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Tubewells and Arsenic in Bangladesh: Challenging a Public Health Success Story

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ABSTRACT

Bangladesh has seen one of the developing world's great public health successes, the conversion of the drinking water source for 94% of the rural population to 'safe water', in the form of tubewells, with the aim of reducing morbidity and mortality from water-borne disease. Now, that success is being endangered by the discovery that 20 million people may be in great danger and another 20 million in lesser danger of being poisoned by arsenic contamination from tubewell water. This article reports findings from the first national probability sample survey of the rural population and a census of tubewells investigating the social, demographic and epidemiological context of the crisis. The survey covered 3780 households containing 20 260 people. The tubewell census covered 9174 tubewells. The article presents data on the respondents' history of drinking tubewell water, knowledge of the arsenic problem, identification of arsenicosis, as well as the impact upon them of the national campaign, the testing of tubewells, and their subsequent sources of water. Eighty-seven per cent of households drank water from ordinary tubewells (at most risk from arsenic poisoning) and 7% from deep tubewells. Among males, 47.5% had heard that something may be wrong with tubewell water, compared with 39.6% of females. A much lower proportion (20.6% males, 11.3% females) had heard that the water contained a poison called arsenic. Only about 1.5% of the entire population had stopped using tubewell water. Of survey respondents, 0.5% of males and 0.4% of females reported symptoms consistent with chronic arsenicosis. Suggestions are made for a more effective programme. **Copyright © 2003 John Wiley & Sons, Ltd.**

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INTRODUCTION

Historically the major impact of poor environment on health has been in fostering conditions conducive to the spread of communicable disease, such as those resulting from poor sanitation and contaminated water and food (notably diarrhoea), overcrowding and poor housing conditions (pneumonia, tuberculosis and measles), and conditions favourable to vector-borne diseases such as malaria. In developed countries the environmental conditions contributing to such

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diseases were largely overcome in the nineteenth and early twentieth centuries by public health measures including clean water and sanitation, better housing, drainage of swamps, as well as other changes such as improved hygiene and better nutrition (McKeown and Record, 1962; Szreter, 1988). In developing countries it has been much more difficult to improve the health environment, simply because most countries have been unable to afford the investments necessary. However, communicable diseases have been greatly reduced by better preventive and curative health services, notably immunisation for childhood diseases and oral rehydration therapy (ORT) for diarrhoeal disease.

Nevertheless, a poor environment continues to be a major factor contributing to poor health in developing countries. In many cases environmental conditions may indeed be worsening, especially with growing urbanisation, and its associated problems of overcrowding and poor sanitation. Added to biological pollution is the increasing chemical pollution of air and water, with few effective countermeasures due to the expense of necessary control measures, coupled with lax enforcement of regulations.

A particularly extreme example of a poor environment contributing to disease is that of Bangladesh. The abundance of water on the alluvial soils of the Ganges-Brahmaputra-Meghna delta, which covers most of Bangladesh as well as the neighbouring Indian state of West Bengal, accounts for one of the world's most intensive concentrations of population, but the same water, partly because of the population density, is a major carrier of water-borne disease. In the deltaic conditions it is impossible to prevent faecal matter and accompanying pathogens from entering the water and the water table. Cholera and dysentery are common, and, until the last few decades, were responsible for up to a quarter of all deaths.[1]

Seemingly miraculously, it appeared that there was a fairly easy way of obtaining microbiologically pure water, and that was through tubewells – tubes bored down 10–200 metres with groundwater raised by hand pumps. Some tubewells had been sunk in British India for agricultural purposes as early as the 1920s, but it was only in the late 1960s and early 1970s that governments and the international community saw them as an alternative to the frustrating attempts to purify ponds, discover means of immunising against water-borne disease, and develop safe latrines. In the 1970s and 1980s there was a sustained and highly successful campaign to promote tubewells.

By the early 1990s there were 2.5 million tubewells, and 95% of rural Bangladeshis were using water from this source; around half were drinking water from private tubewells, the majority of which were in the courtyards of their own *baris* (a group of buildings usually occupied by relatives) (Mitra and Associates, 1992: 14, 41–44). Most of those not using tubewells lived in places like the Chittagong Hill Tracts where there was no underlying aquifer, or on deltaic islands near the coast where the shallow aquifer had been penetrated by seawater. The mass conversion to tubewells was not propelled solely by a desire for hygiene, but also by the convenience of having a nearby source of water often in the family's yard. Indeed, of those conveniences that affluent societies have brought right to the house, such as water, electricity, gas and telephones, for most families water was the first to arrive.

Following the spread of tubewells there was indeed a major decline in mortality from diarrhoeal disease.[2] It is unclear, however, how much of this decline can be attributed to the 'tubewell revolution'. Coinciding with the spread of tubewells were a number of public health measures, notably the widespread adoption of immunisation and the greatly increased use of antibiotics (often misused, but undoubtedly preventing some of the child deaths concerned), and of oral rehydration treatment (ORT), particularly important for reducing diarrhoeal deaths. Most early studies in the International Centre for Diarrhoeal Disease Research, Bangladesh (ICDDR,B) field site of Matlab showed no difference in cholera and other diarrhoeas in the country by water source (Sommer, 1972; Levine *et al.*, 1976; Briscoe, 1978), or at most a very limited protection, the small benefit offered by drinking bacteriologically safe water being of minor significance given the exposure to surface

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water through bathing, food preparation and utensil washing.

Nevertheless, whether or not the use of tubewell water had a major effect on the prevalence of diarrhoeal disease, its abandonment now and the uptake of surface water might well result in a substantial rise in diarrhoeal disease, as old methods of maintaining the cleanliness of surface water have been abandoned. The pollution of most ponds became more marked after most people switched to drinking tubewell water, with the consequence that attempts to protect surface water largely ceased. For example, the use of potash alum (*phitkiri*) which reduced bacterial counts by promoting sedimentation has declined drastically (Kränzlin, 2000: 69). An increase in the use of ponds for commercial fish farming has further reduced the number of ponds with water fit for drinking. Furthermore, it should be noted that even given the changes that have taken place, diarrhoeal disease continues to be a major cause of infant and child death.

Given this background, what was not needed was a new environmental threat, chemical rather than biological, apparently 'natural' in origin, but nevertheless dangerous, and whose solution is arguably at odds with the previous efforts to ameliorate biological contamination by promoting groundwater. This has come in the form of arsenic in the groundwater, which can lead to arsenic poisoning (arsenicosis when symptoms are present) amongst those who drink it.

Questions have been raised about the long-term reality of the supposed health gains of the tubewell programme, and whether technical advances can have offsetting dangers that are difficult at first to discern. A major problem in determining whether tubewells have resulted in a net health gain or a net health risk is the lack of sufficient information, not only epidemiological, but also in the social and behavioural area.

This paper reports a national survey, the first of its kind, designed to examine the impact of the arsenic crisis, and the subsequent attempts to mitigate arsenic poisoning, on the population; and to examine the apparent slowness of authorities and of the population to react to the problem.

Background

The arsenic problem is confined to the Ganges-Brahmaputra-Meghna delta, where a hydrogeological phenomenon as yet not fully understood has resulted in arsenic being present at fairly shallow depths in the soil. The delta is home for around 80% of Bangladesh's 130 million inhabitants, and around 40 million in West Bengal. The presence of arsenic in West Bengal tubewell water was first suggested in 1978, but it did not become an important issue for a further decade (Chatterjee *et al.*, 1995: 643). It was first detected in Bangladesh tubewells in 1987, and the first identification of persons with physical manifestations of arsenicosis occurred in 1994 (Saha, 1995; Ahmad *et al.*, 1999: 187). The World Health Organization (WHO) was in touch with the problem from 1994, and in 1997 declared it to be a 'major public health issue' which should be dealt with on an 'emergency basis' (United Nations, 1999: 34; Yamamura, 1999: 1,5). In 1998 the World Bank approved a credit of US $32.4 million for dealing with the problem.

There is scant epidemiological information on the effect of chronic exposure to low levels of arsenic on morbidity or mortality. In 1958, the WHO published *International Sanitary Regulations*, which defined good drinking water, and revised versions appeared in 1965 and 1978, followed by *Guidelines for Drinking Water Quality* in 1984. In 1958 the suggested maximum level for arsenic in drinking water was placed at 0.2 mg/litre, based on Latin American reported experience that this level appeared to give no problem and no rise in cancer deaths. In 1963 the level was, perhaps cautiously, lowered to 0.05 mg/litre and is now 0.01 mg/litre. The WHO (1996: 162) justified the choice of a guideline of 0.01 mg/litre by mathematically modelling the reported Taiwan experience from this and lower concentrations of arsenic in water, estimating that this concentration, when compared with arsenic-free water, would, over the first 70 years of life, yield one more case of cancer for every 1667 persons. The assumptions underlying this estimate are somewhat controversial. With higher arsenic concentrations this rise in risk was likely to be curvilinear, but there is little evidence of how great the increase would be.

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This risk is unlikely to be equally shared; it has been suggested that it would be higher for the malnourished and those with hepatitis B, and twice as great for men as for women (Mazumder *et al.* 1998: 874; WHO, 1999: 1).

The numbers of arsenic-contaminated wells and the number of people at risk have been variously estimated by extrapolating from studies that tended to select sites reported to be arsenic-infected. Reports have suggested that over 50 million people are in danger (Dhar *et al.*, 1997). But the long-awaited report of the British Geological Survey and Mott McDonald (BGS&MM, 2000) estimates that 21 million people are drinking water with more than 0.05 mg/litre of arsenic, and 42 million drinking water with over 0.01 mg/litre (section S2.5): 15% and 30% respectively of the population. The arsenic is contained in a shallow aquifer and there is little danger in getting water from the first ten metres below the ground (surface wells) or below 200 metres (deep wells used primarily for agriculture). There is little risk for populations in the hills (where the water table is not deltaic) or on the seaward edges of the delta (where the only tubewells are deep ones), and limited danger in the northwest where the aquifer water is flowing faster. Elsewhere, arsenic is not evenly spread, with the result that even wells close by and of similar depths may exhibit very different levels of arsenic. BGS&MM (2000: S2.8) found that the older wells were more contaminated than the newer ones, and surmised that it was possible that the arsenic concentration around a functioning well increased over time. NAMIC, testing 43 affected *thanas* (districts), found 49% of tubewells to be arsenic-free, but 51% were contaminated with at least 0.01 mg/litre (i.e. over the WHO guideline level), 35% with at least 0.05 mg/litre (i.e. over the Bangladesh guideline level), and 3% with over 0.5 mg/litre (Bangladesh Arsenic Mitigation Water Supply Project, 1999: 3).

The major unknown factor in the Bangladesh situation is not so much the concentration of arsenic in the tubewells as the epidemiology of arsenicosis. The WHO (1999: 1–2) lists symptoms roughly in successive order as: changes to the colour of parts of the skin (either hyperpigmentation or depigmentation), a thickening of the skin particularly on the palms and soles (keratosis), skin lesions, skin and internal cancers, peripheral vascular disorders and neurological disorders. The liver and lung may also become affected (Mazumder *et al.*, 1997; Abernathy *et al.*, 1997). There is no clear relationship in individuals between arsenicosis and arsenic intake as measured by the presence of keratosis (Mazumder *et al.*, 1998: 875). But Mazumder *et al.* (1998) did find average keratosis levels rising from 0.1% among these drinking from wells with less than 0.05 mg/litre, to 9.7% from wells with over 0.80 mg/litre, and hyperpigmentation climbing from 0.4% to 17.1% (p. 874). Progression is slow and is as yet unpredictable. Töndel *et al.* (1999), studying 1481 subjects in four villages in West Bengal, found the prevalence of hyper- or hypopigmentation or keratoses ranging from about 18% in those exposed to levels of 0.15 mg/litre to about 30% in those exposed to levels of 1.0 mg/litre. Note that these figures are for any or all of these independent clinical signs, which alone are unlikely to constitute arsenicosis. Ahmad *et al.* (1999), working in a badly affected Bangladesh village close to the Indian border, found 87% of the tubewells to have an arsenic concentration of over 0.05 mg/litre, with 10% of the population suffering from arsenicosis, mostly melanosis and keratosis, 0.6% showing precancerous skin lesions, and 0.08% with cancer (apparently visible skin cancer). There is also an age effect, which is probably largely but not entirely a product of the period over which arsenic-contaminated water was drunk. Mazumder *et al.* (1998: 874) found keratosis rising from 0.4% among persons under 10 years to 1.7% among those aged 20–29 years, and 4.2% for the 50–59 age range; for the same age groups, hyperpigmentation climbed from 1.9% to 4.7% and then 9.1%.

There are few estimates of the prevalence of arsenic-related symptoms. Smith *et al.* (2000: 1097) cited an estimate of at least 100 000 cases and suggested that there may be many more. He commented (p. 1095) that in West Bengal, India, a much smaller population is at risk (1.5 million), but one estimate of those with arsenicosis exceeds 200 000. A Rapid Action Programme surveyed 200 villages with a combined population of 469,424 people and

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found only 1802 cases. However, they also conducted an in-depth study in four villages with arsenic-contaminated tubewells, involving the interviewing and physical examination of 1481 adults, and found 430 with arsenic lesions (Töndel *et al.*, 1999).

While there is reasonable evidence for increases in lung, bladder, kidney and skin cancers, cardiovascular disease and diabetes among those exposed to highly arsenic-contaminated water (levels over 0.15–3 mg/litre), there is no direct evidence of increased risk for mortality and morbidity attributable to chronic exposure to water contaminated with low concentrations of arsenic. There is also no evidence as yet for progression of the skin manifestations of arsenicosis to cancerous or other lesions likely to lead to premature death.

If there are to be rises in arsenic-associated mortality they will be hard to detect unless a major mortality crisis develops. Bangladesh does not have a vital registration system. Only among the quarter of a million persons in the Matlab district covered by the Demographic Surveillance System of the International Centre for Diarrhoeal Disease Research is there a system for recording all deaths (ICDDR,B various years). It is not at present recording a rise in middle or old age mortality. The system attempts to record causes of death, but these are not professionally certified, and are not yet identifying arsenicosis as a contributor to mortality.

THE STUDIES

The basis of the studies reported here was a national probability sample of households involving collaboration between the National Centre for Epidemiology and Population Health, Australian National University, and Mitra and Associates, Bangladesh's foremost organisation for conducting national surveys, including the country's demographic and health surveys. The studies, completed between February and March 2000, had two components: (1) a national sample of households; and (2) a tubewell census of the communities which formed the penultimate stage of the sample. These aimed at exploring the relationship between families and their sources of water, the effect of the information campaign to warn them about the danger of drinking arsenic-contaminated water, the extent to which their tubewells had been tested and their subsequent reactions, and finally their awareness of arsenicosis within their families and the treatments they had adopted.

The Household Survey was a rural one, defined as being the 76% of the country's population living in rural areas; most water in urban areas is not from tubewells or is taken from deep wells that are not believed to be arsenic-contaminated. The sample of households was a subsample of the 1996/97 Bangladesh Demographic and Health Survey (BDHS) (Mitra *et al.*, 1997; 153ff) which was drawn from the Integrated Multi-purpose Master Sample maintained by the Bangladesh Bureau of Statistics. In each of the country's six Divisions, a sample of 15 villages was drawn and in each of these, 42 households were selected from the BDHS household listings. This yielded 3780 households, substitutions being made in 394 cases (10.4%). The total number of persons in the households to which such questions as those on arsenicosis referred was 20,260. In order to test sensitivity by gender to various questions, the respondents were alternated by sex from one household to the next, usually from household head to spouse. Finally, the responses were weighted by the rural population of each division to provide adjusted prevalence estimates.

Next, in each cluster forming the penultimate sampling unit a Tubewell Census was conducted. The 9174 wells censused formed a universe from which households took water, and ensured that public as well as private wells were enumerated. The census also allowed a comparison with the tubewell data obtained from the household survey.

The Tubewell Census showed that 97% of tubewells were of the ordinary hand-pump type; 2% were *Tara* pumps, a more powerful hand-pump designed for deeper wells. The remaining 1% comprised wells with *dheki* (foot-operated treadle) pumps or motor pumps. The great majority of the tubewells are private (86%), compared with 12% installed by public authorities, 1% by non-governmental organisations (NGOs) and 1% by some kind of communal arrangement. Private ownership was up from 71% in the 1991 survey (Mitra

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and Associates, 1992: 13), a reflection of the tremendous increase in private tubewell construction in the 1990s. Initially the government and NGOs drove the installation of tubewells, but subsequently, as tubewells became more acceptable, and indeed desired for their perceived safe water and convenience, most have been installed privately. This is supported by the Household Survey, which showed that over two-thirds of the tubewells in use in the year 2000 had been sunk since 1991. More surprisingly, 95% of all tubewells were functioning, a different situation than that found in the 1980s in south India (Caldwell *et al.*, 1988: 148–9) and probably a reflection both of the high level of private ownership, and of the rather simple tubewells suited to the conditions of the delta.

THE TUBEWELL REVOLUTION

The Household Survey revealed that by 2000, over 87% of households were getting their water from ordinary tubewells, with the most potential for arsenic pollution; 7% were using relatively safe, but much more expensive, deep tubewells; and 0.6% had access to piped water, half at their own dwelling. Deep wells were a significant source of water only in two divisions bordering the Bay of Bengal where parts of the aquifer are salty: Barisal, where 65% of water was supplied by deep wells, and Khulna, where 10% was. Throughout the 1990s the proportion of the rural population drinking surface water continued to decline, from 4.2% in 1991 (Mitra and Associates, 1992: 41) to 2.5% by 2000, and the proportion drinking from hand-dug wells declined from 4.7% to 2.5%.

The proportion using tubewell water for cooking was much lower at 68%, thus lessening the arsenic danger, and dropped to even lower levels for dishwashing and bathing. Nearly 60% had their own tubewell or access to a tubewell in their *bari*, many relatively recently, a quarter having been in this situation for at least 12 years, half for at least seven years, and three-quarters for at least three years.

What drove the overwhelming acceptance of tubewell water? Half the respondents said that the most compelling reason was the need for safe drinking water, while the remainder placed greater emphasis on convenience and no longer having to rely on neighbours through controlling their own water supply. Women were more likely to emphasise convenience and control, but this is readily understood when it is realised that they are the water carriers and also the negotiators with neighbours for access. For water beyond the *bari*, neighbours provide three-quarters, compared with only a quarter from public sources. No longer do governments or NGOs play a significant role in urging families to invest in tubewells. Every family wants its own tubewell and the limiting factor is solely resources – with the exception of a few areas where the water table is very deep. Nevertheless, even in poverty-stricken rural Bangladesh, 87% of those with wells (or 52% of all families) constructed the well with their own resources, while 5% obtained an NGO loan for the purpose, 3% a private loan, and 1% a government loan. Remittances from earnings in the Middle East apparently played a very minor role. The reason is that the cash outlay, over and above that of family labour, is modest, with a median level near *Taka* 1900 – US$38 at the current exchange rate – or around a tenth of the per capita annual income, although a much higher proportion of disposable rural family income (first quartile = US$22, third quartile = US$55). Deep wells are in quite another category. They need machinery to install, heavy pipes, and often powerful pumps, and may cost many times as much as an ordinary tubewell. They are put in place either by the government or by the rich and landed for growing commercial crops. Some households have access to a small amount of this water for drinking.

Water is used for many other purposes than drinking, and arsenic derived from water can be ingested by such other routes as eating irrigated foodstuffs (being investigated in the ongoing work of the project). Table 1 explores the household sources and use of water.

Water when drunk is the major source of arsenic. Irrespective of the amounts of arsenic retained in cooked food, or irrigated vegetables and crops, ordinary tubewell water is used to a lesser extent in these activities. Deep-well water is important for the seaward deltaic

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Table 1. Use of water by source, Bangladesh rural households, 2000 ($n = 3780$).

Source	Use (%)			
	Drinking	Cooking	Irrigating vegetables	Irrigating cereal crops[a]
Ordinary tubewell	87	65	21	12
Deep tubewell	7	3	3	15
Surface well	3	4	0	0
Surface water[b]	2	26	39	16
Other[c]	1	2	0	
No irrigation[d]	–	–	2	24
No activity	–	–	35	33

[a] Rice and wheat.
[b] Pond, tank, lake, river, stream.
[c] Piped water, rainwater from roof.
[d] Rainfall only.
Source: NCEPH, ANU Household Survey 2000, weighted data.

areas and more widely for irrigated crops because deep wells can produce very large flows of water. Only small areas of crops or vegetables can be irrigated by ordinary tubewells.

Two aspects of the tubewells are important for understanding and predicting Bangladesh's arsenic crisis: their depth, and the period over which they have been available for drinking. Both are explored in Table 2.

Tubewells as measured by the tubewell survey are on average shallower than as measured by the household survey. This is an artefact of what is being measured in the two surveys. The tubewell survey measured all wells including many inexpensive shallow wells, particularly in northern Bangladesh, used by relatively few people. Deeper wells, more important in the lower water-table areas of southern Bangladesh, are rarer but are used by more people on average, and hence show up more prominently in the household survey, which measured household use.

The great majority of tubewells, 83–87%, are what we have called 'ordinary tubewells', neither so shallow that they are in danger of surface microbial pollution nor so deep that there is little fear of arsenic contamination. Half lie in a 30-metre band between approximately 15 and 45 metres deep (approximately 50 to 150 feet). There has been a steep rise in tubewell construction in the 1990s, but a much more moderate increase in the numbers drinking from tubewells. This is partly because old tubewells have been replaced, and partly because more families have their own tubewells rather than getting water from other families' pumps or public pumps. A quarter of

Table 2. The nature of Bangladesh's tubewells.

Measure	Source of information	First quartile	Median	Third quartile
Depth (metres)	Household survey	16.5	26.2	46.6
	Tubewell census	13.5	21.0	34.6
Age (years)	Household survey	2.5	6.5	12.5
Period household has used tubewell water for drinking (years)	Household survey (males)	10	20	30
		Less than 10 m (%)		Over 200 m (%)
Extreme depths	Household survey	7.9		8.6
	Tubewell census	11.4		1.2

Source: NCEPH, ANU Household Survey 2000, and Tubewell Census 2000, weighted data.

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the families have been drinking from tubewells for ten years and half for 20 years. Those in greatest danger are the 78.9% of the population who in 1991 (Mitra and Associates, 1992) were drinking from ordinary tubewells: 62% of the current population. The remaining 38% either were drinking deep tubewell water or surface and near-surface water at that time, or they were not yet born.

THE IMPACT OF THE ARSENIC CRISIS

The threat of massive arsenicosis and of substantial increases in the death rate is still only a potential one. It seems unlikely that there have been substantial numbers of deaths to date as a result of the poisoning, but there is no hard evidence on this. No one is quite sure what is going to happen. Very little is known of the epidemiology of arsenicosis. For the modestly high levels of arsenic found in many of the Bangladesh wells, we have no real knowledge at the population level of what this means in terms of evaluation of arsenic mortality levels or of other arsenic-related deaths over different periods. At the individual level we have even less knowledge. It seems possible for different people to take in similar amounts of arsenic with very different arsenicosis outcomes. Certainly, the higher rate of keratosis and skin pigmentation changes among males as opposed to females is only partly explained by different body masses. We do not know in what proportion of cases skin changes will lead to skin lesions, skin cancers, other cancers, gangrene, or liver and vascular damage. This can be seen in the most comprehensive examination of the situation (Abernathy *et al.*, 1997).

Arsenic-induced mortality appears to be associated with a long lead-time, except with such concentrations of arsenic as are rarely found in aquifers. Smith *et al.* (2000: 1095) reported that skin lesions typically have a latency period of about ten years depending on the volume of arsenic ingested. Skin cancers have a typical latency period of over 20 years (Smith *et al.*, 2000: 1096). Over half the population are less than 20 years of age and so are limited in the period they have been ingesting arsenic. Another tenth of the population were over 50 years of age when they began drinking tubewell water, and accordingly were at increasingly high risks of mortality from all causes. The causes of rural deaths can be estimated only in very broad categories, and post-mortems with pathology testing are extremely rare. Changes in skin colour and the thickening of skin on the palms and soles do not usually result in distress but are merely markers of potential arsenicosis. Most villagers find them hard to recognise. They do not examine each other's bodies very much (except for mothers with young children who rarely exhibit these symptoms), and, in any case, even before arsenicosis many people had blotchy skin, and hardworking, barefooted farmers and agriculture labourers did not lack horny soles and palms. These factors mean that we remain unsure of the impact of arsenic exposure in Bangladesh.

Nevertheless it should be possible to move beyond pure guesswork. Half the population has been drinking tubewell water for 20 years and a quarter for 30 years. Amongst this population there should be a fairly strong indication as to the likely size of the potential problem – at least as measured through the occurrence of skin lesions.

So far the rural population has not responded to the arsenic situation with the urgency afforded to it by many commentators. Information campaigns on arsenic are new, and many people remain uninformed of the situation. This point will be examined in more detail in the discussion of the survey data below. In addition to this it should be noted that the resort of nearly all the population to tubewell water for drinking is still relatively recent, and the appearance of individuals with the symptoms of arsenicosis even more recent. Few people are likely to know of deaths from arsenicosis, and fewer still that arsenicosis was the cause of death. Furthermore, there has been a tremendous psychic investment by both individuals and government in turning to bacteriologically pure tubewell water, and a suspicion that it may be years, if ever, before the dangers from arsenic eclipse those from surface water-borne diseases. This is aggravated by a realisation that most of the rural population cannot afford the fuel to boil surface water.

Furthermore, it has been hard for the

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authorities and others to provide reliable information to the local population because there is, as noted earlier, a lack of hard evidence about the impact on populations of modestly high levels of inorganic arsenic in water, either in Bangladesh or elsewhere. This is exacerbated by the lack of mortality or cause-of-death data, and the fact that many people, especially the poor, who being malnourished are most likely to suffer from arsenicosis, never visit a doctor. Moreover, adequate experience and epidemiological data are unlikely to come from elsewhere because the Bangladesh–West Bengal region is almost unique in having a large population – perhaps 200 million – living on an active delta, and one which receives huge quantities of minerals from nearby mountains in monsoonal floods.

MEETING THE CHALLENGE

The household survey sought to explore the effect on the rural population of government and NGO efforts to increase awareness, and to change behaviour so that the arsenic danger can be contained. The campaign has two main parts. The first is an informational effort using the media and the administrative system. The second is the testing of wells to ascertain arsenic levels so that the users can be warned when dangerous amounts of contaminant have been detected.

The informational campaign has been moderately successful, as is shown in Table 3, and will almost certainly reach the whole rural population eventually, just as the warnings about drinking untreated surface water did.

Table 3. The impact of the informational campaign.

Question	Responses	Male respondents, % ($n = 1890$)	Female respondents, % ($n = 1890$)
Has heard that something may be wrong with tubewell water	Yes	47.5	39.6
First source of information:	Administration	3.8	2.5
	NGOs	2.4	3.3
	Media	17.0	8.7
	Relatives, friends, neighbours	15.5	20.0
	Other, not certain	8.8	5.1
	Total	47.5	39.6
Message received:	Water contains poison called arsenic	20.6	11.3
	Water is bad or will cause sickness	18.1	17.9
	Water can eventually cause death	0.8	0.9
	Other	8.0	9.5
	Total	47.5	39.6
Resulting behavioural change:	No change	41.4	34.6
	Stopped using tubewell water for drinking	1.5	1.2
	Stopped using tubewell water for both drinking and cooking	0.3	0.3
	Filtered the water	0.2	0.3
	Boiled the water	1.2	1.1
	Other	2.9	2.1
	Total	47.5	39.6
Subsequent specific question on the worst outcome of the contaminated water	Death	9.9	10.3
	Permanent sickness	4.7	4.7
	Bouts of sickness	15.3	13.1
	Total	29.9	28.1

Source: NCEPH, ANU Household Survey 2000, weighted data.

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Nearly half the population has heard the arsenic warnings, more men than women as might be anticipated in a *purdah* society.

Significantly, the information is reaching the people more from the media, especially the radio, than through direct contact with officials or NGOs. Almost twice as many men as women receive the media messages, a reflection of higher educational levels and greater access to radio and television. In 1996–97, national levels for listening daily to the radio were 64% for men and 40% for women, and for watching television at least once a week, 53% and 27%. Rural levels were around three-quarters of national ones for radio, and half for television. Women's exposure to the radio rose with education (Mitra *et al.*, 1997: 20–21). Women partly made up for their lower media exposure by hearing from others, including husbands.

Seven-eighths of those who have heard of the danger are doing nothing about changing their water supply. Around 1.4% have stopped drinking tubewell water, 0.3% are trying to mitigate the danger by using filters, and 1.2% are futilely boiling the water. Part of the explanation is a low level of awareness of what is involved. Only about a tenth of the population is aware that the possibility of death is threatened. In addition, there is scepticism about the magnitude of the problem, frustration at having no easy solution, and a concern that any alternatives may be more harmful than current practice. The scepticism, or a decision to wait and see, arises, as we will show below, from not seeing people afflicted in the way that the campaign suggests. The delayed response is also explained by a lack of well testing and a suspicion that the lack of poisoning in the family is probably evidence that their well is all right.

The tubewell testing programme appears to be proceeding slowly. Table 4 shows the situation reported in the Household Survey and Tubewell Census. Only around 3% of all tubewells (Tubewell Census 2000) or 5% of wells currently being used at the household level (Household Survey 2000) have been tested (the difference between the estimates of the Tubewell Census and the Household Survey is due to a high concentration of tubewell numbers in the north of the country where arsenic is believed to be a relatively smaller risk and hence fewer tubewells have been tested). The Tubewell Census indicated that around 70% of those tested were marked red, 10% green and 20% were either not marked or were ambiguous. Probably most of the latter were tested as safe, although it is unclear. The proportion marked red is very high given estimates that only 35% of wells in the 43 most affected districts exceeded the Bangladesh Government's recommended level of no more than 0.05 mg/litre (BGS&MM, 2000). Combining data from the Household Survey for currently used wells with previously used wells abandoned following testing and being painted red, suggested a lower percentage of tested wells marked as red, below half, but still higher than national estimates of the proportion of wells over 0.05 mg/litre of arsenic. One explanation is simply that the areas where testing was conducted were those areas where arsenic levels were highest. It may also reflect the inaccuracy of portable measuring equipment, which has led UNICEF to recommend that

Table 4. Tubewell testing and the aftermath ($n = 3780$).

		%
Household Survey 2000		
Family drinks water from ordinary tubewell		87
This tubewell has been tested		5.2
Tubewell marked:	red	1.7
	green	1.9
	not marked, other	1.6
Family has stopped drinking from tubewell as a result of marking		0.3
Family previously drank from a/another tubewell		71
This tubewell was tested		2.3
Tubewell marked:	red	1.6
	green	0.2
	not marked, other	0.5
Tubewell Census 2000		
Tubewell tested		2.7
Tubewell marked:	red	1.9
	green	0.3
	not marked, other	0.6

Source: NCEPH, ANU Household Survey 2000, Tubewell Census 2000, weighted data.

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wells recording more than 0.02 mg of arsenic be marked red (UNICEF, 2000). This procedure will clearly have major economic and health consequences if users of wells with low levels of contamination resort to surface water.

The data indicate that most people whose wells were marked red stopped using water from those wells. It may be noted, however, that many were changing to surface water that had its own risks. Among those who had ceased drinking from a marked tubewell, 45% returned to surface water, 34% moved to an ordinary tubewell not marked as dangerous, and 21% found a deep well source. Those who continued to drink from a well marked as contaminated mostly believed that they had little choice except to return to surface sources, and that such a move would be premature unless there was some sign that their continued drinking of tubewell water was proving deleterious to family health.

The evidence provided to people by symptoms of physical illness among local people has been slow in coming. The respondents were asked a series of questions on possible arsenic-related illnesses. The first was whether there were any household members over the age of 18 years suffering from an illness caused by tubewell water: 0.2% of respondents said there were – this question was restricted to those over 18 years since arsenicosis is believed to be most prevalent amongst the adult population. In answer to a more specific question on whether anyone in the household of any age was suffering from the effects of arsenic, only 0.2% of respondents reported household members of any age suffering – 13 cases in all were identified. Many in the population were unaware of arsenic-related illness and an even higher proportion of its manifestations as the symptoms of arsenicosis, notably changes in skin pigmentation, accompanied by thickening of the skin of the soles and palms, and skin lesions. The survey interviewers asked the respondents about the presence of what the project designers regarded as being key symptoms of arsenicosis present in virtually all cases. These were whether any member of the household had a rash or discoloured skin on: (a) the palms; (b) the soles; (c) the chest; (d) the back; and (e) any other place. The questions were designed to be sensitive rather than specific, leading if anything to over- rather than under-recording of cases. The results are shown in Table 5.

These findings are national and are not directly comparable with individual villages identified as having acute problems. When Ahmad *et al.* (1999) reported on their examination of Samta in Jessore District, 12 kilometres from the Indian border and in the area where high arsenic contamination was first detected in Bangladesh in 1993, they found 87% of the tubewells with over 0.05 mg/litre of arsenic, 10% of the population with some degree of melanosis or keratosis, but only 0.6% with precancerous skin lesions, and 0.08% were identified with cancer. Where people were drinking from wells with less than 0.05 mg/litre, not a single person with arsenicosis was found.

Table 5. Responses to questions on the presence of arsenicosis.

	Male respondents, % ($n = 1890$)	Female respondents, % ($n = 1890$)
Is anyone in your family over the age of 18 years suffering from an illness caused by tubewell water? YES	0.2	0.2
(Question asked before arsenicosis symptoms explained)		
Do you think anyone (any age) in your family is suffering from the effects of arsenic? YES	0.2	0.2
(Question asked after arsenicosis symptoms were explained)		
Has anyone in your family any of the symptoms? YES	0.9	1.5
Proportion of all persons in survey identified as presenting arsenic symptoms	0.2	0.4
Proportion of respondents identified as presenting arsenic symptoms	0.5	0.4

Source: NCEPH, ANU Household Survey 2000, weighted data.

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Arsenicosis takes a long time to develop and may be very capricious in how it strikes. Given the BGS estimate that 35% of wells in 43 high prevalence districts exceed 0.05 mg/litre, Ahmad's figures, if extrapolated, imply substantially higher levels of arsenicosis than reported here. It is interesting to note, however, that 31 (54%) respondents reporting arsenic symptoms were in Khulna (which includes Jessore District and Samta) and Barisal Divisions, which represent 19% of the country's population.

Three points should be noted. First, in the Household Survey females everywhere reported more arsenicosis symptoms than males. This may demonstrate either greater sensitivity or greater suggestibility, or it may mean that women see a larger proportion of the family's bodies than do men. Certainly they are expected to be more sensitive to illness and to symptoms than are men. The second possibility receives some support from the fact that women were more likely to identify symptoms among female family members. Given that many respondents, especially males, may not have been aware of the symptoms of other family members, the figures on the proportion of respondents reporting their own symptoms should be more accurate. Self-reported prevalence was higher, especially for male respondents, but this may partly reflect the fact that the respondents are on average older than their family members and hence more likely to suffer from rashes, whether caused by arsenic or not. The second point is that these are self-reported status figures of arsenicosis symptoms. Doubtless some cases have been missed, but there is also the possibility that other skin conditions have been mistaken for arsenicosis. Clinical examination may result in a higher rate of diagnosis, but as noted, the question was designed to be oversensitive. The authors are currently undertaking a follow-up survey involving the clinical examination of all reported cases of arsenicosis and household members, and a sample of 25% of households reporting no symptoms to verify the findings reported here. The third point is that the arsenic message from the government is not managing to get over the information about arsenicosis symptoms.

The reported level of arsenicosis symptoms is at present low, except in specific villages with long-term use of tubewells and high levels of groundwater arsenic throughout all parts of the area. Even if we take the upper-level estimate provided by the proportion of respondents reported to be afflicted, noticeable symptoms affect only 0.5% of the entire rural population, or if extrapolated to the population as a whole, around 500 000 people. Half a million people is a very sizeable population, but the figures raise important questions as to the priority of arsenicosis in the list of Bangladesh's public health challenges, and the most appropriate means to tackle it. As noted above, half the population has been drinking tubewell water for 20 years, so, while the number affected will increase, the increase is unlikely to be exponential. Furthermore, as reported above, Ahmad *et al.* (1999) found that only 6% of those with any degree of melanosis or keratosis showed pre-cancerous skin lesions, and only 0.08% had cancer.[3]

In terms of the success of government programmes, it is significant that no more than 1.5% of females and 0.9% of males could identify family members as having arsenicosis-associated symptoms, even using a sensitive test. On their estimation the proportion was 0.2%. This is why families are reluctant to give up drinking tubewell water, and probably why the government was at first somewhat slow to react. This reluctance would be reduced if there were obvious alternative and easily accessible sources of good water, but there are not.

OVERVIEW

Probably about 20 million Bangladeshis are drinking water above the Bangladesh Government's recommended maximum acceptable level of arsenic (0.05 mg/litre of water), and many more above the level recommended by the World Health Organization of 0.01 mg, and so may be said to be in danger of arsenicosis. It is doubtful whether more than half a million have symptoms of arsenicosis yet. Too little is known about the effects of long-term exposure to modestly high levels of arsenic to be able to predict with any accuracy what proportion of the 20 million people will develop arsenicosis, let alone die of it. But on the findings of the

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survey and what is known of arsenic poisoning, it is probably safe to say that the considerable majority of these people will not develop arsenicosis, and that most of the rest will not die of it but of some other unrelated condition. The reasons include the following. Most of this population have been drinking tubewell water for at least two decades, and many considerably longer, and are yet to develop symptoms. Many of this group are drinking water in the 0.05–0.10 mg/litre range, and it seems likely that a significant proportion of people can tolerate this level for many years. This includes a disproportionate number of females, better-nourished persons, and those not suffering from hepatitis B. Many people were middle-aged when they first started to drink tubewell water and, in a country with a life expectancy at birth still under 60 years, are at much greater risk of dying from other causes.

These qualifications are needed to place the crisis in perspective, to modify some of the more extreme scenarios, and to explain the relative passivity of the population in the face of the situation. They do not suggest that there is no crisis. In terms of absolute numbers affected and the potential number of victims, it may well be the biggest poisoning in history. Hundreds of thousands and possibly millions are at risk of suffering and in some cases dying from arsenic poisoning unless the situation can be changed. In particular, arsenic poisoning may become a significant cause of adult mortality. It will act to slow the rise in adult life expectancy. Its overall impact on mortality and life expectancy will, however, be much less since it has such a long latency period, rarely affecting people in less than 20 years and usually much longer, in a country where only a few people live to old age.

The Bangladesh programme to improve the situation is still feeling its way, and there are no clear solutions to the difficulties. The first reactions were probably sensible: to place an emphasis on testing tubewell water and the use of relatively safe wells with a concentration of arsenic below 0.05 mg/litre, rather than to adopt the stricter international standard of 0.01 mg/litre. To do the latter would have the effect of forcing many more people either to turn to surface water with its risk of biological contamination, or to treating tubewell water using methods with unproven efficacy and safety. There have been problems with the design and provision of adequate testing equipment, and the programme is by no means in top gear yet. By early 2000, probably no more than 5% of tubewells had been tested, and the same results were often not achieved when two different groups did the tests. Anecdotal evidence suggests that the proportion tested has risen substantially since. The new survey will provide more information on this.

There are some hopeful aspects to the crisis. The population does react to public health promotion, as is evidenced by the almost universal suspicion of drinking untreated surface-water, and by child vaccination rates at around 80% in rural areas (Mitra *et al.*, 1997: 118). In one sense the present programme is working: almost half the population has heard that there may be problems with drinking tubewell water. Most families whose wells were marked red did stop using them for drinking. Many, however, had changed to other sources of water, which may be affected by bacterial contamination.

The programme is not working in the following ways: (1) not enough people know just what the arsenic danger is; (2) too few can recognise arsenicosis symptoms; (3) far too few tubewells have been tested — although as noted, this may be changing; and (4) many people do not know what their alternatives are. The first three problems can be overcome by effort, expenditure and time. The real problem is the fourth, with no clear or simple solutions.

The easiest and perhaps eventual solution may be to concentrate all drinking on safe wells. Nearly every village contains at least some safe wells: perhaps two out of three even in the most arsenic-contaminated Divisions, and one in four even in the worst-affected local areas. But this depends on universal well testing, unambiguous marking, and continued retesting of the wells being used. This may place an excessive load on the safe wells and the households owning them, and may have to be supplemented with the drilling and testing of new wells, and the use of contaminated wells for bathing and even dishwashing. There

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is some danger that, if too much emphasis is placed on the dangers of tubewell drinking, in the absence of appropriate testing people may turn to sources of water which are much more dangerous, at least in terms of microbiological infection.

The use of water from deep tubewells, held to be less affected by arsenic, may seem an obvious solution, until it is realised that such wells may require mechanical pumps and cost many times more than ordinary tubewells. There is the possibility of public investment in community deep wells and of diverting some water from existing agricultural pump wells. In the latter case the water would have to be collected near the pump rather than allowing microbial infection as water passes along earthen surface channels. Almost 7% of households already get their water from deep wells, and the figure rises to over 60% near the coast. There is no certainty, however, that arsenic will not eventually leach into the aquifers from which deep wells draw their water.

Another alternative, although one that most of the rural population now reacts against, is to return to surface water. This would mean a return to the old system of protected tanks, perhaps the treatment of tank water with chemicals, and more boiling of drinking water than in the past. It may also involve the revival of practices such as adding alum (*phitkiri*), which declined after the widespread adoption of tubewell water. This approach could work given that the population is more hygiene-conscious than in the past. Indeed, as noted, the tubewell revolution may be responsible for a smaller fraction of the infant and child mortality decline than is usually attributed to it.

There are possibly more technical fixes, but all have problems and some are expensive. Water can be collected off galvanised iron roofs, or off cheap plastic sheets, as has been done with some success in the salt-water areas bordering the Bay of Bengal, but the length of the dry season would incur considerable storage expenses and the volume of stored water might prove to be insufficient. Small sand-filter treatment systems for surface water can be constructed for populations of 200–500 people, but there are problems of both cost and contamination (Ahmed, 1999: 4.4–4.5). Filtering systems employing cheap chemicals such as alum or ferric salts for precipitation or adsorption can be used on individual pumps to reduce the level of arsenic by as much as two-thirds, but their use has not yet proceeded far beyond the experimental stage (Ahmed, 1999: 4.7–4.8). The Household Survey 2000 found over 1% of households attempting this approach. Ahmed (1999: 4.11–4.12) pointed to problems of quality assurance and dose control, as well as chemical residues, and concluded: 'The use of unknown chemicals and patented processes without adequate information should be totally discouraged'. Most of these approaches also suffer from high financial and labour cost imposition on households, and reduce the control that the households have over their water supply. It is important to remember here that about half the respondents (more women) placed great emphasis on the convenience of tubewells, no longer having to rely on neighbours, and controlling their own water supply. This is a considerable hurdle to overcome in changing households from contaminated water sources. The authors of this study are involved in an investigation examining the health impact and costs of alternative arsenic mitigation approaches. The study is concerned not simply with the impact of arsenic poisoning, but also other health outcomes such as increased diarrhoea from the use of alternative water sources.

The arsenic crisis is a major public health challenge for Bangladesh and potentially the biggest mass poisoning the world has seen. Much yet remains to be learnt about it. The Arsenic Household Survey 2000 and the Tubewell Census 2000 were efforts to provide a balanced national picture. The study has sought to provide some tentative estimates of the public health size of the problem. The data are by no means conclusive, being based on self-assessment, and many of the people at risk in the longterm are yet to show symptoms. Nevertheless, the findings do provide a basis for a national assessment of the likely size of the problem. The studies have also shown how little the rural population know at present about arsenicosis. Hesitation at both the family and governmental level to adopt effective policies lies less in lack of will than in a

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justified uncertainty at the household level about what to do in the absence of water testing; and at the household and government levels, what to do once arsenic is detected.

The problem will be on its way to a solution only when highly professional government and NGO teams arrive in villages with an agreed-upon programme for combating arsenic poisoning. This must include locating and testing all tubewells, informing local officials, and educating the people. At present tubewell testing is likely to proceed faster than knowledge of arsenicosis symptoms and outcomes. But the decisive part of the programme will be a high degree of certainty in advice on what to do next, and some help in moving in that direction. Until the more technical solutions are really practicable at an affordable cost, these decisions may be in some areas to use only the safe tubewells, in others to depend more on deep tubewells, and, in places where it can be afforded, to boil surface water from protected ponds. Programmes suited to each village will have to be agreed upon and implemented, even if different programmes replace them in subsequent years. The solutions, however, will have to be balanced. There will be no benefit to the people of Bangladesh if a programme is undertaken which is unrealistic and overly difficult or costly to implement – in a country that is currently struggling to meet other health priorities such as reducing maternal mortality. It is particularly important that any proposed interventions should not detract from other health priorities such as control of diarrhoeal disease among infants.

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NOTES

(1) Data from ICDDR,B's Matlab field site indicated that for the period, 1966–77, 26% of all deaths were due to diarrhoea, and 47% of deaths of children aged 1 to 4 years. For the latter period, 1978–87, the rate fell slightly to 20% of all deaths (in the control area), and 34% of deaths of children aged 1 to 4 years – the figures are only approximately comparable because of changes in the methods used for determining cause of death (Baqui *et al.*, 1994: 177).

(2) Recent Matlab data indicate that in 1999, 9% of all deaths were due to diarrhoea and dysentery, and 20% of deaths of children aged 1 to 4 years (ICDDR,B 2001:31–2).

(3) To put this in context, this is fewer than would be measured in such a study in Australia where the prevalence of skin cancer is estimated to be over 1% (Marks, 1997), and estimates for precancerous solar keratosis are up to 46% (Frost *et al.*, 2000).

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