A REVIEW OF ARSENIC AND ITS IMPACTS IN THE GANGES-BRAHMAPUTRA-MEGHNA DELTA, BANGLADESH

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Introduction to ESPA Deltas

Environmental change and people’s livelihood is complex in deltaic environments. There is a lack of understanding of the relative importance of the above factors. The ESPA-funded “Assessing Health, Livelihoods, Ecosystem Services and Poverty Alleviation In Populous Deltas” project (2012-16, http://www.espadelta.net/) aims to address this gap in a policy relevant way. The project was founded on the recognition of the interaction of the biophysical, governmental and socio-environmental factors unfolding on the delta and has established an integrative research process based upon these three main themes. The project is providing policy makers with the knowledge and tools to evaluate the effects of policy decisions on people’s livelihoods in the tidal influenced delta plain. It is being conducted by a multidisciplinary and multi-national team (24 institutes from UK, Bangladesh, India and China) of policy analysts, social and natural scientists and engineers using a participatory, holistic approach to formally evaluating ecosystem services and poverty in the context of the wide range of changes that are occurring. The approach is being developed in the coastal Bangladesh study area (Figure 2) but is designed to be generic and transferable to other deltaic settings. The methodology is built upon a combined system-based conceptualisation of the human-environmental interactions and stakeholder engagement. The four major building blocks of the project are: (1) policy analysis, (2) understanding of social interactions, (3) understanding of the status and changes of the biophysical environment, and (4) integrative modelling of the system using scenarios.

The ESPA Deltas methodology is built on substantial stakeholder engagement and iterative learning throughout the project. There is participatory involvement of stakeholders (from government to civil societies) in all stages of the research starting from the identification of research questions to developing scenarios and exploring these within model frameworks. This ensures trust, interest and willingness to participate. This integrative tool will be used as an iterative learning instrument to explore a range of climate, social and governance scenarios in close collaboration with decision makers. The project will identify perceived critical threats and inform policy makers of the potential benefits of policy changes to promote sustainability, to reduce poverty and to embrace integrated management.

What is an ESPA Deltas Working Paper?

These working papers represent preliminary outputs of the project which will be developed for peer reviewed publication. The intention of this document is to disseminate these new results in a timely manner and promote debate and discussion and raise awareness of these key issues. For further information see www.espadeltas.net or email Jon Lawn (j.lawn@soton.ac.uk)

Citation of this paper.

This should be cited as:

Abstract

Arsenic in drinking water is the single most important environmental issue facing Bangladesh with between 35 and 77 million of its 125 million inhabitants considered to be at risk from drinking As-contaminated water. This dominates the list of stress factors affecting health, livelihoods and the ecosystem of the Delta region. There is a vast literature on the subject so this review provides a filter of the more important information available on the topic. Within the context of the ESPA project this review focuses on the geological and geochemical controls of arsenic in groundwater, its occurrence and distribution, arsenic in the local environment relating to anthropogenic factors, identifying occurrences of safe drinking water (especially ground water), as well as arsenic mitigation, socio-economic considerations and management. The arsenic problem arises from the move in the 1980s and 1990s by international agencies to construct tube wells as a source of water free of pathogens, groundwater usually considered a safe source of water. Since arsenic was not measured during routine chemical analysis and also is difficult to measure at low concentrations it was not until the late1990s that the widespread natural anomaly of high arsenic was discovered and confirmed. The problem was exacerbated by the fact that the medical evidence of arsenicosis only appears slowly. The problem arises in delta regions because of the young age of the sediments deposited by the GBM river system. The sediments contain minerals such as biotite which undergo slow “diagenetic” reactions as the sediments become compacted, and which, under the reducing conditions of the groundwater, release in the form of toxic As^{3+}. The problem is restricted to sediments of a certain age and groundwater of a certain depth (mainly 30-150m), coinciding with the common well depth. The problem is most serious in a belt across southern Bangladesh, but within 50m of the coast the problem is only minor; salinity here is the main issue for drinking water. The Government of Bangladesh adopted a National Arsenic Policy and Mitigation Action Plan in 2004 for providing arsenic safe water to all the exposed population and to provide medicare for those who have visible symptoms of arsenicosis. There is now a national monitoring strategy. Various mitigation strategies have been tested, but generally the numerous small scale technological remedies have proved unworkable at village level. The current policy favours use of deep groundwater (below 150m) as well as rainwater harvesting.

INTRODUCTION

Arsenic contamination in drinking water remains the single most important environmental issue facing Bangladesh and the Delta region and even at the global scale, probably the most serious in terms of the numbers of people affected (upwards of 30M). It has been cited variously as a disaster (Ahmed et al. 2005) and as mass poisoning (Nickson et al. 1998; Hassan et al. 2005). This review focuses on the arsenic issue within Bangladesh and places the problem within a global context, especially for areas with similar geology (low-lying deltaic sediments of Quaternary age). It also recognises that arsenic can be a natural baseline problem in several other types of aquifer and is a problem exacerbated by human activity, especially mining, although this aspect is not dealt with in the review.

The ESPA DELTAs Project entitled ‘Assessing health, livelihoods and ecosystems, poverty alleviation in populous deltas’ aims to provide policy makers with the knowledge and tools to enable them to evaluate the effects of policy decisions on people's livelihoods. This is being undertaken by a multidisciplinary and multi-national team of policy analysts, social and natural scientists and engineers. Collectively they will use a participatory approach to create a holistic approach to formally evaluating ecosystem services and poverty in the context of the wide range of changes that are occurring. These changes include subsidence and sea...
level rise, land degradation and population pressure in delta regions. The approach is being
developed, tested and applied in coastal Bangladesh and also tested conceptually in two
other populous deltas in India. Arsenic is of key concern to people in Bangladesh and this
review aims to provide a baseline set of knowledge from which to review likely future
differences in climate, land use, sea level and population in the deltas region of Bangladesh.

The Ecosystem Services (ES) of river deltas often support high population densities,
estimated at over 500 million people globally, with particular concentrations in South, South-
East and East Asia and Africa. Further, a large proportion of delta populations experience
extremes of poverty and are highly vulnerable to the environmental and ecological stress
and degradation that is occurring.

Rural livelihoods are inextricably linked with the natural ecosystems and low income farmers
are highly vulnerable to changes in ecosystem services. Their health, wellbeing and financial
security are under threat from many directions such as unreliable supplies of clean water,
increasing salinisation of soils and arsenic-contaminated groundwater, while in the longer
term they are threatened by subsidence and sea-level rise. This study will contribute to the
understanding of this present vulnerability and help the people who live there to make more
informed choices about how best to reduce this vulnerability.

Within the terms of reference of the ESPA Deltas Project this review of arsenic and related
elements focuses on the occurrence, the security of water quality, arsenic in the local
environment, identifying occurrences of safe drinking water (especially groundwater) as well
as arsenic mitigation in affected areas. There is already a very extensive literature on the
subject of arsenic contamination, probably the most widely studied of all pollution issues,
and the purpose of this paper is to act as a filter of the extensive material available which is
of relevance to the current research area.

Bangladesh and West Bengal have been shaped by natural processes over recent
geological time and also during the historical period, with agrarian development and
population growth; with the intensification of development it has moved from a natural to
human dominated ecosystem (Messerli et al. 2000). The arsenic problem is first of all a
natural phenomenon related to geology. It has become exacerbated by rapid development
through abstraction of groundwater as a resource upon which millions of people have
become dependent.

Arsenic may therefore be added to the list of stress factors affecting health, livelihoods and
the ecosystem of the delta region. Groundwater abstracted for domestic use has both
immediate and medium-term health impacts in affected areas, but the widespread
introduction of high-arsenic water into the environment through irrigation can have
secondary effects on food and fodder, the ecosystem and also on the economy (Acharyya et
al., 2000).

As regards the specific concerns of the ESPA Project, it is noted that the immediate coastal
region of Bangladesh with very young sediments sometimes only a few hundred years old, is
relatively unaffected and that the persistent problem of high arsenic commences some 50km
inland where potable water supplies are derived from established older sediments tapped by
tube wells in excess of 30m depth. In the coastal regions there is greater dependency on
shallow wells in young sediments, well flushed by rain water where an arsenic problem has not fully developed. In these areas the main water quality problem is salinity caused by flooding and also saline intrusion caused by excessive pumping.

GLOBAL OCCURRENCE OF GROUNDWATER ARSENIC - THE SPECIFIC PROBLEM OF DELTA REGIONS

Investigations worldwide (Fig.1) have now revealed the scale of the arsenic health problem occurring in groundwaters (Smedley and Kinniburgh. 2013). The most common locations with extensive occurrences of high arsenic are alluvial sediments and deltaic areas as well as inland deltas and sedimentary basins in inland areas (mainly in semi-arid areas). The former occur largely in reducing sediments and the latter under oxidising groundwater conditions.

Fig. 1. Distribution of documented world problems with As in groundwater in major aquifers as well as water and environmental problems related to mining and geothermal sources. By far the most serious problems in terms of those affected occur in Quaternary delta regions in south east Asia.(after Smedley and Kinniburgh 2005).

Geologically young (Quaternary) aquifers are particularly prone to developing and preserving high-arsenic groundwater. Alluvial and delta plains with recognised groundwater arsenic problems include the Bengal Basin (Bangladesh, India), Mekong Valley (Cambodia, Laos, Vietnam), Red River Delta (Vietnam and the Yellow River Plain (China). These major deltas derive sediments from tectonically active areas of the Himalayan region where geologically-rapid uplift leads readily to physical and chemical erosion of fresh bedrock. The bedrock often consists of granitic and other igneous rocks containing fresh rock forming minerals such as biotite and other mafic (iron-rich) minerals and feldspar. Such minerals formed at high temperatures and are transported rapidly by the GBM and other rivers to the delta regions. Deltas form rapidly and the newly derived sediments become buried rapidly. In the
Dhaka region for example, using radiocarbon dating evidence from wood, some 60m of sediments have accumulated in 60,000 yr. Under the newly-created, low temperature sedimentary environments the transported minerals are very reactive and undergo “freshwater diagenesis” during which new more stable (secondary) minerals including clays and oxides will form and in the process release impurities not required for their stabilisation. These include various trace elements including arsenic which would have been included in minerals at high temperatures, in sulphide minerals (eg pyrite, FeS$_2$), or within mafic minerals such as biotite. The specific conditions relating to the GBM are further described below.

THE NATURE AND HISTORY OF THE ARSENIC PROBLEM

Arsenic has been used therapeutically and also as a poison and its toxicity has been recognised for centuries (Webb 1966; Whorton 2011). Geochemists have understood the geochemical cycle of arsenic and its potential toxicity in drinking water for half a century (Ferguson and Gavis 1972). However, the widespread extent of its environmental distribution and occurrence is a recent phenomenon, a product of rapid global development in the late 20th century. One of the first cases recognising arsenic toxicity in water came from studies of mining areas in Taiwan (Tseng et al. 1968).

The first recognitions of an arsenic problem in the GMB region came in 1983 from West Bengal (Garai et al.1984) and in 1993 from Bangladesh (BGS and DPHE 2001).The earliest cases of arsenic-induced skin lesions in the sub-continent were identified in Kolkata, India (Smith et al., 2000); the patients seen were from West Bengal but by 1987 several patients had already been identified who came from neighbouring Bangladesh. The contamination of groundwater by arsenic in Bangladesh was first confirmed by the Department of Public Health Engineering (DPHE) in Chapai Nawabganj in late 1993 following reports of extensive contamination in the adjoining area of West Bengal.

One of the main reasons for the slow recognition of the scale of the problem and its environmental significance has been the issue of its chemical analysis at the μg/l level, which may still present problems (Jain and Ali, 2000). Natural baseline concentrations in groundwater are low in many geological environments due its low geochemical abundance. In many major well-developed aquifers which have been used for water supply and monitored for decades, arsenic was rarely seen as a problem. In a study of 23 European aquifers in a range of lithologies (Edmunds and Shand, 2008), the overall median As concentration was only 0.5μg l$^{-1}$; only in three minor aquifers did the median reach a value of 6 μg l$^{-1}$. The global scale of the problem became an issue only when improved analytical procedures were applied to water quality investigations especially in small scale aquifers in Quaternary sediments.

Until the mid-20th century rural populations in Bangladesh relied mainly on often-contaminated surface water and shallow wells for water supply. From the 1960s hand-pumped tube wells accessing purer, pathogen-free water were widely introduced especially by development agencies and this practice accelerated significantly from the 1980s onwards as the technology became very cheap and easily available all over the rural areas. This led to a vast increase in the access of rural populations to what was considered a superior and safe source of drinking water from the readily available groundwater resources contained in
the shallow alluvial aquifers (Smedley and Kinniburgh, 2002). Of the existing shallow water wells in the country only 10% are installed by government agencies like the Department of Public Health Engineering (DPHE) and various NGOs, remaining 90% are privately owned. The number of wells is increasing continuously with an annual growth rate of about 10%.

ARSENIC AND HEALTH ISSUES

It is only in the past two decades that the real significance and extent of arsenic contamination has become an environmental health issue, now a global issue, due specifically to the situation in Bangladesh, where between 35 and 77 million of its 125 million inhabitants are considered to be at risk from drinking As-contaminated water (Smith et al. 2000). In 2003, studies by the Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP) (see) estimated the total exposed population at nearer 20M (Hussain et al. 2005). Much has been learned of the health effects of long term human exposure to arsenic through the evidence collected in Bangladesh (Quamruzzaman et al 1999; Smith et al. 2000).

The millions of tube wells drilled mostly by the private sector and by national and international agencies to improve water quality in the 1980s and 1990s were tested mainly for pathogens and gastro-intestinal diseases; by 1997, UNICEF (1998) was able to claim that 97% of the population had been provided with “safe” drinking water. Subsequently as noted above, arsenic was not routinely tested until the late 1990s due to difficulties in low level and routine chemical analysis.

Chronic arsenic poisoning, arsenicosis, can increase the risk of several health hazards including skin lesions, cancers, restrictive pulmonary disease, peripheral vascular disease, gangrene, hypertension, non-cirrhotic portal fibrosis, ischemic heart disease, and diabetes mellitus. Skin changes due to arsenic poisoning include a raindrop pattern of pigmentation and depigmentation that is particularly pronounced on the extremities and the trunk. Although less common, other patterns include diffuse hyperpigmentation (melanosis) and localized or patchy pigmentation, particularly on skin folds. Hyperkeratosis (hardened skin) appears predominantly on the palms and the planter surface of the feet. Skin cancer resulting from chronic arsenicosis is quite distinctive. Multiple lesions are common and involve covered areas of the body, contrary to non-arsenical skin cancers which usually appear as a single lesion and which occur in exposed parts of the body.

The health effects of ingesting arsenic-contaminated drinking-water appear slowly and the problem of estimating the affected population has to take into account the past and continuing exposure to arsenic. Since large numbers of tube-wells were installed in Bangladesh over the previous 20 years and, assuming the population continues to drink arsenic-contaminated water, then a major increase in the number of cases of diseases caused by arsenic, over and above those clinically-confirmed may be predicted (Smith et al 2000). Recent investigations also predicted higher rate of cancer death in the coming years.

The main manifestations of the disease are skin lesions or keratosis, which appear typically around 10 years following first exposure, although may appear in children younger than 10 years old. The main manifestations are black lesions (discoloured skin) on the feet and hands in particular. This is a peripheral vascular disorder with similarities to gangrene. The
affected skin gradually thickens, cracks, and ulcerates. The skin discolouration led to the term “black-foot disease” from the localised disease occurrence in groundwaters of Taiwan from where it was first well documented (Lewis et al. 2007).

The impact of arsenic on children’s nutritional status and intellectual development has been studied by Minamoto et al, 2005. Small numbers of skin cancers had started to appear in Bangladesh by the end of the millennium but no long term studies of the disease were available at that time (Smith et al. 2000). Previously, a study of a large population in Taiwan (Tseng et al. 1968) found a clear dose-response relationship between arsenic concentrations in drinking water and the prevalence of skin cancer.

Table 1. Key statistics on arsenic poisoning in Bangladesh (after UNICEF 2010)

<table>
<thead>
<tr>
<th>Description</th>
<th>Number</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household drinking water tested for arsenic in 2009</td>
<td>13 423</td>
<td>100</td>
</tr>
<tr>
<td>Household drinking water exceeding Bangladesh standard in 2009</td>
<td>12.6</td>
<td></td>
</tr>
<tr>
<td>Household drinking water exceeding WHO guideline in 2009</td>
<td>23.1</td>
<td></td>
</tr>
<tr>
<td><strong>Estimated number of tube wells in Bangladesh in 2002</strong></td>
<td><strong>8 600 000</strong></td>
<td>100</td>
</tr>
<tr>
<td>Tube wells tested for arsenic in 2002 and 2003</td>
<td>4 750 000</td>
<td>55</td>
</tr>
<tr>
<td>Tube wells marked green (safe)</td>
<td>3 300 000</td>
<td>39</td>
</tr>
<tr>
<td>Tube wells marked red (unsafe)</td>
<td>1 400 000</td>
<td>16</td>
</tr>
<tr>
<td><strong>Estimated total villages in country</strong></td>
<td><strong>87 319</strong></td>
<td>100</td>
</tr>
<tr>
<td>Villages screened for arsenic</td>
<td>54 041</td>
<td>62</td>
</tr>
<tr>
<td>Villages where &lt;40% of the wells are contaminated</td>
<td>70 610</td>
<td>81</td>
</tr>
<tr>
<td>Villages where 40-80% of the wells are contaminated</td>
<td>8 331</td>
<td>10</td>
</tr>
<tr>
<td>Villages where 80-99% of the wells are contaminated</td>
<td>6 062</td>
<td>7</td>
</tr>
<tr>
<td>Villages where all wells are contaminated</td>
<td>2 316</td>
<td>3</td>
</tr>
<tr>
<td><strong>Active public safe water options in arsenic affected areas</strong></td>
<td><strong>705 094</strong></td>
<td>100</td>
</tr>
<tr>
<td>Shallow tube well with hand pump (safe)</td>
<td>417 960</td>
<td>59.3</td>
</tr>
<tr>
<td>Deep tube well with hand pump</td>
<td>154 264</td>
<td>21.9</td>
</tr>
<tr>
<td>Shallow well with Tara pump (safe)</td>
<td>82 880</td>
<td>11.8</td>
</tr>
<tr>
<td>Deep tube well with Tara pump</td>
<td>10 350</td>
<td>1.5</td>
</tr>
<tr>
<td>Dug well</td>
<td>9 163</td>
<td>1.3</td>
</tr>
</tbody>
</table>
In this latter study the average concentration of arsenic in water was about 500 mg/l and by age 60 more than 1 in 10 had developed skin cancer. The lifetime risk of developing skin cancer, from a daily intake of 1 mg kg body weight of arsenic in water, ranges from 1 per 1000 to 2 per 1000. Using geostatistical studies, Yu et al (2003) predict that long-term exposure to present arsenic concentrations will result in approximately 125,000 cases of skin cancer and 3000 fatalities per year from internal cancers. It is also reasonable to expect marked increases in the incidence of the other health effects (Smith et al 2000).

CAUSES OF THE PROBLEM – THE HYDROGEOCHEMISTRY OF ARSENIC

Despite the numerous papers on the subject, there is still not complete agreement on the causes of the high As concentrations, which result from a combination and interaction of geological, hydrological and geochemical controls. It is important to stress that arsenic is not a particularly rare element (52nd in terms of geochemical abundance) and is quite widely distributed in the earth’s crust, especially associated with iron. Nevertheless as discussed above, it is the nature of the sediments with above average concentrations of micaceous minerals, amounts of colloidal-sized iron oxides and their geologically young age that provide the setting for a reactive environment.

The aqueous geochemistry of arsenic is among the most complex of any of the metals and other toxic elements, being controlled by a very wide range of geological, physicochemical as well as biogeochemical processes. The environmental and especially the aqueous geochemical behaviour of arsenic is now well documented as a result of the intense interest in its health significance and occurrence in groundwater (Cherry et al.1979; Smedley and Kinniburgh 2002; 2013, Welch and Stollenwerk, 2003). A summary of the main features of arsenic hydrogeochemistry are summarised here drawing heavily on the comprehensive review by Smedley and Kinniburgh (2002). It should be noted that arsenic mobility is unlikely to be controlled by a single geochemical factor and therefore routine prediction of its occurrence and behaviour is exceedingly difficult.

**Redox properties and speciation of arsenic**

The development of a strongly reducing environment is probably the single most important factor leading to the mobilising the arsenic. Arsenic is one of a number of metals (As, Se, Mo, V, Cr, U) forming oxyanions (eg AsO₃³⁻) and which are mobile at the pH values typically found in low temperature groundwaters (pH 6.5–8.5). Arsenic can occur in several oxidation states but in natural waters is mostly found in inorganic form as oxyanions of trivalent arsenite [As(III)] or pentavalent arsenate [As(V)]. Organic As forms may be also be produced by biological activity especially in surface waters. It can also form ligands with other anions especially carbonate and reduced sulphur (Smedley and Kinniburgh 2002).
The ratio of As (III) to As (V) has been used for some time as a redox indicator (Cherry et al. 1979; Smedley and Edmunds, 2002). This ratio depends on the abundance of the redox-active solids, including organic carbon and iron/manganese oxide, the flux of potential oxidants (oxygen, nitrate and sulphate) and on microbial activity (Smedley and Kinniburgh 2002). As (III) is the dominant species under reducing conditions such as the deltaic groundwater environment and is oxidised rapidly on mixing with surface conditions. As(V) is predominant under aerobic conditions typical of semi-arid environments.

Arsenic concentrations and mobility are influenced by changes in redox conditions measured by redox potential (Eh) and pH. Speciation in aqueous solution will also vary. Under oxidising conditions, $\text{H}_2\text{AsO}_4^-$ is dominant at low pH (less than about pH 6.9), whilst at higher pH, $\text{HAsO}_4^{2-}$ becomes dominant. Under reducing conditions at pH less than about pH 9.2, the uncharged arsenite species $\text{H}_3\text{AsO}_3^0$ will predominate (Brookins, 1988). In the presence of extremely high concentrations of reduced sulphur, dissolved As-sulphide species can also be significant.

**Role of sorption**

At near-neutral pH arsenic mobility is severely limited by adsorption reactions, precipitation, or co-precipitation with oxide or hydroxide minerals (eg FeOOH) and/or with clay minerals or organic matter. Hydrous ferric oxide (HFO), a high surface area form of iron oxide, often forms when Fe is precipitated rapidly (Smedley and Kinniburgh 2002; 2013). This oxide is able to adsorb As on its surface and the adsorbed As (HFO-As) can become the dominant form of As. HFO is subject to both acid dissolution at low pH and reductive dissolution at low pe (redox potential or Eh) which results in the release of As to solution. Adsorption of arsenate to hydrous Fe oxides is particularly strong and sorbed loadings can be appreciable even at very low As concentrations in solution (Manning and Goldberg, 1996), most oxyanions, including arsenic, tend to become less strongly sorbed and more mobile as the pH increases (Dzombak and Morel, 1990). However as the sediments undergo diagenesis, the HFO tends to transform slowly to more stable forms of iron oxide with lower specific surface area, such as goethite and this tends to lower the sorption at higher pH. As pointed out by Smedley and Kinniburgh (2002) adsorption reactions are responsible for the relatively low (and non-toxic) concentrations of As found in most natural waters.

**Role of organic carbon**

It is widely known that deltaic sediments contain significant quantities of organic debris as remnant vegetation and smaller particles including humic and colloidal substances, some of which may be reactive. Dissolved organic matter is generally the control on removal of oxygen and with reduced iron, maintaining reducing conditions. There had however been little discussion until recently of the role of TOC in the control of arsenic. It has been shown McArthur et al. (2004) showed that a correlation may exist between peat lenses and arsenic concentrations, but peat horizons are not widespread in the delta region. Debate was also triggered from evidence of the shallow groundwater environment (Harvey et al. 2002; Polizzotto et al. 2005) that pollution sources, drawn down by pumping abstraction were the source of reactive organic matter causing arsenic mobilisation. This hypothesis was reviewed and has been strongly refuted by Meharg et al. (2006) who showed from core material from deep profiles from widely separated sites, that arsenic and organic carbon
were co-deposited and provide the reducing conditions to dissolve iron(III) oxides and release arsenite into the porewater. Klump et al. (2006; among others) also question the drawdown hypothesis showing that the irrigation water does not coincide with the depths where the arsenic peaks occur.

ARSENIC IN SOILS

The background level of As in non-irrigated soils in Bangladesh is around 5-10 mg/kg but, in irrigated soils concentrations are regularly several tens of mg/kg (Meharg and Rahman, 2003). Most of the arsenic in soils of the GBM (West Bengal Delta Plain) is derived from the Fe-bearing silicates of the delta sediments (biotite and chlorite) and concentrated especially in the newly formed oxyhydroxides (Norra et al. 2005). Although much lower in amount, the oxyhydroxides hold almost as much arsenic as the silicate fractions (within which the As is much less mobile). During the irrigation cycles more arsenic is then taken up by the oxyhydroxide fraction of the soils and cycles during redox variations. Very high arsenic (169-178 mg/kg) is found in Fe-rich mineral plaque coating the roots of rice but in the grains of rice and wheat were found to be low in As (0.3-0.7 mg/kg).

THE OCCURRENCE OF ARSENIC IN SURFACE WATER SAND ECOSYSTEM OF THE GBM REGION

Global average baseline concentrations of As in river waters lie in the region 0.1–0.8 mg l⁻¹ but can range up to ca. 2 mg l⁻¹ (Smedley and Kinniburgh, 2002). They vary according to the composition of the surface recharge, the contribution from baseflow and the bedrock lithology. There are relatively few measurements of arsenic in the GBM system in India and Bangladesh. Dissolved arsenic concentrations in the Ganges, Brahmaputra Rivers and their confluence show important seasonal variations and maximum arsenic concentrations are observed during the monsoon season (July–October). Here the arsenic is concentrated in suspended particulate matter derived from flooding (Figure 2) and from run-off from agricultural lands, irrigated with arsenic rich groundwaters (Islam et al. 2012). The high summer temperature (maximum 30°C) enhances the biological activity through microbial reduction of As (V) to less particle-active As (III) species and contributes to the seasonal variations in arsenic concentrations in river waters.

Figure 2. Water discharges (m³ s⁻¹), SPM concentrations (mg l⁻¹), dissolved arsenic concentrations (ng l⁻¹ and particulate As concentrations (mg kg⁻¹) at the Ganges-Brahmaputra confluence Jan-Dec 2008. (after Islam et al. 2012).
In sea water, arsenic occurs as arsenate (As III) with average As concentrations in open seawater usually showing little variation and typically around 1.5 μg l\(^{-1}\) (Smedley and Kinniburgh 2002). Concentrations in estuarine water are more variable as a result of varying river inputs and salinity or redox gradients but are also usually low, at typically less than 4 mg l\(^{-1}\) under natural conditions. In areas with industrial pollution, concentrations may be higher. However there is a tendency for the concentration of arsenic and other metals to be removed and deposited on entering surface waters. The flocculation of Fe oxides at the freshwater-saline interface is an important consequence of increases in pH and salinity. This can lead to major decreases in the As flux to the oceans (Cullen and Reimer, 1989).

Delta areas are subject to significant changes in surface water conditions with periods of low flow plus inundations from river flooding, widespread wetlands and marine inundation. Strong vertical seasonal gradients are likely to exist allowing natural recycling between the river and the shallow groundwater system. The likely fluxes of water and associated arsenic concentrations for the shallow (50m) environment under minimally undisturbed conditions are shown (Fig 3) for a modelled section of the Mekong (Polizzotto et al, 2008). These studies draw general attention to the risks involved for example in excessive irrigation pumping, sediment excavation, levee construction and upstream dam installations.

Bangladesh relies heavily on groundwater for the irrigation dry-season rice (boro) which is exposed to high arsenic with some 1360 tons of arsenic being added annually to the soils. More than 75% of the current irrigation is provided by groundwater sources, mainly pumped from the Holocene alluvial and the Pleistocene Dupi Tila aquifers. Under natural conditions wetlands can act as a source of groundwater recharge, recycling water back to the river on a centennial scale. However, the heavily populated delta areas at the present day are strongly affected by irrigation pumping and this increases the risk of arsenic build up (Polizzotto et al. 2008).

Figure 3 Groundwater flow paths and arsenic concentrations for a minimally disturbed section of the Mekong river (Polizzotto et al. 2008)

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The impact of seasonal monsoon flooding on these soils was studied in one area of rice paddies in central Bangladesh (Munshiganj) by Roberts et al. (2010). It was estimated that between 13-62% of the arsenic is removed by monsoon floodwaters (up to 4.6m) and that non-flooded soils are at risk of arsenic accumulation.

**ARSENIC IN THE FOOD CHAIN**

A good number of studies have demonstrated that significant amounts of As can be ingested through food, mainly rice. However, the uptake depends on a number of factors including concentrations in irrigation water. Total intake also depends on cultural issues such as cooking practices and amount of rice taken. Rice irrigated with groundwater is generally higher in arsenic than non-groundwater sources and may be a significant dietary intake (Duxbury et al. 2003). Human exposure to arsenic through rice was calculated to be equivalent to half of that from drinking water in 14% of the rice samples (using daily intake levels of 400 g and 4L for rice and water, respectively, an arsenic concentration in water of 50 mg/kg and assuming equal bio-availability of arsenic in water and rice). Duxbury and Pannaulah (2007) have demonstrated a halving of rice yields at soil As concentrations of around 50 mg/kg. Furthermore, significant uptake of arsenic by rice may occur in irrigated regions, as well as non-irrigated crops (Williams et al. 2006). Processing of rice (parboiling and milling) does not appear to substantially reduce human exposure to arsenic through rice consumption.

Studies by Meharg and Rahman (2003) demonstrate that there is clear variation in As speciation and concentration in rice grown in different countries. When this variation is related to dietary exposure it is evident that countries whose rice is elevated in inorganic As and who are reliant on rice as a dietary staple are most at risk.

**ARSENIC IN GROUNDWATER OF THE GBM REGION**

Although arsenic may form over 200 minerals associated principally with ore deposits its geochemical distribution is diffuse and this is related, primarily with its affinity for iron (Smedley and Kinniburgh, 2002). Thus it is commonly found in primary and secondary minerals in the reduced form associated with pyrite and other metal sulphides (Fe,(As)S₂) and in weathered oxidising environments associated with iron oxides. But arsenic, as mentioned above, in the GBM region is also present in other mafic minerals, still associated with iron, such as micas such as biotite and amphiboles such as hornblende transported with more common minerals to form the deltaic sediments – and which then can weather slowly as sediment diagenesis occurs. It is worth remembering that the mass of arsenic contained in the sediments is large yet groundwater concentrations of interest and concern are measured only in microgrammes per litre.

Once arrived in the delta, the various processes mentioned above, lead to the mobilisation and fixation of arsenic in the sediment pore waters and groundwater bodies. The processes take place at the scale of the pore solution with groundwater movement leading more widely to the distribution of the solutes. Thus, it is important to establish and visualise the arsenic
occurrence and distribution at different scales and especially in three dimensions (Fig. 4) as shown by Smedley and Kinniburgh (2013).

Figure 4. Schematic diagram showing the geological environment of the GBM and main geochemical processes leading to arsenic mobility (BGS and DPHE 2001)

Hydrogeological controls

The hydrogeology of Bangladesh has recently been described in some detail by BGS and DPHE (2001), building on other studies notably that of UNDP (1982). The Quaternary system can be considered as comprising three aquifer units (Table 2):

Table 2 Main aquifer units of the Quaternary delta (BGS/DPHE 2001)

<table>
<thead>
<tr>
<th>Aquifer Type</th>
<th>Fluvial areas</th>
<th>Delta areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper shallow aquifer</td>
<td>Grey highstand braided floodplain (U Dhamrai Formation)</td>
<td>Grey highstand floodplain aquifer of dendritic distributary system</td>
</tr>
<tr>
<td>Lower shallow aquifer</td>
<td>Grey coarse grained transgressive tract/lowstand aquifer in incised channels (L Dhamrai Formation)</td>
<td>Grey transgressive tract lowstand aquifer within incised channels</td>
</tr>
<tr>
<td>Deep aquifers</td>
<td>Red-brown DupiTila of the Chandina area, and Barind</td>
<td>Grey sub-150m deep aquifers composed of cyclic,</td>
</tr>
</tbody>
</table>
Groundwater flows southwards through the fluvial sediments of the northern part of the GBM system, mainly through the coarser sands and gravels of the lower shallow aquifer. As the aquifer thickens towards the south the groundwater flow feeds through the stacked main channel deposits, derived from several cycles of glacio-eustatic deposition. Each of these units is a fining-upwards sequence so that both horizontal and vertical permeabilities will vary within the aquifer. Within the coastal zone the shallow and deeper aquifers have been invaded by and mix with sea water and saline formation water of the subsiding delta.

Groundwater movement is strongly influenced by the incision by rivers into the stacked sedimentary sequence and also by the strong seasonal hydraulic gradients, although any fluctuation in water levels is nowadays heavily modified by irrigation pumping. The location of significant former channel deposits through the delta may also afford areas of greater transmissivity. The magnitude of the groundwater flow through the complex sedimentary sequence, flushing out porewaters and removing diagenetic products is a critical consideration in relation to the arsenic anomalies. It is considered that the lowstand sediments of the Brahmaputra valley will have been flushed at least once since their deposition, whilst the high-stand deposits will have only been flushed once (BGS/DPHE 2001).

The variations in arsenic concentrations clearly relate to the turnover of water in the sediments, depending in turn on the age of the sediments, aquifer hydraulic properties and the past and present groundwater flow regimes (BGS/DPHE 2001). From the consideration of the hydrogeology it was concluded that high or low arsenic was likely to be found in specific locations (see Table 3).

**Table 3 Predicted settings of high and/or low arsenic (BGS/DPHE 2001)**

Low arsenic concentrations may be associated with:

i) coarse sands at the base of incised channels in fluvial areas or possibly in stacked channels in delta regions

ii) relatively high hydraulic conductivity, medium porosity;

iii) high present day groundwater gradients and/or historically high gradients due to the influence of the past glacial maximum

iv) relatively rapid flushing, some 2-10ka per pore volume

v) sediments greater than 10ka years old;
High arsenic concentrations may be associated with:

i) areas with low recharge

ii) silts and fine sands within alluvial floodplains and delta areas leading to low groundwater flow rates

iii) areas with low groundwater gradients even at the time of the last glacial maximum

iv) areas where flushing takes 50-200 ka per pore volume even during the LGM

v) areas with low gradients at the present time leading to flushing times of 200ka

vi) regions of especially low flow, eg inside river meanders, in closed basins and in dead zones of aquifers

The hydrogeology predicts and supports the finding that the deeper aquifers should be largely free of arsenic and offer a potential mitigation for the arsenic problem. In this case pumping will induce flow vertically as well as laterally and there is still the possibility for contamination of the deeper groundwater with uncontrolled pumping. Well design, screen placement and pumping regimes need to be carefully considered.

Arsenic occurrence and distribution

A national survey of arsenic in groundwater (BGS and DPHE 2001), using some 3,500 groundwater samples, found that 27% of samples from the Holocene shallow aquifer (<150 m depth) contained arsenic at concentrations exceeding 50 μg L⁻¹, and 46% exceeded 10 μg/l. This affected an estimated 35 million people, with 57% affected by concentrations above 10 μg/l. The aquifer sediments are made highly reducing by the presence of significant amounts of organic carbon deposits in the sediments (Smedley and Kinniburgh 2012). As well as high arsenic under the reducing environment the groundwaters are often enriched in Fe, Mn, HCO₃, NH₄, but concentrations of NO₃ and SO₄ are low; this indicated that denitrification and sulphate reduction were occurring aided by the reducing environment. Methane was also detected in some groundwaters (Ahmed et al.1998).

The occurrence of arsenic in groundwaters in Bangladesh (BGS and DPHE,2001) is shown in Fig 5 where it is seen that arsenic concentrations exceeding drinking water limits (50μg/l*) were concentrated in the south and south-east of the country. A later survey by UNICEF/DPHE of 317 000 tube wells from the south of Bangladesh found that 66% contained arsenic above the threshold concentrations with only 10% with lower than 10 μg/l.

The problem is little less severe in India but it is estimated that about 6.5 million people are drinking water with arsenic concentrations greater than 50μg/l. In India the arsenic also
occurs principally in alluvial aquifers in the states of Bihar, Tripura, Uttar Pradesh, Jharkhand and Assam (Chakraborti et al. 2003, 2004; Mukherjee et al. 2006).

The distribution of arsenic, as described above, is quite strongly correlated with depth, which in turn relates to the age of the sediment and the aquifer properties and flow characteristics. The main depth range of the high arsenic is between 10-80m (BGS and DPHE 2001; McArthur et al. 2004), almost entirely within the shallow aquifer (Fig 6). However there is consistent evidence that, below 150m in the lower aquifer, comprising older alluvial sediments from Holocene alluvium, concentrations of As are much reduced. Concentrations from the deep aquifer in Lakshmipur and Faridpur and Chapai Nawabganj, focal points of the BGS/DPHE survey, consistently gave low-arsenic waters and offer an alternate source of supply. Later surveys in other parts of the country demonstrated that arsenic safety is not determined by depth but by the nature of sediments occurring at a particular depth. A Columbia University study in Araihazar, Narayanganj reported village scale variations of safe depths

* European and US EPA regulations implement the current recommended WHO guideline for As in drinking water (10μg L⁻¹). Bangladesh like several other countries continue to use the pre-1993 WHO standard, partly due to difficulties in testing as well as difficulties in compliance.
Figure 5. Arsenic concentrations in groundwaters in Bangladesh showing high (>50mg/l) concentrations in red associated with the delta of the GBM river system (BGS and DPHE, 2001).

Figure 6. Arsenic concentrations in relation to tube well depth showing the predominance of high arsenic between 10-60m depth and the widespread low arsenic abundance in groundwaters below 150m (BGS and DPHE, 2001).

Dug wells to a few metres depth also often have low arsenic. The UNICEF/DPHE survey found that 11% of the shallow dug wells had arsenic concentrations above 50μg/l. However these wells are prone to microbiological contamination, the main problem that the tube well programmes of the 1980s sought to resolve.

It is widely accepted that the reducing conditions in the aquifer involve reduction of As(V) to As(III) with resultant changes in sorption behaviour. The process of reductive dissolution and reductive adsorption of arsenic are the main processes leading to the increase in dissolved arsenic concentrations (Nickson et al, 1998, Smedley and Kinniburgh, 2013). The mobilisation of arsenic is still not fully understood however and involves a complex sequence of diagenetic reactions as outlined above. These reactions may also involve microbial mediation (Islam et al. 2004), which are favoured by the presence of organic matter in the young sediments and dissolved in the groundwater. The organic matter is preserved under reducing conditions in the rapidly forming sediments and is both reactive and assimilable for microbially-mediated reactions. This is a natural biogeochemical process and any anthropogenic origin of organic matter has been largely rejected (van Geen et al 2003; Klump et al. 2006).

Groundwater radiocarbon age was determined on samples from piezometers the three aquifers at research sites (Special Study Areas or SSA’s) in Chapai Nawabganj, Lakshimipur and Faridpur (BGS and DPHE, 2001). From 10-40m depth the groundwater had values of
83% modern carbon (pmc) indicating modern water no more than several decades, some of these waters also containing tritium. Groundwater from 150m (Faridpur) with 51% pmc gave a model age of 2000yr. Deep groundwater from Lakshmpur had values of 28pmc indicating ages in the range 2000-12000 yrs old. Using modelling studies and environmental tracers (³H, ³He/³H, δ¹⁸O), Klump et al. (2006) have also shown that modern water is found to a depth of 25m and likely to have been influenced hydrodynamically by pumping. However, the major zones of As enrichment lie below the depth of the modern water, supporting the hypothesis of enrichment from natural diagenetic processes.

Thus, it is clear that the hydraulic gradients, transmissivity and extent of flushing of the aquifer have been important in concentrating and then distributing the arsenic rich waters away from the sedimentary zones undergoing active diagenetic processes. Borehole drilling in recent decades has intercepted a layered aquifer and has undoubtedly affected flow patterns with intensive pumping for irrigation. Pumping can influence the water chemistry by removing arsenic from zones of enrichment, but also, depending on the vertical permeabilities, drawing down arsenic-rich water from overlying horizons (say below 20m). Modelling studies have shown the importance of careful abstraction regimes and that it is unlikely the low-arsenic groundwater at depth would be disturbed by hand-pumps. The irrigation from the shallow aquifer (with higher concentrations of arsenic) would also provide an effective hydraulic barrier (Burgess et al. 2010).

National surveys of arsenic

The first national hydrochemical survey for arsenic comprising 3534 samples was conducted (DPHE/BGS) during 1998-99 over most of the country with 7 to 8 water samples taken randomly, mostly from shallow wells each of the upazilas (administrative sub-districts). However, mostly deep wells were sampled in the coastal areas where shallow water is brackish and not suitable for drinking. The survey produced the National Map of As distribution in shallow groundwater (Fig 7) and was subsequently used for designing the Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP); 29% of the sampled shallow wells and 2% of the deep wells exceeded the 50 ppb limit for drinking water.

The percentage of wells exceeding 50 ppb in 462 upazilas of the country combining the results of the BAMWSP national screening and UNICEF/DPHE screening in arsenic non-affected upazilas are shown in Figure 8. This consolidates the wells survey distribution maps of the previous BGS/DPHE studies.

The Government of Bangladesh estimated the number of people exposed to 50 ppb level at 29.3 million as shown in Table 3. Of these, more than 10 million people have been identified in 8511 villages of 1236 unions in 191 upazilas of 51 districts where tubewells have As above 50 ppb as shown in Table 3 (BAMWSP, 2004). About 13 000 suspected arsenicosis patients have been reported from these villages.
Figure 7: Percentages of wells exceeding 50 ppb in various Upazilas (combined data of BAMWSP national screening in As affected upazilas and DPHE/UNICEF screening in non-affected upazilas). Note the relative rarity of the problem in coastal regions.
Figure 8 Summary of DPHE/BGS National Hydrochemical Survey Arsenic Analysis of 3534 wells

Table 3: People exposed to 50 ppb or more arsenic in drinking water (GOB, 2002)

<table>
<thead>
<tr>
<th>Modes of water supply</th>
<th>Population coverage (millions)</th>
<th>% tubewells contaminated with As&gt;50μg/l</th>
<th>Population exposed to As&gt;50μg/l (millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piped water supply</td>
<td>13.10</td>
<td>7.2</td>
<td>0.94</td>
</tr>
<tr>
<td>Manually operated Deep Tubewells</td>
<td>8.20</td>
<td>1</td>
<td>0.08</td>
</tr>
<tr>
<td>Manually operated Shallow Tubewells</td>
<td>103.00</td>
<td>27.4</td>
<td>28.2</td>
</tr>
<tr>
<td>Dug wells</td>
<td>1.30</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>PSF, VSST, SST, RWH, etc</td>
<td>1.50</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Others</td>
<td>2.15</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>129.25</td>
<td>35.6</td>
<td>29.24</td>
</tr>
</tbody>
</table>

Related groundwater quality issues

In the original survey of the arsenic problem (BGS/DPHE) a wide range of inorganic constituents were also screened from the whole region and especially from SSA samples to assess any natural anomalies that could present problems for drinking water and other usage. By far the major problem was arsenic-related but for example some 35% of samples
exceeded the WHO guideline value (0.5mg/l) for manganese. Wells in western Bangladesh tend to be high in Mn but relatively lower in As, but the reverse is true in southern Bangladesh. Only 2% of the deeper groundwater sampled in the national survey had Mn exceeding 0.5 mg/l).

It is notable that due to the strongly reducing nature of all but the shallow aquifer, nitrate is absent (or has been reduced to values below detection by natural remediation). In the shallow (mainly aerobic) aquifer, the presence of nitrate can mainly be used as an indicator of anthropogenic contamination and recently recharged water.

**ARSENIC IN FISH**

In both marine and freshwater aquaculture, use of groundwater has long been encouraged in Bangladesh because of its purity and appearance as pollutant-free at various stages of the culture cycle such as in hatchery operation, nursery management and even in grow-out stages. Therefore, the sector has long been believed in a potential risk of being affected by arsenic toxicity. No proper attention, however, has yet been paid to evaluate the toxicity level of fish and other aquatic organisms at different stages of the value chain – production, harvesting, processing, preservation, transport and marketing in Bangladesh (Ahmed et al. 2008).

Fish have long been an integral part of everyday diet of Bangladeshi people and the adage – “machhe bhate bangali” – which literally means – fish and rice make the people of Bangladeshi is well known. Although the people may be exposed to high levels of toxic arsenic from fish consumption (Al-Ramalli 2012), to date, only a few fish of both freshwater and marine origin from Bangladesh have been analyzed and little published information is available.

In aquatic ecosystems, a number of microorganisms are responsible for making arsenic available biologically to organisms including fish (Duker et al. 2005). Among the aquatic organisms, fish appear to be particularly vulnerable to arsenic contamination as they are continually exposed to it through the gills, the entire permeable body and by feeding on arsenic-contaminated food. Fish are able to amass high levels of arsenic as a result of water contamination, with the subsequent transfer arsenic during consumption into the human food chain. Arsenic in fish shows a general trend of higher concentrations in marine species compared to freshwater ones (FSA 2005; Shah et al. 2009).

Arsenic present in water is not the only route for arsenic transfer into fish species. The transfer pathway of the metal through the food chain is important and eventually how the metal behaves after it enters the chain – as biomagnifiable or biodiminishable. Fish species are classified as herbivore or planktivore (vegetarian, feed mainly on phytoplankton and plant materials), carnivore or piscivore (meat eater – feed mainly on other fish, insects and zooplankton) and omnivore (opportunistic – feed on either plant or animal sources) based on their food habits. Chen and Folt (2000) show that planktivore fish might contain significantly higher arsenic than omnivore or carnivore species. Accordingly, in Bangladesh, total arsenic concentration in freshwater and marine fish will vary from one species to another (Mukherjee and Bhattacharya 2001). Thus, analysis of all species or groups of edible fish is required to determine the exact scale and extent of arsenic contamination. In Bangladesh people for
most of the regions and particularly in the east coast and north east and north west are very fond of dried and fermented marine and freshwater fish products. Arsenic concentrations increase (more than 5 times compared to fresh fish) under the dried condition and therefore the dried and fermented products also need to be evaluated for arsenic.

The toxic and non-toxic levels of arsenic in different food fish are known from global studies. These include different marine fish and shellfish: - dogfish, rays and sole (Lima et al. 1984), blue tilapia, smallmouth buffalo and Rio Grande cichlids (Mora et al. 2001), lake-whitefish (Pedlar and Klaverkamp 2002), sharks (Storelli and Marcotrigiano 2004), different marine fish (Baeyeans et al. 2009), ten freshwater fish (Shah et al. 2009), three pelagic marine fish - sardine, chub and horse mackerel (Vieira et al. 2011), and tilapia and tiger shrimp (Kar et al. 2011).

In Bangladesh, Das et al. (2000) and Das et al. (2004) conducted the first studies to detect arsenic in fish. Trace amounts of arsenic were found in two popular food fish, stinging catfish, Heteropneustes fossilis locally known as singh collected from a canal of Begumganj upazila (Das et al. 2000) and spotted snakehead, Channa punctatus locally known as taki or lata collected from a canal of Kachua Upazilla, Chandpur (Das et al. 2004) both on the south central coast of Bangladesh. The authors also found levels of arsenic in canal water and sediments from the same area at an acceptable limit. A positive correlation was established between the arsenic present in groundwater and arsenic present in fish.

Eleven freshwater and one marine fish and pertinent fish products (frozen product imported from Bangladesh and Myanmar mainly for the ethnic Bangladeshi living in UK) were analysed by Al-Ramalli (2012) and it was found that the highest arsenic was present in the eggs of hilsha shad, ilish flesh and eggs. Mean concentrations of arsenic ranged from 0.005-3.4 mg/kg for big fish flesh (40 to 75 cm) and 0.1-2.5 mg/kg for small fish flesh (less than 15 cm). In the speciation analysis of ilish, it was found that the fish contained dimethyl arsenic acid - DMA (69% of total As), arsenobetaine (11%) and arsenosugars (20%). Although inorganic arsenic was not detected in ilish, it contained high amount of DMA known to be more toxic than arsenobetaine. Large fish as analyzed in the study contained a high ratio of toxic elements compared to small fish and therefore, the suggestion was that smaller fish might be a healthier food than the larger fish.

In view of the limited research on arsenic in fish in Bangladesh, as well as the impact on the human food chain and human health, long term R&D projects need to be implemented. This would require an improved data base for all aspects of fish culture in all aquatic environments and across the different fish products and marketing. Laboratory experiments should be continued into arsenic toxicity and speciation in fish and their habitat. Further research is also needed in relation to fish size and arsenic as well as mitigation measures to limit arsenic exposure

ARSENIC AND SOCIO- ECONOMIC ISSUES

Various recent studies have highlighted the economic issues associated with arsenic contamination (Hassan et al, 2005; Oper et al, 2007; Nahar et al, 2008; Brienkel et al, 2009; Sarker, 2010; Ahmed et al, 2011; UNICEF 1998, 2010).
Estimates of the economic impact of poor health arising from arsenic in groundwater in Bangladesh suggest that the cost of inaction is extremely high. The Gross Domestic Product (GDP) output lost due to illness and people becoming unable to work is estimated to be US$23 billion (FAO, UNICEF, WHO and WSP, 2010) while the cost of treating arsenic-related diseases is estimated to be much lower at US$0.6 billion for a constant discount rate of 10% over a 50-year period. This suggests that while the costs to the health care system are large, the costs to the economy due to loss in productivity are at least an order of magnitude greater.

People with lesions from arsenic poisoning still suffer social stigma in Bangladesh, although the situation has improved. Ten years ago, many people believed arsenic poisoning was contagious or a curse. Parents were reluctant to let their children play with children suffering arsenic poisoning. Arsenicosis patients were shunned within their villages. For women, the situation was worse and still remains an issue. In Bangladesh, a woman's attractiveness is often associated with the pale complexion. This makes it harder, in some cases impossible, for single women suffering from arsenic poisoning to marry. Once married, women face the risk of divorce if they develop arsenicosis skin lesions. This can be a dire situation in Bangladesh's male-dominated society, where unmarried women are more vulnerable to poverty and social exclusion (UNICEF 2010).

The discovery of widespread arsenic contamination in tube wells, installed initially to provide bacterially safe water presents a double challenge: to ensure that the health gains on diarrhoea would not be lost while also reducing the health impact of arsenic. The challenges are both technical and socio-economic. In certain arsenic-affected areas there are few if any affordable safe water options for rural households with average income. Many alternatives are safer, but less convenient or more costly than arsenic-contaminated shallow tube wells. Solutions such as rainwater harvesting have shown low social acceptability. It is not rare to still see people drinking arsenic contaminated water from red painted tube wells. It is hard to compete with the low-cost easily maintained and convenient shallow tube wells when it comes to water supply to rural households.

**ARSENIC MITIGATION AND MANAGEMENT**

The first substantive overview of the response to the arsenic emergency was provided by the World Health Organisation (WHO, 2001). Arsenic removal is generally expensive and technically difficult and solutions can pose their own health risks; the reduction of standards from 50mg/l to 10mg/l leads to a skyrocketing of costs. Whatever national standards are, it is of key importance that priority be given to measures that reduce the absolute intake of arsenic as much as possible, even if the standard is not met immediately. From lessons learned worldwide, communities must be fully committed to take an appropriate level of managerial and financial responsibility for the construction, operation and maintenance of any mitigation system. The government’s role lies in developing national plans of action, and ensuring that mitigation efforts by external support agencies and civil society organisations are implemented in a coordinated fashion. For a problem as complex as arsenic contamination the Government also works with academic and research institutions to improve the understanding of the causes, extent and impact of arsenic contamination.
Substitution of arsenic-free water such as rainwater (with adequate storage and treatment) presents one possible option.

The understanding of the occurrence of arsenic is sufficient to direct national strategies for lowering exposure (Ahmed et al. 2006). Field kits were used in the very extensive 1999 campaign to test tube wells in the most affected regions of the country. Some 1.4M tube wells that did not meet the local standard for arsenic in drinking water of 50 μg per liter were painted red. Another 3.5M wells with up to 50 mg per litre arsenic were painted green (BAMWSP, 2004). Such testing did not however reduce the rate of private well installation. Sadly, most tubewells that were installed after the national testing campaign remained untested by time of the study.

More than half of the population in Bangladesh remains at risk from arsenic. To reach a greater fraction of the population several actions have been proposed (Ahmed et al. 2005): (i) stimulate vastly the periodic monitoring of water quality, no matter what the mitigation option, (ii) encourage rather than discourage the wise use of deep aquifers that are low in arsenic, and (iii) include the newly demonstrated effects of arsenic on the mental development of children in information campaigns (Wasserman et al. 2004).

The Government of Bangladesh adopted a National Arsenic Policy and Mitigation Action Plan in 2004 for providing arsenic safe water to all the exposed population, to provide medicare for those who have visible symptoms of arsenicism and also to investigate the issue of arsenic in agriculture. The policy demonstrates the political will in recognising the severity of the problem and needs for its mitigation. The mitigation action plan provides guidelines for implementation of projects in order to reduce arsenic exposure by use of surface water, rain water and deep groundwater. Surface water was given higher priority as the source of arsenic safe water; deep groundwater was considered as the source where no other options were available. This created some problems in arsenic mitigation as availability and quality of surface water were major constraints. Eventually groundwater, more specifically deep groundwater, has become the prime source of safe water.

Various mitigation options had been installed by 2005 by the Government of Bangladesh and NGOs to provide As-safe water in the areas where more than 50 ppb As had been detected. A large number of arsenic removal technologies were introduced in the country using various different methods. However, the government took an initiative to verify the technology and issue certificates before they could be used. Accordingly five household and one community level arsenic removal technologies were given an approval certificate. Due to various management and technological issues the overall contribution of the removal technologies to arsenic mitigation is insignificant. Thousands of removal units have been distributed under various projects but very few are currently found operational.

DPHE/APSU (2005) conducted a national survey to identify the number of options installed by various government and non-government programs. A large number of agencies installed some 107 000 safe water options based on surface water, rain and groundwater; 70% of the mitigation by that time had been provided by low arsenic deep tube wells, followed by 12.5% rain water. In a more recent study, Ravenscroft et al. (2009) compiled the number of safe water options installed for As mitigation in Bangladesh. Deep tube wells provided 84.4% followed by shallow tube wells (5.1%) and dug wells (4.9%). Therefore, low arsenic
groundwater accounted for more than 94% of safe water options followed by 3.2% by rainwater and 1.4% by surface water (PSF). The contribution of arsenic removal technologies was insignificant.

A vast effort was made in the first decade of the arsenic crisis into technologies for arsenic removal with numerous scientific publications on the subject. The experience has been that, whilst these technologies are capable of removing As to a safe level in majority of cases, maintenance is a major issue and performance falls significantly as soon as project support is withdrawn. Moreover, there is a better future for community-based units rather than household based solutions. Although these technologies were proposed as a means for emergency response, the certification procedure took too long a time for the effective use of the removal technologies. It is very unlikely that household removal technologies will be widely used in the future as a safe water option in the country.

The conclusions from the BGS/DPHE studies, that deep tube wells offer a safe source of low or arsenic-free water have now been more widely corroborated. As a result, over 200,000 deep wells had been installed by DPHE by 2007. Rural piped water supplies have been evolving as a source of safe water, both in and outside the arsenic affected areas of the country (DPHE/JICA 2008).

A risk assessment of various arsenic mitigation options was carried out to understand the relative health risk, risk management potential and social acceptability of the widely used technology options including DTW (deep tube well), DW (dug well), PSF (surface water) and RWH (rain water harvesting), (DPHE/APSU, 2005). The study aimed at assessing the potential health risk through quantitative health risk assessment. The study included 36 DWs, 36 DTWs, 42 PSFs and 42 RWHs randomly selected from 26 clusters. A quantitative health risk model was developed which showed that there was a significant health risk substitution for DWs and PSFs with respect to pathogens. There was much lower risk substitution in DTWs and RWHs in relation to either pathogens or other chemicals. DTWs had the highest aggregate water safety followed by RWHs, while disease burdens from DWs and PSFs were unacceptably high. The disease burden increased significantly for the DWs and PSFs in the wet season with greater deterioration of microbiological water quality.

A map of the mitigation situation and technologies in use for number of upazilas was produced (DPHE/APSU/JICA, 2006) under the GOB-UNICEF project based on criteria such as depth of water table, arsenic, salinity and presence of the deep aquifer (Figure 9). It should be noted that, other than deep tube wells, no other option can be prescribed as a solution for the entire country. Deep tube wells also have some limitations in certain parts of the country. The local geology, and hydrogeology has to be considered as well as decisions about alternative technology. Also the overriding issue of providing safe water rather than just arsenic-safe water should get due importance in introducing new/alternative options. The relative risks of various ‘arsenic-safe’ water sources still has to be assessed in order to avoid inadvertent risk substitution.
Figure 9. Situation regarding arsenic mitigation strategies as of 2009. Note that there is relatively little available data on mitigation in the coastal regions.

A visual comparison of the arsenic contamination maps of 2009 and 2005 (not shown) indicates that there have been some changes for the worse in degree of contamination in some areas. It is worth noting that more upazillas were studied in 2009 and also the reorganisation of administrative boundaries by government since 2005 has also impacted the distribution pattern of arsenic contamination and the affected population.

While comparing the patient numbers of 2009 with those of 2005 the first point of note is that the latter were collected from the BAMWSP data of 2004 while the 2009 patient data was collected from DG Health sources. The BAMWSP data came from various uncoordinated.
sources while the DG Health data records patients who were medically treated by qualified medical professionals. In the comparison it can be seen that that the 2005 position paper in 2004 records 38,118 patients for 270 upazilas (BAMWSP, 2004), and 12853 patients for 191 upazilas. The 2009 study recorded 37015 patients for 301 upazilas most of which were also part of the 191 upazilas covered in 2005 study. A good indicator of the trend in patient number distribution is to look at the patient-population ratio; although the patient numbers have increased the percentage compared to the total population is on a positive declining pattern.

A similar trend can be visually interpreted from the arsenicosis patient map for both 2005 and 2009. Another table produced in the 2005 report showed a list of 41 unions where the number of arsenic patients exceeded 100 per 10,000 population. Similar calculations carried out for the 2009 study showed that 26 unions fell in the same category. Comparison was also made between the arsenic mitigation situation in 2009 with that of 2005. The number of SWDs has increased significantly (1245%) which has helped improve the mitigation situation. In 2005 38% of the total households within the study area had safe water coverage. In comparison 54% of the population had safe water coverage in 2009. This also could be the likely reason for reduction in the patient percentage in 2009.

CONCLUSIONS

This paper has provided an overview of the history of the exposure of the population to arsenic in Bangladesh over some three decades. It gives a summary of the large number of studies into the origins of this huge problem from a geological, hydrogeological and geochemical point of view. As well as detailing the health statistics, details of the medical conditions resulting from the exposure as well as the social impacts on the people of Bangladesh and the impacts on its economy are given. The impacts on agriculture, food and fish which are as important as the occurrence in ground and surface water are also shown.

A large number of people are still exposed to arsenic at levels above the acceptable limit, mostly in the southern deltaic part of the country. Significant efforts have been undertaken in order to mitigate the problem which does not match the severity and magnitude of the problem. This is despite the adoption of a National Policy for Arsenic Mitigation in 2004,

Various options have been introduced for providing arsenic safe water ranging from household removal technologies targeting small groups to piped water supplies targeting up to 1000 people. Groundwater is the main source of arsenic-safe water and more than 80% of new sources are based on it. Contribution of rainwater comes second and surface water is the least used source. The relative risk of various sources has to be assessed properly before introducing an alternative. More than 40,000 patients have been registered with the government hospitals and are under government arsenic healthcare coverage. But it is widely believed the actual number of affected people is larger. Also the number of deaths linked to arsenicosis is predicted to increase over the coming years.

The impact of arsenic in irrigated agriculture and on fisheries is a matter of serious concern but not yet well understood. However, this has been considered as another major issue and further data and targeted research is needed in these areas.
Arsenic has significant impacts on the economic growth and livelihoods. More focussed mitigation actions are needed to provide safe water to the population still exposed to arsenic above the drinking water limits, not just at the present but in the long term. The arsenic issue is particularly severe in the deltaic region of the country. Any project dealing with livelihood of the region must consider synergy with the issue of arsenic very seriously

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