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Research paper

Arsenic and manganese in shallow tubewells: validation of platform color as a screening tool in Bangladesh

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ABSTRACT

This study aimed to evaluate the potential of handpump tubewell platform color as a low-cost, quick and convenient screening tool for As and Mn in drinking water tubewells. For this study, groundwater samples and corresponding tubewell platform pictures were collected from 272 shallow tubewells in Matlab Upazila of South-Eastern Bangladesh. The result shows that arsenic concentration within the surveyed (n = 272) tubewells, 99% (n = 269) exceeded the World Health Organization (WHO) guideline value of 10 μg/L, and 98% (n = 267) exceeded the Bangladesh drinking water standards (BDWS) of 50 μg/L. In relation to the platform color concept, within 233 (total 272) red colored platform tubewells, 230 (99%) exceeded the WHO guideline value of 10 μg/L, and 229 (98%) tubewells exceeded BDWS of 50 μg/L. This result shows a strong correlation between the development of red color stain on tubewell platform and As concentrations in the corresponding tubewell water. This study suggests that red-colored platform can be used for primary identification of tubewells with an elevated level of As and thus could prioritize sustainable As mitigation management in developing countries where water comes from reductive shallow aquifers. This study did not confirm the potential for Mn screening, as red discoloration by Fe oxides was found to mask the black discoloration of Mn oxides. It is recommended to further investigate this screening tool in regions with a higher well-to-well variability of As contaminations, as in the presented study As was found > 10ug/L in 99% of the tubewells.

1. Introduction

The geogenic occurrence of arsenic (As) and manganese (Mn) in shallow depth groundwater is a severe drinking water quality problem all over the world (Bhattacharya et al., 2004; Nriagu et al., 2007; Mukherjee et al., 2008; Naidu and Bhattacharya, 2009; Bhattacharya et al., 2017; van Halem et al., 2009; Gude et al., 2016). This problem is an extreme severity in South-East Asia especially in Bangladesh and West Bengal, India (Mukherjee and Bhattacharya, 2001; Ahmed et al., 2004; Mukherjee et al., 2009; Charlet and Polya, 2009; Kumar et al., 2010; Li et al., 2011; Singh et al., 2015). The majority of the population in this region depends on privately installed shallow drinking water wells (< 70 m) as their main source of drinking water supply (Hossain et al., 2015; Mihajlov et al., 2016). Unfortunately, the discovery of As and their widespread occurrence in shallow aquifers drastically reduced the safe water access, and a huge population is exposed to high levels of As from drinking water sources. The major As related health outcomes are different types of cancer, childhood intellectual health, and cardiovascular disease (Kapaj et al., 2006; Ravenscroft et al., 2009; Mihajlov et al., 2016). Arsenic primarily released into groundwater system under

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the anoxic condition prevailing in the subsurface aquifer sediments.

Along with As, the recent reports on the presence of elevated concentration of Mn is also recognized as a significant drinking water quality problem in many areas in Bangladesh (von Brömssen et al., 2007; Biswas et al., 2012a, 2012b; Vega et al., 2017). Although Mn exposure is less harmful to human health than As (Hug et al., 2011), consumption of drinking water with high level of Mn causes neurotoxic effects, such as reducing the intellectual capacity of children (Rahman et al., 2015; 2017).

As a part of sustainable drinking water management, regular monitoring of As and Mn in all the handpumped tubewells in a region is necessary. For fast and low-cost determination and monitoring of As levels in tubewells, several field test kits have proven worthy for As screening by researchers such as van Geen et al. (2005) and Jakariya et al., (2007). Other applied test kits include Merck, Hach EZ, Quick arsenic, Wagtech Digital Arsenator (WFTK), and Chem-In Corp field test kit (CFTK) (Steinmaus et al., 2006; Sankararamakrishnan et al., 2008; Biswas et al., 2012a). However, these kits are developed based on the generation of arsine gas, which may pose a severe occupational health hazard to the field testing personnel (Hussam and Munir, 2007). Moreover, these analysis techniques are time-consuming (> 20 min) and rural people have limited access to these test kits. Besides that, there is a risk of misclassification of the tubewells in some cases due to analytical errors during field test kits application to determine As concentration. This uncertainty may need a re-evaluation of the field test kits results by expert personnel. Tonmoy et al. (2016) found significant inconsistencies in the results of the kit during a screening of As concentration in the tubewells.

On the contrary, there are a limited number of field test kits for the determination of Mn concentration in tubewell water. Hach field test kit (Model MN-5) is one of the Mn concentration measurement kits, whose consistency has not been proven yet. Research is still ongoing to develop rapid methods that would facilitate the screening of As and Mn in a in short time in a convenient way. Overall, it is difficult to identify the contaminated aquifers by testing a small number of tubewells through conventional field kits and laboratory analysis (Tonmoy et al., 2016). In this context, a quick screening of the tubewells based on visible features may aid to identify the respective tubewells and thereby to delineate the contaminated domains within a given area.

Studies by McArthur et al. (2011) and Biswas et al. (2012a) indicated that color stain developed on tubewells platforms could function as a screening tool for As and Mn in drinking water wells. In a major part of Bangladesh and India tubewell platforms are often characterized either by red stains due to the precipitation of Fe-oxides or black stains due to the precipitation of Mn-oxides which have implications on water quality in generic terms (McArthur et al., 2011; Biswas et al., 2012a). These stains indicate the presence of high concentrations of dissolved Fe which associated with As (> 10 µg/L) developing red stains and elevated Mn due to precipitation of Mn-oxides in water which is As safe (< 10 µg/L). This particular color formation on tubewells platform and relation with Fe, Mn and As concentration in groundwater is governed by different biogeochemical interactions (Bhattacharya et al., 2002, 2009; Biswas et al., 2012a, 2012b). Biogeochemical interactions follow the sequence of terminal electron accepting processes (TEAPs) where the redox conditions primarily governed by microbial oxidation of organic matter. This oxidation followed by reduction of Mn-oxyhydroxides before Fe-oxyhydroxides. Since Mn is a stronger electron acceptor than Fe, reduction of Mn-oxyhydroxides, releases both Mn and As in groundwater and the released As is readily reabsorbed to Fe-oxy-hydroxides in the less reduced aquifer sediments (Stuben et al., 2003; von Brömssen et al., 2008) and water become Mn-enriched. During extraction of this Mn-enriched water by pumping, this soluble Mn(II) is (microbially mediated) oxidized by atmospheric oxygen to Mn-oxides, which produces black coloration on tubewell platform and indicates that the well is As safe. When the redox status reaches the Fe reduction stage, Fe as well as absorbed As is being released to groundwater resulting in Fe and As enriched aquifer and water extraction from this aquifer. Upon extraction, Fe is rapidly oxidized by atmospheric oxygen to Fe oxides, producing a red coloration on tubewell platform. Please note that, Mn is more soluble than Fe in water at normal pH and Fe oxidation kinetics are faster than for Mn, hence Fe precipitates before Mn and vice-versa for higher Mn/Fe ratio (Gingborn and Wåhlén, 2012). Thus the color stain developed on tubewell platform may be used as screening tool for Mn and As in groundwater. In this study, we have assessed the tubewell platform color as an As and Mn screening tool in Bangladesh tubewells water, for wide application in As and Mn affected areas. For As, the tool is evaluated corresponding to both WHO drinking water guideline value of 10 µg/L and BDWS of 50 µg/L. At present WHO does not have any recommended guideline for Mn in drinking water (WHO, 2011) and hence, the evaluation is done corresponding to BDWS of 100 µg/L.

2. Material and methods

2.1. Study area

The study area is located at a distance of about 65 km southeast of Dhaka city, covering an area of approximately 25 km^2 (23.41819–23.48980 N to 90.59529–90.63375 E) in the northwestern part of Matlab North Upazila in Chandpur district, Southeastern Bangladesh. The study area includes Satnal, Kalakanda, Sengarchar, and part of Sadullahpur Unions demarcated by the confluence of Ganges (Padma), Brahmaputra (Jamuna) and Meghna rivers. The river Dhanagoda separates the study area from Matlab South Upazila (Fig. 1). The local weather is hot and humid with temperature ranges from 11 °C in winter (December to February) to 35 °C during summer (June to October). The average annual rainfall is 2000 mm (Mozumder, 2011). There is no long-term groundwater fluctuation in the study area, however, due to seasonal variation in rainfall, periodic groundwater fluctuation is visible. The groundwater elevation reaches its peak after the rainy season (in September) and minimum (April/May) at the beginning of the rainy season. The peak was 7.12 m, and the minimum was 0.74 m respectively from MSL (Table 1).

According to National Water Management Plan (NWMP, 2000), the Matlab area is a part of the southeastern hydrologic region of Bangladesh. This area is situated in the Lower Meghna Flood Plain (LMFP) and characterized by, meander channels, natural levees, and scrolls and back swamps prepared by river scheme (Mozumder, 2011). The redox characteristics of Matlab subsurface geology divided into oxidizing and reducing aquifers and distinguished by sediment color and water chemistry (Hossain et al., 2015). Compared to oxidized aquifers, reduced aquifers produce As enriched water than oxidized aquifers (Jonsson and Lundell, 2004; von Brömssen et al., 2007; Biven and Haller, 2007; Robinson et al., 2011). Several studies also revealed that brown (or orange/yellow) sediments in the aquifer system mainly contain iron (oxy)hydroxides and the pore water in this sediment contains low dissolved arsenic and the porewater of grey sand sediments contains high dissolved arsenic (van Geen et al., 2003; McArthur et al., 2004; Hossain et al., 2014, 2015).

According to a hydrogeological investigation from different organizations, there are four different major groundwater bearing zones. In 1986, Master Plan Organization (MPO), Bangladesh divided the country aquifer system into upper and lower aquifer sequences based on hydrogeology. According to this classification, upper aquifer system consists of sands, silts, and clays recharged through precipitation, flood water, while the deeper confined aquifers are recharged through the regional groundwater flow systems from the Tripura hills (von Brömssen et al. 2014).

A 3-D aquifer model was conceptualized for Matlab study area based on a series of vertical electric soundings (VES) and sediment characterization of the lithologs prepared during the installaton of the piezometer nests (Hossain et al. 2010; Mozumder, 2011, von Brömssen

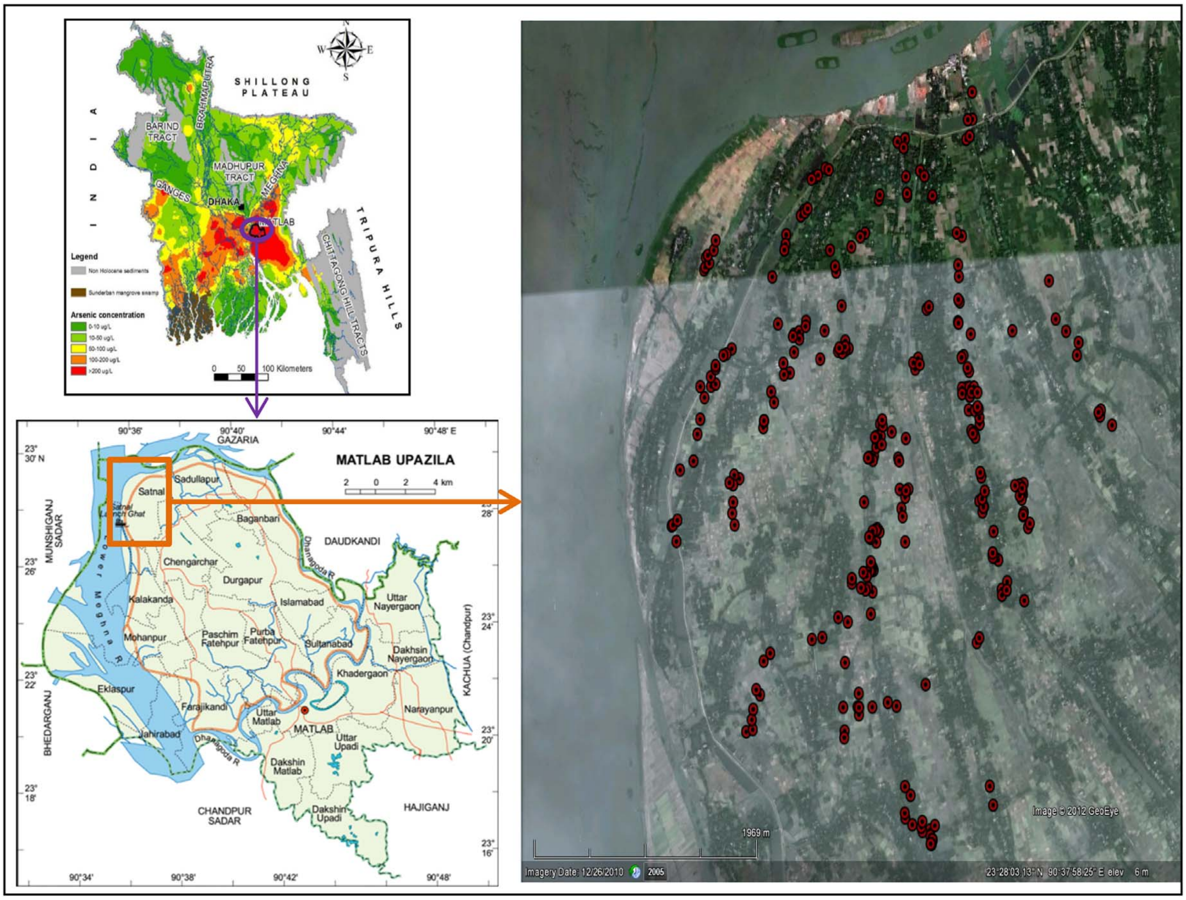

Fig. 1. Map of the Bangladesh (center) with the general distribution of arsenic and the location of the study area in Matlab (right). The Google Earth® map (left) shows the locations of the tubewells investigated during the study.

et al., 2014). The region is characterized by five distinct hydrostratigraphic units and represented by three predominantly fine to medium sand aquifer units of variable thickness, denoted as Aquifer 1, Aquifer 2 and Aquifer 3, with two dominantly silty clayey aquitards, Aquitard 1 and Aquitard 2 separating the Aquifers 1 and 2 and Aquifers 2 and 3 respectively (Fig. 2).

Aquifer 1 has a general thickness of 25-60 m and comprises predominantly fine to medium sand of predominant black color formed as a part of Meghna floodplain deposits. Most of the shallow tubewells installed in this aquifer are enriched with As in groundwater. Aquitard 1 act as a hydraullic barrier between Aquifers 1 and 2 is dominated by intercalations of silty and sandy clay units with thickness varying between between 3 and 59 m (von Brömssen et al. 2014). The underlying hydrostratigraphic unit designated as Aquifer 2 generally occurring between depths of 40-100 m formed as a part of the Chandina deltaic floodplain deposits, is dominated by medium to fine sand. The thickness of this aquifer unit ranges between 25 and 60 m and characterized by red and off-white color encountered in the upper part of this unit

Table 1
Average of hydraulic head measurements (groundwater elevation) observed in SASMIT piezometers (Mozumder, 2011).

SASMIT piezometer	Dry Season (09/10)			Wet Season (09/10)			Fluctuation (09/10)		
	Shallow	Intermediate	Deep	Shallow	Intermediate	Deep	Shallow	Intermediate	Deep
3P	0.75	0.734	0.706	4.85	4,519	4,206	4.1	3,785	3.5
4P	2.34	−0.779	−1.61	5,386	4,126	3,452	3,045	4,905	5.05
5P	15,865	−0.811	−1.25	50,315	3,804	3,804	3,445	4,615	4.55
7P	76,795	7,066	6,283	100,195	9,226	8,763	2.34	2.16	2.48
6P	5,236	47,525	4.31	6,511	65,275	6.59	1,275	1,775	2.28
7P	76,795	7,066	6,283	100,195	9,226	8,763	2.34	2.16	2.48
8P	5,393	50,715	4,707	6,758	67,115	6,977	1,365	1.64	2.27
9P	1,951	1,748	−0.2	3,831	3,928	3.5	1.88	2.18	3.7
10P	5,051	–	4,307	6,881	–	6,527	1.83	–	2.22
11P	1,666	–	1,611	3,796	–	3,491	2.13	–	1.88
12P	3,311	3,857	2,799	5,601	4,797	–	2.29	0.94	–
13P	8.64	6.7	6,643	–	–	–	–	–	–
14P	1,705	0.294	0.08	–	–	–	–	–	–
15P	0.775	–	0.21	–	–	–	–	–	–
16P	1,402	−0.466	−0.72	–	–	–	–	–	–
17P	−2,251	−3,896	−5.59	–	–	–	–	–	–

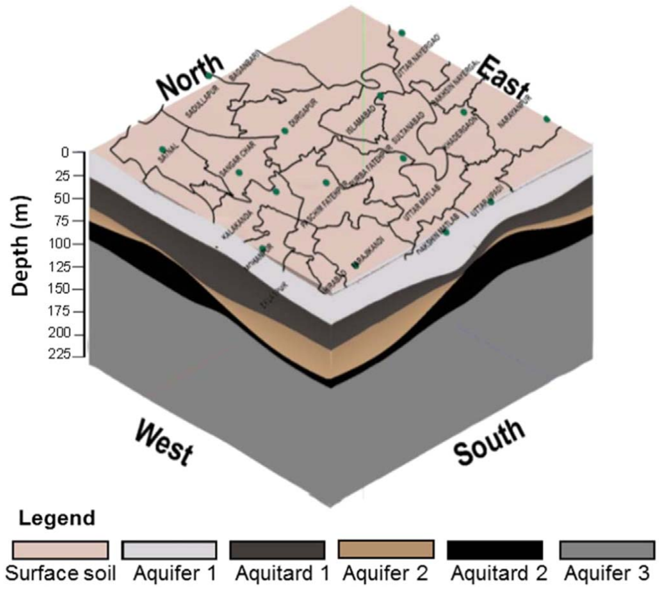

Fig. 2. A generalized 3-D model generated by Rockworks® (v. 2004) showing the hydrostratigraphic framework of the study area in Matlab region using the sediment borelogs from piezometer nest sites. For the color version of the figure, the reader isreferred to the web version of this article.

especially in the southern part of the Matlab region. The tubewells installed in this aquifer is generally arsenic-safe water. This unit is separated from the underlying thick sequence of grey colored fine, medium to coarse sand forming the Aquifer 3 by Aquitard 2 comprising silty-clayey sediments with variable thickness at depths of around 100 m.

2.2. Hydraulic head measurements by piezometer nests

Fifteen piezometers nests, each with a set of six wells (P1-P6), were installed at different depth levels from 20 m to 235 m with an objective to study the hydraulic head characteristics within the arsenic hot spot area around Matlab (Fig. 3). For shallow wells, hand percussion used for drilling and for deeper wells done by rotary reverse circulation drilling which is also known as "donkey drilling". Groundwater levels were measured in each piezometer well during the period 2009 pre-monsoon through 2013 post-monsoon for monitoring the groundwater level fluctuations, and groundwater samples were collected from the wells twice a year during the pre-monsoon and post-monsoon periods.

2.3. Groundwater sampling

Groundwater sampling from shallow (< 70 m) tubewells was carried out from a total of 272 drinking water wells in September and October 2011. During sampling, each tubewell were adequately purged for few minutes depending on the depth prior to the collection of water samples from the wells sampling to get the screening level water sample for the analysis of As, Fe, and Mn in the laboratory. The samples were filtered through 0.45 μm Sartorius membrane filter and 10 ml sample water collected in 15 ml pre-washed high-density polyethylene vials and the sampling bottle prepared by 1.5% acidification (14 M HNO_3) to prevent the risk of acid handling in the field. The geographical coordinates collected for each tubewell by Global Positioning System (GPS, Garmin-GPS60). Besides this, the major coloration on the platform examined carefully and recorded the owner and surveyors opinion on coloration. A picture captured for each tubewells platform by a digital camera (Sony Cyber-Shot-W220, 12MP, 4x optical zoom). The tubewells depths and installation year for both tubewells and platform also recorded from the owner. The platform color re-examined in the laboratory by an unbiased operator for cross-verification of the identified colors. The reciprocal agreement on platform color was more than 74% (n = 202). All disagreements (n = 70) was due to the separation of mixed color from red and black colored platform.

Water samples shipped to the water chemistry laboratory at KTH Royal Institute of Technology, Stockholm, Sweden for trace element analysis. The water samples analyzed for As, Fe and Mn using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) (model: iCAP 6000) equipped with autosampler at the Department of Geological Sciences, Stockholm University, Sweden.

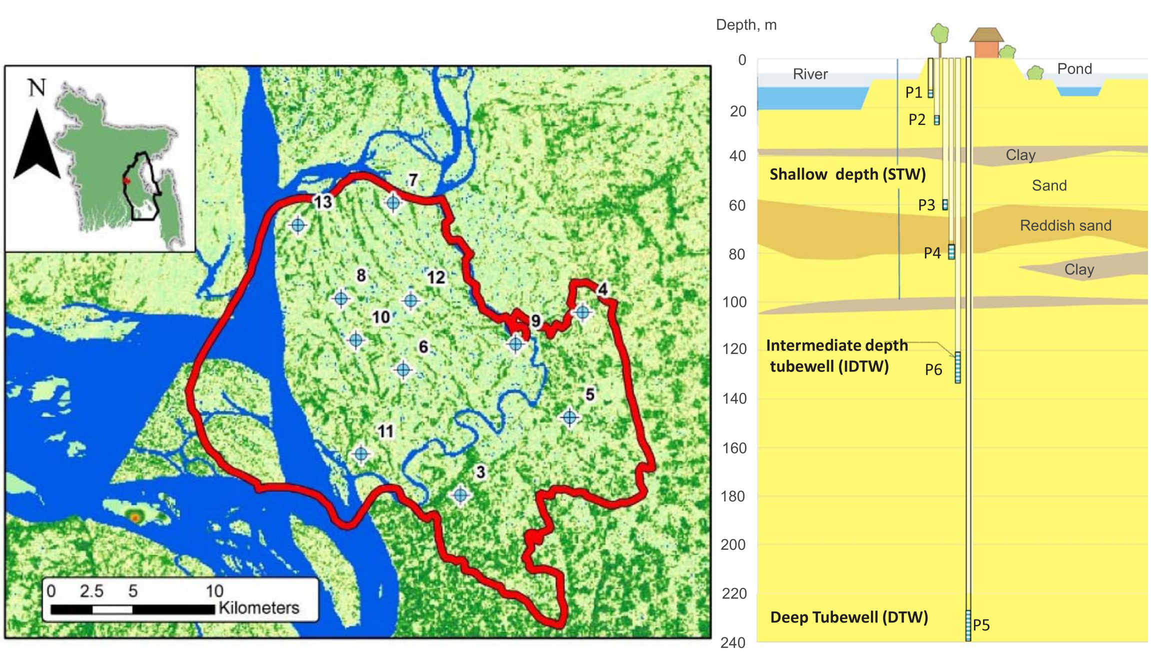

Fig. 3. Map showing the locations of the piezometer nests (left) and the depths of the piezometers (P1-P6) for measurement of groundwater levels and water quality monitoring (adapted from von Brömssen et al., 2014; Hossain et al, 2017).

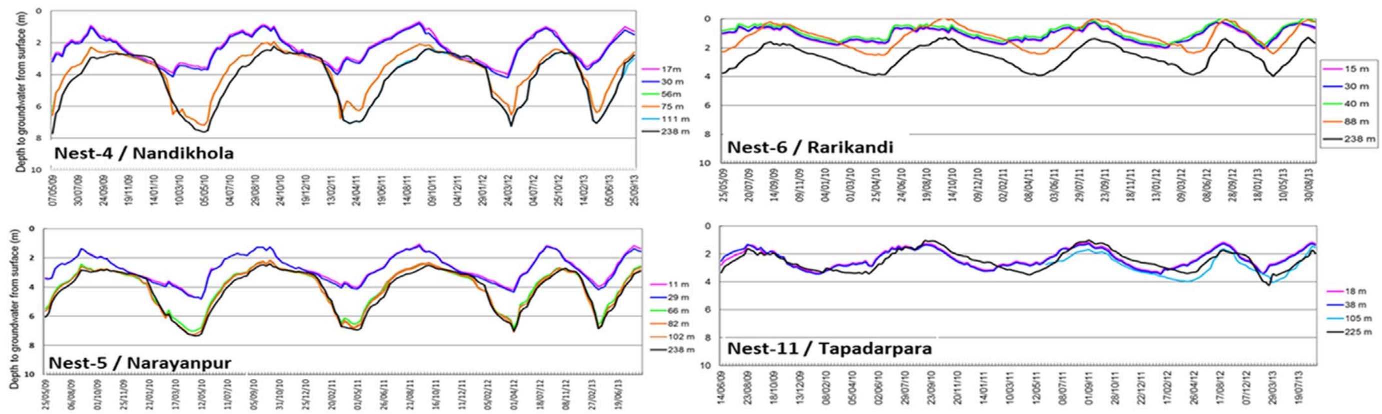

Fig. 4. Groundwater level fluctuations in the piezometer nests 4, 5, 6 and 11 in Matlab regions monitored during the years 2009 and 2013.

Table 2
The average concentration of As, Mn, and Fe concerning depth ranges and the total number of tubewells are in each depth class.

Depth (m)	Number of Tubewells, n	Mean Concentrations (μg/L)		
		As	Mn	Fe
12–15	22	212	1128	7095
15–18	42	256	1029	8189
18–21	122	336	1069	7502
21–25	58	277	1108	6620
25–30	18	308	1025	5214
30–52	10	246	1038	5401

2.4. Statistical analysis

The effectiveness of platform color stain as As screening tool was evaluated by statistical analysis package based on Bayesian statistics. At the same time, sensitivity, specificity, efficiency and predictive values were determined, concerning WHO drinking water guideline value of 10 μg/L and BDWS of 50 μg/L for both As and Mn to validate the platform color as a screening tool.

3. Results and discussions

3.1. Hydraulic head, arsenic, and redox characteristics

The hydraulic head measurements from piezometer nests reveal that shallow aquifers are hydraulically separated from intermediate and deep aquifers (Fig. 4). Shallow depth groundwater level measurements from P1 and P2 clearly indicates that they are from a same hydrostratigraphic unit called aquifer 1. However, shallow piezometers P3 and P4 provides hydraulic head data from aquifer 2. And finally, intermediate (P5) and deep (P6) piezometers reveals similar pattern with some overlaps and belongs to same aquifer (aquifer 3) system.

The hydrochemical composition of the groundwater samples from three different hydrostratigraphic unit showed distinct variations for shallow, intermediate and deep aquifer system. Groundwater samples abstracted from shallow black colored sands, which are dominated by Ca-Mg-HCO_3 to Na-Cl-HCO_3 type in off-white and red sediments. These variations depict the generic variations in the color of the aquifer sediments. However, the water samples collected from intermediate-deep and deep aquifers are rather Na-Ca-Mg-Cl-HCO_3 to Na-Cl-HCO_3 type. The groundwater in the shallow aquifers (aquifer 1) are characterized by high As concentrations with median values of 71–646 μg/L derived from the black sand of the aquifer 1. These groundwaters also characterized by elevated DOC, HCO_3 Fe, NH_4-N and PO_4-P with relatively low Mn and SO_4 concentration and justified As release in groundwater system due to reductive dissolution of Fe-oxy-hydroxides (Bhattacharya et al., 2002; von Brömssen et al., 2007).

According to a previous study (Hossain et al., 2015), the tubewell screen which is installed in the aquifer that consists of grey sands, are generally in reducing condition and facilitate to produces Fe and As rich water. During further installation of shallow tubewells, the local drillers can choose reddish-brown sediments instead of grey sediments to avoid As rich water. Reddish-brown sediments are produced due to oxidation of iron and sorbed As to produces comparatively low As water compared to grey sand aquifer (< 50 μg/L).

3.2. Tubewell classification according to screening depth

To visualize the distribution pattern of As, Fe, and Mn related to depth, the concentration level of As, Fe, and Mn observed per depth interval (up to 52 m), such as 12–15, 15–18, 18–21, 21–25, 25–30 and 30–52 m are presented in the following table (Table 2). Almost 90% (n = 244) of tubewells installed at a depth of 12–25 m, were characterized by a very high concentration of As, Fe, and Mn. With the increase in depth, As concentration indicated high with some minor variation, but for Fe and Mn, the concentrations are slightly decreasing. Overall, the tubewells within this shallow depth range are unsafe for drinking by considering both As and Mn (Table 2).

3.3. Tubewell classification according to platform color

Based on the platform color, the tubewells classified into three different color group namely red, black and non-identified (NI) (Fig. 5). Within 272 tubewells, 237 tubewell platforms (87%) were classified into a particular color group; where 233 (86%) tubewell platforms identified as red, 4 (1%) as black, and rest 35 (13%) as NI due to undeveloped platform color. Undeveloped color may be the reasons for regular cleaning of the platform, biofilm formation or algal growth on the platform. The age of the platform also has an effect on color formation on the platform because newly built platforms are less exposed to develop coloration on the platform regardless of excessive Mn or Fe in tubewells water. Some tubewells platform have complex color (neither red nor black), which may be due to overlapping redox transition of Fe and Mn in the aquifer.

3.4. Assessment as an As screening tool

Amongst the surveyed (n = 272) tubewells, 99% (n = 269) exceeded the WHO guideline value of As (10 μg/L), and 98% (n = 267) exceeded BDWS (50 μg/L).

Considering the platform color, among 233 red colored platform tubewells, 99% (n = 230) exceeded the WHO guideline value of 10 μg/L, and 98% (n = 229) tubewells exceeded BDWS (50 μg/L). Tubewells with black colored platform (n = 4) were also found to contain As at

Fig. 5. Typical colors developed on the platforms of the tubewells a) Red; b) non identified (NI); and c) Black. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

levels exceeding the BDWS value of 50 µg/L. However, the tubewells, with platforms without any identifiable color (NI color group) NI color were 97% (n = 33), and these also exceeded BDWS of 50 µg/L. Considering the WHO guideline value of 10 µg/L, all the tubewells exceeded this level of concentration which assigned as NI (n = 35). Alternatively, if it was considered by As safe tubewells, without considering platform color, it was shown that only 1% (n = 5) within the cohort of 272 tubewells were safe considering BDWS (50 µg/L) and only three tubewells were safe considering WHO guideline value (10 µg/L). When categorized in accordance to the platform color, it was found that among all red colored platform tubewells, only three and four were safe (n = 233) when comparing with the WHO drinking water guideline and BDWS respectively. Among all NI colored tubewell platforms (n = 35), only one was found arsenic safe according to BDWS, but none of the black colored platform tubewells were safe for both WHO and BDWS. Thus, it was clear that NI color tubewells can be consider as As enriched and thereby unsafe for drinking purposes.

3.5. Usefulness as As screening tool

The effectiveness of platform color as a screening tool for predicting the presence of As in tubewells depends on the high probability of true-positive and negative values and correspondingly on the low probability of false-positive and negative values relating to specific drinking water standards (WHO and BDWS). Fig. 6 shows the relationship of the relevant true-positive and negative, false-positive and negative values for WHO and BDWS values. Table 3 summarizes the sensitivity, specificity, efficiency and positive and negative predictive values which also used as the indicators of effectiveness for screening capacity.

At WHO guideline value for As (10 µg/L), the positive predictive value (PPV) of red colored platform tubewells was 98.7%, while negative predictive value (NPV) was zero. The corresponding efficiency, specificity, and sensitivity of the tool were 97%, 0% and 98.3% accordingly. Wherein, specificity and sencitivity means the test correctly identified those without and with As rich in red colored platform tubewells. This result showed that platform color could use as an initial As screening tool in drinking water tubewells that installed in shallow aquifers (< 70 m). According to the BDWS (50 µg/L), the PPV was 95.4%, and NPV was zero due to the deficiency of of black colored platform tubewells. The corresponding efficiency, specificity, and sensitivity of the tool were 96.6%, 0% (no black colored tubewells with < 50 µg/L) and 98.3%. The result also specified at BDWS that, the red color platform could use as As screening tool to identify As unsafe tubewells, but black colored platform tubewells cannot be used as a screening tool to identify As safe tubewells. It is also worth mentioning that there was a low coverage of arsenic tubewells < 50ug/L, resulting in a low number of non-discoloured tubewells. Therefore it is recommended to further investigate this screening tool in areas with higher well-to-well variability of As concentrations.

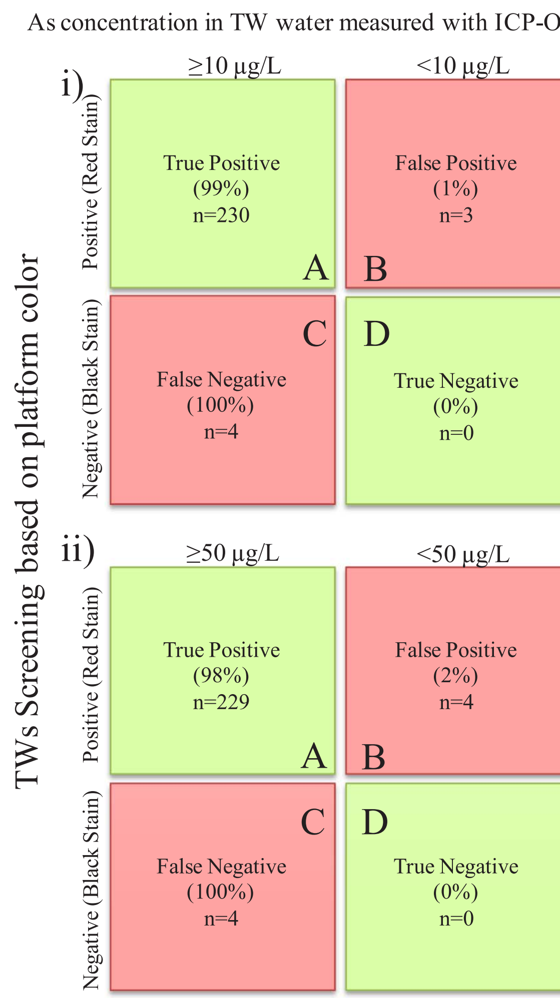

Fig. 6. A generic approach for validation of platform color as As screening tools in shallow depth tubewells.

3.6. Assessment and usefulness as Mn screening tool

The Mn distribution over the surveyed tubewells (n = 272) without considering platform color, showed that almost all (n = 271) exceeded 100 µg/L of Mn. According to the platform color distribution, within 233 red colored platform tubewells, 99.6%, (n = 232) exceeded Bangladesh standard (100 µg/L). This result displayed that red-colored platform tubewells cannot be used as a screening tool to identify Mn safe tubewells at BDWS of 100 mg/L and this result was distinctly opposite as shown by Biswas et al. (2012a). On the other hand, all the tubewells with black (n = 4) and NI (n = 35) colored platform

Table 3
Assessment of the effectiveness of tubewell platform color as a screening tool for As.

Indices for Validation of Platform Color Tool (%)	Basis for Calculation	WHO guideline (10 μg/L) 95% Confidence interval			Bangladesh Standard (50 μg/L) 95% Confidence interval		
		Estimated value	Lower limit	Upper limit	Estimated value	Lower limit	Upper limit
Sensitivity	A/(A + C)	98.3	95.4	99.4	98.3	95.4	99.5
Specificity	D/(B + D)	0	0	69.0	0	0	60.4
Efficiency	(A + D)/(A + B + C + D)	97	–	–	96.6	–	–
Positive Predictive Value (PPV)	A/(AB)	98.7	96.0	99.7	98.3	95.4	99.4
Negetive Predictive Value (NPV)	D/(C + D)	0	0	60.4	0	0	60.4

tubewells exceeded 100 μg/L (BDWS). These results reveal that the co-occurrence of high Fe concentrations in the groundwater mask potential black discoloration by Mn oxides, due to the stronger staining of reddish Fe oxides. It should also be noted that the number of identified black colored platform wells (4 out of 272) is too limited to evaluate the concept that black colored platform tubewells produce As-safe water.

3.7. Predictive value and prevalence of As and Mn screening tool

The relation between prevalence and predictive values also indicate the effectiveness of platform color as screening capacity of As and Mn in handpump tubewells to extract drinking water from shallow groundwater aquifer. Since the black colored tubewells were hardly encountered in this study area (only 4), the prevalence and predictive values could not be calculated for Mn screening. However, this calculation was conducted for red colored platform tubewells to evaluate the screening capacity for As. The Bayesian model was used at a different cutoff level to evaluate the effect of prevalence and predictive values results on the tool. The results shows that the PPV varies linearly with prevalence for both drinking water standard as WHO (10 μg/L) and BDWS (50 μg/L) due to very few black colored platform tubewells (n = 4) compared to red colored (n = 233). This result also specified that highly As contaminated shallow depth tubewells should have a high level of Fe which produces red coloration on the tubewell platform. Thus the performance of the color tool to identify a tubewell as As-unsafe increases if the concentration of Fe in that tubewell raise up and vice versa.

4. Applications

From this study it can be concluded that tubewell platform color can be used as a rapid screening tool for As (red color) occurrence in reduced aquifers. This study did not confirm the potential for Mn screening, as red discoloration by Fe oxides was found to mask the black discoloration of Mn oxides.

So, it is clear that red color platform can be introduced at the policy level to tackle the problem associated with As safe drinking water supply as well as a primary guide to screen As enriched tubewells. This indicator may save time and cost of testing tubewells significantly. The great advantage of platform color tool is its simplicity in operation. The villagers can use to identify the tubewells, whether it is As safe or unsafe who have not access to conventional test kits and which also leads to reduces As exposure.

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