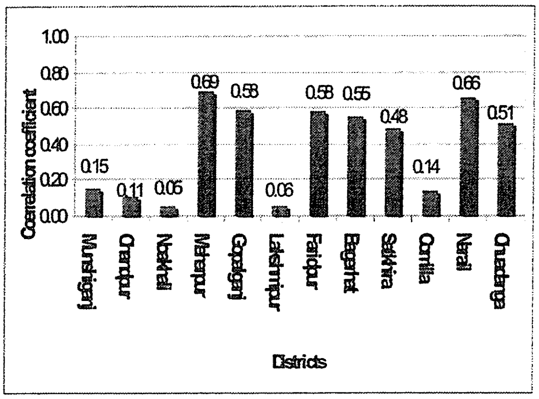

Figure 5: Correlation coefficient of 12 most arsenic contaminated districts.

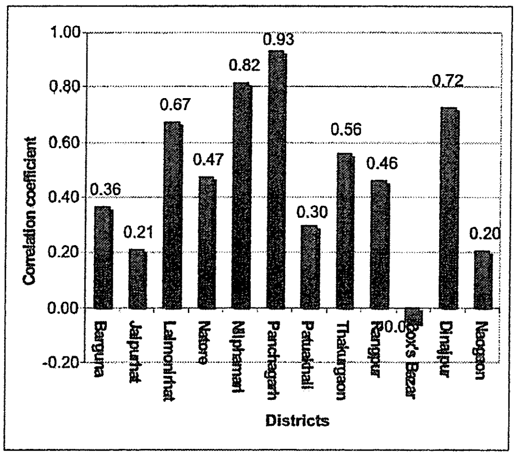

Figure 6: Correlation coefficient of 12 least arsenic contaminated districts.

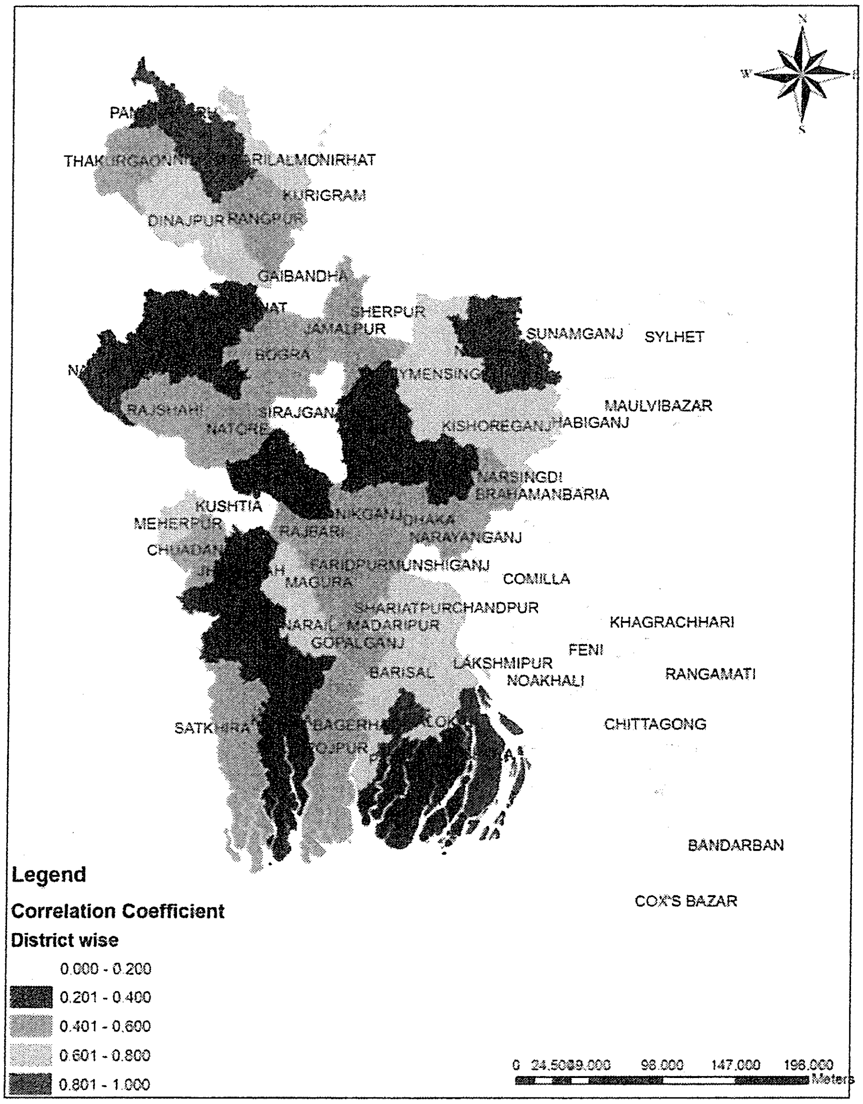

Figure 7: GIS map of correlation between arsenic and iron concentration of ground water of Bangladesh.

districts were separated as per their geographical locations. It can be summarized (Figure 7) that districts of similar range of correlation coefficient reside in a close belt. A belt of districts showing less correlation can be found in Khulna, Jessore, Jhinaidah, Kustia, Pabna, Sirajganj, Tangail Gazipur. Figure 8 shows the districts which have correlation coefficient between 0.4 and 0.6. Bagerhat, Gopalganj Faridpur, Rajbari, Manikganj, Dhaka, Narayanganj and Narshingdi form a belt which shows similar correlation between As and Fe. If this 0.4–0.6 range is considered as moderate correlation then this belt represents moderate correlation.

For experimental analysis correlation coefficient between the ranges of 0.4 to 0.8 is statistically considered moderate to high. If this ranges of data are separated from the GIS map, Figure 9, can be produced to show the districts of moderate to higher correlation coefficients between arsenic and iron concentration. It is evident from Figure 9 that a belt of similar correlation (moderate to high) exists in the middle and southern part of Bangladesh.

Mymensingh, Kishoreganj, Magura, Narail, Shariatpur, Barishal and Pirojpur districts show correlation coefficient between 0.6 and 0.8. If these seven districts are added with the map shown in Figure 8 another map can be produced (Figure 9) for similar correlation zone. There is a high possibility that similar sort of sediment characteristics trigger this zone of similar correlation between arsenic and iron concentration.

Correlation coefficient between the ranges of 0.4 to 1 is statistically considered moderate to higher. Figure 10 shows the districts which have correlation coefficient between 0.4 and 1. Pirojpur and Bhola are showing higher correlation coefficient between 0.8 and 1. Adding these districts with the map shown in Figure 9 makes a complete zone of moderate to higher arsenic and iron correlation map. This reveals that a geographical belt is evident where correlation between arsenic and iron concentration of ground water is moderate to higher. Another similar type of zone of moderate to higher correlation coefficient is found in the northern part of Bangladesh. Panchagarh, Thakurgaon, Nilphamari,

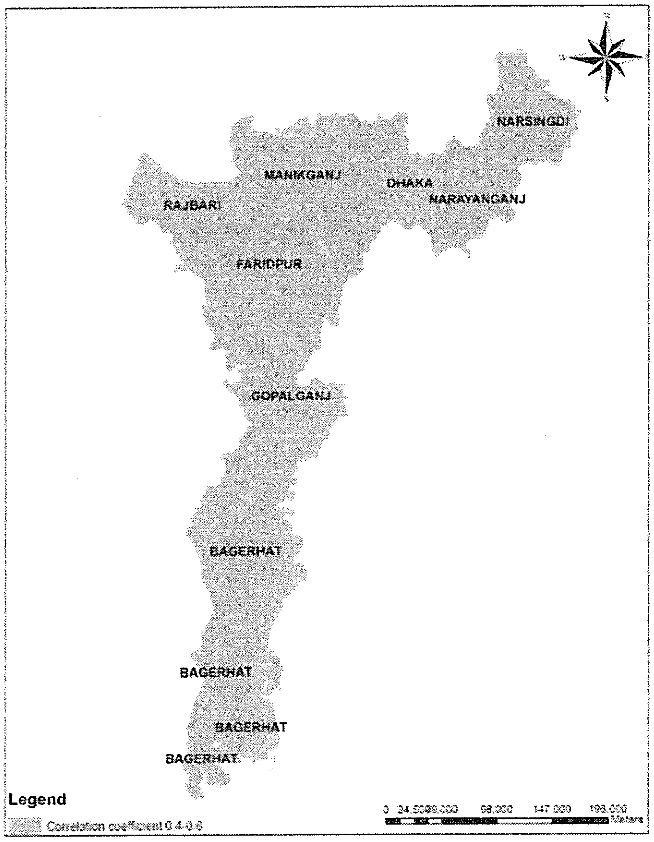

Figure 8: Districts showing correlation coefficient in the range between 0.4 and 0.6.

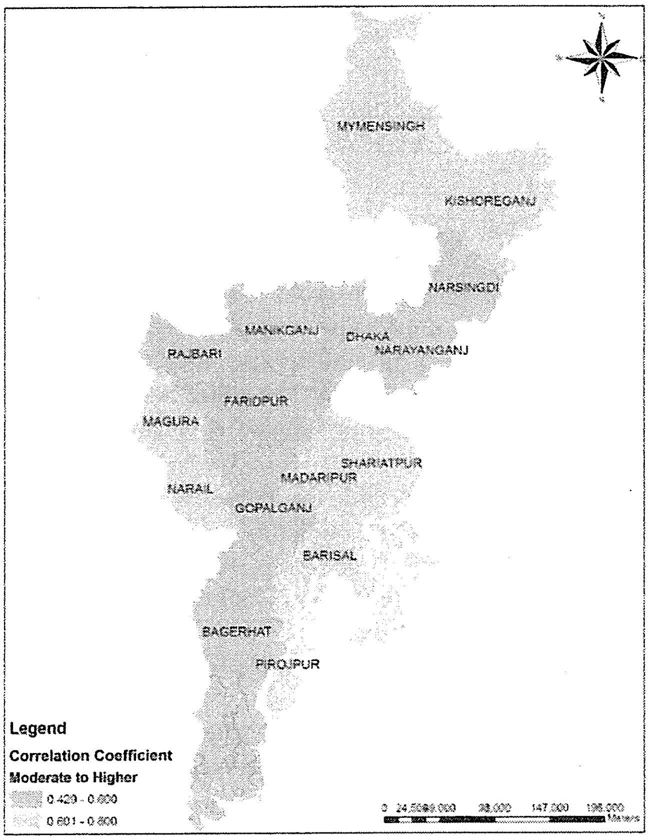

Figure 9: Districts showing correlation coefficient in the range between 0.4 and 0.8.

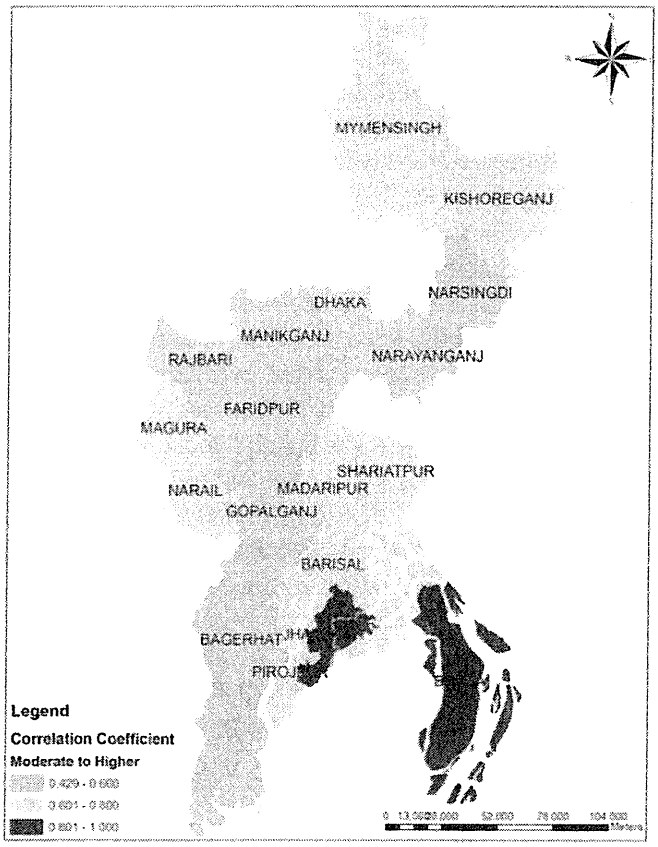

Figure 10: Districts showing correlation coefficient in the range between 0.4 and 1.

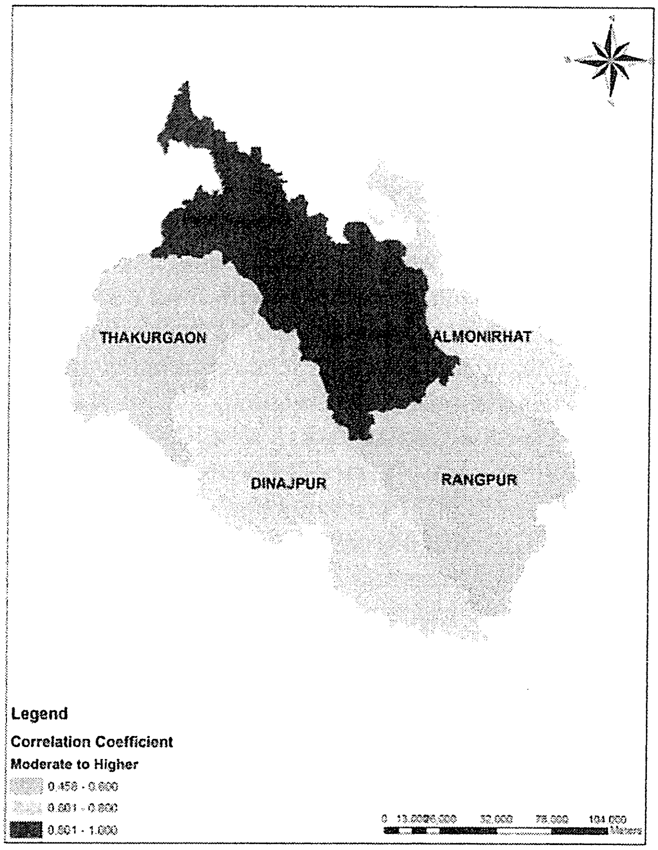

Figure 11: Districts in the northern part of Bangladesh showing correlation coefficient in the range between 0.4 and 1.

Lalmonirhat, Dinajpur and Rangpur districts show correlation in a range between 0.4 and 1 (Figure 11).

Seven out of twelve most arsenic contaminated districts show moderate to high correlation. But Chandpur, the most As contaminated district shows very little correlation (0.108). On the other hand six out of twelve least arsenic contaminated districts show very little correlation.

Table 4 shows the state of arsenic contamination in the districts which show moderate to higher correlation coefficient. Eight out of seventeen of these districts have more than 20% of their wells contaminated by arsenic. It means that 47% of these 17 districts, which show moderate to higher correlation coefficient, are arsenic contaminated.

An important observation from the maps (Figures 7, 8, 9, 10, 11, 12) is – correlation pattern is not scattered over the country. In most of the cases a belt of similar correlation pattern in observed. A belt of low correlation zone is found in the eastern part on the country. Sylhel, Moulovibazar, Habiganj, Sumanganj, Brahmanbaria, Comilla, Cox's Bazar are the districts forming a belt which shows almost no correlation (Figure 12).

Table 4: State of arsenic contamination in the districts which are showing moderate to higher correlation coefficient

District	*% of wells exceeding As>50 μg/L*
Faridpur	55.4
Bagerhat	47.4
Narail	41.7
Shariatpur	39.5
Madaripur	37.3
Barisal	30.4
Dhaka	24.6
Narsingdi	23.8
Narayanganj	18.9
Kishoreganj	17.2
Rajbari	17.0
Manikganj	14.9
Pirojpur	14.8
Mymensingh	12.8
Magura	9.7
Jhalakati	6.1
Bhola	4.2

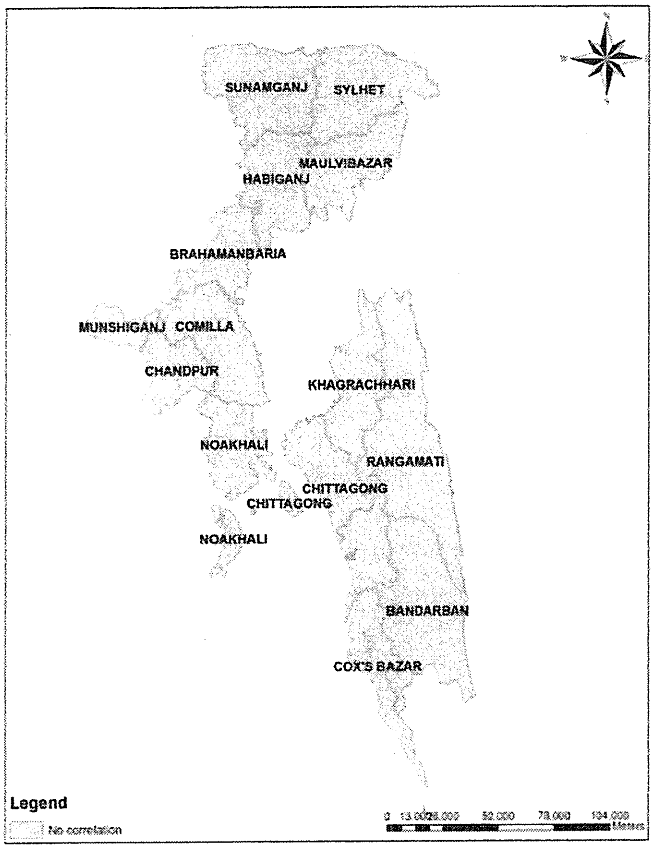

Figure 12: Districts in the eastern part of Bangladesh showing less or no correlation.

Regression Analysis of Data

It is evident from the analysis that correlation between arsenic and iron concentration is not a national phenomenon rather it is a zonal phenomenon. Therefore an attempt has been made to correlate arsenic and iron for the zones where correlation coefficient between arsenic and iron concentration is higher. When regression analysis was performed using the data separating them as per their geographical locations results were found as shown in Table 5. In this analysis arsenic is taken as the dependent variable.

Linear model (Equation 1) was assumed for regression analysis between arsenic and iron. A and B are the constants of the regression model. In this model iron concentration is taken as milligram/Litre and arsenic concentration as microgram/Litre. In Table 5 "r-square" value for each model is provided. "r-square" is the square of correlation coefficient "r" and it represents the proportion of variance in one variable accounted for (or explained) by the other variable.

$$\text{Arsenic } (\mu g/L) = A + (B) \text{ (Iron in mg/L)} \quad (1)$$

where A, B = constants from regression model

Using this regression model for 61 districts of Bangladesh (Table 5) arsenic concentration of any well of those districts can be tentatively measured, if iron concentration of that well is known.

For example, the iron concentration of a well of Bagerhat district, Thana kochua, union Raripar and mouza Bandarkhola (Lat 22.606, Long 89.85) is found to be 9.4 mg/L. From Table 5 the value of regression coefficients found of the regression model for Bagerhat district are found to be 39.37 and 17.019. The equation for this district becomes like the following one.

$$\text{Arsenic } (\mu g/L) = A + (B) \text{ (Iron in mg/L)}$$

$$\text{Arsenic } (\mu g/L) = 39.37 + 17.019(9.4)$$

$$= 199.35$$

r-square for this value is 0.3.

Actual arsenic concentration of that well was measured as 177 µg/L.

Conclusion

Total 4367 number of data is used for analysis in this research. Data of 61 administrative districts of Bangladesh were available for analysis. When all the data were used collectively and analysed without any grouping, the correlation coefficient was found to be very insignificant of 0.195. When the data were separated as per geographical location which is 61 districts of Bangladesh the correlation coefficient varied significantly in different districts. 37.7% districts showed correlation coefficient more than 0.5 which is considered to be moderate to high correlation. 50.4% districts shows correlation coefficient more than 0.4

GIS maps were produced with the results of the analysis. GIS map in Figure 7 shows the nation wide correlation status. GIS map in Figure 8 shows the districts which has correlation coefficient between 0.4 and 0.6. Bagerhat, Gopalganj Faridpur, Rajbari, Manikganj, Dhaka, Narayanganj and Narshingdi forms a belt which shows similar correlation between As and Fe. If we consider this 0.4–0.6 range moderate correlation, then this belt shows moderate correlation. Another similar type of belt is found in Rajshahi, Natore, Bogra and Jamalpur districts. If 0.6 to 1 is considered to be as high correlation coefficient then through Figure 10 shows the districts which has moderate to high correlation between As and Fe. This reveals that a geographical belt exists where correlation between arsenic and iron concentration of ground water is moderate to high.

Seven out of twelve most arsenic contaminated districts show moderate to high correlation. But Chandpur, the most As contaminated district shows very little correlation (0.108). Six out of twelve least arsenic

Table 5: Regression model for 61 districts of Bangladesh

District	*A*	*B*	*r-square*	*District*	*A*	*B*	*r-square*
Bagerhat	37.92	17.02	0.299	Magura	4.22	19.93	0.372
Barguna	0.73	1.94	0.132	Manikganj	13.02	2.42	0.191
Barisal	23.85	36.04	0.36	Maulvibazar	18.52	0.12	0.000
Bhola	–4.21	31.63	0.734	Meherpur	–10.96	48.44	0.482
Bogra	4.04	4.53	0.187	Munshiganj	164.95	5.20	0.023
Brahamanbaria	43.07	6.53	0.036	Mymensingh	4.65	8.44	0.579
Chandpur	287.12	7.60	0.012	Naogaon	2.82	2.38	0.042
Chittagong	21.61	–0.60	0.006	Narail	38.44	14.29	0.432
Chuadanga	5.12	30.00	0.261	Narayanganj	22.75	7.52	0.184
Comilla	79.33	7.59	0.018	Narsingdi	20.20	11.05	0.281
Cox's Bazar	4.84	–0.09	0.003	Natore	0.98	1.43	0.223
Dhaka	16.21	5.05	0.194	Nawabganj	5.35	1.84	0.042
Dinajpur	–0.22	2.23	0.524	Netrokona	28.00	4.08	0.095
Faridpur	25.79	25.92	0.338	Nilphamari	–0.05	0.79	0.664
Feni	50.87	–1.11	0.005	Noakhali	154.98	5.61	0.003
Gaibandha	14.98	1.18	0.011	Pabna	17.14	6.78	0.106
Gazipur	0.64	7.25	0.075	Panchagarh	0.49	0.83	0.869
Gopalganj	46.78	20.67	0.341	Patuakhali	3.36	1.39	0.087
Habiganj	15.29	0.56	0.008	Pirojpur	–1.93	14.61	0.361
Jaipurhat	1.17	0.16	0.044	Rajbari	9.76	10.48	0.308
Jamalpur	1.73	3.00	0.203	Rajshahi	3.20	6.20	0.283
Jessore	9.40	9.79	0.153	Rangpur	–2.29	2.45	0.210
Jhalakati	–19.91	48.50	0.767	Satkhira	27.96	20.78	0.231
Jhenaidah	7.39	11.43	0.131	Shariatpur	11.50	32.35	0.457
Khulna	12.44	9.54	0.128	Sherpur	18.47	0.76	0.029
Kishoreganj	2.54	16.93	0.387	Sirajganj	21.91	1.17	0.037
Kurigram	13.22	1.22	0.035	Sunamganj	47.24	–1.81	0.026
Kushtia	68.21	7.45	0.005	Sylhet	19.12	0.34	0.013
Lakshmipur	168.14	4.18	0.003	Tangail	9.66	2.04	0.106
Lalmonirhat	0.36	0.44	0.449	Thakurgaon	0.55	0.46	0.310
Madaripur	1.09	46.03	0.552				

contaminated districts show very little correlation. A belt of districts showing less correlation can be found in Khulna, Jessore, Jhinaidah, Kustia, Pabna, Sirajganj, Tangail Gazipur. Arsenic-iron correlation pattern is not scattered over the country (Figure 7). In most of the cases a belt of similar correlation pattern in observed. Such a less correlative zone is found in the eastern part on the country (Figure 12). Sylhel, Moulovibazar, Habiganj, Sumanganj, Brahmanbaria, Comilla, Cox's Bazar etc districts are forming a belt which shows almost no correlation.

Recommendations

The present study analyses the correlation between arsenic and iron on an administrative zone basis in the groundwater samples of Bangladesh. Further study is needed where the analysis is performed considering (i) the variation of groundwater depth and (ii) the concentration of arsenic and iron, in the ground water.

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ORIGINAL ARTICLE

Health Effects of Flooding in Rural Bangladesh

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Background: There is little information available on nontraumatic health risks as the result of floods, and on the factors that determine vulnerability to them (especially in low-income settings). We estimated the pattern of mortality, diarrhea, and acute respiratory infection following the 2004 floods in rural Bangladesh.

Methods: We conducted controlled interrupted time-series analysis of adverse health outcomes, from 2001 to 2007, in a cohort of 211,000 residents of the Matlab region classified as flooded or nonflooded in 2004. Ratios of mortality, diarrhea, and acute respiratory infection rates in flooded compared with nonflooded areas were calculated by week for mortality and diarrhea, and by month for acute respiratory infection. We controlled for baseline differences as well as normal seasonal patterns in the flooded and nonflooded areas. Variations in flood-related health risks were examined by age, income level, drinking-water source, latrine type, and service area.

Results: After fully controlling for pre-flood rate differences and for seasonality, there was no clear evidence of excesses in mortality or diarrhea risk during or after flooding. For acute respiratory infection, we found no evidence of excess risk during the flood itself but a moderate increase in risk during the 6 months after the flood (relative risk = 1.25 [95% confidence interval = 1.06–1.47]) and the subsequent 18 months.

Conclusions: We found little evidence of increased risk of diarrhea or mortality following the floods, but evidence of a moderate elevation in risk of acute respiratory infection during the 2 years after flooding. The discrepancies between our results and the apparent excesses for mortality and diarrhea reported in other situations, using less- controlled estimates, emphasize the importance of stringent confounder control.

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Floods are the most frequent natural disaster. They have affected >2.8 billion people during the past 30 years[1] and killed >200,000. Their frequency has tended to intensify in recent decades, and this trend is projected to increase with climate change.[2,3] Among the health effects often associated with floods are diarrheal diseases (especially among children in low-income countries),[4] and acute respiratory infections in children (particularly <5 years of age)—a major cause of illness and death in populations displaced by natural disasters.[5] Crowding and lack of access to health-care facilities and to antimicrobial agents for treatment increase the risk of death from acute respiratory infection. Floods adversely affect water sources and supply systems, as well as sewerage and waste-disposal systems, and the transmission of enteric pathogens is likely to be increased during a flood.[6] Ingestion of a few copepods, which carry a high concentration of *Vibrio cholerae*, can initiate an infection,[7] and this occurs more frequently with exposure to untreated water during flooding.

There is conflicting evidence on the long-term impact of flooding on mortality. A cohort study in Bristol of people forced from their homes by flooding in 1968 found a 50% increase in deaths during the year after the flood.[8] However, an Australian study found no difference in mortality between those who had been affected by flooding and those who had not, although those who had been affected made more visits to medical providers.[9] Heightened psychologic stress was suggested to have played a part in the increase in visits in both studies.

In this paper, we report a detailed analysis of the health impact of the 2004 floods in rural Bangladesh, considered to be the worst flood event since 1998. It affected 36 million people[10,11] and caused substantial damage to housing, livestock, and farmland[12] and a reported epidemic of diarrheal illness.[13]

METHODS

The aim of this study was to quantify the effects of the severe flooding of 2004 on the rate of mortality, diarrhea, and acute respiratory infection in the Matlab region of Bangladesh. We hypothesized that the rates of these outcomes would be higher in flooded areas compared with nearby nonflooded

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The views expressed in this paper are those of the authors, and do not necessarily reflect those of the contributing agencies.

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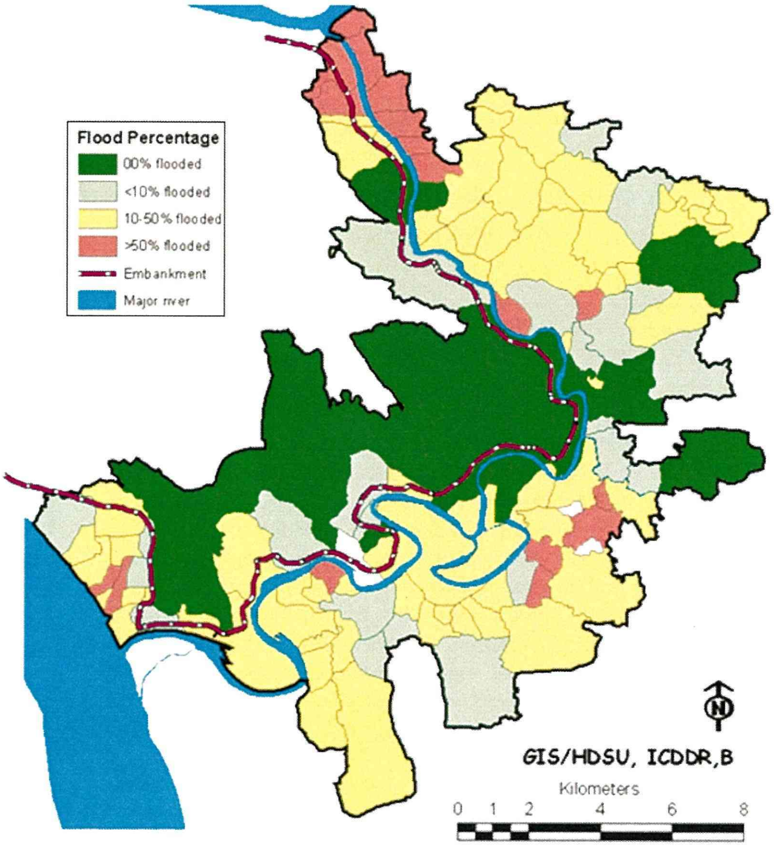

FIGURE 1. Percentage of flooded baris in villages in the monsoon flood 2004 in Matlab.

areas over the year after the flood event, as well as during and immediately after the flood period.

Study Area

Matlab is a typical rural and riverine delta area in Bangladesh, situated about 55 km south east of the capital city Dhaka. The most common livelihoods are rice cultivation and fishing. The Dhonagoda River runs from north to south through the Matlab region. An embankment was built along the river in 1988–1989, dividing the region into 2 parts, one of which remains vulnerable to seasonal flooding and one which is mostly protected against it (Fig. 1). The area has 142 villages, of which 75 are served by government health services similar to those in other rural areas of Bangladesh and 67 are served by high-quality primary- health-care services provided by the International Centre for Diarrheal Disease Research, Bangladesh in addition to the normal government services. All residents, both in the government and Centre service areas, are eligible to access Centre facilities.[14] The 2 forms of service areas are represented in both the area with embankment protection and the area without it.

Data

The health and demography data of the area have been recorded by the Centre since 1966 through the Health and Demographic Surveillance System. In 2007, a population of 224,000 was under demographic surveillance (114,000 in the Centre service area and 110,000 in the government service area). The field procedures and methods for detecting demographic events are described elsewhere in detail.[15] Briefly, the field staff recorded demographic events during their monthly visits to the households and determined the causes of deaths by interviewing families of the deceased within 2–10 weeks of the deaths. We retrieved the data from the Surveillance System database on sex, age, date, and cause of death or migration, including moving residence, address of residence, and whether each person lived inside or outside the embankment.

Data on acute respiratory infection cases in children under 5 years of age were collected by field staff who visited and interviewed mothers (or guardians) every month. Acute respiratory infection was diagnosed when cough and fever were present. The child was diagnosed as having severe acute respiratory infection if in-drawing of the chest was observed by the mother or guardian. A total of 48,794 acute-respiratory-infection cases were recorded and analyzed for 2001–2006.

Data on hospitalized cases of diarrhea in Matlab were obtained from the hospitals under Centre surveillance. Treatment in these hospitals is provided free of charge.[10] Data on clinical outcome, duration of episode, and pathology (ascertained from stool samples) are routinely collected from every patient residing in an area under the surveillance system. We analyzed the weekly counts of a total of 8378 cases of diarrhea admitted to Centre facilities from 2001 to 2007 that could be linked with flood exposure and socioeconomic data defined later in the text.

Exposure to flooding was ascertained from an interview survey of the heads of 9524 *baris* (patrilineally related clusters of households with an average of 5–6 households per *bari*) carried out during 2008. For the purpose of this study, residents were classified as "flooded" if the floor of any household in the *bari* had been under water during the flood period (Fig. 1). The information on flooding was linked with surveillance data by *bari* of residence at the time of the 2004 flood. Socioeconomic data were available at the household level for the entire Matlab surveillance area. We extracted household information based on 2005 data for main income source; drinking water source; types of latrine, roof, and wall structure of the houses; and the highest education levels of the father and mother.

Ethical approval for this study was granted by the International Centre for Diarrheal Disease Research, Bangladesh; the Research Institute for Humanity and Nature, Japan; and the London School of Hygiene and Tropical Medicine.

Definition of Flood, Preflood, and Postflood Period

The term "flood," unless otherwise qualified, is used here to refer to the major monsoon flood of 2004; a "flooded area" is one affected by that flood. A nonflooded area signifies an area that did not flood in the 2004 monsoon period, regardless of its flood status before or after that event.

The monsoon season in Bangladesh normally starts in June, with the water level rising gradually to a peak around mid-July and remaining high until about mid-August. Water levels then start falling gradually, and by mid-September, the water level has usually returned to the premonsoon level. This is the "normal" flood (monsoon water level rise) that occurs every year. Because the floods in the Matlab region are not flash floods, but rather inundations caused by overspill from ponds, small rivers, and rice fields, it is difficult to identify a flood period from meteorologic data. In this study, the 2004 flood period was defined as week 29 to week 33 (15 July to 18 August) based on evidence from a government report that recorded the dates on which the water level rose above and fell below a "normal" flood level.[16] We refer to the "preflood period" as the 3 years before week 29 of 2004 and the "postflood period" as the 3 years after week 33 of 2004. Weekly mortality and diarrhea data were analyzed in 5-week blocks up to 25 weeks (approximately 6 months) after the end of the flood, and in annual blocks thereafter. Note that the preflood period in our analyses does not include the previous major flood of 1998.

Statistical Analysis

The study was conceptualized as a controlled interrupted time-series analysis. We calculated ratios of the rates (cases per person-time at risk) of mortality, diarrhea, and acute respiratory infection in the flooded area compared with the nonflooded areas by week (mortality and diarrhea) or month (acute respiratory infection) for the years 2001 to 2007 (2001 through 2006 for acute respiratory infection). To control for any preexisting differences in health outcomes between the flooded and nonflooded areas, these weekly (or monthly) rate ratios (RRs) were entered into a second-stage (meta-regression) model. Within this model, we compared aggregated rate ratios for the flood period and selected postflood periods with the rate ratio for the preflood period as a whole (RRs "controlled for preflood period"). To account for seasonality in the RRs, seen as being independent of any 2004 flood effect, Fourier terms (sine–cosine pairs) up to the sixth harmonic per year were introduced into the second-stage model (RRs "controlled for preflood period and seasonality"). Modeled seasonality in RRs for each outcome, adjusting for the 2004 flood effect, is shown in the eAppendix (eFigure 1, http://links.lww.com/EDE/A531).

In additional analyses, we stratified by age (0–15 years, 15–60 years, ≥60 years), socioeconomic status (3 income levels), hygiene and sanitation practices (drinking water sources, latrine type), and service area (Centre or government service) to examine potential modification of flood effects. The statistical significance of heterogeneity in controlled RRs by putative modifiers was tested using Cochran's Q χ^2 test.[17] We performed all statistical analyses using Stata 11 (Stata Corporation, College Station, TX).

RESULTS

Analyses were based on 66,777 residents in the flood areas and 144,362 in the nonflood areas. Characteristics of the study population at the time of flood onset are described in Table 1. The populations in flood and nonflood areas were similar in age and latrine sanitation. Income tended to be more extreme (low or high) in the flooded areas. The majority of people drank water from tube wells, but drinking of surface water was more common in the flooded areas. Most of the flooded areas were not protected by the embankment.

Mortality

During the study period, there were 5280 deaths from all causes in the nonflooded area and 2388 deaths in the flooded area among persons for whom we had all information necessary for analyses. Mortality rates in the flooded and nonflooded areas were broadly similar, although there were some differences in the seasonal/annual variation (Fig. 2A). Rate ratios (flooded vs. nonflooded) were close to 1.0 (Fig. 2B).

During the flood period, the mortality rate per 1000 person-weeks at risk was 0.11 in the flooded areas and 0.10 in the nonflooded areas (36 and 70 deaths, respectively). The ratio of those rates (flooded to nonflooded areas) was 1.11 (95% confidence interval [CI]= 0.74–1.66), and 1.14 (0.76–1.72) when additionally controlled for the preflood RR; it was 1.10

TABLE 1. Characteristics of the Study Population in Matlab at the Time of Flood Onset (15 July 2004)

	Nonflooded Area (n = 144,362) No. (%)	Flooded Area (n = 66,777) No. (%)
Age (years)		
0 to 15	49,323 (34)	23,488 (35)
15 to 60	82,181 (56)	38,095 (57)
≥60	12,858 (8)	5194 (7)
Income level		
Low	24,283 (16)	12,976 (19)
Middle	72,067 (49)	29,684 (44)
High	48,003 (33)	24,103 (36)
Unknown	9 (0)	14 (0)
Drinking water source		
Surface water	4620 (3)	6396 (9)
Filtered water	5930 (4)	3085 (4)
Tube well	133,159 (92)	56,549 (84)
Others/unknown	653 (0)	747 (1)
Latrine type		
Nonsanitary	117,113 (81)	55,461 (83)
Sanitary	24,847 (17)	10,317 (15)
Unknown	2402 (1)	999 (1)
Service area		
ICDDR, B	68,765 (47)	36,415 (54)
Government	75,597 (52)	30,362 (45)
Embankment		
Protected	62,682 (43)	1367 (2)
Unprotected	81,630 (56)	65,376 (97)
Unknown	50 (0)	34 (0)

(0.71–1.73) when further controlled for season (Table 2). In the postflood period up to 10 weeks after the flood, the adjusted and controlled RRs were only slightly higher. Results stratified by cause of death, age, socioeconomic status, and hygiene and sanitation level did not show evidence of a differential flood effect in any of the subgroups examined (Table 3).

Diarrhea

We identified 4250 diarrhea cases from nonflooded area and 2852 cases from the flooded area who met our study criteria (Fig. 2C, Table 4). Figure 2C shows that there is usually a higher risk of diarrhea in the flooded area compared with the nonflooded area during the monsoon season (June–September). Seasonality in the RRs was apparent after controlling for the rates in nonflooded areas.

During the flood period, the rate of diarrhea per 1000 person-weeks at risk was 0.22 in the flooded area and 0.10 in the nonflooded areas, giving a rate ratio of risk in flooded to nonflooded areas of 2.16 (95% CI = 1.57–2.98). However, rates of diarrhea were higher in the flood area before exposure to the 2004 flood (Table 4). Indeed, the RR in the period weeks 5 to 1 week before the flood was the same as during the flood period itself (RR = 2.16; 95% CI = 1.55–3.02). After controlling for baseline differences in rates of diarrhea in the flooded and the nonflooded areas, adjusted RRs were still elevated in the flood period (1.55 [1.12–2.15]) but not in the postflood period. An exception to this was during the second year after the flood when an unexplained Salmonella outbreak occurred. Additional adjustment for seasonality further diminished the RRs for the flood effect (1.16 [0.77–1.74]).

Analyses by pathogen (eTables 1–3 and eFigures 2,3, http://links.lww.com/EDE/A531) showed little evidence for excesses of cholera in the flooded area during or after the flood after controlling for season. Before adjusting for season, the rate ratio for rotavirus was elevated (2.42 [1.46–4.00]) but not afterward (1.54 [0.79–3.00]). A salmonella outbreak in weeks 26–27 of 2006 was centered in the 2 villages in the flooded area, and this outbreak largely explains the excess of diarrhea in the flooded area in the second year after flooding (Table 4).

Stratified analyses gave little evidence for variation in risk by age, income level, sanitation and hygiene level, and service area (Table 3).

Acute Respiratory Infection

In 2001–2006, there were a total of 23,163 and 11,310 acute respiratory infections from nonflooded and flooded areas, respectively, in children under 5 years. Figure 2E shows marked peaks of acute respiratory infection morbidity in July–August of the preflood years of 2002 and 2003, in both flooded and nonflooded areas. A small seasonal pattern with high RRs in the monsoon season and in the winter months was also observed. In the period up to 11 months after the flood, the acute-respiratory-infection rates appeared higher in the flooded compared with the nonflooded area, although the CIs were wide. A high RR (2.51 [95% CI = 1.81–3.46]) was observed in September 2005, but the RRs were low in the months immediately before. The reasons for this pattern are unclear.

In the flood period, the rate of children's acute respiratory infection was 14.0 per 1000 person months at risk in the flooded area (227 cases) and 14.6 in the nonflooded area (501 cases), with an unadjusted RR of 0.95 (95% CI = 0.81–1.11). There was no evidence of higher acute respiratory infection during the flood period with further adjustment for preflood differences in RRs and seasonality.

The RR of flooded to nonflooded areas was higher in the month after the flood (unadjusted RR = 1.45 [1.22–1.72]); these higher unadjusted RRs persisted for most of the postflood period (Table 5). However, by adjusting for preflood differences in acute respiratory infection and for seasonality, the ratios were diminished. Results by the level of severity of acute respiratory infection showed some apparent differences in time pattern between severe and nonsevere acute respiratory infection (eFigure 4, http://links.lww.com/EDE/A531).

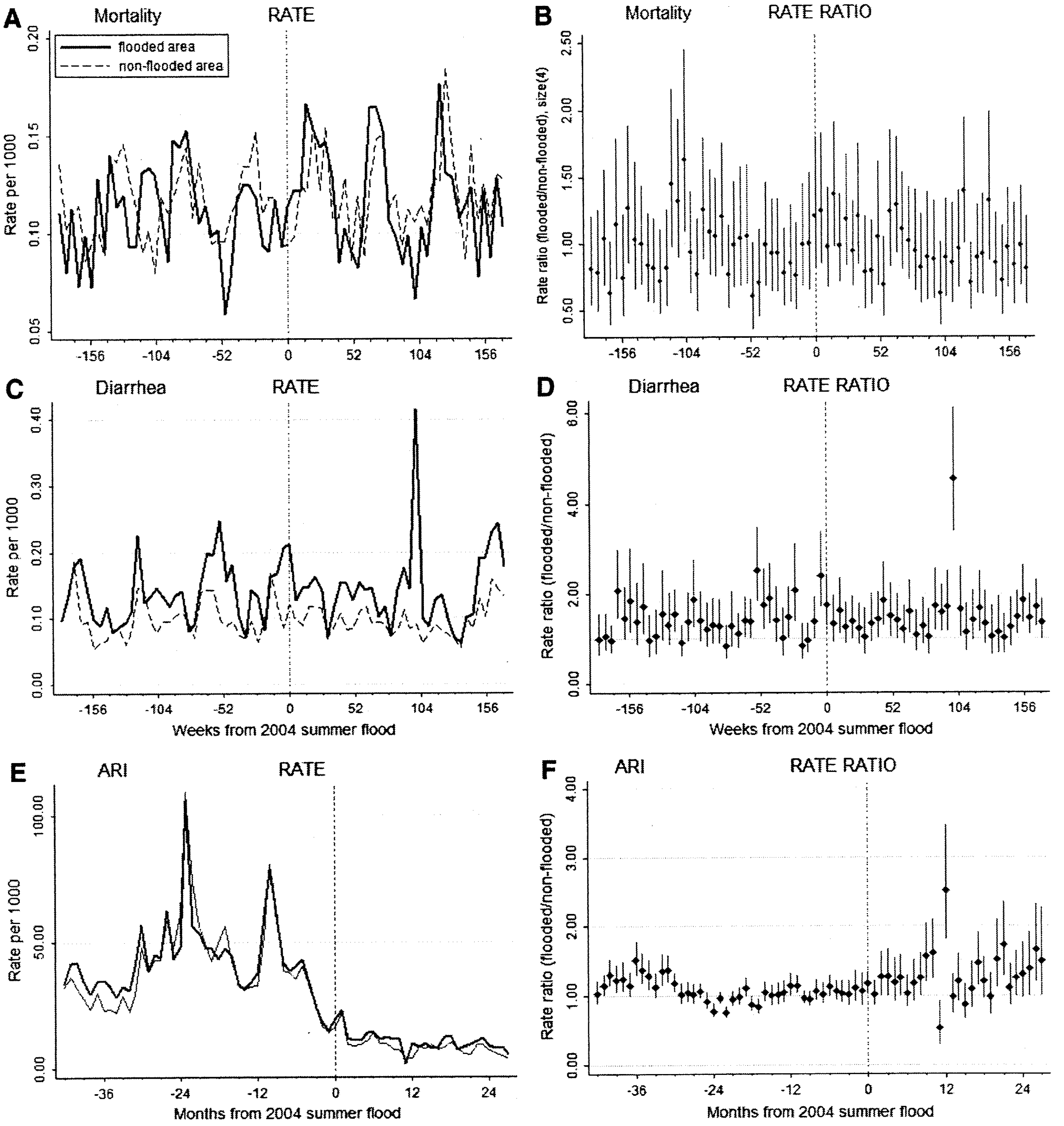

FIGURE 2. Rate (left) and rate ratio (right) of flooded to nonflooded area of outcomes. A and B, mortality; C and D, diarrhea; E and F, acute respiratory infection.

No clear differences in the 2004 monsoon flood effects on acute respiratory infection were seen by income level, drinking-water sources, or latrine type. However, the service area did appear to modify the effect of the 2004 monsoon flood: season-controlled RR of acute respiratory infection in the 6 months postflood relative to preflood period was 1.29 (95% CI = 1.06–1.56) for the Centre service area and 0.77 (0.62–0.96) for the government service area ($P < 0.01$ for test of heterogeneity, Table 3) (as mentioned in eFigure 5).

DISCUSSION

This study provides detailed quantitative evidence on the flood-related risk of mortality, diarrhea, and acute respi-

TABLE 2. Mortality: Preflood and Postflood[a] Mortality in the Flooded and Nonflooded Areas. Rate Ratios of Flooded Compared With Nonflooded Areas

	No. Deaths		Rate per 1000		Crude RR (95%CI)	RR Controlled for Preflood Period (95% CI)	RR Controlled for Preflood Period and Seasonality[b] (95% CI)
	Nonflooded	Flooded	Nonflooded	Flooded			
Preflood							
−3 years	796	361	0.11	0.11	1.00 (0.89–1.14)		
−2 years	831	406	0.11	0.12	1.07 (0.95–1.20)		
−1 year to −26 weeks	442	174	0.11	0.10	0.86 (0.72–1.02)		
−25 to −21 weeks	115	40	0.16	0.12	0.76 (0.53–1.08)		
−20 to −16 weeks	84	30	0.12	0.09	0.77 (0.51–1.17)		
−15 to −11 weeks	79	29	0.11	0.09	0.80 (0.52–1.22)		
−10 to −6 weeks	89	39	0.12	0.12	0.95 (0.65–1.38)		
−5 to −1 weeks	66	35	0.09	0.10	1.15 (0.76–1.73)		
Flood	70	36	0.10	0.11	1.11 (0.74–1.66)	1.14 (0.76–1.72)	1.10 (0.71–1.73)
Postflood							
1 to 5 weeks	70	39	0.10	0.12	1.20 (0.81–1.78)	1.23 (0.83–1.84)	1.25 (0.81–1.94)
6 to 10 weeks	78	42	0.11	0.12	1.16 (0.80–1.69)	1.19 (0.81–1.74)	1.22 (0.80–1.87)
11 to 15 weeks	95	45	0.13	0.13	1.02 (0.71–1.45)	1.05 (0.73–1.50)	0.87 (0.59–1.30)
16 to 20 weeks	107	59	0.15	0.17	1.18 (0.86–1.63)	1.22 (0.88–1.68)	1.08 (0.76–1.55)
21 to 25 weeks	106	54	0.15	0.16	1.09 (0.79–1.52)	1.12 (0.80–1.57)	1.26 (0.86–1.83)
26 weeks to 1 year	455	202	0.12	0.11	0.95 (0.81–1.12)	0.98 (0.81–1.17)	0.99 (0.82–1.20)
2 years	890	396	0.12	0.11	0.95 (0.85–1.07)	0.98 (0.85–1.12)	0.97 (0.85–1.12)
3 years	907	401	0.12	0.12	0.95 (0.84–1.06)	0.97 (0.85–1.11)	0.97 (0.84–1.12)

[a] Flood period is defined as week 29 to 33 in 2004 (5 weeks, from 15 July to 18 August).

[b] Controlled for season by meta-linear regression with Fourier transformed functions with annual cycle up to an order of 6.

TABLE 3. Estimates of Flood-related Impact on Mortality, Diarrhea, and Acute Respiratory Infection by Selected Potential Risk Modifiers. Controlled Ratio of Outcome Rate Relative to Preflood Period[a]

	Death		Diarrhea		Acute Respiratory Infection	
Possible Modifier of Flood Impact	During the Flood Period RR (95% CI)	During the 24 Weeks After the Flood RR (95% CI)	During the Flood Period RR (95% CI)	During the 24 weeks After the Flood RR (95% CI)	During the Flood Period RR (95% CI)	During the 6 Months After the Flood RR (95% CI)
All	1.10 (0.71–1.73)	1.11 (0.92–1.34)	1.16 (0.77–1.74)	0.99 (0.80–1.22)	1.00 (0.73–1.35)	1.25 (1.06–1.47)
Age (years)						
0 to 15	0.71 (0.25–1.99)	0.98 (0.59–1.65)	1.05 (0.68–1.63)	0.84 (0.66–1.08)	—	—
15 to 60	0.95 (0.33–2.75)	0.96 (0.61–1.52)	0.82 (0.31–2.16)	1.08 (0.74–1.60)	—	—
≥60	1.39 (0.75–2.56)	1.22 (0.96–1.55)	3.92 (0.28–55.47)	1.16 (0.33–4.14)	—	—
Income level						
Low	1.11 (0.32–3.83)	1.06 (0.62–1.82)	1.64 (0.65–4.19)	0.87 (0.56–1.35)	1.25 (0.85–1.83)	1.32 (1.06–1.64)
Middle	1.20 (0.65–2.22)	1.15 (0.89–1.49)	1.15 (0.67–1.97)	1.13 (0.84–1.52)	0.98 (0.69–1.39)	1.23 (1.01–1.51)
High	0.89 (0.35–2.27)	1.21 (0.82–1.81)	1.07 (0.52–2.21)	0.83 (0.58–1.18)	0.86 (0.58–1.27)	1.23 (0.98–1.54)
Drinking water source						
Surface or Filtered	1.00 (0.28–3.59)	0.76 (0.33–1.78)	0.46 (0.07–3.24)	0.53 (0.16–1.69)	1.07 (0.56–2.06)	1.05 (0.73–1.52)
Tube well	1.01 (0.61–1.66)	1.15 (0.94–1.41)	1.31 (0.86–2.02)	1.01 (0.82–1.26)	1.02 (0.76–1.36)	1.33 (1.12–1.57)
Latrine						
Nonsanitary	0.98 (0.59–1.62)	1.12 (0.91–1.38)	1.15 (0.75–1.77)	0.93 (0.75–1.17)	1.03 (0.77–1.37)	1.28 (1.08–1.51)
Sanitary	0.60 (0.17–2.09)	0.94 (0.54–1.63)	1.22 (0.47–3.14)	1.15 (0.70–1.90)	0.91 (0.52–1.59)	1.20 (0.90–1.62)
Service area						
ICDDR,B	1.13 (0.60–2.11)	0.94 (0.72–1.24)	1.17 (0.75–1.83)	0.93 (0.74–1.17)	1.01 (0.73–1.40)	1.29 (1.06–1.56)
Government	0.84 (0.43–1.61)	1.25 (0.93–1.58)	0.86 (0.37–2.01)	0.94 (0.62–1.44)	0.68 (0.47–0.98)	0.77 (0.62–0.96)

[a] The rate ratio for flooded versus nonflood area, controlling for the analogous ratio in the preflood period and seasonality, as explained in the text. Baseline is 3 years before the flood for death and diarrhea and 2 years for ARI.

TABLE 4. Diarrheal Illness: Pre- and Postflood[a] Episodes in the Flooded and Nonflooded Areas

	No. Diarrhea		Rate per 1000		Crude RR (95% CI)	RR Controlled for Preflood Period (95% CI)	RR Controlled for Preflood Period and Seasonality[b] (95% CI)
	Nonflooded	Flooded	Nonflooded	Flooded			
Preflood							
−3 years	619	371	0.09	0.12	1.32 (1.16–1.51)		
−2 years	786	479	0.11	0.14	1.33 (1.19–1.49)		
−1 years to −26 weeks	322	254	0.08	0.14	1.72 (1.46–2.02)		
−25 to −21 weeks	55	44	0.08	0.13	1.74 (1.17–2.58)		
−20 to −16 weeks	55	27	0.08	0.08	1.06 (0.67–1.69)		
−15 to −11 weeks	124	52	0.17	0.16	0.91 (0.66–1.26)		
−10 to −6 weeks	92	56	0.13	0.17	1.32 (0.94–1.84)		
−5 to −1 weeks	69	69	0.10	0.21	2.16 (1.55–3.02)		
Flood	75	75	0.10	0.22	2.16 (1.57–2.98)	1.55 (1.12–2.15)	1.16 (0.77–1.74)
Postflood							
1 to 5 weeks	74	43	0.10	0.13	1.25 (0.86–1.83)	0.90 (0.61–1.32)	0.96 (0.62–1.51)
6 to 10 weeks	65	49	0.09	0.15	1.62 (1.12–2.35)	1.16 (0.80–1.70)	1.12 (0.72–1.75)
11 to 15 weeks	86	47	0.12	0.14	1.18 (0.82–1.68)	0.84 (0.59–1.21)	0.90 (0.58–1.40)
16 to 20 weeks	86	56	0.12	0.17	1.40 (1.00–1.96)	1.00 (0.71–1.41)	1.11 (0.73–1.69)
21 to 25 weeks	90	47	0.12	0.14	1.12 (0.79–1.59)	0.80 (0.56–1.15)	0.91 (0.59–1.41)
26 weeks to 1 years	338	235	0.09	0.13	1.49 (1.26–1.76)	1.07 (0.89–1.28)	1.01 (0.82–1.23)
2 years	698	556	0.09	0.16	1.70 (1.52–1.90)	1.22 (1.07–1.39)	1.16 (1.00–1.35)
3 years	616	392	0.08	0.12	1.36 (1.20–1.54)	0.98 (0.84–1.13)	0.95 (0.81–1.12)

[a] Flood period is defined as week 29 to 33 in 2004 (5 weeks, from 15 July to 18 August).

[b] Controlled for season by meta-linear regression with Fourier transformed functions with annual cycle up to an order of 6.

TABLE 5. Acute Respiratory Infection (ARI): Pre- and Postflood[a] Episodes in the Flooded and Nonflooded Areas

	No. ARI		Rate per 1000		Crude RR (95% CI)	RR Controlled for Preflood Period (95% CI)	RR Controlled for Preflood Period and Seasonality[b] (95% CI)
	Nonflooded	Flooded	Nonflooded	Flooded			
Preflood							
−2 years	10,646	4729	54.20	50.17	0.93 (0.89–0.96)		
−1 years to −7 months	5036	2483	49.99	52.01	1.04 (0.99–1.09)		
−6 months	633	306	37.57	38.51	1.02 (0.89–1.17)		
−5 months	599	320	35.35	40.13	1.14 (0.99–1.30)		
−4 months	684	343	40.38	42.89	1.06 (0.93–1.21)		
−3 months	546	270	32.20	33.56	1.04 (0.90–1.21)		
−2 months	398	193	23.41	23.91	1.02 (0.86–1.21)		
−1 months	285	151	16.71	18.61	1.11 (0.91–1.36)		
Flood	501	227	14.64	13.95	0.95 (0.81–1.11)	0.97 (0.83–1.14)	1.00 (0.73–1.35)
Postflood							
1 months	310	214	18.00	26.05	1.45 (1.22–1.72)	1.48 (1.24–1.76)	1.23 (0.82–1.84)
2 months	384	188	22.26	22.83	1.03 (0.86–1.22)	1.05 (0.88–1.25)	1.22 (0.81–1.83)
3 months	164	100	9.47	12.10	1.28 (1.00–1.64)	1.30 (1.02–1.67)	1.34 (0.85–2.11)
4 months	151	93	8.71	11.17	1.28 (0.99–1.66)	1.31 (1.01–1.70)	1.37 (0.86–2.17)
5 months	163	94	9.42	11.27	1.20 (0.93–1.54)	1.22 (0.95–1.58)	1.17 (0.74–1.86)
6 months	195	119	11.19	14.16	1.27 (1.01–1.59)	1.29 (1.03–1.62)	1.23 (0.79–1.91)
7 months to 1 year	898	533	8.59	10.60	1.23 (1.11–1.37)	1.26 (1.13–1.40)	1.22 (1.00–1.49)
2 years	1570	947	7.80	9.78	1.25 (1.16–1.36)	1.28 (1.18–1.39)	1.28 (1.11–1.48)

[a] Flood period is defined as July to August in 2004.

[b] Controlled for season by meta-linear regression with Fourier transformed functions with annual cycle up to an order of 6.

ratory infection in a rural population of Bangladesh following the severe monsoon flood of 2004. Somewhat against our expectations (and contrary to previous reports[13,16]), there was no clear evidence of flood-related increases in mortality or diarrhea, either during the flood period itself or afterward, once analyses were controlling for preflood rate differences between flood and nonflood areas and seasonality.[18] This was true also for cause-specific forms of diarrheal illness (cholera, noncholera, and rotavirus infections). Although our results do not exclude a flood effect on diarrhea, the upper bound of the confidence interval (RR = 0.99 [95% CI = 0.80–1.22] in Table 3) suggests that an excess of >22% above the preflood rate is unlikely for the 6 months after flooding, and an excess of >74% is unlikely for the flood period itself (1.16 [0.77–1.74] in Table 3).

With less stringent control for confounding, there was some evidence of an increase in diarrhea risk during the flood period itself in analyses carried out without seasonal control. However, we interpreted this as residual confounding by season, rather than as evidence of a flood effect.

The evidence for acute respiratory infection in children under 5 years was more equivocal. There was no evidence of increased risk during the period of flooding itself, but for 6 months and longer after flooding, the rate ratios showed higher risks in the flooded populations even after adjustment for both preflood rate differences and seasonality. The difficulty of interpretation here arises from 2 features of the data: (1) the apparent persistence of the relatively high acute-respiratory-infection rates in the flooded population for an implausibly long period after the flood (evident as an undiminished relative excess in the second year after the flood); and (2) an apparent and unexplained steep decrease in the number of acute-respiratory-infection cases recorded in both flood and nonflood areas from around the third month after the time of the flood. These observations weaken the evidence for a causal association.

The broadly negative evidence of our analyses for diarrhea contrasts with that of some previous reports. For example, a study of Hashizume et al[19] reported a persistent flood effect on both cholera (until 8 weeks after the end of the flood) and non-cholera diarrhea (until 4 weeks postflood) after the1998 flood in Dhaka. Studies also have reported an apparent diarrhea effect that was greater in population subgroups with poorer hygiene and sanitation or lower socioeconomic status.[19,20] However, these findings were from an analysis of diarrhea cases irrespective of flood exposure of individuals, and where potential seasonal differences in the flood effects between flooded and nonflooded populations were not considered. A limitation of many previous published studies of flood-related diarrhea was that they lacked outcome data in the preflood period or for control areas. In our analyses, adjustment for preflood differences and seasonality had an appreciable impact on the interpretation, reducing an apparent diarrhea increase into a smaller and less certain difference. By controlling for season, our analysis specifically tested whether the 2004 flood was associated with excesses in the diseases above those seen seasonally in normal years, and not simply whether flooding was associated with any increase.

The difference in findings between our study and earlier studies could also be due to the different settings (particularly regarding urban or rural locations). Generally, water sources, sewerage, and waste-disposal systems more severely affect the community's health in crowded areas. Different types and patterns of flooding may also be relevant; sudden and prolonged flooding is likely to have a different impact on health than more gradual and transient inundation associated with heavy seasonal rainfall.[21] In the 1998 flood in Bangladesh, the water level remained high for 2 months, whereas in 2004, although much heavier rainfall occurred, the water level remained high for only 1 month.

The persistence of diarrhea risk after flooding may also be influenced by local environmental conditions and by variation in disaster management and adaptation strategies. In a region where some degree of flooding is common, and health systems are prepared to treat the infectious-disease outbreaks that occur, there may be a more rapid return to baseline levels of disease (even after an exceptional event), compared with regions in which such events are rarer and the infrastructure and health systems are not adequately prepared. It is possible that people in other settings may experience greater and more persistent increases in rates of diarrhea following floods.

There are fewer robust studies on the effects of flooding on acute respiratory infection. Our observation of a modest increase in acute respiratory infection in the period after flooding, although somewhat unclear, is broadly consistent with previous evidence. For the 1998 Bangladesh floods, respiratory problems were the second-most-common (14%) health problems among flood victims after diarrhea (27%).[20] Acute respiratory infection was also the second-most-common cause of illness (17%) and death (13%) among victims of the 1988 flood.[22] However, it is not clear whether the high number of postflood acute respiratory infection cases was due to the flood or was the result of a usual seasonal increase, because these studies had neither baseline incidence data nor detailed exposure status of the subjects. Acute respiratory infections are a recognized problem among populations displaced by natural disasters,[5] and the risk of death appears to be related to crowding, exposure to indoor cooking using an open flame, poor nutrition, and lack of access to health care facilities and antimicrobial agents for treatment. The reported incidence of acute respiratory infection increased 4-fold in Nicaragua in the 30 days after Hurricane Mitch in 1998,[23] and acute respiratory infection accounted for the highest number of cases and deaths among those displaced by the tsunami in

Aceh in 2004.[24] There was no major population displacement in Matlab during and after the flooding in 2004.

Several limitations also merit comment. First, exposure to the 2004 flood was indirectly ascertained—based on the results of an interview with the head of each *bari* in 2008. Although there was no major flood or heavy rainfall after the summer 2004 flood, until the date of the interview, the long time interval could cause recall bias. If our flooded *baris* are more likely than nonflooded *baris* to experience flooding in other years, our reported effects may be overestimated. However, the interview also sought information about the experience of flood or heavy rainfall from 2000 through 2003, and the stratified analysis by those experiences showed no difference in the effect estimates of the 2004 flood.

Second, there was also imprecision in definition of the flood period. Redefining the flood period with more precise data on its duration in this region might reveal slightly different patterns of rates, but this is unlikely to have a material effect on the overall results, given the 3-year pre- and postflood observation period.

Third, because most people (84%) in the Matlab area use tube-well water, it was more difficult to examine variations in vulnerability to diarrheal illness. Luby et al[25] found that tube wells in flood-prone regions of Bangladesh were commonly contaminated with low levels of fecal organisms, regardless of its external characteristics. Latrine sharing has also been found to be associated with increased risk of cholera.[26] We had no measure of the number of people sharing latrines in this population, or of various other potential risk factors such as distance to surface water, that could be a reservoir of pathogens during and after the flood. Similarly, we did not know the distance to the nearest hospital and treatment centers, which could affect ascertainment.[27]

In conclusion, our analyses show the importance of careful control for temporal confounding in the analysis of the affects on health of monsoon floods. For mortality and diarrheal illness, we found little evidence of elevated risks once the analyses were controlled for preflood rate differences and seasonality. We can exclude a relative excess of >74% in diarrheal illness for the flood period itself and of >22% for the 6 months after the flooding. The evidence for acute respiratory infection was more equivocal, with evidence of a persistent, moderate elevation of acute respiratory infection risk over the 2 years after the flood, although questions remain about the interpretation of this as a direct causal effect of flooding.

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バングラデシュ国及びカンボジア国の地下水砒素汚染地域における安全な水供給技術の普及手法に関する研究

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1.　研究の背景と目的

近年カンボジア王国(以下、「カ」国)において、バングラデシュ人民共和国(以下、「バ」国)と同様な地下水のヒ素汚染が確認され、地下水を多飲する村落部で慢性ヒ素中毒(Arsenicosis)の症例が報告されている。汚染対策として適正技術による数種の砒素除去装置が両国で建設されてきた。我々の研究や類似の先行研究では、これら除去装置による砒素除去の技術的な有効性を確認している。

今回実施した本研究では、これら装置の技術的有効性の評価をさらに進め、両国の村落への導入及び、健康障害を低減する可能性を検討することを目的とした。

具体的には、各装置（ハード面）の普及手法（ソフト面）に着目し、両国における、地下水汚染の度合い、導入装置の技術的類型、ヒ素に関する住民意識、水使用形態、地下水利用期間、装置普及のためサプライチェーン、水に対する支払意思額、支払可能額(ATP: Affordable to pay)、ボトル水や浄化剤の市場価格等のフィールド調査を行い、村落部において持続可能な安全な水供給を行う際の経済的妥当性を考慮した適正な水供給装置の普及方法や、装置の普及による健康障害の改善に資する内発的発展の可能性を考察した。

2.　研究手法

研究グループは、2010年8月及び12月に「バ」国、同年8月及び2010年2月に「カ」国おいて現地調査を以下の通り実施した。

（１）研究体制及び現地調査

① 「バ」国：BUET(Bangladesh University of Engineering and Technology)をカウンターパートとし、調査対象地は、マニガンジ県、ギオール郡、バイカンタブール村

② 「カ」国：ITC(Institute of Technology of Cambodia)をカウンターパートとし、対象村落はカンダール州, キンスバイ村、 バンフェイデック村、 クソン村及びカンダールレウ村

（２）質問表によるヒアリング調査及び浄化剤等の市場価格調査

①村落住民ヒアリング調査：両国の調査村落住民（「バ」国 12 サンプル、「カ」国 41 サンプル）、を対象とし、両国ほぼ同じ調査項目（住民意識、水使用形態の把握、水に対する支払額、塩素剤や水浄化剤の使用率、地下水等の水源別等）を整備した質問表によるインタビュー形式調査。

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②村落部の商店における、塩素剤、水浄化剤やボトル水の現地市場価格等の聴き取り調査。

（3）地下水質調査

①分析項目：ヒ素(As)及び鉄(Fe)（ヒ素と鉄は 1:40 の割合で共沈する点に着目）*

②分析方法：各分析項目の濃度レベル計測するフィールドキット(ヒ素(As)：HACH As Test Kit, 0-500ppb、鉄(Fe)：メルコクアントシリーズ 鉄テスト, 3-500mg/L)

3. 現地調査結果

（1）地下水ヒ素濃度と水使用形態

表-1. 実測結果

濃度 ヒ素(ppb)	Banglades| 井戸数	Cambodia
0	3	5
5	2	5
10	4	0
15	0	1
25	1	3
50	1	3
75	1	3
100	0	2
175	0	2
250	0	4
450	0	1
500	0	6
計	12	35

表-2. 実測結果

濃度 鉄(mg/L)	Banglades| 井戸数	Cambodia 井戸数
0	1	4
1	3	5
2	0	3
3	5	0
5	1	4
9	0	1
10	1	11
15	0	1
20	0	1
25	1	3
30	0	1
50	0	1
計	12	35

各調査対象村落では、両国の地下水ヒ素濃度基準値(50ppb)以上を超えるヒ素が検出された。特に「カ」国では、調査した井戸の約 60%が同基準値を超え、その内の 30%の井戸は基準値の 10 倍に当たる 500ppb が検出された(表-1)。一方、鉄濃度*に関し、「バ」国は、約 83%が 5mg/L 以下であったが、「カ」国では、5mg/L 以上が全体の約 55%を占める(表-2)など、両国の砒素汚染*の状況は同じでない。

次に両国の水使用形態をみると、「カ」国の村落部では管井戸(TW: Tube well)から未処理の地下水を飲用している世帯が約 24%(乾期)、約 7%(雨期)と「バ」国に比し て低い(表-3)。即ち、「カ」国の調査対象村落では地下水のヒ素濃度は高いが、通年では地下水を飲用(ヒ素に暴露されていない)していない。さらに、「カ」国における地下水以外の代替飲用水源は、雨水利用や購買水(水源は河川水)を使用する世帯が 50%であること、池や雨水を溜める水瓶から直接飲用する(水系性疾患が懸念される)習慣も見受けられた。一方で、「カ」国では水を煮沸し、お茶を飲む習慣もあることを文献やヒアリング調査で確認した。

表-3 Water use practice in Bangladesh and Cambodia

Purpose and water source		Cambodia						Bangladesh					
		TW	Dug well	Pond	River	Rain	Water vendor	TW	Dug well	Pond	River	Rain	Water vendor
Dry season	Drinking	24.8	0.0	12.5	26.9	37.5	26.9	91.7	0.0	0.0	8.3	0.0	0.0
	Cooking	26.7	0.0	12.5	26.9	35.6	26.9	83.3	0.0	0.0	25.0	50.0	0.0
	Cook rice	26.7	0.0	12.5	26.9	33.7	26.9	91.7	0.0	0.0	33.3	41.7	0.0
	Washing plates	79.3	0.0	15.6	3.1	0.0	1.9	83.3	0.0	0.0	8.3	8.3	0.0
	Washing clothes	79.3	0.0	15.6	3.1	0.0	1.9	58.3	0.0	0.0	25.0	8.3	0.0
	Washing hands	82.5	0.0	12.5	3.1	0.0	1.9	91.7	0.0	0.0	0.0	0.0	0.0
	In the toilet	82.5	0.0	12.5	3.1	0.0	1.9	83.3	0.0	0.0	16.7	0.0	0.0
	Cleaning house	82.5	0.0	12.5	3.1	0.0	1.9	75.0	0.0	0.0	16.7	0.0	0.0
	Domestic animals' drinking water	84.4	0.0	12.5	3.1	0.0	0.0	50.0	0.0	0.0	8.3	0.0	0.0
	Bathing (Women)	84.4	0.0	12.5	5.0	0.0	1.9	50.0	0.0	0.0	41.7	8.3	0.0
	(Men)	69.0	0.0	12.5	3.1	0.0	0.0	50.0	0.0	0.0	50.0	0.0	0.0
Rain season	Drinking	7.7	0.0	6.3	6.3	91.1	7.7	91.7	0.0	0.0	8.3	8.3	0.0
	Cooking	11.5	0.0	6.3	6.3	91.1	7.7	91.7	0.0	0.0	33.3	50.0	0.0
	Cook rice	11.5	0.0	6.3	6.3	91.1	7.7	91.7	0.0	0.0	33.3	50.0	0.0
	Washing plates	77.4	3.1	9.4	3.1	8.2	1.9	83.3	0.0	0.0	8.3	8.3	0.0
	Washing clothes	77.4	3.1	9.4	3.1	8.2	1.9	58.3	0.0	0.0	33.3	8.3	0.0
	Washing hands	77.4	3.1	9.4	3.1	8.2	1.9	83.3	0.0	0.0	0.0	0.0	0.0
	In the toilet	75.5	3.1	9.4	3.1	8.2	1.9	75.0	0.0	0.0	16.7	0.0	0.0
	Cleaning house	75.5	3.1	9.4	3.1	8.2	1.9	66.7	0.0	0.0	16.7	0.0	0.0
	Domestic animals' drinking water	77.4	3.1	9.4	3.1	8.2	1.9	41.7	0.0	0.0	16.7	0.0	0.0
	Bathing (Women)	79.3	3.1	9.4	5.0	8.2	0.0	41.7	0.0	0.0	41.7	0.0	0.0
	(MEN)	71.6	3.1	9.4	3.1	8.2	0.0	50.0	0.0	0.0	50.0	0.0	0.0

「バ」国の調査村落では、水購入をする世帯は皆無で、90%以上の世帯が通年を通し TW の水を飲用している(表-3)。なお、「バ」国の水使用形態として、生活用水（調理、炊事や洗濯等）は TW の水の使用が多く続いて、河川水を利用している(表-3)。

以上、両国の水使用習慣の違いから住民の水支払意識は、「カ」国のほうが「バ」国より高いと考察される。但し、本考察は対象村落が限定されているため、対象地を拡大し一般化する必要がある。

（2）水に対する支払可能額

表-4 水へのATP

ATP(S/月)	世帯数
0	21
1.5	2
5	4
10	4
15	1
30	2
計	34

両国の調査村落の「支出額」における購買水への ATP の割合を検討した結果、「バ」国の村落部では 0%、「カ」国の村落部では約 6%(表-4)であることが明らかになった。この結果は、上記(1)の両国の水使用形態からの考察を裏付けるものと考えられる。なお、日本では上下水道料金への家計支出額の割合が 1.6%とされており、また、世

銀は可処分所得の約3%が水に支出可能している。このことからも、「カ」国のATP(6%)は高いと評価できる。

（3）代替水源等の市場価格

「バ」国で利用可能なヒ素除去装置、雨水タンクや、深井戸などの水供給装置のコストは300TK(1TK=1.3円)から45,000TKと多彩な価格の水供給装置が現地に存在している(表-4)。

「カ」国では、主に3種類のボトル水が販売され、価格の差が倍近くある。一方「バ」国におけるボトル水は10倍の価格差(表-5)があることを確認した。

次に、現地入手可能な凝集沈殿剤（ミョウバン(Alum)）や次亜塩素酸カルシウム(Bleaching powder)は、両国の村落部内の商店での取り扱いは無く、行政単位が上位にある県等の商店で販売されていることが現地調査から明らかになった。

表-4 バングラデシュにおける水供給形態のコスト

水供給形態	水源	処理方法	建設コスト(TK)	維持管理(TK/人/年)	ユニット当たりの世帯数(家族サイズ=5)
ピッチャーフィルター(PF)*	地下水	砂ろ過	300	1	1
雨水利用(RWH)	雨水		6,200	20	1
ヒ素除去装置(AIRP)	地下水	砂ろ過	15,000	5	3
ダグウェル(DW)	地下水		35,000	1	25
ポンド・サンド・フィルター(PSF)	池	砂ろ過	35,000	10	50
深井戸(DTW)	深層地下水		45,000	1	50

「バングラデシュ人民共和国バングラデシュヒ素汚染対策プログラム評価報告書」国際協力機構、p36より参照
*筆者らのヒアリング調査値参照

表-5 現地で入手可能なボトル水と水浄化剤

Country	Market	Product	Price	Dosage	Cost Effectiveness
Cambodia	Ko-Ki market	Mineral Water (Rabir)	500 R / 0.5 L	-	1000 R / L
			3000 R / 6 L	-	500 R / L
		Mineral Water (HI-TECH)	1000 R / 0.5 L	-	2000 R / L
			2 $ / 0.5 L / 12 piece	-	1333 R / L
		Mineral Water (Lyyon)	1000 R / 0.5 L	-	2000 R / L
			2 $ / 0.5 L / 12 piece	-	1333 R / L
			2000 R / 1.5 L	-	1333 R / L
			10000 R / 1.5 L / 6 piece	-	1111 R / L
		Blue-Bottled water (20L)	5$ / 20 L	-	1000 R / L
		-Water	1$ / L	-	4000 R / L
		-An Empty Bottle	4 $	-	-
		Alum	500 R / 150g	1g / L	3 R / L
			3000 R / kg		3 R / L
		Breaching Powder	-	-	-
Bangladesh	Manikganji market	Mineral Water	12 TK / 0.5L	-	24 TK/L
			20 TK / 1.5L	-	13.3 TK/L
			60 TK / 5L	-	12 TK/L
		Filter water	2.5 TK / L	-	2.5 TK/L
			50 TK / 20L	-	2.5 TK/L
		Alum	18 TK / 300g	10g / L	0.6 TK/L
			60 TK / kg		
		Bleaching powder (High quality)	100 TK / kg	5g / L	0.5 TK/L
		Bleaching powder (Low quality)	60 TK / kg	10g / L	0.6 TK/L
			16 TK / 250g	10g / L	0.64 TK/L

R: 4000R=1 $、 TK: 1TK=1.3円

4. 除去装置及び水浄化剤の経済的妥当性と考察

現地で入手可能な代替水は、各世帯収入額における水への支払可能額以内でなければ購入や所有が困難である。即ち、代替水の選択は式①となる。

$$I \cdot r > \alpha \quad \cdots ①$$

ここで、I:月世帯収入額、r:水に対する可処分所得の支出割合、α:代替水の価格

水浄化剤を含む代替水源の市場価格調査結果から式①を用いて1世帯当たりの代替水源に対する月支出額を算出した。最初に、ヒ素除去装置や井戸掘削より安価で、表流水等を浄水する目的で、途上国で通常用いられている次亜塩素酸カルシウムやミョウバンの価格の妥当性についての評価を行う。

「バ」国では、次亜塩素酸カルシウムやミョウバンによる浄水の1L当たりの費用は，前者が0.5TK/L、後者が0.6TK/Lであり、家族構成が4～6人/世帯（出所：文献7)）で一人当たりの飲料量は約3L/日以下とされていることから，前者は約225TK/月・世帯、後者は約270/月・世帯）支出が必要と算出される（家族数は平均値を使用）。これを式①より、月収入額が7500から9000TKの世帯が購入可能であることが判る(世銀の値を参照しr=0.03とする)。バングラデシュ統計書（出所：文献7)）によれば、7,500TK以上の収入がある世帯は全農村世帯数の約10%とされ、90%の世帯はそれ以下の収入であることから、これら浄水剤のBOP層への普及は難しいと考えられる。

次に、「カ」国では、ミョウバンの1L当たりの費用は3R/L(約4,000R＝1US$)であることが確認されたが、次亜塩素カルシウムは確認できなかった。これよりミョウバンを使用した水への出費額は「カ」国の家族構成が4.7人/世帯であることから、約1,270R/月・世帯であることが判る。これを式①を用いると、必要月収入額が約42,000R/世帯と算出される。つまり約11$以上の収入がある世帯がミョウ

バンを購入することが可能であり、調査対象村の月平均世帯収入額は約 240$であることから、水浄化剤等は安価であることが判る。

以上から、両国の村落住民の収入額における水浄化剤への支払額を比較すると、「バ」国では非常に高く、「カ」国では安価であることが明らかになった。

次に、ボトル水や除去装置価格は水浄化剤より高価であるため、式①の I と r は大きく変化しないと仮定した場合、α の低減が求められる。このためには、スケールメリットによる α 価格を低くさせることが考えられるが、I と r に限界のある村落部で市場の活性化には長期的視野に立つ手法が必要となる。即ち、I と r の範囲で支払いが可能となるリース、マイクロクレジットやリボルビングファンド等によるファイナンスの仕組みが求められる。この仕組みの導入には、今回の現地調査の結果から、次の 3 点が考察される。

a. 安全な飲用水の必要性（安全な水供給により健康障害が低減するという長期のメリット）を貨幣価値等に置き換えて示し、住民側の理解を得ること。

この場合、従来、事業が「ある場合(with)」と「ない場合(without)」による比較による評価が行われ、計画倒れやパイロット事業を実施するのみで、持続性が担保されない事例は数多くある。

b. 今後は、有効な技術を普及させ、健康改善さらには経済改善に繋がる手法として、地元の企業等からの出資とサプライチェーンの構築によるビジネスとしての視点を持つこと。

以上二つの必要条件を満たすことが、途上国村落部住民の内発的発展に繋がると考えられる。但し、行政による補助金による手法は BHN(Basic Human Needs)の観点からは求められる。

c. しかし、補助金依存とさせないためには、ファイナンスやビジネスの工夫を行うことで、住民の内発的発展による健康改善と経済発展にフィードバックすることも必要な条件となると考えられる。

5. 結論

今回の両国における調査から、有効な技術を村落部に普及するためには、考察した 3 つの必要条件が揃っていなこと、一般の浄水剤等よりはるかに高価でありサプライシステムが未完成であることが明らかになった。今後はこれら必要性を明確にする調査研究を継続したい。

6. 謝辞

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7) Statistical Yearbook of Bangladesh 2004 年版及び 2009 年版

カンボジア国村落部における地下水砒素汚染の影響予測と外的支援策に関する研究

－バングラデシュ国の教訓を活かして－

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1．背景及び研究目的

本研究は、近年、地下水中の砒素による健康被害が注目されているカンボジア国(以下、「カ」国)を研究対象とし、砒素対策の先行事例であるバングラデシュ国(以下、「バ」国)における外部援助の経験活用の可能性を探ることを目的とした。即ち、「バ」国と同様に「カ」国では Unicef 等の援助機関の介入により病原性微生物の観点からは管井戸による安全な地下水供給が実施された結果、「バ」国と同様なパターンで健康障害が時間差を置いて発生するものと考えた。この仮説に基づき「バ」国における介入経緯及び健康影響をレビューし、砒素汚染問題対応の黎明期にある「カ」国における効果的な砒素問題介入方法の検討を行なった。

その結果、村落民の地下水飲用量、砒素濃度の度合い、水使用形態や衛生教育等から地下水砒素汚染による健康影響の現状を定量化することを試みた。さらに、適正技術による簡易砒素装置の普及、教育や医療面からのアプローチ等による仮説介入モデルと、そのアプローチの持続性を確保することを考察した。

2．研究方法

(1) 既存文献のレビュー

両国の、ドナー介入による管井戸掘削数の推移、地下水汚染の推移、砒素慢性疾患(Arsenicosis) 症例数、地下水砒素問題に対するドナー等介入の経緯を始め、政府の対応、国際機関等各ドナーの砒素汚染問題に対する動向等を把握し砒素汚染問題の時系列による分析を実施した。

(2) 現地調査による基礎データ収集

2009 年、2010 年及び 2011 年に、「カ」国の砒素汚染が高いと報告されている 7 州の内の 3 州(Kandar, Prey Veng 及び Kampong Cham 各州)及び、砒素汚染が確認されていない 1 州(Takeo 州)で現地調査を実施した。現地調査では、地下水砒素汚染の状況を確認するための簡易実測調査(As、Fe 等)、水使用形態や砒素に関する住民意識調査、および「カ」研究機関、「カ」政府関連組織、国際機関(Unicef、WHO、世銀等)および NGO 等を訪問し研究に必要なデータや情報等を入手し分析を行った。

3．カンボジア国の砒素汚染と対策の検証

(1) 研究仮説と「カ」国の砒素汚染対応現状と課題

研究目的で記した、介入(井戸掘削)と時間差による健康影響仮説を図 1 に示す。この仮説を検証するための基礎データの収集を試みたが、現地調査では多くの場合入手は困難であった。これは単にデータ収集やアーカイブ制度(保健省では Arsenicosis という統計処理はしてない)不足ということのみならず関連組織からの聴き取り調査 [1)] から以下の点が明らかになった。

- 「カ」国村落部の地下水砒素汚染問題は、経済開発政策を推進する同国にとって対外的なネガティブキャ

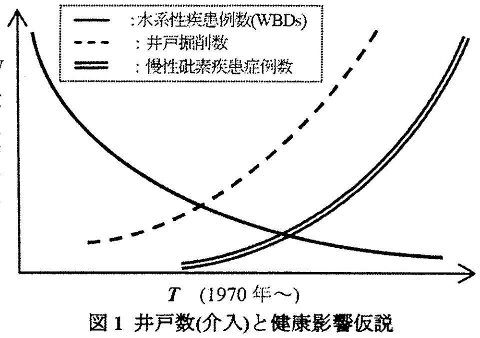

図 1 井戸数(介入)と健康影響仮説

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ンペーンとなる可能性がある。

- 特に安全な水供給が十分とは言えない村落部の社会的不安を煽る等のマイナス効果の発現を恐れている。

これらの「カ」国政府の地下水砒素汚染の対策に内在する消極的な面を裏づけるものとして、「カ」国政府は AISC を組織したものの政策や行動計画が未承認(2010 年末現在)、「カ」国版 PRSP である NPRS に地下水砒素汚染問題が含まれていない[1),2)](表 1)。このためドナーが地下水砒素問題への円滑な介入ができない状況にあると考えられる。

特に「カ」国の開発の優先課題は「経済発展」にあり、保健医療面に関してはマラリア、デング、HIV/AIDS 等の感染症が早急に解決すべき問題として掲げられている。即ち、「カ」国政府は経済発展や緊急を要する感染症への対応が優先され、砒素の低濃度暴露による影響が約 10 年後に慢性疾患(WHO)として顕著となる地下水砒素汚染問題へは消極的な対応であると評価される。さらに、「カ」国政府の砒素問題への対応の背景には多くの解決すべき政策的判断、開発過程、「カ」国政府や村落部の社会経済的背景など固有の課題や事情により、砒素問題より優先すべき「開発課題」があるものと推察される。

表1 地下水砒素汚染問題における両政府の対応比較

カンボジア政府	バングラデシュ政府
・ 2002 年、関連5 省からなるAISC*を組織。 ・ 2006 年「砒素5 ヵ年戦略的アクションプラン」を作成→2010 年末現在、同プラン政府未承認。 ・ 国家貧困削減戦略(NPRS)**に砒素問題は含まれてない。 ・ 開発の優先課題：経済発展、マラリア・デング・HIV/AIDS等。	・ 2004 年「国家砒素緩和政策」及び「実行計画」を採択。 ・ 2005 年PRSP に砒素対策を含む安全な水の供給を重要な一課題として位置付け。 ・ 我が国をはじめとするドナーの砒素問問題の介入実施(JICA技プロ等)。

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** NPRS; National Poverty Reduction Strategy (「カ」国版PRSP)

(2) フィールド調査結果

2009 年に実施した現地調査(Kandar, Prey Veng、Kampong Cham 及び Takeo の 4 州)では、砒素濃度簡易検査(サンプル数 12 井戸)、砒素問題認識、飲料水確保習慣、砒素除去に対する支払意思額(WTP: Willingness to Pay)等の住民意識を把握する目的で、ヒアリング調査(サンプル数 12 名)を実施した。本調査で判明した地下水砒素濃度、住民の習慣や意識として特筆すべき点を以下に整理する[1),2)]。

- 「カ」国の飲料水基準(CDWQS)の 50μg/L(WHO 基準は 10μg/L)を超える砒素濃度を 8 井戸(約 66%)から検出し、内 7 井戸(約 58%)からは 250～500μg/L の高濃度の砒素を確認した。
- 習慣として雨季は雨水及び表流水を、乾季は表流水のみを飲用している点。
- IEC 等の衛生教育等が実施されている
- 村落ほど砒素問題の認識や砒素除去簡易フィルタ装置導入に対する WTP(US$7-10)が高い傾向がある点。

次に、2010 年及び 2011 年に実施した現地調査は、地下水砒素汚染が最も顕著であるカンダール州の数村落を調査対象に絞り込み、2009 年と同様の調査を実施し水使用形態等をより明確にした[3),4)] (表 2)。

- 調査した 35 井戸の内、約 60%が CDWQS の砒素基準(50μg/L)を超え、その内 30%の井戸水は同基準の 10 倍に当たる 500μg/L が検出された。
- 管井戸(TW)の地下水を直接飲料している世帯は、24%(乾期)及び 7%(雨季)であった。
- 水源として、雨水や購買水(水源は河川水)を利用する世帯が約 50%あることが判った。
- 雨水を留める水瓶(約 $1m^3$)から直接飲用する習慣があることをヒアリング及び現地で目視した。
- 水を煮沸し、お茶を飲む習慣があることを関連文献やヒアリング調査で確認できた。

表 2「カ」国の水源別水使用形態(%)

Purpose and water source		TW	Dugwell	Pond	River	Rain	Water vendor
Dry season	Drinking	24.8	0.0	12.5	26.9	37.5	26.9
	Cooking	26.7	0.0	12.5	26.9	35.6	26.9
	Cook rice	26.7	0.0	12.5	26.9	33.7	26.9
	Washing plates	79.3	0.0	15.6	3.1	0.0	1.9
	Washing clothes	79.3	0.0	15.6	3.1	0.0	1.9
	Washing hands	82.5	0.0	12.5	3.1	0.0	1.9
	In the toilet	82.5	0.0	12.5	3.1	0.0	1.9
	Cleaning house	82.5	0.0	12.5	3.1	0.0	1.9
	Domestic animals' drinking water	84.4	0.0	12.5	3.1	0.0	0.0
	Bathing (Women)	84.4	0.0	12.5	5.0	0.0	1.9
	(Men)	69.0	0.0	12.5	3.1	0.0	0.0
Rain season	Drinking	7.7	0.0	6.3	6.3	91.1	7.7
	Cooking	11.5	0.0	6.3	6.3	91.1	7.7
	Cook rice	11.5	0.0	6.3	6.3	91.1	7.7
	Washing plates	77.4	3.1	9.4	3.1	8.2	1.9
	Washing clothes	77.4	3.1	9.4	3.1	8.2	1.9
	Washing hands	77.4	3.1	9.4	3.1	8.2	1.9
	In the toilet	75.5	3.1	9.4	3.1	8.2	1.9
	Cleaning house	75.5	3.1	9.4	3.1	8.2	1.9
	Domestic animals' drinking water	77.4	3.1	9.4	3.1	8.2	1.9
	Bathing (Women)	79.3	3.1	9.4	5.0	8.2	0.0
	(Men)	71.6	3.1	9.4	3.1	8.2	0.0

TW: Tube well(管井戸)

以上から、「カ」国村落部の習慣として地下水以外に、特に雨季には雨水を水瓶に貯留し飲用しているため、この習慣がある村落では、通年での地下水砒素による暴露がないと評価できる。即ち、雨水飲用習慣は Arsenicosis 発症期間が通年の砒素汚染水飲用より遅延するものと考えられ、同症例発生予測をする際の必要なパラメータとして考慮する必要があること、また Arsenicosis 発生抑制を促す介入アプローチの一つとして検討すべきと考えられる。