Assessing the radiological impact of the Caetité uranium production center (Brazil) on local water resources

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Background & Relevance

• The only uranium production center in Brazil → URA;
• Operated by state-owned company → Brazilian Nuclear Industries (INB);
• U → supply the domestic demand;
• Strategic for the BNP;
• Semi-arid climate → Water conflict;
• Main water resource → fractured aquifer;
• Groundwater must be protected;
• Overexploitation and contamination;
• **Public perception** → high radionuclide concentrations in waters from some wells are caused by the mining operations;
• Social license;
Main Questions

The high uranium concentrations found in groundwater (in some wells) are natural or anthropogenic?

What are the human health risks arising from the consumption of this water?
Objectives

• Assess the potential contamination of groundwater based on the location of the main source-terms of the URA;

• Perform human health risk assessment due to ingestion of groundwater;
Study Area

- CEB – Caetité Experimental Basin
- URA – Unit of Uranium Concentration

- Area = 75 km²
- Surface water
- Groundwater
- URA’s source-terms (Open pit; Waste deposit; Tailing ponds; Chemical plant)
Hydrogeological system

- Characterized by smooth landscape, supported by crystalline rocks (granites and gneisses).
- The main aquifer in the CEB is related to intrusion of diabase dike, and is located on the left side of the main creek.
- The mean annual rainfall is ~ 700 mm/y (semi-arid condition)
Assessing the uranium concentration in groundwater

in the CEB (direct influence of the URA)

Surrounding communities (indirect influences of URA)

Source data: mining company – INB monitoring program

\(^{238}\text{U}, \, ^{226}\text{Ra}, \, ^{228}\text{Ra}, \, ^{210}\text{Pb}, \, ^{232}\text{Th}\)
GW assessment - direct influence of the URA

- Wet Well
- Dry Well
- Open pit
- Waste deposit
- Tailing pond
- Chemical Plant
- Diabase dikes (N40W/70NE)
- URA’s boundary
Upstream the open pit

PC18 - Fazenda Cachoeira

<table>
<thead>
<tr>
<th></th>
<th>Bq/L</th>
<th>mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>72</td>
<td>72</td>
</tr>
<tr>
<td>Min</td>
<td>0.017</td>
<td>0.001</td>
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<tr>
<td>Max</td>
<td>1.574</td>
<td>0.062</td>
</tr>
<tr>
<td>Mean</td>
<td>0.502</td>
<td>0.020</td>
</tr>
<tr>
<td>Median</td>
<td>0.539</td>
<td>0.021</td>
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</table>

Dose_{PC18} \rightarrow 0.17 \text{ mSv/y}

Downstream the open pit

PC01

<table>
<thead>
<tr>
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<th>Bq/L</th>
<th>mg/L</th>
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<tbody>
<tr>
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<td>131</td>
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<tr>
<td>Min</td>
<td>0.17</td>
<td>0.01</td>
</tr>
<tr>
<td>Max</td>
<td>18.87</td>
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<tr>
<td>Mean</td>
<td>8.18</td>
<td>0.32</td>
</tr>
<tr>
<td>Median</td>
<td>8.03</td>
<td>0.31</td>
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</tbody>
</table>

Dose_{PC01} \rightarrow 0.50 \text{ mSv/y}
Varginha village

PC43 – Varginha village

<table>
<thead>
<tr>
<th></th>
<th>Bq/L</th>
<th>mg/L</th>
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<tr>
<td>N</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>Min</td>
<td>0.0055</td>
<td>0.0002</td>
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<tr>
<td>Max</td>
<td>0.2367</td>
<td>0.0093</td>
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<tr>
<td>Mean</td>
<td>0.0586</td>
<td>0.0023</td>
</tr>
<tr>
<td>Median</td>
<td>0.0431</td>
<td>0.0017</td>
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Dose_{PC43} → 0.06 mSv/y

Outflow of the CEB

PC34

<table>
<thead>
<tr>
<th></th>
<th>Bq/L</th>
<th>mg/L</th>
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</thead>
<tbody>
<tr>
<td>N</td>
<td>38</td>
<td>38</td>
</tr>
<tr>
<td>Min</td>
<td>0.034</td>
<td>0.001</td>
</tr>
<tr>
<td>Max</td>
<td>1.124</td>
<td>0.044</td>
</tr>
<tr>
<td>Mean</td>
<td>0.526</td>
<td>0.021</td>
</tr>
<tr>
<td>Median</td>
<td>0.528</td>
<td>0.021</td>
</tr>
</tbody>
</table>

Dose_{PC34} → 0.15 mSv/y
Dose$_{LR001}$ → 0.52 mSv/y

Dose$_{LR042}$ → 0.15 mSv/y

Dose$_{PC68}$ → 0.37 mSv/y

Dose$_{LR213}$ → 0.15 mSv/y

GW assessment → indirect influence of the URA

LR001 – District Maniaçu
Population center located
~ 10 km from URA
Water → Well supply

LR042 – Juazeiro Village
Population center located
~ 13 km from URA
Water → Well supply

PC68 – Juazeiro Village
Population center located
~ 6 km from URA
Well → artesian well

LR213 – District São Timóteo
Population center located
~ 10 km from URA

Uranium anomalies (36? Mapped – 1200 km²)
Summary

Uranium concentration (mg/L)

- W-18 (upstream) 0.024
- LR-276 (Waste Deposit) 0.03
- PC-20 (Mangabeira creek) 0.006
- PC-23 (Varginha) 0.004
- PC-34 (Limit of the URA) 0.021
- PC-285 (Quessengue Farm) 0.011
- LR-042 (Juazeiro village) 0.006
- LR-213 (São Timóteo village) 0.06

Flow line

MAC
Dose Calculation and Risk Analysis
Methodology

We use a screening approach:

This approach comprises:

- **CONSERVATIVE** – Overestimate the exposure → identify contaminants and exposure pathways that have a **low priority for further investigations**.

- **NON-CONSERVATIVE** – “Realistic” exposure → identify contaminants and pathways that would have a **high priority for further investigations**.

### Source data: mining company – INB monitoring program

- **29 wells used by the population**
- **14 villages**
- **506 samples**

Radioactive and nonradioactive pollutants:

- **Non-carcinogenic** → **Hazard Index (HI) = 1** was used as the noncarcinogenic screening criteria (HI is the ratio of the daily intake of the contaminant and the Reference Dose);

- **Carcinogenic** → **Dose of 1 mSv/year** was used as the screening criteria to distinguish between low priority, potentially high priority and high priority contaminants and pathways.
Localization of wells by villages

<table>
<thead>
<tr>
<th>Villages</th>
<th>Wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gameleira Farm</td>
<td>LR211, LR211A</td>
</tr>
<tr>
<td>Cercadinho</td>
<td>PC050, PC051, PC054, PC059</td>
</tr>
<tr>
<td>Varginha</td>
<td>PC043, PC052</td>
</tr>
<tr>
<td>Coroneiras Farm</td>
<td>PC033, PC034, PC074, PC077</td>
</tr>
<tr>
<td>Lajedo Farm</td>
<td>PC031, PC115</td>
</tr>
<tr>
<td>Engenho Farm</td>
<td>PC127, PC130</td>
</tr>
<tr>
<td>Bela Vista</td>
<td>PC085</td>
</tr>
<tr>
<td>Quessenguë Farm</td>
<td>LR265</td>
</tr>
<tr>
<td>Juazeiro</td>
<td>LR042, PC067, PC068</td>
</tr>
<tr>
<td>São Timóteo</td>
<td>LR043, LR213</td>
</tr>
<tr>
<td>Lagoa Grande</td>
<td>LR007</td>
</tr>
<tr>
<td>Maniaçu</td>
<td>LR001, LR002, LR301</td>
</tr>
<tr>
<td>Olho D'água</td>
<td>PC105</td>
</tr>
<tr>
<td>Pinga</td>
<td>PC137</td>
</tr>
</tbody>
</table>
# Analysis of non-radioactive pollutants

**Potentially high priority HI>1.0**
- Contaminants: Ba, Fe, Al, Mn, F, NO$_3$, NO$_2$, Zn, Unat
- Exposure pathways: water ingestion, dermal contact, milk and meat ingestions

<table>
<thead>
<tr>
<th>Villages</th>
<th>Adult exposure</th>
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<tbody>
<tr>
<td></td>
<td>Water Ingestion</td>
</tr>
<tr>
<td></td>
<td>CONSERVATIVE</td>
</tr>
<tr>
<td>Gameleira</td>
<td>Ba</td>
</tr>
<tr>
<td>Cercadindo</td>
<td>-</td>
</tr>
<tr>
<td>Varginha</td>
<td>-</td>
</tr>
<tr>
<td>Coroneira</td>
<td>F</td>
</tr>
<tr>
<td>Lajedo</td>
<td>Mn, Fe, F</td>
</tr>
<tr>
<td>Engenho</td>
<td>NO$_3$</td>
</tr>
<tr>
<td>Bela Vista</td>
<td>F, NO$_3$</td>
</tr>
<tr>
<td>Quessenguê</td>
<td>F</td>
</tr>
<tr>
<td>Juazeiro</td>
<td>F, U$_{nat}$, NO$_3$</td>
</tr>
<tr>
<td>São Timóteo</td>
<td>-</td>
</tr>
<tr>
<td>Lagoa Grande</td>
<td>Al</td>
</tr>
<tr>
<td>Maniaçu</td>
<td>NO$_3$</td>
</tr>
<tr>
<td>Olho D’água</td>
<td>-</td>
</tr>
<tr>
<td>Pinga</td>
<td>-</td>
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</tbody>
</table>
## Analysis of radioactive pollutants

Radionuclides: $U_{238}$, $U_{234}$, $Ra_{226}$, $Ra_{228}$, $Pb_{210}$, $Th_{232}$

<table>
<thead>
<tr>
<th>Villages</th>
<th>Dose (mSv/year)</th>
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<tbody>
<tr>
<td></td>
<td>CONSERVATIVE</td>
<td>NON- CONSERVATIVE</td>
<td></td>
</tr>
<tr>
<td>Gameleira</td>
<td>0.74</td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>Varginha</td>
<td>0.09</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Coroneira</td>
<td>0.20</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>Lajedo</td>
<td>0.15</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>Quessenguê</td>
<td>0.23</td>
<td>0.14</td>
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</tr>
<tr>
<td>Juazeiro</td>
<td>0.53</td>
<td>0.27</td>
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</tr>
<tr>
<td>São Timóteo</td>
<td>0.19</td>
<td>0.13</td>
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</tr>
<tr>
<td>Maniaçu</td>
<td>0.69</td>
<td>0.53</td>
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<tr>
<td>Olho d´água</td>
<td>0.18</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Pinga</td>
<td>0.12</td>
<td>0.07</td>
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</tr>
</tbody>
</table>
Conclusion 1.1

• The geologic framework of the CEB works as a barrier to the flow (limiting contamination);

• The dynamic of water in the CEB depends on a complex system of fracture connection (not all wells in the basin are connected to each other).

• In mineralized areas, when we analyze the constituents of groundwater, it is not always possible to distinguish what is of anthropogenic origin and what is natural:
  – Most wells show natural variation in uranium concentration over time;
  – **CEB:** PC-01 ($r^2=0.15$) and PC-29 ($r^2=0.20$) showed a weak tendency of increase in uranium concentration over time;
  – **Surrounding areas:** The high uranium concentrations found in some wells in Juazeiro village (PC-68) reflect natural geochemical processes and not the influence of the URA activities.
Conclusion 1.2

- Temporal variations in rainfall and in the hydrodynamic patterns (pumping regime) may affect the radionuclides concentration and should be investigated in more detail;
- All the estimated doses are below 1mSv /a (associated with low risk);
- However, several wells show uranium concentrations above the maximum allowable limit, taking into account only the chemical toxicity of this radionuclide.
- Analysis of non-radioactive pollutants show that only nitrate was identified as a high priority pollutant.
National Project – BRA7010

Sustainable Water Resources Management in an Uranium Production

- Improved water resources management in a center of uranium production by the use of sustainability criteria
- Database established
- Experimental watershed implemented
- Water budget quantified
- Hydrogeology modeled
- Water quality diagnosis

- Human health risk estimated
- Water management plan revised
- Improved qualification of the operator, regulatory authorities and support organizations in issues related to uranium mine
- Individuals and organizations qualified to deal with stakeholders engagement

- UFRJ
- COPPE UFRJ
- INB Indústrias Nucleares do Brasil
Thank you for your attention !!!!!

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