INSA

FIMI – 1st Year   5/05/2023

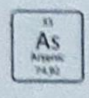
Classics + Scan + Eurinsa+ Amerinsa

Enjeux de la Transition Ecologique (Challenges of the Ecological Transition) - ETRE

Time allowed : 1h

(No documents allowed – calculators permitted)

Exercise 1 : Arsenic pollution (~/ 11.5 points)



Arsenic is a chemical element that cannot be tasted or smelled, and which is naturally present in soil. It can be accumulated locally through industrial activities such as the fabrication of pesticides or dyes, metal extraction, etc...

The system that we will study is composed of two rivers that meet each other (at a confluence). River A passes near a former mine (giving rise to a high arsenic concentration) and river B crosses a village.

The concentrations of pollutants are denoted C and the volume flow rates of the rivers are denoted Q. Just before arriving at the confluence :

- River A has a volume flow rate Q_A of 10 m^3/s and an arsenic concentration C_A of 480 µg/L.
- River B has a volume flow rate Q_B of 30 m^3/s and an arsenic concentration C_B of 8 µg/L.

The quantity of water is considered a conservative quantity (no notable evaporation) and the system is considered to be in the stationary regime.

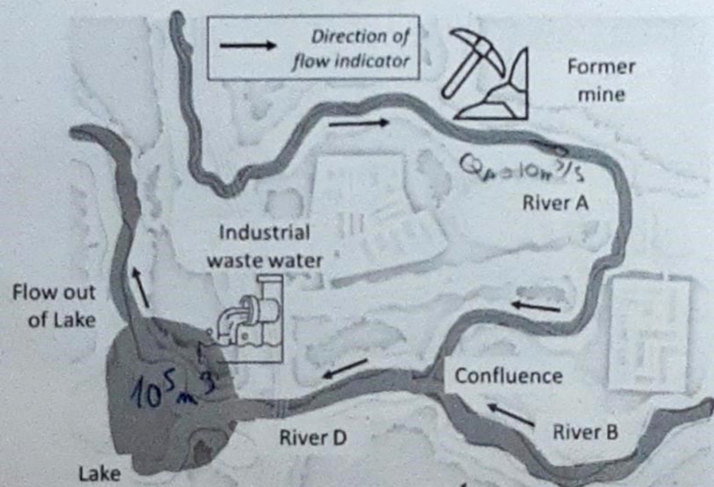


Figure 1: Schematic representation of the system.

1.1. **After writing a balance equation for the arsenic at the confluence (taking into account conservation of the pollutant and the stationary regime), show that the volume flow rate and the concentration of the arsenic downstream of the confluence (called river D) are Q_D = 40 m^3/s and C_D = 126 µg/L, respectively.**

The volume flow rate Q_D and the concentration C_D calculated previously correspond to those of river D, which flows into a lake. Into this lake, which has a volume $V_L = 10^5$ m^3, pre-treated waste water from an industrial facility is also added. Despite the pre-treatment, the concentration C_I of arsenic arriving in the waste water pouring into the lake from the industrial facility is C_I = 80 µg/L (with a volume flow rate Q_I of 5 m^3/s). We know that 1% of the arsenic contained in the lake is deposited as a sediment at the bottom every hour (k=0,01 h^{-1}). We call C_L the concentration of arsenic in the lake.

1.2. **Make the balance calculation for the « lake system » for the arsenic pollutant, considering the non conservation of the pollutant and a stationary regime.**
Calculate the volume flow rate out of the lake Q_S in m^3/s and the concentration of arsenic $C_S = C_L$ un µg/L in the water flowing out of the lake.

The maximum admissible concentration of arsenic in water for human consumption is 10 µg/L since 2003 in France. Above this value, there is an unacceptable risk due to the weakly-mutagenic and also cancerogenic nature of this pollutant. Indeed, it is responsible for different cancer types in human beings (skin, lung, bladder).

1.3. In your opinion, what are the possible contamination routes (direct or indirect) for humans when considering arsenic in water ?

1.4. Give the definitions of « mutation » (in its biological sense) and of « DNA ».

1.5. Amongst the challenges linked to the anthropocene, the so-called « planetary limits » (or « planetary boundaries ») are nowadays widely discussed.

(a) How would you define a « planetary limit » ?

Concerning the question of arsenic in water courses such as rivers or lakes :

(b) In your opinion, what (which) would be the principle planetary limit(s) impacted ?

(a) Indirectly, what (which) other limit(s) could be affected ?

1.6. If you were an engineer in charge of managing the previously studied problem of water pollution by arsenic, what solutions would you propose ? (NB, the rivers are not polluted at their sources)

Exercise 2 : Kaya's Equation (~/ 8.5 points + bonus question)

As a reminder, Kaya's equation allows us to differentiate between different mechanisms of action in order to reduce greenhouse gas emissions :

$$GHG = \underbrace{\left(\frac{GES}{E}\right)}_{d} \cdot \underbrace{\left(\frac{E}{GDP}\right)}_{c} \cdot \underbrace{\left(\frac{GDP}{POP}\right)}_{b} \cdot \underbrace{POP}_{a} \quad \text{(equation 1)}$$

where GHG = annual greenhouse gas emissions (tCO_2 / year)
E = annual energy consumption (TWh / year, where 1 GW = 8,76 TWh / year)
GDP = annual gross domestic product (in \$ or €)
POP = population (number of people)

2.1. Show that 1GW corresponds to 8,76 TWh / year

2.2. Does GDP represent a flow or a stock ? Explain in one sentence.

2.3. In succinct terms, what do each of the factors b, c, d in the equation 1 represent ?

Please turn over for the following questions ...

Global emissions of	in 2010
CO_2* (in Gt CO_2)	33.4
GHG (in Gt CO_2 eq)	50.3

Table 1: Annual emissions of GHG (greenhouse gasses) in 2010. (changes in ground use not included) [Source: Our World in Data based on the Global Carbon Project (2023) • CC BY]*

Global heating target	Carbon budget ($GtCO_2$)
+ 1.5°C	400
+ 1.9°C	1 000
+ 2.3°C	1 550

Table 2: Estimation of the carbon budget from 2020 so as to have a 67% chance of remaining below the stated global heating targets. [Source: Table 5.8, chap. 5 IPCC, AR6 - Working Group I (2021)]

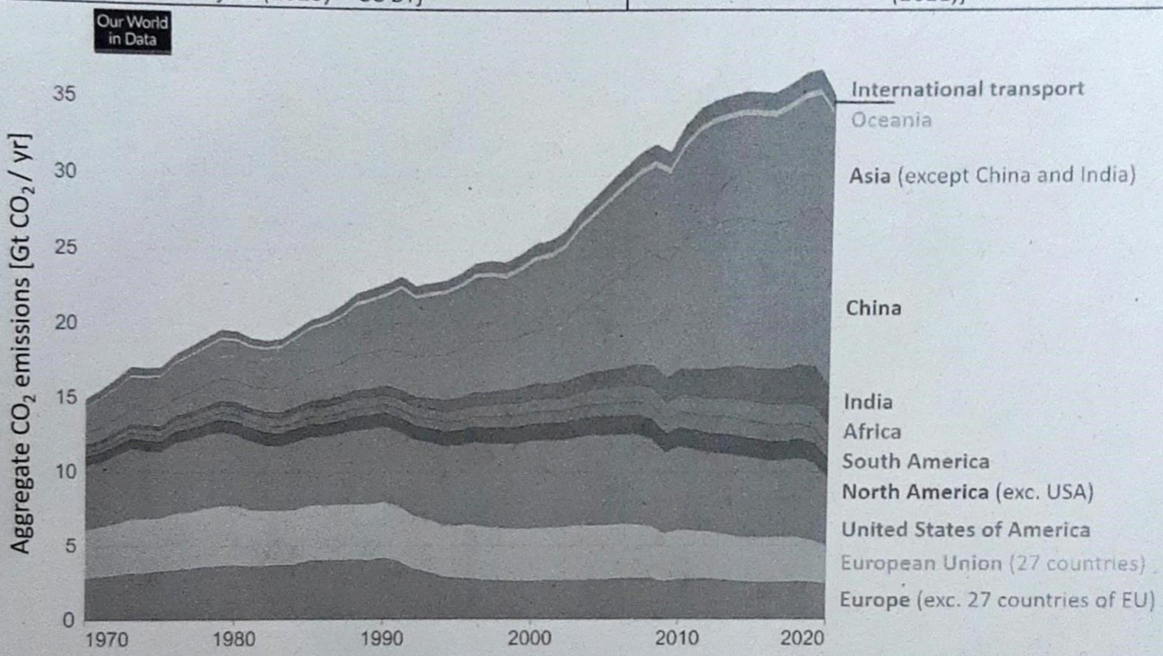


Figure 2: Annual CO_2 emissions by global region.
[Source: Our World in Data based on the Global Carbon Project (2023) • CC BY]

Using data from figure 2 and tables 1 and 2 :

2.4. In table 1, explain the unit tCO_2eq (that reads « tons of CO_2 equivalent »).

2.5. How many $GtCO_2$ can we emit from 2020 so as to respect the « Paris agreement » (i.e. continue efforts to limit global warming to 1.5°C above pre-industrial levels) ? We will call this quantity M_{Paris}.

2.6. In this question, we are going to consider different trajectories (scenarios) taking the common starting point of the global emission rate of CO_2 in 2020.

(a) Trajectory a : if emissions continue at the rate observed in 2020, in what year would total emissions from 2020 onwards reach the carbon budget M_{Paris} ?

(b) Trajectory b : with the help of a graph, in what year would the carbon budget M_{Paris} be reached if we were to have reduced from 2020 the rate of emissions linearly down to zero (i.e. the global emission rate of CO_2 reaches zero exactly when the total emitted mass of CO_2 from 2020 onwards reaches M_{Paris}). Compare the two scenarios (a) and (b).

(c) In scenario b, by what percentage would the emission rate decrease in the first year (between 2020 and 2021) ? And the last year ? Comment.
(For comparison, the Covid-19 pandemic reduced the GHG emission rate by 6,4% in 2020 [*source : IPCC report, AR6 - Working Group I (2021)*])

BONUS QUESTION – How to react ?

2.7. (a) Let us suppose that we need to acheive a decrease of 5% in GHG emissions in a year to respect a given carbon budget, propose a combination of percentage reductions to be applied to each factor a, b, c and d of Kaya's equation, justifying your choices. You could choose to make a distinction between different global regions.

(b) Discuss the pertinence and reasoning behind Kaya's equation (equation 1).