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Groundwater arsenic contamination status and its impact on humans' health in Bangladesh

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ABSTRACT

From our preliminary survey (1995 to 2000), 33,092 hand tube wells water samples, collected from all 64 districts and found arsenic in 60 districts above WHO recommended value in drinking water (10 µg/L) and in 50 districts above maximum permissible limit, 50 µg/L. In these 50 districts the actual arsenic status is, 37% contains arsenic less than 10 µg/L, 63% and 42% contain arsenic above 10 µg/L and 50 µg/L, respectively. Total population of these 50 districts is about 104.9 million. This does not mean all populations in the 50 districts are drinking arsenic contaminated water or suffering, but undoubtedly, they are at risk. From our study, it appears that groundwater of Hill Tract and Table Land are almost free from arsenic contamination but that of Flood Plain and Deltaic areas are highly arsenic contaminated. During our preliminary survey, people suffering from arsenical dermal lesions have been identified in 31 out of 33 districts where we had made a preliminary dermatological investigation with medical team. From a random of 18,840 examination people in arsenic affected villages where people were drinking arsenic contaminated groundwater during last 6 years. We had registered 3,427 adults (both females and males) and 298 children (both girls and boys), having arsenical dermal lesions, such as: melanosis, leucomelanosis, keratosis, hyperkeratosis, dorsal, non-petting oedema, gangrene, cancer, etc. If children are included, then 19.77% (n=3,725) have arsenical dermal lesions and for separately adults and children these are 24.52% and 6.13%, respectively.

Thousands of hairs, nail, and urine samples from the people of arsenic affected villages were collected and analyzed. From our study we have observed that arsenic in hair, nail, and urine increases with increasing arsenic in drinking water. It appears that correlations are not strong positive [for hair samples $r = 0.251$, $p = 0.01$, $n = 739$; for nail samples $r = 0.220$, $p = 0.01$, $n = 691$, and for urine $r = 0.547$, $p = 0.01$, $n = 910$]. Probable reason, people are not drinking water from the same source all the times. Our field data indicates that most of the villagers drink water from more than one tube wells. From multi-elements analysis of some hair and nail samples it appears that Zn and Se concentration decreases with increasing arsenic concentration in both hair and nail. The concentration of Zn and Se also less in affected people's hair and nail than control hair and nail (drinking water contain arsenic <3 µg/L). But the linear regression shows positive correlation between As & Pb, As & Hg, and As & Sb in both hair and nail of exposed population. The concentrations of As, Pb, Hg, and Sb also high in affected people's hair and nail than control hair and nail. Our last 6 years of field experience in Bangladesh show that normally children under 11 years of age do not show arsenical dermal lesions. But we have observed few exceptions when (a) the arsenic content in water consumed by children is very high (1000 µg/L) and (b) the arsenic content is not very high (500 µg/L) but the children get poor nutrition.

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Introduction

In early 1960, physicians in Antofagasta, Chile noticed dermal manifestations and some deaths among those drinking supplied water contaminated with arsenic. The contamination culminated from leaching of arsenic wastes from mining operations into spring water. The symptoms were metamorphosis of skin color and hyperkeratosis; children were suffering from bronchopneumonia and bronchitis. The arsenic contamination incident in well water of Taiwan (1961-1985) is also well known. Limited incident of black-foot disease and arsenism were found and was associated with a variable of high concentration of arsenic (100 to 1,810 µg/L in drinking water). Some cases of cancer (bladder, kidney, and liver) were also noted in endemic areas. Over the years, perhaps it was believed that arsenic alone was responsible for the black foot disease is that area. In 1975, the discovery of fluorescent compounds in these well waters led to the isolation of humic substances and now arsenic in combination with humic substances is considered to be the probable cause for the black-foot disease. In Monte Quemado of Cordoba Province, North Argentina similar incident of arsenic in groundwater was reported. It is known as the "illness of Bell Ville (Cordoba)". From the observations in Cordoba, it was concluded that the regular intake of drinking water containing more than 100 µg/L of arsenic leads to clearly recognizable signs of toxicity and ultimately causes, in some cases, skin cancer. Chronic arsenic poisoning was also reported in some parts of Region Lagunera, situated in the central part of North Mexico during 1963- 1983. The arsenic concentration in groundwater to the exposed population was 410 µg/L. Other incidents pertaining to groundwater, a small population was drinking arsenic contaminated water only some arsenical cutaneous manifestation was reported in Poland Ontario - Canada, Nova Scotia - Canada, Hungary, Millard County- Utah, USA.

In 1987, Chakraborti and Saha reported arsenical dermal lesions in 5 districts of West Bengal-India and found 197 patients' sufferings from arsenical dermal lesions in 48 families. During January 1989 to June 2001 survey was conducted by School of Environmental Studies (SOES), Jadavpur University, Kolkata in nine arsenic affected districts and present estimates indicate that 74 blocks (2,600 villages including some municipal areas) mainly by the eastern side of the river Ganga and adjoining areas are affected. More than 6 million people are drinking arsenic contaminated water above 50 µg/L and more than 300,000 people may have arsenical dermal lesions.

During field survey of School of Environmental Studies (SOES) in arsenic affected districts of West Bengal-India particularly at the bordering area of Bangladesh in 1990, a woman arsenic patient who came to West Bengal-India after her marriage had been identified. Till 1994 more arsenic patients from Bangladesh were identified from the bordering area of West Bengal-India with Bangladesh. During the international conference "Arsenic in groundwater, cause, effect and remedy" held at Jadavpur University, Kolkata in February 1995, the problem of Bangladesh was highlighted by SOES. Subsequently the preliminary survey during 1995-1996 by SOES, jointly with the department of Geology, University of Rajshahi and National Institute of Preventive and Social Medicine (NIPSOM), Bangladesh, pointed out the arsenic contamination of groundwater and resultant sufferings of people in Bangladesh. In the meantime, representatives of the Dhaka Community Hospital (DCH), Bangladesh, came to SOES in November 1996 and analyzed water, hair, nail, urine, and skin-scale samples of some victims from arsenic affected districts of Bangladesh. For a detail study, SOES, Jadavpur University, Kolkata carried out a joint survey with the Dhaka Community Hospital Trust from December 1996 to January 1997 and found groundwater highly arsenic contaminated and arsenical dermal lesions among the people of 14 affected districts of Bangladesh.

To avoid microbial and chemical contamination from surface water, groundwater is becoming the major source of drinking water round the world, especially in the developing countries. Another reason for wide use of groundwater is its easy access and economic viability. Not only groundwater is used for drinking, but also by the farmers in many developing countries like Bangladesh, India, and China, groundwater is their main source of irrigation. These countries have made green revolution with the help of underground water. Earlier, India and Bangladesh could get only one crop a year and that too was rain dependent. But now usually three to four crops in a year are common and the source of water for irrigation lies underground (Fig. 1). In Bangladesh and West Bengal-India irrigation using groundwater was first started in and around the sixties. In both these countries, there is no groundwater withdrawal regulation; as a result, groundwater exploitation goes on unchecked. In Bangladesh and West Bengal-India more than 95% of the Rural Water Supply Schemes (RWSS) depend on underground water. Dhaka (population about 11 million, 2000) is the only city in the world where more than 95% of the domestic water requirement comes from underground water schemes.

Figure 1: Using groundwater for irrigation

The incidents of arsenic contamination in groundwater and sufferings of people from chronic arsenic toxicity resulting from the drinking of the contaminated water. Around the world are documented now.

There are approximately 21 counties in the world where cases of arsenic contamination of groundwater are known. Out of these, Bangladesh calamity is considered to be the largest in the world.

Materials and Methods

The materials and the methods were previously described 1-7.

Results and Discussion

The total population of Bangladesh is around 120 million (2000). In our study for over last 6 years in Bangladesh, we had analyzed till December 2000, 33,092 hand tube wells water samples, collected from all 64 districts and found arsenic in 60 districts above WHO recommended value in drinking water (10 µg/L) and in 50 districts above maximum permissible limit, 50 µg/L (Figs. 2 and 3). In these 50 districts the actual arsenic status is, 37% contains arsenic less than 10 µg/L, 63% and 42% contain arsenic above 10 µg/L and 50 µg/L, respectively (Fig. 5). Total population of these 50 districts is ~104.9 million. This does not mean all populations in the 50 districts are drinking arsenic contaminated water or suffering, but undoubtedly, they are at risk.

There are four principal geomorphological areas/regions in Bangladesh, (a) Hill Tract, (b) Table Land, (c) Flood Plain, and (d) Deltaic area including coastal belt. From my study, it appears that groundwater of Hill Tract and Table Land is almost free from arsenic contamination but that of Flood Plain and Deltaic area are highly arsenic contaminated (Figs. 2-4).

During our survey we had also collected hair, nail, skin scales (skin scale from those having keratosis), and urine samples from the people of these villages. Biological samples were collected from 40-50% of those having skin lesions and rests of the samples were from those without skin lesions. Parametric presentation of arsenic situation (from six years study) in Bangladesh is shown in Table 1.

During this survey, arsenic patients were identified in 222 villages of 69 police stations under 31 out of 33 districts.

Where survey was conducted (Fig. 6). The numbers of people we had examined, including children were 18,840 and 3,725 people were identified with arsenical skin lesions. Table 2 shows our overall findings among adults and children in different districts. Normally, there were 6-8 people in our team, including at least 2 medical personnel. But I feel the number of days we spent to survey in 34 districts were negligible compared to the number of days actually needed. In most of the cases we had superficially surveyed the villages without any in-depth study. Sometimes, due to time constrain we had to leave one village for the next village without recording patients. At present, we have information of about 74 more villages where people have arsenical skin lesions, but we could not visit those sites. From our experience of the last about 6 years from arsenic affected districts of Bangladesh we feel we have identified only a small

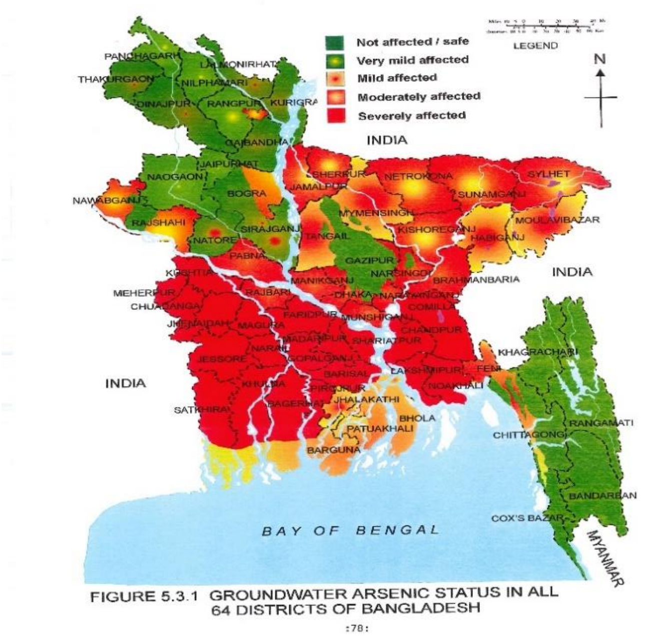

Figure 2: Groundwater arsenic status in all 64 districts of Bangladesh

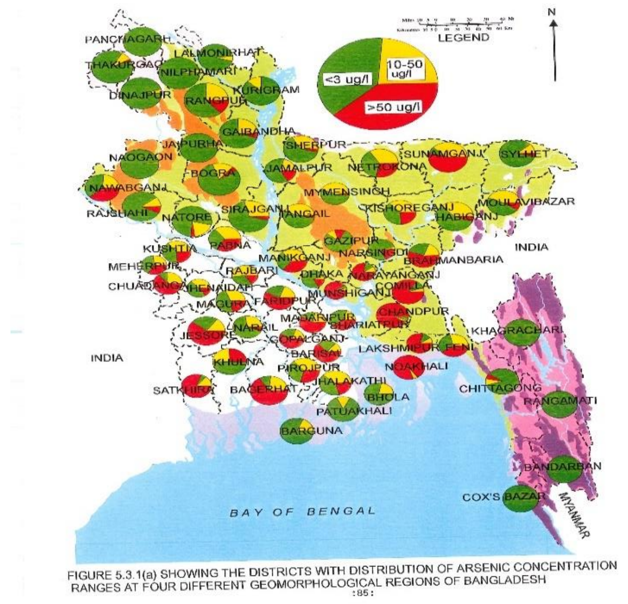

Figure 3: Showing the districts with distribution of arsenic concentration ranges at four geomorphological regions of Bangladesh

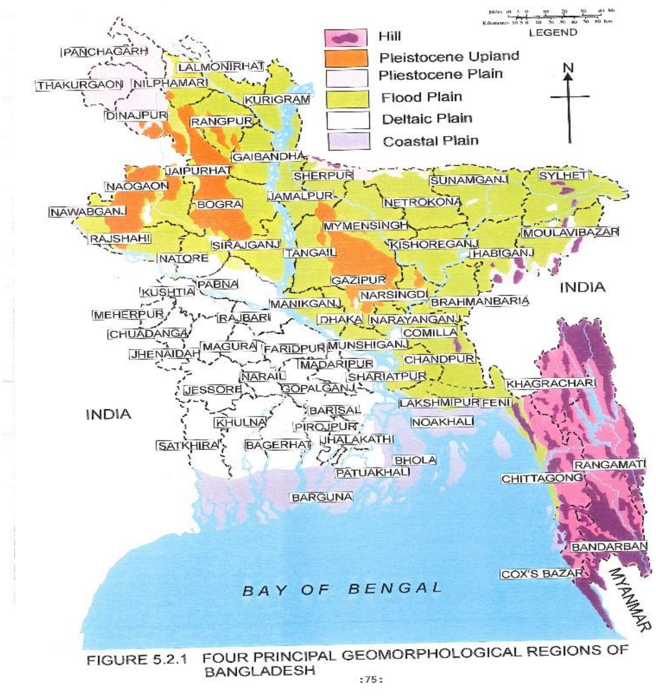

Figure 4: Four principal geomorphological regions of Bangladesh

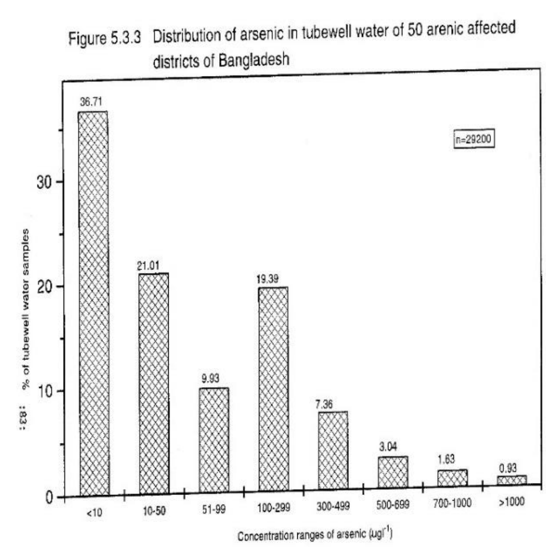

Figure 5: Distribution of arsenic in tube wells water of 50 arsenic affected districts of Bangladesh

Table 1: Parametric presentation of arsenic situation in Bangladesh

S. No.	Parameters	
01	Total No. of districts in Bangladesh	64
02	No. of district we have surveyed	64
03	No. of districts where arsenic in groundwater> 10 µg/L	60
04	No. of districts where arsenic in groundwater >50 µg/L	50
05	No. of districts where we have surveyed for arsenic patients	33
06	No. of districts where we have identified for arsenic patients	31
07	No. of police stations surveyed for arsenic patients	77
08	No. of police stations where we have identified arsenic patients	69
09	No. of villages surveyed for arsenic patients	253
10	No. of villages where we have identified arsenic patients	222
11	Total No. of people examined for arsenic patients	18,840
12	No. of patients identified	3,725
13	Total No. of adult examined	13,976
14	No. of adult patients identified	3,427 (24.52%)
15	Total No. of children examined	4,864
16	No. of children patients identified	298 (6.13%)
17	Total No. of hair samples analyzed	4,386
18	% of hair samples content arsenic above toxic level	83
19	Total No. of nail samples analyzed	4,321
20	% of nail samples content arsenic above normal level	94
21	Total No. of urine samples analyzed	1,084
22	% of urine samples content arsenic above normal level	95
23	Total No. of skin scales samples analyzed	705
24	Arsenic concentration range in skin scales samples with mean value	600 to 53,390 µg/kg (mean value 5,730 µg/ kg)

percentage of the total number of people affected in the villages we had surveyed. In our study procedure, the expert group (medical personnel and others) sits in a camp in the affected village and villagers were informed to come to the camp for examination. Those who came to our camp were examined and registered in the format.

But discussing with villagers it appeared that 15-20% of the total number of people suffering from arsenicosis really came to the arsenic camp for examination.

Table 2: shows overall findings among adults and children in different districts.

Name of the districts	Area in sq.km	No. of police stations (P.S.)	Population	No. of police stations surveyed	No. of police stations where patients identified	No. of villages surveyed	No. of villages where patients identified	No. of people examined	No. of patients identified	Adult male patients	Adult female patients	Child patients
Bagerhat	3959	9	1611000	2	2	9	9	670	200	133	60	7
Barisal	2791	10	2481000	3	2	5	5	358	57	25	32	-
Bogra	2920	11	3053000	1	I	I	1	280	21	6	11	4
Chuadanga	1158	4	921000	1	I	7	3	219	119	53	48	18
Chandapur	1704	7	2309000	6	5	33	33	1605	157	98	55	4
Camilla	3089	12	4751000	4	4	6	6	509	68	32	29	7
Faridpur	2073	8	1678000	3	3	14	13	804	151	76	60	15
Gopalganj	1490	5	1169000	4	2	7	7	267	34	14	15	5
Gazipur	1741	5	1899000	1	1	1	I	92	7	5	2	-
Jessore	2567	8	2387000	5	4	9	9	1871	476	187	218	71
Jhenaidaha	1961	6	1540000	2	2	2	2	235	56	33	19	4
Jamalpur	2032	7	2111000	1	1	3	3	222	79	35	35	9
Kushtia	1621	6	1691000	3	3	15	15	891	240	108	94	38
Khulna	4395	14	2417000	2	2	5	5	684	105	60	36	9

Name of the districts	Area in sq.km	No. of police stations (P.S.)	Population	No. of police stations surveyed	No. of police stations were patient identified	No. of villages surveyed	No. of villages where patients identified	No. of people examined	No. of patients identified	Adult male patients	Adult female patients	Child patients
Kishoreganj	2689	13	2574000	1	1	3	3	307	18	14	4	-
Lakshmipur	1456	4	1502000	3	3	27	25	2283	521	314	191	16
Meherpur	716	2	555000	2	1	11	7	580	190	103	64	23
Madaripur	1145	4	1185000	3	3	11	9	1038	81	24	57	1
Magura	1049	4	815000	3	3	3	3	296	41	15	21	5
Munshiganj	955	6	1309000	1	1	2	2	27	5	1	4	-
Mymensingh	4363	12	4450000	1	1	8	1	46	3	2	1	-
Manikganj	1379	7	1293000	3	2	7	3	103	8	3	2	3

Nawabganj	1702	5	1346000	2	2	7	7	459	212	119	88	5
Narsingdi	1141	6	1864000	3	2	2	2	178	12	8	3	1
Narayanganj	759	5	2013000	1	1	11	8	602	93	46	44	3
Noakhali	3601	6	2547000	3	3	13	13	1246	216	86	120	10
Pabna	2371	9	2266000	5	5	19	16	1860	342	171	146	25
Rajshahi	2407	13	2255000	3	3	5	5	443	107	52	43	12
Rajbari	1119	4	941000	1	1	2	2	103	8	4	4	-
Rangpur	2308	8	2475000	1	1	2	1	297	38	25	10	3
Satkhira	3858	7	1780000	3	3	3	3	266	60	34	26	-
TOTAL=31	66515	227	61188000	77	69	253	222	18840	3725	1885	1542	298

People suffering from arsenical dermal lesions have been identified in 31 out of 33 districts where we had made a preliminary dermatological investigation with medical team. From a random of 18,840 examination people in arsenic affected villages where people were drinking arsenic contaminated water during last 6 years. We had registered 1,885 males, 1,542 females, and 298 children, having arsenical dermal lesions, such as: melanosis, leucomelanosis, keratosis, hyperkeratosis, dorsal, non-petting oedema, gangrene, cancer, etc. (Figs. 7-9). If children are included, then 19.77% (n=3,725) have arsenical dermal lesions and for separately adults and children these are 24.52% and 6.13%, respectively.

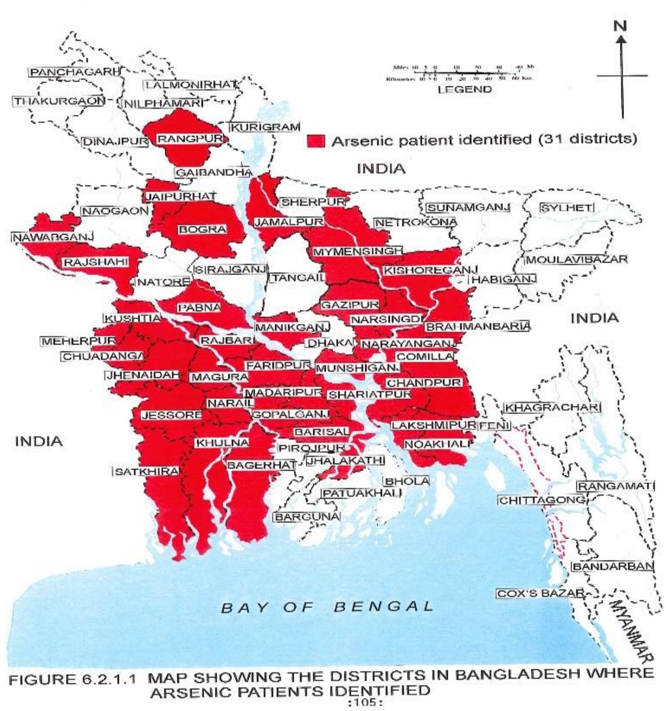

Figure 6: Map showing the districts in Bangladesh where arsenic patients identified

Figure 7: People suffering from arsenical dermal lesions (a few examples) have been identified in Bangladesh

Figure 8: People suffering from arsenical dermal lesions (a few examples) have been identified in Bangladesh

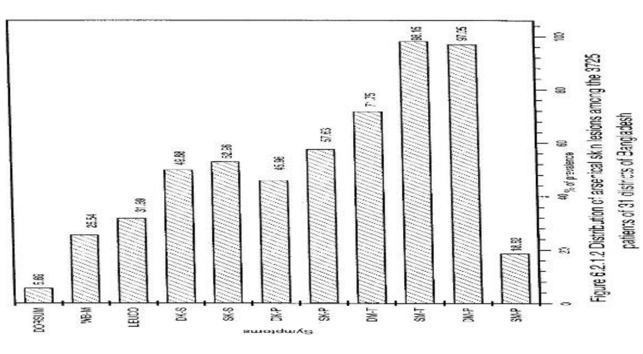

Figure 9: Distribution of arsenical skin lesions among the 3,725 patients in 31 districts of Bangladesh

We had identified people with arsenical manifestation such as dorsum, whole body melanosis (WBM), leucomelanosis (Leuco), diffuse keratosis on sole (DKS), spotted keratosis on sole (SKS), diffuse keratosis on palm (SKP), spotted keratosis on palm (SKP), diffuse melanosis on trunk (DMT), spotted melanosis on trunk (SMT), diffuse melanosis on palm (DMP), and spotted melanosis on palm (SMP). Buccal mucus membrane melanosis (MMM) on tongue, gums, lips, etc. also found. Rough dry skin often with palpable nodules (spotted keratosis) on dorsal of hand, feet, and legs are the symptoms seen in severe cases (Figs. 7-9).

Thousands of hairs, nail, and urine samples from the people of arsenic affected villages were collected and analyzed. Statistical presentation of arsenic in hairs, nail, urine (arsenic metabolites), and skin scale samples from the villagers of the arsenic affected villages of Bangladesh where we have found arsenic patients are presented in Table 3.

Table 3: Status of biological samples collected from the people of arsenic affected villages in Bangladesh were we have found arsenic patients.

Parameter	Arsenic in hairs (µg/kg)	Arsenic in nail (µg/kg)	Arsenic in urine (µg/L)	Arsenic in skin scales (µg/kg)
No. of observation	4386	4321	1084	705
Mean	3390	8570	280	5730
Median	2340	6400	116	4800
Minimum	280	260	24	600
Maximum	28060	79490	3086	53390
Standard deviation	3330	7630	410	9790
% Of samples having arsenic above normal/toxic (hair) level	83.15	93.77	95.I I	-

Normal level of arsenic in hair ranges from 80 - 250 µg/Kg; 1000 µg/Kg is the indication of toxicity[8]

Normal level of arsenic in nail ranges from 430 - 1080 µg/Kg[9]

Normal excretion of arsenic in urine ranges from 5 - 40 µg/day[10]

There is no normal value for skin scale in literature

About 40-50% of these samples were from people having arsenical skin lesions and rest of the samples from non-patients but they were living in the arsenic affected villages. The analytical report shows that 95.11%, 83.15%, and 93.77% of the samples we had analyzed have arsenic in urine, hair, and nail above normal/ toxic level (hair), respectively. During our dermatological survey in the affected villages, we have observed that out of 5 people drinking the same arsenic contaminated water, 2 may not show arsenical skin lesions, but their hair, nail, and urine contain high level of arsenic like other members. Thus, many of the villagers may not have arsenical skin lesions, but they are sub-clinically affected. However, we do not expect such elevated level of arsenic in biological samples from all villagers. The probable reason for such elevated levels of arsenic in hair, nail, and urine is that we have collected these samples from those villagers where arsenic patients exist and many tube wells are highly contaminated. The picture may be different in areas where groundwater is not much contaminated. The overall results from 50 districts show that 37% of the tube wells are safe to drink, according to the WHO recommended value (10 µg/L). Therefore, about 37% of the people should not show an elevated level of arsenic in the biological samples. A study was carried out by our group in 1998[11] to understand why body burden is higher among those using safe water for drinking and cooking, while living in arsenic affected villages. In this study, safe water from a source having less than 3 µg/L arsenic was supplied for 2 years to 5 affected families to study the loss of arsenic through urine, hair, and nail. The study finally showed that despite having safe water for drinking and cooking, the study group could not avoid an intake of arsenic from contaminated food, food materials contaminated by washing, and the occasional drinking of arsenic contaminated water[7]. Arsenic in groundwater and in hair, nail, and urine of the controlled population is presented in Table 4. From our study we have observed that arsenic in hair, nail, and urine increases with increasing arsenic in drinking water. Figures 10- 12 show our findings. It appears that correlations are not strong positive [for hair samples $r = 0.251$, $p = 0.01$, $n = 739$; for nail samples $r = 0.220$, $p = 0.01$, $n = 691$; and for urine $r = 0.547$, $p = 0.01$, n = 910]. Probable reason people are not drinking from the same source all the times. Our field data indicates that most of the villagers drink water from more than one tube wells.

Table 4: Parametric presentation of arsenic in hair, nail, and urine of control population of Patiya police station of Chittagong district, Bangladesh where arsenic in groundwater was below 3 µg/L

Parameters	Arsenic in hair (µg/kg)	Arsenic in nail µg/kg)	Arsenic in Urine (µg/L)
No. of observation	62	62	62
Mean	410	830	31
Minimum	210	90	6
Maximum	850	1580	94
Standard deviation	180	680	20

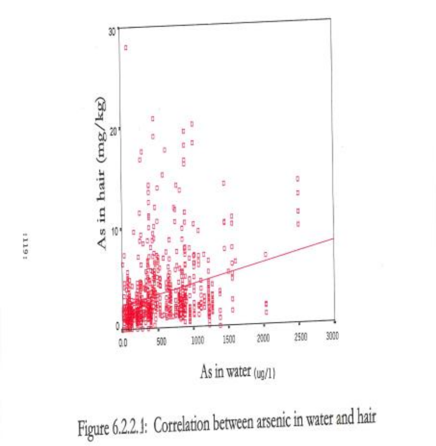

Figure 10: Correlation between arsenic in water and hair

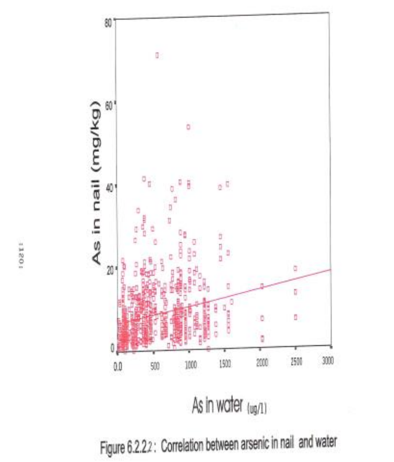

Figure 11: Correlation between arsenic in water and nail

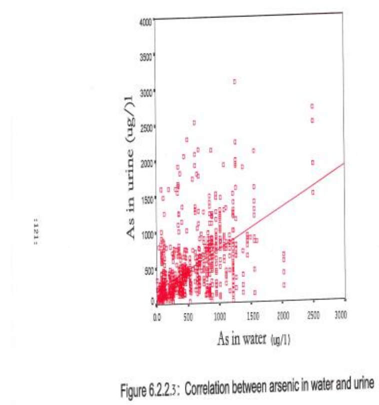

Figure 12: Correlation between arsenic in water and urine

From multi-elements analysis of some hair and nail samples it appears that Zn and Se concentration decreases with increasing arsenic concentration in both hair and nail. The concentration of Zn and Se also less in affected people's hair and nail than control hair and nail (drinking water contain arsenic <3 µg/L). But the linear regression shows positive correlation between As & Pb, As & Hg, and As & Sb in both hair and nail of exposed population.

Our last 6 years of field experience in Bangladesh show that normally children under 11 years of age do not show arsenical dermal lesions. But we have observed few exceptions when (a) the arsenic content in water consumed by children is very high (1000 µg/L) and (b) the arsenic content is not very high (500 µg/L) but the children get poor nutrition.

In Bangladesh and West Bengal-India more and more underground water is being extracted because of increasing demand for agricultural irrigation. It was calculated that in arsenic affected areas of Bangladesh and West Bengal-India a few thousand tons of arsenic (through underground water) is falling on agricultural land every year and it is important to know whether there is an increase concentration of arsenic in vegetable and crops that grow in this region. It appears from in our preliminary selected agricultural fields (n = 10) that average arsenic concentration in contaminated soil, rice, and vegetable are 3.81, 4 and 3.8 times higher than control samples (from non-contaminated area), respectively[2]. Our rice and vegetable analysis of arsenic species show 95% and 5% are inorganic arsenic and organic arsenic in rice, and 96% and 4% of inorganic arsenic and organic arsenic in vegetable, respectively. Bangladesh known as land of rivers. We finally, Bangladesh and West Bengal have huge available surface water, rainwater resources and to combat the arsenic crisis we need better watershed management.

Conclusion

According to our survey, the present arsenic (2000) situation in Bangladesh is 2000 villages in 50 out of 64 total districts groundwater contains arsenic above 50 µg/L. In a report [Pearce, F. Arsenic in the water. The Guardian (UK), 19/25 February 1998; 2-3], World Bank's local chief stated that tens of millions of people are at health risk and that 43,000 villages of total 68,000 in Bangladesh are presently at risk or could be at risk in future. In the same report, the World Health Organization (WHO) predicted that within a few years death across much southern part of Bangladesh, one in ten adults could be from cancers triggered by arsenic. Out of 21 countries in different parts of the world where groundwater arsenic contamination and suffering of people have been so far reported, the magnitude is considered highest in Bangladesh. Even after working for last 6 years in Bangladesh with School of Environmental Studies (SOES) and Dhaka Community Hospital (DCH), I feel that I have seen only the tip of the iceberg. So, for there is no medicine for chronic arsenic toxicity and millions are drinking arsenic contaminated water in Bangladesh. If scientific community and medical people all over the world will not immediately come forward to combat the arsenic problem in Bangladesh, the situation will be worse.

To eliminate arsenic crisis, I suggest the followings:

Elimination of the arsenic crisis in the Ganges Basin requires concerted action that includes:

A moratorium on the installation of more tube wells in contaminated areas until all the installed tube wells are checked for arsenic contamination. The local and national governments should frame and implement regulation of new tube wells. Around 90% of the people in Bangladesh and West Bengal, India depends on tube wells for drinking water. If the mouths of all safe tube wells are colored green, and while unsafe wells are colored red, villagers can use green tube wells for drinking and cooking purposes, and the red tube wells be closed completely. We have disturbing evidence from West Bengal, India that previously safe tube wells now show arsenic contamination. The currently safe tube wells require monitoring every 3-6 months to track this new development.

Proper watershed management.

Traditional water management like dug-well, three-Kalsi system, and rainwater harvesting with controls of bacterial and other chemical contamination.

Immediate action be taken for developing water filtration units for removing arsenic.

Public awareness of the arsenic calamity and assurance that it is not a curse of God.

Recognition that, so far, there is no effective therapy. Safe water and optimal nutrition are the only proven measures.

Investigation of the possible benefits of essential elements as we have reported for selenium. Hepatic selenium is abnormally low in patients with increased arsenic, the reverse of the normal association.

The potential benefits of selenium supplements require investigation.

A world-wide effort by the scientific community addressing the problem that has put 100 million people in Bangladesh and West Bengal-India at risk for cancer, vascular disease, and other complications.

Although tube wells provide drinking water free of microbial contamination, the merciless exploitation of groundwater for irrigation without effective watershed management to harness huge surface water resources and rainwater is seen as a gross miscalculation. In Bangladesh and West Bengal-India, there are huge surface resources of sweet water in the rivers, wetlands, flooded river basins, and ox-bow lakes. Per capita available surface water in Bangladesh is about 11,000 cubic meters. These 2 delta areas, known as the land of rivers, have approximately 2,000 mm annual rainfall. Watershed management and villager participation are needed to assure the appropriate utilization of these huge water resources.

The massive extraction of groundwater for irrigation has so altered the aquifer beneath Bangladesh and West Bengal-India that even deep tube wells are now unsafe in many arsenic-contaminated areas. Analysis of samples from almost all 374 deep (>100 m) tube-wells from

Deganga block of North 24 Paraganas, West Bengal, India shows 13.9% with arsenic >50 µg/L. Water held in deep aquifers takes decades, even centuries, to accumulate and is inadequately replenished by rainfall. Rapid depletion may result in a deleterious influx from the arsenic contaminated strata. The current intensive efforts to provide deeper tube wells may be counterproductive if the deep aquifer is simultaneously depleted by irrigation.

I want to dedicate this paper to the memory of the people who died or affected due to arsenic toxicity in Bangladesh, India, and all over the world.

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