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Short Communication

Confirmation of elevated arsenic levels in groundwater of Myanmar

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HIGHLIGHTS

- Of 55 wells sampled in Myanmar, the groundwater of only 24 contained <10 μg/L As.
- Reductive dissolution of Fe oxyhydroxides is inferred as the mechanism of As release.
- Observations in the Ayeyarwady are consistent with predictions and field-kit data.
- Well testing is urgently needed in order to help reduce the human exposure.

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ABSTRACT

Millions of villagers across South and Southeast Asia are exposed to toxic levels of arsenic (As) by drinking well water. In order to confirm the field-kit results that Myanmar is also affected, a total of 55 wells were tested in the field in January 2013 and sampled for laboratory analysis across seven villages spanning a range of As contamination in the lower Ayeyarwady basin. Elevated concentrations of As (50–630 μg/L) were measured in wells up to 60 m deep and associated with high levels of Fe (up to 21 mg/L) and low concentrations of SO_4 (<0.05 mg/L). Concentrations of As <10 μg/L were measured in some shallow (<30 m) grey sands and in both shallow and deep orange sands. These results indicate that the main mechanism of As release to groundwater in Myanmar is the reductive dissolution of Fe oxyhydroxides, as in the neighboring Bengal, Mekong, and Red River basins. Concentrations of As in groundwater of Myanmar are therefore unlikely to change rapidly over time and switching to existing low-As wells is a viable way of reducing exposure in the short term. However, only 17 of the 55 well owners interviewed correctly recalled the status of their well despite extensive testing in the region. A renewed effort is thus needed to test existing wells and new wells that continue to be installed and to communicate the health risks of exposure to As for infants, children, and adults.

1. Background

The most dramatic impacts of drinking well water elevated in arsenic (As) such as cancerous skin lesions and loss of limb were recognized in India in the mid-1980s (Chakraborty and Saha, 1987). Public health scientists have since shown that As exposure also increases infant mortality (Rahman et al., 2010), reduces intellectual function in children (Wasserman et al., 2004), and increases adult mortality (Argos et al., 2010) due to cardiovascular disease (Chen et al., 2011) and cancers of the lung, liver, and bladder (Smith et al., 2000). It is now estimated that over 100 million in Pakistan, Nepal, India, Bangladesh, Cambodia, Vietnam, and China are chronically exposed to As by drinking groundwater that does not meet the World Health Organization guideline of 10 μg/L (Ravenscroft et al., 2009).

Elevated concentrations of As in groundwater have been predicted for the lower Ayeyarwady basin on the basis of geologic and climatic factors (Fig. 1a; Winkel et al., 2008) and confirmed by field-kit testing of over 200,000 wells and a smaller number of laboratory measurements (Tun et al., 2003; WRUD/UNICEF, 2006; MOH/UNICEF, 2013) by the Ministry of Health and the Water Resources Utilization Department with support from UNICEF over the past decade. There is a broad consensus that the reductive dissolution of iron (Fe) oxyhydroxides is a key factor leading to naturally elevated As concentrations in anoxic groundwater over large expanses of South and Southeast Asia (Ravenscroft et al., 2009; Fendorf et al., 2010). In some semi-arid areas such as the Indus River basin, however, other mechanisms operating under oxic conditions instead have been shown to result in the accumulation of As in groundwater (Farooqi et al., 2007). Central Myanmar is

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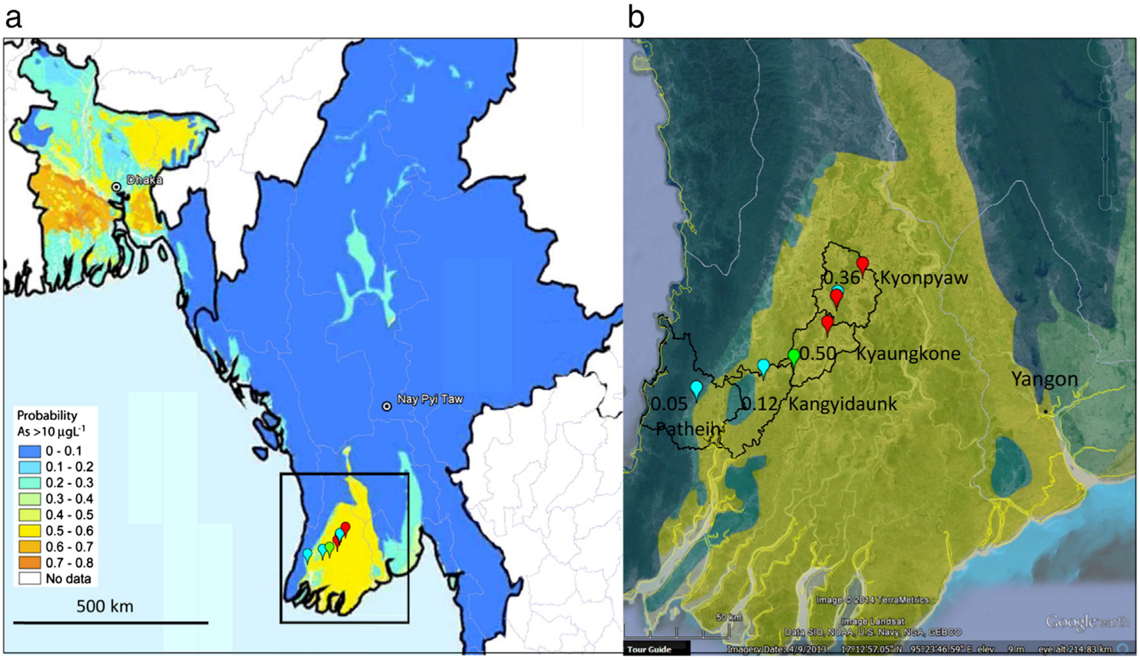

Fig. 1. (a) Map from Winkel et al. (2008) showing the probability of encountering groundwater with >10 μg/L As groundwater in Myanmar and Bangladesh and Myanmar. (b) Close-up of the lower Ayeyarwady basin combined with satellite imagery from Google Earth. Also shown are the boundaries of four townships labeled with their names and, according to MOH/WRUD field-kit data, the proportion of wells with >10 μg/L, starting from the north with Kyonpyaw (19,301 wells tested), Kyaungkone (6,996), Kangyidaunk (3,696), and Pathein (3,342). Symbol color indicates the average As content of wells <60 m in each of the 7 villages sampled: light blue ≤10 μg/L; green 10–50 μg/L; red >50 μg/L.

also a semi-arid region, although it is located well upstream of the focus of the present study in the lower Ayeyarwady basin.

2. Methods

Test results mapped by the Water Resources Utilization Department of the Ministry of Agriculture and Irrigation were made available for the planning of a short sampling campaign to verify the results and identify the mechanisms underlying the release of As to groundwater. A total of 55 wells were sampled on 23–27 January 2013 in 7 villages distributed along a 100-km transect that extends across four townships of the Ayeyarwady region. According to previous field-kit testing, the proportion of wells in those four townships containing >10 μg/L As ranges from 0.05 to 0.50 (Fig. 1b). Villages are referred to hereon according to their distance in kilometers along the transect, starting from the north. In the field, As concentrations were measured visually with the ITS Econo-Quick arsenic kit and the Wagtech portable kit using a digital reader (George et al., 2012). In the laboratory, acidified groundwater was analyzed by high-resolution inductively coupled plasma mass spectrometry on a Thermo Element2 for As, Fe, and other groundwater constituents (Cheng et al., 2004). The reproducibility was better than ±3%, the detection limit <0.1 μg/L, and the accuracy was verified against reference standards NIST1640A and NIST1643. Unacidified samples were analyzed for sulfate (SO_4) and other anions using a Dionex DX2000 ion chromatograph in gradient mode equipped with an AS-11HC column (see Supplemental Table for these and additional measurements). The reproducibility for SO_4 was better than ±2% and the detection limit <0.05 mg/L. Before sampling, the owner of a well or a household member was informed of the purpose of the testing and asked about the status of the well with respect to As.

3. Results

Visual field-kit measurements identified a total of 23 wells that met the WHO guideline for As of 10 μg/L, another 9 wells with As concentrations up to the national standard of 50 μg/L, and 23 wells with >50 μg/L As. As documented in previous studies, the ITS kit results were generally consistent with laboratory measurements (Fig. 2) as well as field data using the considerably more costly and elaborate Wagtech procedure (George et al., 2012; van Geen et al., 2014). Relative to laboratory measurements, the ITS kit shifted 3 samples with <10 μg/L up to the next less safe category and another 2 samples containing 10–50 μg/L up to the unsafe category. The ITS kit did not underestimate the As content of any of the 55 samples relative to these categories.

In samples from the three most affected villages located at km 00, 21, and 32, in Kyonpyaw and Kyaungkone townships, laboratory measurements of As in wells <50 m deep in each village average 80–380 μg/L (23 wells sampled altogether). None of these samples contain >1 mg/L SO_4 whereas most contain >5 mg/L Fe (Fig. 3). At the other end of the spectrum, As concentrations samples collected from wells <50 m deep in the least affected villages in Kyonpyaw and Pathein townships at

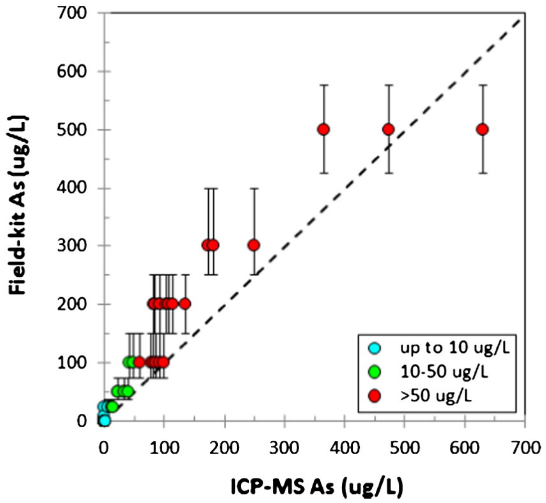

Fig. 2. Comparison of As concentrations in water samples measured by ICP-MS and the field ITS Econo-Quick field kit. Vertical error bars indicate the range of As concentrations for a particular measurement, calculated by assuming a mid-range cutoff between adjacent readings.

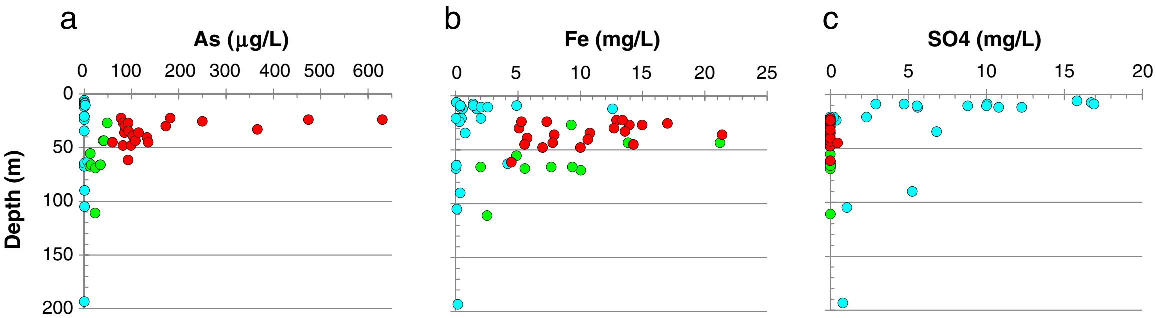

Fig. 3. Vertical profiles of groundwater composition for all 55 samples collected in January 2013 along the 100-km transect. The same symbol colors corresponding to the (a) As content of groundwater measured by ICP-MS measurements (light blue ≤10 μg/L; green 10–50 μg/L; red >50 μg/L) are used for (b) dissolved iron and (c) sulfate.

km 19, 69, and 103 average <1 μg/L As (18 samples). Most of these samples contain >1 mg/L SO_4 and <5 mg/L Fe. The 10 wells in the seventh village at km 54 are intermediate in terms of their average As (23 μg/L) and average Fe (5 mg/L) content. These wells tap the 62–69 m depth range that separates the 41 wells <50 m deep spanning the full range of As concentrations and 4 wells in the 90–200 m depth range containing <1 to 23 μg/L sampled in the 3 highest-As villages (Fig. 3).

4. Discussion

Although the evidence is anecdotal, some links between groundwater As and the local hydrogeology established in the Bengal basin seem to apply to the lower Ayeyarwady. In the low-As village at km 19, wells are shallow (9–12 m), paths are very sandy, and rice has been replaced in the fields surrounding the village by other crops. Rice in this region is typically grown under flooded conditions, which are difficult to maintain in the absence of the fine-grained sediment required to form an impermeable pan. The surface features of this village therefore point to the lack of a silt/clay layer capping the local aquifer. The even shallower 6–11 m depth range of wells in the low-As village at km 69, combined with the mildly reducing conditions indicated by low Fe and elevated SO_4 levels (Fig. 3), again suggests rapid local recharge. In the Bengal basin, low As concentrations have been associated with rapidly recharged sandy aquifers that essentially extend to the surface (Aziz et al., 2008). The presence of detectable levels of SO_4 in many of the low-As wells in the lower Ayeyarwady basin may indicate, in addition, the attenuation of As release by the precipitation of As-sulfides documented elsewhere in the region (Lowers et al., 2007; Buschmann and Berg, 2009).

In the three high-As villages at km 00, 21, and 32, instead, the lack of wells <20 m deep suggests the presence of a thick impermeable layer that locally caps the sandy aquifer, inhibits recharge, and generates more strongly reducing conditions, as confirmed by high Fe levels combined with low SO_4 (Fig. 3). In the Bengal basin, such conditions have been associated with groundwater As concentrations rising rapidly with depth (Aziz et al., 2008).

The local geology of the village at km 103 at the southern end of the transect appears to be different. The 21–35 m depth range of these low-As wells suggests the presence of an impermeable surface layer but, in contrast to the five other villages where the color of the sand in the local aquifer was reportedly grey, the color of the sand at km 103 was described as orange. Further to the north in the high-As village at km 32, orange instead of grey cuttings were also recovered but starting at a depth of about 90 m while drilling the deepest of these wells as a community source. The color of aquifers sands is closely associated with the extent of reduction of Fe oxyhydroxides and, therefore, the likelihood of elevated As in groundwater (Fendorf et al., 2010). The topography of the area suggests that the southern portion has been uplifted as part of the folding mountain belt that separates Myanmar from Bangladesh and that the orange sands at km 32 and 103 may therefore be part of the same formation. Although the orange sands in the lower Ayeyarwady, to our knowledge, have not been dated, it is tempting to relate their depositional history to that of the orange Pleistocene Dupi Tila formation in the neighboring Bengal basin (Ravenscroft et al., 2009). Pleistocene orange sands are typically encountered at depths of 50–100 m in parts of the Bengal basin but at considerably shallower depths around Dhaka, which was built on top of an uplifted terrace and where groundwater is therefore consistently low in As. The situation around Dhaka may therefore be an analog for the shallow orange sands at the southern end of the Ayeyarwady transect.

5. Implications

This report contains, to our knowledge, the first systematic comparison of field and laboratory measurements of As with other groundwater parameters from Myanmar. The results are consistent with a much larger data set obtained with field kits and indicate that reductive dissolution of Fe oxyhydroxides is widespread in aquifers of the lower Ayeyarwady basin. Within the four townships that were sampled, the proportion of high-As wells documented with field kits matches the predictions by Winkel et al. (2008). The spatial distribution of As in groundwater of the lower Ayeyarwady, the relationships between As and other groundwater constituents, and the relationship to hydrogeology inferred from local surface features are all consistent with observations elsewhere in South and Southeast Asia. Whereas elevated groundwater As concentrations under oxic conditions have been documented in semi-arid regions such as the Indus river basin (Farooqi et al., 2007), the dominant mechanism in the lower Ayeyarwady basin appears to be the reductive dissolution of Fe oxhydroxides. The implication is that elevated As concentrations in the lower Ayeyarwady are of natural origin and that the observed pattern is unlikely to shift rapidly over time (Fendorf et al., 2010). As in Bangladesh, the form of mitigation that is likely to be more effective is therefore the sharing of existing safe wells and the installation of deeper low As community wells (Ahmed et al., 2006). However, only 18 of the owners or caretakers of the 55 sampled wells knew the status of their well despite extensive testing in the area over the last decade. This is in part because over one-third of these wells were installed within the last 5 years. This means a renewed effort is urgently needed to test all wells in all As-prone areas of Myanmar (Fig. 1a). A field kit that is inexpensive yet reliable such as the ITS EconQuick is preferable because of the greatly simplified logistics of informing a household of the test result compared to a laboratory measurement. An encouraging sign is that well status relative to the local standard of 50 μg/L was correctly recalled in all but one of the 18 cases.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.scitotenv.2014.01.073.

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