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Sediment color tool for targeting arsenic-safe aquifers for the installation of shallow drinking water tubewells

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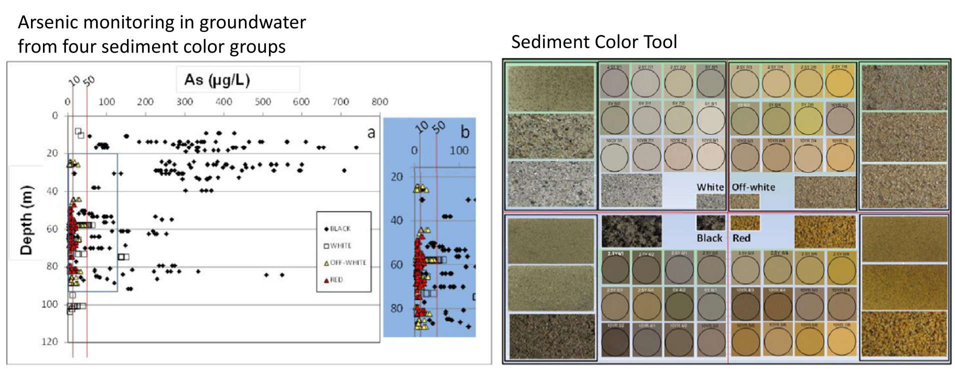
HIGHLIGHTS

- More than 90% tubewells in Bangladesh are installed privately by the community.
- Local drillers are the main driving force in tubewell installations.
- Long term monitoring validated arsenic in water with respect to sediment color.
- A sediment color tool is developed based on local driller's color perception.
- This tool would play a significant role to scale-up safe water access.

GRAPHICAL ABSTRACT



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ABSTRACT

In rural Bangladesh, drinking water supply mostly comes from shallow hand tubewells installed manually by the local drillers, the main driving force in tubewell installation. This study was aimed at developing a sediment color tool on the basis of local driller's perception of sediment color, arsenic (As) concentration of tubewell waters and respective color of aquifer sediments. Laboratory analysis of 521 groundwater samples collected from 144 wells during 2009 to 2011 indicate that As concentrations in groundwater were generally higher in the black colored sediments with an average of 239 µg/L. All 39 wells producing water from red sediments provide safe water following the Bangladesh drinking water standard for As (50 µg/L) where mean and median values were less than the WHO guideline value of 10 µg/L. Observations for off-white sediments were also quite similar. White sediments were rare and seemed to be less important for well installations at shallow depths. A total of 2240 sediment samples were collected at intervals of 1.5 m down to depths of 100 m at 15 locations spread over a 410 km^2 area in Matlab, Bangladesh and compared with the Munsell Color Chart with the purpose of direct comparison of sediment color in a consistent manner. All samples were assigned with Munsell Color and Munsell Code, which eventually led to identify 60 color shade varieties which were narrowed to four colors (black, white, off-white and red) as perceived and used by the local drillers. During the process of color grouping,

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participatory approach was considered taking the opinions of local drillers, technicians, and geologists into account. This simplified sediment color tool can be used conveniently during shallow tubewell installation and thus shows the potential for educating local drillers to target safe aquifers on the basis of the color characteristics of the sediments.

1. Introduction

Access to safe water supply is a basic human right and one of the most essential requisites of good health. Natural arsenic (As) in groundwater exposes millions of people to health risks of various magnitudes through drinking water and is a big challenge globally (Bundschuh et al., 2010). A recent publication (Argos et al., 2010) has raised serious concern that incidences of As in drinking water would cause a large number of deaths due to cancer alone if the problem is not properly managed.

For drinking water supply, the Bangladeshi population almost entirely depends upon groundwater sources. The remarkable achievement in reducing the scale of cholera and diarrheal diseases and infant mortality in the 1970s and 80s became possible from the increased use of groundwater for drinking (Steer and Evans, 2011). The occurrence of natural As in groundwater and its exposure drastically reduced the safe water access across the country with more severity in the southern half. In cities and urban areas, the supply is based on a piped water supply system. But in rural Bangladesh, water supply is mostly obtained by manually operated hand pumps in tubewells installed by the communities themselves.

Despite significant progress in our understanding of the source and distribution of arsenic (As), and its mobilization through sediment–water interactions (Bhattacharya et al., 1997, 2002; Nickson et al., 1998; BGS, DPHE, 1999, 2001; Harvey et al., 2002; van Geen et al., 2003; Ahmed et al., 2004; Islam et al., 2004; Mukherjee and Bhattacharya, 2001; McArthur et al., 2004; Charlet et al., 2007; Saunders et al., 2005; Polizzotto et al., 2008; Nath et al., 2009; Polya and Charlet, 2009; Bundschuh et al., 2010; Mukherjee et al., 2011; Biswas et al., 2012a, 2012b), there has been limited success in mitigation attempts in Bangladesh (Ahmed et al., 2006). A social survey conducted in 96 villages of Matlab for a parallel study by the same research group during 2009–2011 revealed that only 18% of the total tubewells provided safe water. Among these, the safe water access also varied widely between 0 and 90% with respect to the total tubewells installed in villages surveyed (SASMIT Annual Report, 2011; Hossain et al., 2012). In addition to poverty, unplanned development programs and lack of awareness, inadequate knowledge of local geology was also found as an important cause for installing tubewells in unsafe aquifers.

Different alternative safe drinking water options, such as, Arsenic Removal Filter (ARF), Rain Water Harvester (RWH), Pond Sand Filter (PSF), and Arsenic-safe tubewells have been provided in various affected areas in Bangladesh (Jakariya et al., 2005, 2007; Inauen et al., 2013). A recent evaluation of these options conducted in Matlab (Hossain et al., 2011) reveals that the tubewells are the most widely accepted option with almost no-cost of operation and availability of good quality water throughout the year.

At present, the main problem is the huge gap between the extent of exposure and the pace of mitigation. Therefore the main challenge is to develop a simple cost-effective tubewell option which would be easily acceptable by the people and possible to install and maintain by themselves. Hand percussion drilling is the most common method of tubewell installation used by the local drillers. This is a local technology, cost-effective and needs readily available inexpensive equipment. Although government programs and non-government projects extend their cooperation through installation of tubewells, nevertheless most of the tubewells (about 90% in the whole country) are installed by the community with the help of the local drillers.

In order to change the scenario of safe water access in the arsenic affected areas, importance largely lies with the development of a method/tool by which the local drillers can identify and target safe aquifers without the aid of technical expertise. This kind of knowledge and education of the local drillers can be extremely useful in scaling-up safe water access.

Based on the color perception of the local drillers, the four color (black, white, red, off-white) hypothesis was proposed by von Brömssen et al. (2007) based on the study carried out in two villages of Matlab. The relationship of aquifers' sediment color and corresponding As concentration in waters derived from those sediments was evaluated based on monitoring of 40 wells sampled in May 2004. Color of screen layer sediments was depicted mainly by the respective drillers who had installed the wells before the study. Local drillers have been installing tubewells targeting red/off-white aquifers for low-iron water for the last few years and eventually now they have acquired the knowledge that the color could be related to As concentration in tubewell water. Relevance of sediment color with respect to As in water has also been reported from Araihazar (e.g. van Geen et al., 2004), Savar (e.g. Stollenwerk et al., 2007) and this study area Matlab (e.g. Hossain et al., 2010a) and Munshiganj (e.g. Hug et al., 2011) in Bangladesh and West Bengal, India (McArthur et al., 2004; Pal and Mukherjee, 2008, 2009; Datta et al., 2011; Biswas et al., 2012a, 2012b, 2014), which reflects similar observations from a wider geographic range. According to the existing four color hypothesis as shown in Fig. 1, highest risk lies with the black color sediments and gradually reduces towards red. Although we are dealing with four colors, black and red colors carry more importance considering their wider occurrence in the field of shallow tubewell installation.

The main objective of this study is to validate the four color hypothesis through an extensive hydrogeological investigation and thereafter to develop a sediment color tool (Hossain et al., 2010b, 2013) for a wider spatial coverage at different depths so that the driller's perception have a scientific basis for targeting arsenic-safe aquifers. If the drillers can identify the aquifers in the field, it would bring a significant change to minimize the gap between arsenic exposure and safe water access in rural Bangladesh.

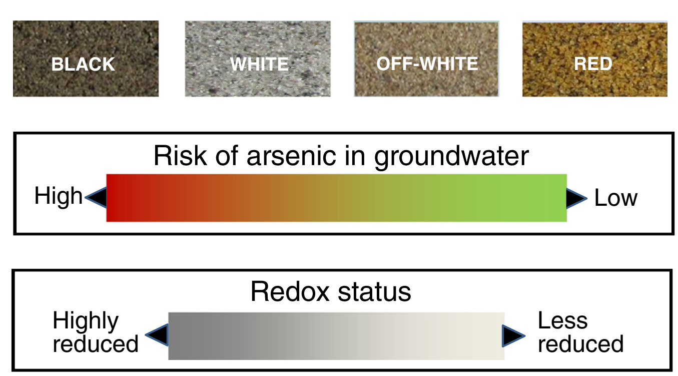

Fig. 1. Four color sands with corresponding risks of As concentration in water under varying redox status. For the color version of the figure, the reader is referred to the web version of this article.