Arsenic Concentrations in Drinking Water and Food in Burkina Faso

Long-term arsenic exposure poses serious health hazards. A 4-year project investigated the extent and magnitude of groundwater arsenic contamination in Burkina Faso. Low-cost arsenic removal filters were also tested and arsenic uptake pathways via food explored. A. Bretzler[1], G. Clair[2], F. Lalanne[3], J. Nikiema[4], K.D. Kienou[5], M. Schirmer[1,6], S. Hug[1], S. Marks[2], Ch. Zurbrügg[2]

Introduction

The Sustainable Development Goal 6, Target 6.1, represents a framework for ensuring safe and affordable drinking water for all, not only free from microbiological contamination, but also from dangerous chemical contaminants such as arsenic. Long-term exposure to arsenic in drinking water greatly increases the risk of developing cancers of the internal organs during one's lifetime [1]. Widespread geogenic (naturally occurring) arsenic contamination of groundwater has been under-investigated in Africa [2], as compared to Asia and South America.

In Burkina Faso, arsenic in groundwater stems from sulphide minerals, such as arsenic-containing pyrite (FeS_2) or arsenopyrite (FeAsS), both of which commonly occur in mineralised zones and are associated with gold ores [3]. In contact with oxygenated groundwater at circum-neutral pH, these minerals are oxidised, releasing arsenic. During the course of a 4-year project supported by the Swiss Agency for Development Cooperation (SDC), a research team from Eawag and from the Institut International d'Ingénierie de l'Eau et de l'Environnement (2iE) in Ouagadougou investigated the extent of groundwater arsenic contamination in Burkina Faso. A major aim of the project was to produce maps that identify priority areas for water quality testing and mitigation. In addition, low-cost arsenic treatment technologies were tested, targeting remote rural areas where water treatment is needed due to a lack of alternative, uncontaminated sources of drinking water. Since arsenic can also be transferred to the human body via other pathways than drinking water, the ingestion of arsenic through food was explored.

Arsenic dataset

Many tens of thousands of tube wells equipped with hand pumps exist throughout Burkina Faso, supplying the rural population with drinking water. We assembled a comprehensive dataset of groundwater arsenic measurements of tube wells from various regions of the country, consisting of already existing data (~1 200) and new samples collected during field trips (~300). About 15 % of the tube wells in this dataset exceeded the WHO guideline value for arsenic in drinking water of 10 µg/L (Burkina Faso has adopted this as its national guideline). However, the high concentrations that are especially harmful to human health (> 50 µg/L) are much less frequent in these regions (2.3 % of all tube wells).

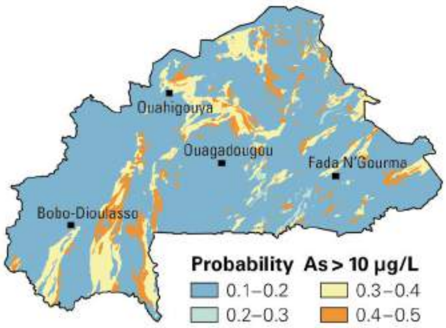

Figure 1: Arsenic hazard map showing the probability that arsenic in groundwater exceeds the guideline.

Arsenic hazard maps

Arsenic analysis should be carried out every time a borehole is drilled or rehabilitated. However, testing all the wells of the country would be unrealistic because it is time-consuming and costly. Maps pinpointing areas where arsenic testing should be prioritised are, therefore, useful and valuable tools for Burkina Faso's water sector. By combining freely available geospatial data of geological and mineralogical parameters (rock types, mineral deposits, fault zones, etc.) with the above mentioned arsenic concentration dataset (separated into calibration and validation data), we computed arsenic prediction maps using multivariate logistic regression. This method allows for the identification of statistically significant parameters that correlate with elevated arsenic in groundwater. Results showed that groundwater in volcano-sedimentary schists and volcanic rocks of the Birimian formation has a three to four times higher probability of containing arsenic > 10 µg/L than in other regions (Figure 1). Figures of population density in these high-risk regions combined with the approximation that one in five tube wells has arsenic > 10 µg/L led to the estimation that ~560 000 people in Burkina Faso (roughly 3 % of the population) are potentially exposed to arsenic concentrations exceeding the guideline value in their drinking water.

Experimenting with low-cost arsenic removal technologies

Arsenic removal by water treatment is challenging for remote rural communities due to the considerable costs and efforts involved. It would, therefore, be preferable to switch to alternative, uncontaminated water sources (e.g. uncontaminated tube well, improved shallow well or treated surface water) if they are available and sustainable throughout the year. Where switching the source is not possible, water treatment remains the only option to reduce households' arsenic exposure. Numerous arsenic treatment technologies exist, but many require sophisticated materials and/or infrastructure that are expensive for small communities and challenging to maintain. In Burkina Faso, we tested the acceptability and effectiveness of low-cost arsenic removal methods based on the design of the SONO filter [5]. This two-bucket

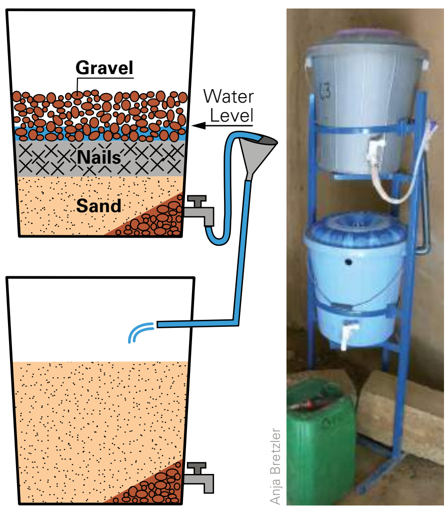

Figure 2: Cross-section of the arsenic removal filter constructed and tested in Burkina Faso.

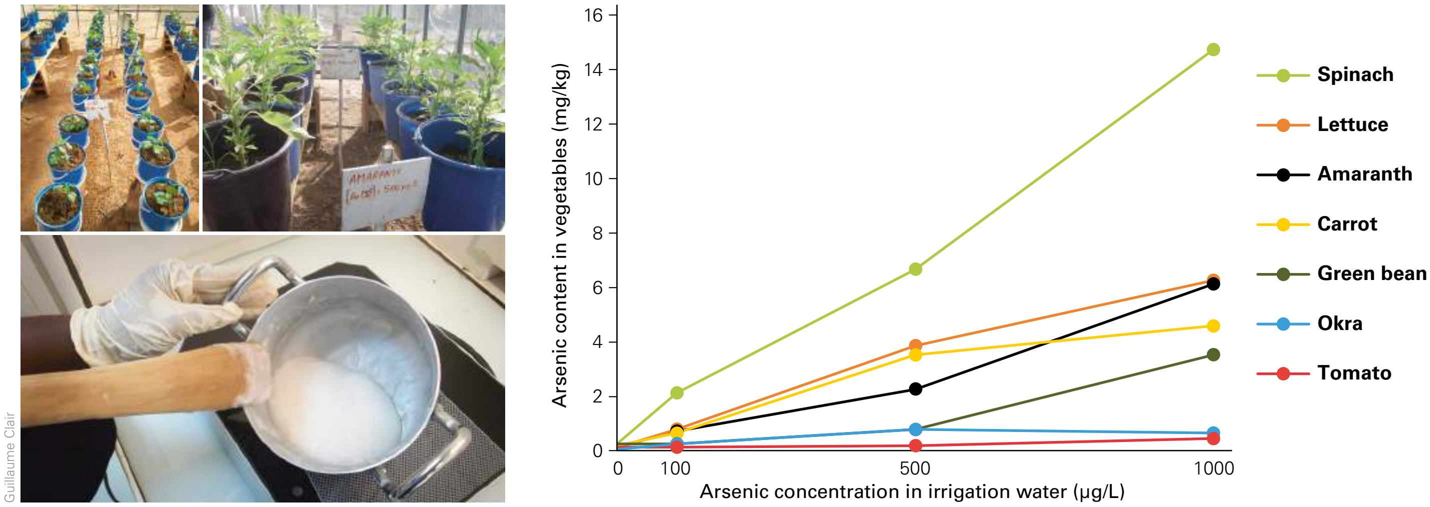

Figure 3: Vegetables and a dish (tô) irrigated/cooked with arsenic contaminated water (left) and arsenic content in vegetables (right).

household system uses simple and widely available materials, such as sand, scrap iron and brick chips. Arsenic is adsorbed on iron (hydr)oxides produced during the corrosion of scrap iron filings in the filter.

Filter construction and installation

Due to a lack of clean scrap iron filings, we opted for small, widely available iron nails as a source of iron oxides for arsenic removal. Additional filter materials were gravel and sand to stabilise the water flow and to remove residual iron precipitates (Figure 2). Four nail-based filters were tested during the course of one year in a remote village in northern Burkina Faso, where tube well arsenic concentrations were between 450 and 1 350 µg/L. Filters were operated at flow rates of 8–12 L/h, with a total of 60 L filtered per day, providing the daily drinking and cooking water needs for a 6–8 people family.

Filter efficiency

Regular monitoring and sampling by an employee of the partner NGO "Le soleil dans la main" provided insights into the functionality of the filter and arsenic removal efficiency. On average, the filters removed 70–90 % of arsenic, but effluent concentrations still remained above 10 µg/L due to the very high arsenic levels in the influent. Villagers did not report any problems with filter clogging or changes in water taste, and filters required no maintenance during the one-year study period. Due to the cheap raw materials and simple construction, these filters can be rapidly built and employed as a first emergency measure to lower the arsenic exposure of a population. However, more efficient long-term water treatment options are recommended to reliably meet the guideline values.

Uptake of arsenic in food products

Arsenic-contaminated water is also used for cooking and irrigation purposes, posing risks due to the migration of arsenic into food and vegetables. To investigate the transfer of arsenic from cooking water to food, water artificially spiked with arsenic (V) (0, 100, 500 and 1 000 µg/L) was used to prepare five common dishes: rice, "tô", yam, beans and gari. Also, vegetables traditionally cultivated and consumed (green bean, tomato, carrot, lettuce, amaranth, spinach and okra) were irrigated with the same arsenic-spiked water. Food samples (cooked meals, and roots, stems and leaves from plants) were freeze-dried, acid-digested and analysed by ICP-MS to determine their arsenic content.

The arsenic content increases as its concentration increases in irrigation water (Figure 3). Roots had the highest arsenic content, followed by leaves and stems, and then fruits. Spinach had more arsenic than lettuce, amaranth, carrot and green beans, while okra and tomato had the least. Cooking food with a large volume of arsenic-free water reduces the arsenic content in the raw vegetables, while cooking with contaminated water transfers arsenic to the cooked food. Adapting the cooking method could be a solution; for instance, the arsenic transfer is much less if yams or rice are cooked with steam than in boiling water.

Conclusion

This project revealed the extent and magnitude of groundwater arsenic contamination in Burkina Faso, with half a million people potentially exposed to arsenic levels exceeding drinking water guidelines. Further research is necessary and targeted mitigation activities involving stakeholders from the health, water supply and rural development sectors should be developed.

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