populations **FALSE ✗**
   Heavy metals can enter the food chain if contaminated water is used to irrigate crops, and by biomagnification in fish and shell fish

3. Biomagnification is a process by which certain metals increase in concentration in living organisms higher up the food chain **TRUE ✔**

Tutor instruction: Spend a moment to briefly explain any incorrect answers.

Evaluating chronic toxicity risk

TIDE

The risk of someone developing chronic toxicity due to exposure to a metal can be estimated using a hazard quotient

$$\text{Hazard Quotient (HQ)} = \frac{\text{Average daily Intake}}{\text{Recommended daily intake}}$$

Actual intake level (µg/day/kg) [Average daily Intake]

Safe intake level (µg/day/kg) [Recommended daily intake]

If HQ < 1 no risk of chronic toxicity

If HQ > 1 risk of chronic toxicity

To protect populations from dangerous levels of metal exposure, it is important to evaluate the risk posed by exposure to different metals, via different exposure routes/activities (i.e. drinking water, eating fish etc).

To do this, the estimated daily metal intake (per kg of body mass) is compared to a level that is considered safe, using a hazard quotient (HQ). If HQ > 1 then metal intake exceeds the safe level and people are a risk of developing chronic toxicity problems. If HQ < 1, then metal intake is below the safe level and people are not at risk of developing chronic toxicity problems

Evaluating chronic toxicity risk

TIDE

$$\text{Hazard Quotient (HQ)} = \frac{\text{Average Daily Intake}}{\textbf{Recommended daily intake}}$$

The **recommended daily intake** is the amount of metal exposure that is considered to be safe

Below this intake amount no harmful toxicity effects are thought to occur
Above this amount there is a risk of developing toxicity problems

The units are amount of metal (µg) per day, per kg of body mass (µg/day/kg)

Cd	1	µg/day/kg
Cr	1500	µg/day/kg
Cu	40	µg/day/kg
Pb	0.14	µg/day/kg
Hg	0.16	µg/day/kg

Recommend daily intakes (also known as reference doses) specified by the US Environmental Protection Agency for several key metals

Safe intake levels are normally evaluated using experiments on animals

Shown in the table are some reference doses used by the US EPA for environmental impact assessments.

Evaluating chronic toxicity risk

TIDE

$$\text{Hazard Quotient (HQ)} = \frac{\textbf{Average Daily Intake}}{\text{Recommended daily intake}}$$

Average daily intake (ADI) of a metal, by ingestion of water or food can be calculated using;

$$\textbf{ADI} = \frac{C \times IR \times EF \times ED}{BW \times AT}$$

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)

The average daily intake of metals by ingestion (eating and drinking) over long time periods can be estimated using this equation (developed by the US EPA).

Other, similar equations can be used to assess intake by inhalation and dermal absorption.

In the practical, you will learn to use this equations to assess chronic toxicity to risks form various heavy metals via different exposure activities (drinking water versus eating different foods), in a hypothetical case study. Importantly you will also critically think about different variables in this equation and how you might approach choosing suitable values for different groups of people.

Part 1; Key learning objectives

1. What are 'heavy metals' and why are they important water quality parameters?
   - *A group of metal elements on the periodic table. They are important water quality parameters because some act as nutrients, while most are toxic at high concentrations*

2. What are the routes by which people can be exposed to heavy metals?
   - *Inhalation (breathing), ingestion (eating and drinking) and dermal (absorption through skin). Ingestion is typically the main exposure route for the general population.*

3. How can the toxicity risks of chronic metal exposure be evaluated?
   - *Chronic toxicity risks can be evaluated by comparing the average daily intake rate of a metal by a particular exposure route over a long period of time, to the recommended 'safe' intake rate using a metric known as a hazard quotient (HQ)*

To end this first lecture of the course, we revisit the 3 key questions set out at the start of this lecture, which you hopefully can now all answer.

Tutor instruction: run through each question and the answer in turn

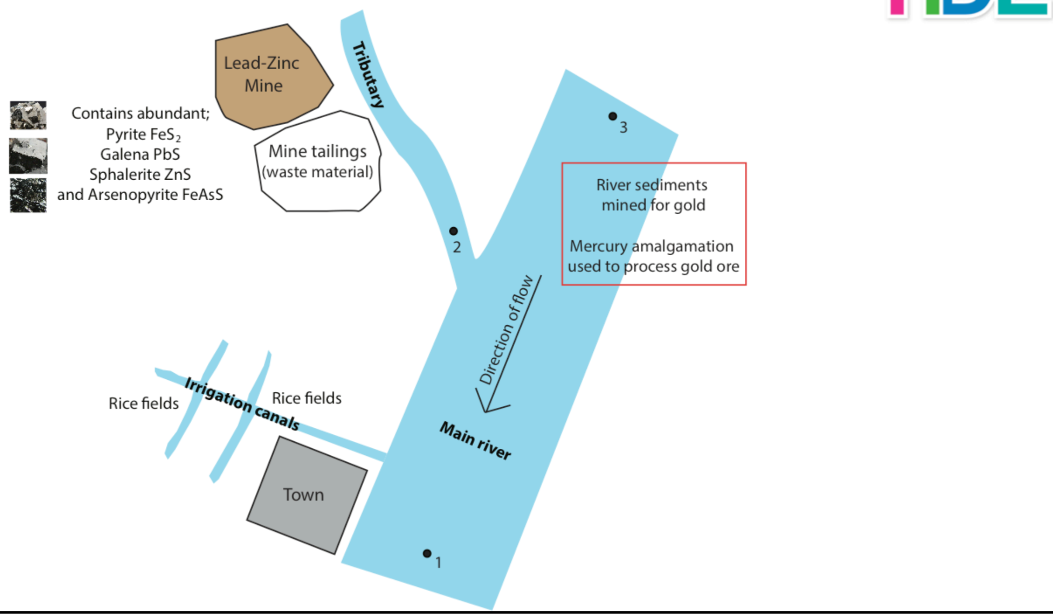
Heavy metal pollution from mining activities

Practical 1: Exposure of local people to heavy metals

Luke Bridgestock
Department of Earth Sciences,
University of Oxford

Tutor instruction: Depending on time availability it is good to pause for a 5 minute break at this point to give the participants to discuss the lecture materials among themselves. It is also a chance for participants to ask the tutor questions about the lecture material individually (i.e. not in front of the whole class), which they are often more confortable/willing to do.

Case study



in this practical, you are going to assess the chronic toxicity risks to people living in a hypothetical town due to exposure to various heavy metals, via different exposure routes.

The town is next to a river, and upstream there is a lead-zinc mine and an area were river sediments are mined for gold by artisanal miners (we will focus on assessing the impact of these mining activities on releasing heavy metals to the river in part 2).

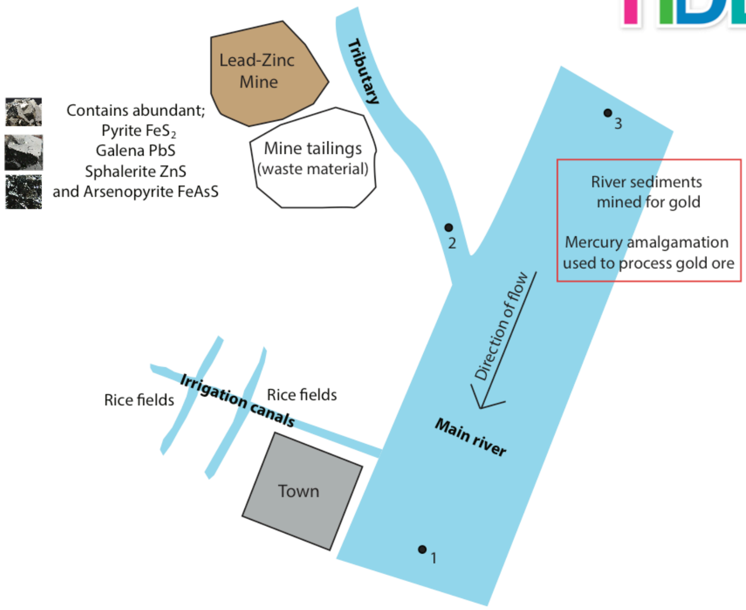
Evaluating chronic toxicity risk

TIDE

Local people use water form the main river for drinking and to irrigate their rice fields

They also eat fish caught in the river

Are they at risk from developing chronic metal toxicity?



The people living in the town use the river as a source of drinking water, and to irrigate their rice fields. They also eat fish caught in the river.

The important question you are going to answer, is are they at risk from developing chronic metal toxicity via these exposure routes?

Evaluating chronic toxicity risk

TIDE

Are they at risk from developing chronic metal toxicity?

To answer this question we can calculate hazard quotients (HQ) for exposure to different metals, by different activities

Actual intake level (µg/day/kg)

$$\text{Hazard Quotient (HQ)} = \frac{\text{Average daily Intake}}{\text{Recommended daily intake}}$$

Safe intake level (µg/day/kg)

If HQ < 1 no risk of chronic toxicity

If HQ > 1 risk of chronic toxicity

To answer this question you are going to calculate hazard quotients (HQ) for different metals and these different activities (drinking water, eating rice and eating fish).

The hazard quotient is the ratio of the average daily metal intake to the recommended daily metal intake considered to be the 'safe' level, in micro grams of metal per day per kg of body weight.

If this ratio is higher than 1, then metal intake exceeds the safe level and there is risk of developing health issues due to chronic metal toxicity. The higher the ratio the greater the risk.

Evaluating chronic toxicity risk

TIDE

$$\text{Hazard Quotient (HQ)} = \frac{\textbf{Average Daily Intake}}{\text{Recommended daily intake}}$$

Average daily intake (ADI) of a metal, by ingestion of water or food can be calculated using;

$$\textbf{ADI} = \frac{C \times IR \times EF \times ED}{BW \times AT}$$

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)

The recommended daily intake (safe level) for metals are provided by the US EPA are listed in the handout.

To calculate the HQs you must however first calculate average daily intake (ADI) for the different metals and exposure activities (drinking water, eating rice, eating fish), using this equation.

This equations features 6 variables that must be set by the environmental scientist conducting the risk assessment

Evaluating chronic toxicity risk

TIDE

$$\text{Hazard Quotient (HQ)} = \frac{\textbf{Average Daily Intake}}{\text{Recommended daily intake}}$$

Average daily intake (ADI) of a metal, by ingestion of water or food can be calculated using;

$$ADI = \frac{C \times IR \times EF \times ED}{BW \times AT}$$

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)

C – is the concentration of the metal in the water or the food. This variable is set by collection of samples of this material and measurement of metal concentrations in a lab

The remaining variables however must be set according to local knowledge of the population of people being considered in the risk assessment

Evaluating chronic toxicity risk

TIDE

$$\text{Hazard Quotient (HQ)} = \frac{\textbf{Average Daily Intake}}{\text{Recommended daily intake}}$$

Average daily intake (ADI) of a metal, by ingestion of water or food can be calculated using;

$$ADI = \frac{C \times IR \times EF \times ED}{BW \times AT}$$

ADI	Average daily intake	Average amount of metal, consumed per day, per body mass (µg/day/kg)
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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)

IR – is the ingesting rate, the amount of water or food that is consumed per day (likely to vary between different groups of people depending on lifestyle, so is desirable to obtain local knowledge)

Evaluating chronic toxicity risk

TIDE

$$\text{Hazard Quotient (HQ)} = \frac{\textbf{Average Daily Intake}}{\text{Recommended daily intake}}$$

Average daily intake (ADI) of a metal, by ingestion of water or food can be calculated using;

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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)

BW – is the average body weight of the group of people subject to the risk assessment, in kg (again will vary between different groups of people, but assuming an average of 70kg for adults is generally suitable).

Evaluating chronic toxicity risk

TIDE

$$\text{Hazard Quotient (HQ)} = \frac{\textbf{Average Daily Intake}}{\text{Recommended daily intake}}$$

Average daily intake (ADI) of a metal, by ingestion of water or food can be calculated using;

$$\text{ADI} = \frac{C \times IR \times \mathbf{EF \times ED}}{BW \times \mathbf{AT}}$$

ADI	Average daily intake	Average amount of metal, consumed per day, per body mass (µg/day/kg)
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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)**

EF, ED and AT, are exposure frequency, exposure duration and averaging time.

Exposure frequency is the number of days per year which the activity occurs. For example of drinking water is likely to be every day (so 365 days/year), but eating fish and rice may be less frequent (e.g. eating fish just once a week, so 52 days per year). Is important to have knowledge of lifestyles of the group of people this assessment applies too to set this value.

Exposure duration and the averaging time reflect the total length of time (in years for ED, and days for AT) which the risk assessment is being conducted for – typically set to the average life span of the people being considered.

Your task

(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		0.14	
Cd	2		1	
Hg	0.01		0.16	

$$ADI = \frac{C \times IR \times EF \times ED}{BW \times AT}$$

$$\text{Hazard Quotient (HQ)} = \frac{\text{Average Daily Intake}}{\text{Recommended daily intake}}$$

Then repeat for eating rice and fish

Your task is to use this equation to calculate ADI and HQ values for Pb, Cd and Hg for drinking water (question 1), eating rice (question 2) and eating fish (question 3)

Tutor instruction: make sure everyone has found the correct part of the handout for the practical questions

Group discussion questions

1. 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?)

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

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

Once you have done these calculations I want you to considered these 3 summary questions, which we will then discuss together at the end.

Answers

(1) Drinking water

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

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

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**

Tutor instruction: Once they have had the time to complete the calculations, bring up this slide to show the answers, and point out the place in the handout where they can find these answers to check for themselves.

Group discussion questions

TIDE

1. 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?)

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

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

Tutor instruction: In the final 5-10minutes go though these 3 summary questions together as a group. Ask the participants to volunteer to share their answers with the rest of the class d fill in any gaps/miss-understandings where needed, rather than just talking them through yourself (as done on the recorded version).

Question 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.

Question 2: 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,

Group discussion questions

TIDE

1. 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?)

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

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

Question 3: 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.