定できる式を構築した。式における定数及び変数を決定するために，同国農村部の調査対象村において，地図の作成，地下水中ヒ素濃度の水質ヒ素分析，並びに農村部住民における水使用形態及び収入額等に関する社会調査，並びに現地マーケット等におけるボトル水や水処理薬品などの市場価格に関する聞き取り調査を行った。また首都ダッカでは，バングラデシュ工科大学，「バ」国公衆衛生技術局，JICA 現地事務所，「バ」国統計局において現地統計データや水処理薬品の使用習慣に関する情報取集を行った。

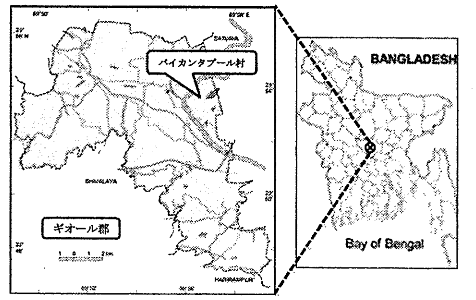

図 1　調査対象地域地図 [5]
Fig.1 Field Map

Ⅲ　調査対象地概要

本研究における調査対象村は，「バ」国農村部の代表的飲料水供給方式である管井戸が普及している地域であること，聞き取り調査におけるバイアスが生じないようにヒ素対策の外部援助がなされていないこと等を条件として選定した。その結果，首都ダッカ西方 80km にある，人口約 900 人（2006 年ヒアリング）のマニガンジ県ギオール郡バイカンタプール村（以下，調査対象村）を選定した。

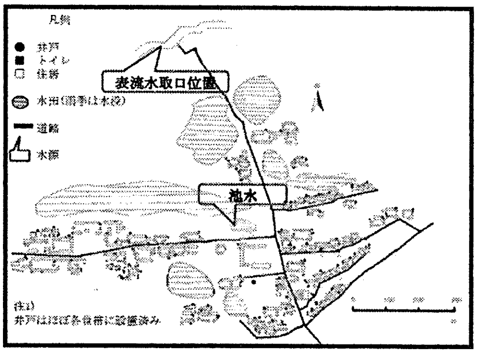

図 2　調査対象村地図 [6]
Fig.2 Baikunthapur Village

Ⅳ　調査結果

1　収入額と支払意思額

調査対象村において数年にわたり世帯当たりの平均収入額の調査を行った結果 [6)7)8)]('06-'07:n=51, '09:n=12, '10:n=13)を図 3 に示す。図 3 より調査対象村において収入は年約 15%程度の伸びを示していることがわかる。また図 4 には'05 年の全国の農村部の収入額分布と調査対象村の'06-'07 年の収入分布を合わせて示す。調査対象村の'05 年の値は図 4 に示したものよりやや低いと考えられるが，低所得者層の分布は全国平均と似た形状を示している。また中所得者層はサンプル数の関係で回答が一部の収入範囲に偏ってはいるものの，概ね全国平均に近い割合を占めている。なお月に 9,000TK(1 TK=1.3 円)以上の高所得者層は全国平均を上回っているが，これは調査対象村が首都ダッカに近いため就業機会が比較的多いためではないかと考えられる。調査対象村において安全な飲料水に対する支払い意思額を'09 年に調査したところ，平均 225TK/世帯・月であり [9]，図 3 に示す同年の平均収入額に対して 2.3%と計算される。なおこの値は世界銀行が途上国における水への支出額を計算する際の仮定値として用いている可処分所得の約 3% [10] と，先進国である我が国における上下水道料金の家計支出額に対する割合 1.6% [11] の中間的な数値となっている。

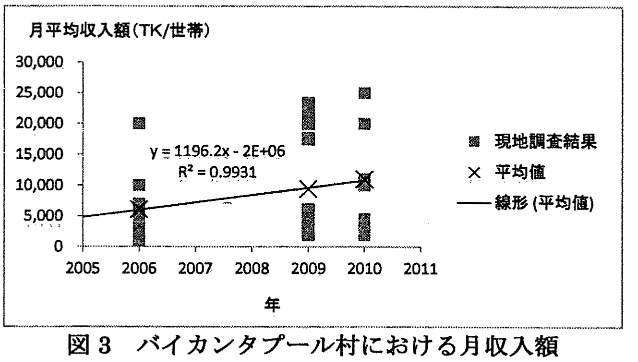

図 3　バイカンタプール村における月収入額
Fig.3 Monthly income in Baikunthapur

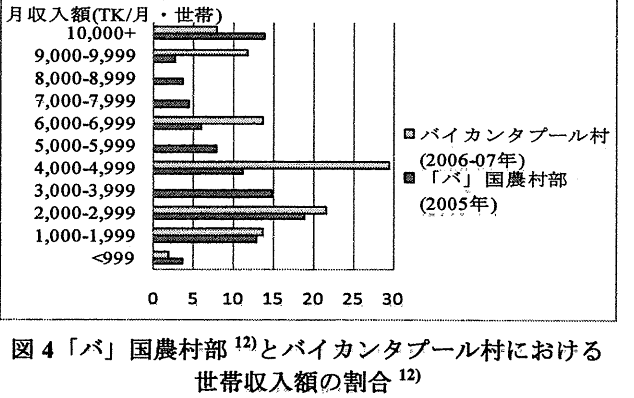

図 4「バ」国農村部 [12] とバイカンタプール村における世帯収入額の割合 [12]
Fig.4 Monthly Income of Household in Rural Bangladesh and Baikunthapur village

2 現地住民の水使用形態

調査対象村において，12 本(1 世帯 1 本の井戸を所有)の井戸の水質（ヒ素濃度）調査を行った結果，7 本の井戸で世界保健機関(WHO)のヒ素濃度基準値である 0.01mg/L 以上を検出した。なお，「バ」国の同基準は 0.05mg/L（WHO の基準値より 5 倍許容している）であるため，2 本の井戸が同国の基準値を上回っている。

水使用形態調査では，水購入をする世帯は皆無で，90%以上の世帯が通年を通し管井戸の水を飲用していることを確認した。これらの結果から，慢性ヒ素中毒の患者の存在が懸念される。また，地下水以外の水源として，表流水(雨水や河川水)を使用し，主に炊事及び洗濯に利用されている(表 1)。これは地下水に含まれる鉄による繊維着色等を忌避するために表流水を利用していることがヒアリング調査から明らかになった。即ち，地下水に含まれる鉄の除去にもニーズがあることが確認された。

表 1 バイカンタプール村における水使用形態

Table.1 Water Use Practice in Baikunthapur Village

用途別水源	バイカンタプール村							
	乾期				雨期			
	管井戸	雨水	河川水	購買水	管井戸	雨水	河川水	購買水
飲料用	11	0	1	0	11	1	1	0
調理用	10	6	3	0	11	6	4	0
炊飯用	11	5	4	0	11	6	4	0
食器洗い	10	1	1	0	10	1	1	0
衣類洗濯	7	1	3	0	7	1	4	0
手洗い	11	0	0	0	10	0	0	0
トイレ使用	10	0	2	0	9	0	2	0
屋内清掃	9	0	2	0	8	0	2	0
家畜等の飲料	6	0	1	0	5	0	2	0
水浴び(女性)	6	1	5	0	5	0	5	0
水浴び(男性)	6	0	6	0	6	0	6	0

(注:1 回答者には複数選択可としている。　単位:世帯

(注:2 2009年現地調査結果

3 設備投資を必要としない水供給製品の市場価格

調査対象村では表流水を 1 世帯の住民が飲用していることを確認した(表 1)。また，表流水を安全に飲料できる塩素剤，凝集剤は，「バ」国の農村部内において入手困難であり，県レベルの市場であれば入手可能なことが現地調査から明らかとなった。市場では，主に凝集剤として使用されるミョウバンや次亜塩素酸カルシウム(さらし粉)が販売されており，雨期の洪水時にニーズが高くなることを聴取り調査から明らかになっている(表 2)。

4 設備投資を必要とする水供給装置の市場価格

現地では，汚染された地下水を除去できる砂ろ過手法を用いた PF(Pitcher Filter)や鉄とヒ素を同時に除去する AIRP(Arsenic and Iron Removal Plant)が存在する。また安全な深い帯水層から地下水を汲み上げる DTW(Deep Tube Well)や手掘りの井戸である DW(Dug Well)がある。他の水源として雨水を利用するための RWH(Rain Water Harvesting)や池の水をろ過する PSF(Pond Sand Filter)が現地で使用されている。これらの装置により処理された水は，ヒ素や鉄を含まないため，現地住民の川までの水汲みに消費する時間軽減や住民の健康増進につながる事からインセンティブがあると考察する。

表 2 バングラデシュ国における水供給装置・製品の市場価格と供給形態

Table.2 Water Supply System and Price of Water Supply Goods in Bangladesh

水供給形態	水源	必要な処理方法	販売価格(TK)		薬品の投入量	1L当たりの価格(TK)	耐用月数(注1
ミョウバン(注1	表流水	凝集沈殿	18/300g		10g/L	0.6	-
			60/kg			0.6	-
次亜塩素カルシウム(良質)(注1		消毒	100/kg		5g/L	0.5	-
次亜塩素カルシウム(注1		消毒	60/kg		10g/L	0.6	-
			16/250g			0.64	-
ミネラルウォーター(注1	地下水	-	12/0.5L		-	24	-
		-	20/1.5L		-	13	-
		-	60/5L		-	12	-
フィルターウォーター(注1		-	2.5/L		-	2.5	-
		-	50/20L		-	2.5	-
			設備投資費用	維持管理費(TK/月・世帯)	最大共用世帯数(家族サイズ=5)		
深井戸(13		-	45,000	0.42	50		240
ピッチャーフィルター(注1		砂ろ過	300	0.42	1		12
ヒ素除去装置(注1		砂ろ過	15,000	2.08	3		48
ダグウェル(13		-	35,000	0.42	25		120
雨水利用(13	雨水	砂ろ過	6,200	8.33	1		48
ポンド・サンド・フィルター(13	池	砂ろ過	35,000	4.17	50		72

(注:1 2010年ヒアリング調査結果

V 経済的に妥当な代替水及び装置の算出

1 水処理薬品及びボトル水の経済的妥当性の算出

処理薬品及びボトル水等が使用者に経済的に妥当かを判断するために式の構成を行う。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，経済的妥当な代替水の選択は不等式(1a)で算出される。

$$I \cdot r > W \cdot V \cdot e \tag{1a}$$

ここで

I ：月収入額(TK/月・世帯),

r ：水に対する家計支出額の割合

W ：一人当たりの水使用量(L/人・月)

V ：各製品の１L 当たりの単価(TK/L)

e ：家族構成数(人/世帯)

2 設備投資を必要とする装置の費用算出

(1) 初期投資額の算出

ヒ素除去装置等は，個人資産や国際機関等のドナーによる補助金や援助を用いて建設が行われている。また，NGO や銀行等による借入金による物品の購入等を行っている地域もある。よって除去装置等における使用者の

初期投資額の算出は，装置価格から補助金及び借入金の差額で表すことができる。従って，使用者の初期投資額は，式(1b)により算出される。

$$U_I=(C_T-C_S)-C_L \tag{1b}$$

ここで
U_I：使用者の初期投資額(TK)，　C_T：装置価格(TK)
C_S：補助金(TK)，　C_L：借入額(TK)

(2)　装置に対する月支出額の算出

「バ」国農村部では，グラミン銀行によるマイクロクレジットを用いた貸し付けが行われている。農村部におけるマイクロクレジットの返済方法は，借入金額（元本）に金利（アドオン率）と期間を掛けて利息額を算出し，この利息を元本に加えた金額を均等に分割して各月または週に返済する手法を用いるのが一般的である[14]。これは，返済計画が立てやすいアドオン返済方式を用いていると考えられる。農村部での成功事例があるマイクロクレジットのアドオン返済方式は，装置に対する支払手法として用いることが「バ」国農村部において適正であると考察する。また装置購入を行う際，減価償却を考慮する必要がある。減価償却も定額法を用いることにより，使用者に返済計画が立てやすいと考えている。アドオン返済方式を用いた装置使用者の毎月の支払い額は，借入額，アドオン率，返済月数，運転維持管理費，減価償却費を用いて式(1c)より算出できる。

$$U_M=C_L(1+\frac{q}{100})/m+\sum_{i=1}^{k}(C_O+C_D)/k \tag{1c}$$

ここで
U_M：使用者の毎月の支払い額(TK/月)
q：アドオン率(%)，　m：返済月数(月)
C_O：運転維持管理費(TK/月)，C_D：減価償却費(TK/月)
k：使用期間及び減価償却期間(月)

(3)　使用者の総支出額の算出

初期投資額と運転維持管理費により，使用者の総支払い額を求めることができる。また運転維持管理費及び減価償却費は，耐用月数(使用期間)中支払わなければならないため，総和として求める必要ある。つまり，使用者の総支払額は，装置価格，補助金，借入額，アドオン率，耐用月数(使用期間)，運転維持管理費，減価償却費を用いて式(1d)により算出できる。

$$U_T=(C_T-C_S)-C_L+C_L(1+\frac{q}{100})+\sum_{i=1}^{k}C_O+\sum_{i=1}^{k}C_D \tag{1d}$$

ここで
U_T：使用者の総支払額(TK)

3　使用者の収入額に対する装置支払い額の定式化

式(1c)おける毎月の支払額は，使用者の水に対する支払い額可能額未満でなければならない。また，水供給装置等の購入は一世帯とは限らず，複数世帯(h 世帯)で共同購入・使用することも考えられる。月々の支払い可能額は式(1e)により与えられる。

$$C_L(1+\frac{q}{100})/m+\sum_{i=1}^{k}(C_O+C_D)/k<I\cdot r\cdot h \tag{1e}$$

ここで
h：各装置における共用世帯数(世帯/基)。また，1 以上で各装置の最大共用世帯数(h_{max})内の整数とする。

Ⅵ　水供給代替案の経済的妥当性の検討

1　水処理薬品の経済的妥当性

不等式(1a)を用いて 1 世帯当たりの代替水に対する月支出額を算出した。最初に，ボトル水より安価で，表流水等を処理する目的で，使用され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評価を行う。「バ」国における，次亜塩素酸カルシウムやミョウバンの単価を用いると，飲料水の 1L 当たりの処理に必要な費用は，前者が 0.5TK/L(V=0.5)，後者が 0.6TK/L　(V=0.6)となる。これより 1 世帯当たりの処理水利用における費用は，一人当たりの飲料量を約 90L/月(W＝90)とし，5 人家族(e=5)とした場合(家族構成が 4～6 人/世帯[15])，前者が約 225TK/月・世帯，後者は約 270/月・世帯と算出される。これを不等式(1a)に代入し，水に対する家計支出の割合を 2.3%(r=0.023)と仮定すると，それぞれ月収入が 9,800TK 及び 12,000TK 以上の世帯が購入可能であることが判る。これより調査対象村の平均所得('09 年 9,400TK)世帯は，水処理薬品の購入が困難であることが明らかになった。また処理薬品より高価であるボトル水も，飲料として使用する事は経済的に困難である。

2　設備投資を必要とする装置の経済的妥当性

(1)　計算条件

市場価格調査結果(表 2)から式(1b,1e)を用いて 1 世帯当たりの代替水の購入に対する月支出額と必要世帯数を算出する。式(1b)より，初期投資の支払い方法を補助金(C_S)またはローン(C_L) 手法に分けて分析を行う。分析を行うための式(1b,1e)の定数である，維持管理費(C_O)，耐用月数及び使用期間(k)は，表 2 の調査結果を代入し，ユニット当たりの共用世帯数(h)及び収入額(I)は変数として使用した。また，農村部で行われているマイクロクレジットの数値に基づき[16]，月返済期間を 1 年(m=12)，アドオン率を 20% (q=20)とし，水に対する家計支出額の

割合を 2.3% (r=0.023)と仮定して算出する。

(2) 初期投資を補助金で支出した場合(C_T=C_S)

初期投資を補助金で支払う場合，使用者は運転維持管理費及び減価償却費を支払うことになる。不等式(1e)より，6,500TK の月世帯収入額があれば，PF，RWH は 1 世帯，AIRP，DW，PSF，DTW は複数世帯で共同使用することにより購入可能であることが算出された(表 3)。これより不等式(1e)に代入した数値と同年の 09 年における調査対象地域の月平均世帯収入額世帯では，共同で使用するものも含め，すべての装置を使用することができる。

表 3　月収入額に応じた必要共同世帯数(初期投資を補助金で支出した場合)

Table.3 Number of Household to be required by Income for the System with Subsidy for Initial Cost

収入額 TK (月/世帯)	PF	RWH	AIRP	DW	PSF	DTW
10500	1	1	2	2	3	1
9500	1	1	2	2	3	1
8500	1	1	2	2	3	1
7500	1	1	2	2	3	2
6500	1	1	3	2	4	2
5500	1	2	3	3	4	2
4500	1	2	4	3	5	2
3500	1	2	4	4	7	3
2500	1	3	6	6	9	4
1500	1	4	10	9	15	6
500	3	12	28	26	43	17
最大共用世帯数 (h max)	(h≦1)	(h≦1)	(h≦3)	(h≦25)	(h≦50)	(h≦50)

注:1) 塗り潰し箇所は供給不可能　　単位：世帯

(3) 借入のみで運用した場合(C_T=C_L)

初期投資額の支払いにローン手法を用いた装置の妥当性について評価する。補助金を用いた場合と比較すると，6,500TK の世帯において，RWH，AIRP や DW は，最大共用世帯数を超えてしまうため，使用することが困難であると算出された。しかしながら，実際の水利用を考慮すると，h_{max} を超えていても共同する世帯が出てくると考えられる。ローンを用いた場合，調査対象村では RWH や AIRP の使用が困難であることが示された。

表 4　月収入額に応じた必要共同世帯数(初期投資をローンで支出した場合)

Table.4 Number of Household to be required by Income for the System with Loan for Initial Cost

収入額 TK (月/世帯)	PF	RWH	AIRP	DW	PSF	DTW
10500	1	4	8	16	17	20
9500	1	4	9	18	19	22
8500	1	5	10	20	21	25
7500	1	5	11	23	24	28
6500	1	6	13	26	28	32
5500	1	7	15	31	33	38
4500	1	8	19	38	40	46
3500	1	10	24	48	51	59
2500	2	14	33	67	72	83
1500	2	23	55	112	119	137
500	6	69	164	335	356	411
最大共用世帯数 (h max)	(h≦1)	(h≦1)	(h≦3)	(h≦25)	(h≦50)	(h≦50)

注:1) 塗り潰し箇所は供給不可能　　単位：世帯

(4) 初期投資額を補助金及び借入金で支出した場合 (C_T=C_S+C_L)

同額の補助金及び借入金で支払う(C_S=C_L)場合は，表 3, 表 4 で示した値の中間値を取ることにより求められる。借入金が少ないことから，使用者の負担少ないと考察する。また補助金より借入金が大きい(C_S<C_L)場合は，借入金(ローン)が大きくなるため，表 4 に近似することが考えられる。一方，補助金より借入金が小さい(C_S>C_L)場合は，表 3 に近似すると考察され，使用者の負担は減少すると考えられる。

3 代替装置等における普及手法の考察

水供給設備が住民にとって経済的に妥当となるのは，月収 I と共同利用する世帯数 h とが先に示した不等式(1e)を成立させることができる範囲にある場合である。すなわち I は不等式(1e)の不等号を等号に置き換えた場合の境界線の上側に位置しなければならない。一方 h は共同利用できる世帯数の物理的上限とされる h_{max} 以下でなければならない。この 2 つの条件を満たす範囲が，住民が経済的・物理的に使用可能な範囲となる。図 5 には代替水源としての深井戸が住民にとって利用可能かどうかを，全額補助金を投入した場合（表 3 より転記，境界線 l_1）および建設費をローンで賄った場合（表 4 より転記，境界線 l_2）について境界線を示した。補助金を投入した場合はかなりの低所得者層まで普及できることがわかる。

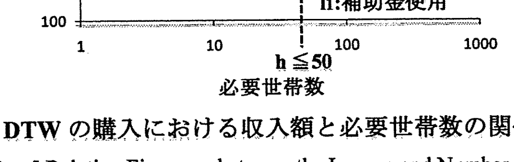

図 5 DTW の購入における収入額と必要世帯数の関係図

Fug.5 Relation Figure on between the Income and Number of Household for Purchase of Deep Tube Well

Ⅶ 結論

本研究では，住民の水使用形態からニーズの把握や現地で入手可能な処理・給水装置の市場価格を明らかにし，式(1a)及び式(1e)を用いて現地住民に経済的に妥当な装置を選択した。その結果，調査対象村において次亜塩素酸カルシウム，ミョウバンやボトル水は経済的に妥当で

ないことが明らかになった。また，設備投資が必要なヒ素除去装置等の場合は，初期投資に補助金を用いると，購入可能な世帯が拡大することが確認された。また，算出された表3，表4よりAIRPとDTWを比べると，建設コストは前者が低いが，収入額に対する必要な共同世帯数は多いことが明らかになった。これより，維持管理費が少なく減価償却期間が短い装置が調査対象村では妥当である。またDTWのように行動変容を伴わない装置は文化的にも妥当であると考えられるが，初期投資額が高いため，低所得者であるBOP層に普及する場合は，ソフトローンや助成金等の経済的手段が必要であると考察する。また，住民へのヒ素に対する啓蒙活動や金融リテラシーのような教育も普及を促すと考えられる。今後の課題としは，対策装置等の普及に伴う売り手やNGO等の出資機関を考察したビジネスモデルを構築する必要がある。また「バ」国だけではなく，地下水ヒ素汚染に苦しんでいるインド，カンボジア等の諸国に適正技術を用いた代替水の普及を行う必要がある。そのために，各国の文化，社会的背景や水使用習慣，ジェンダーなどの要因も定量的に分析する必要があると考える。

謝辞：本研究を進めるにあたり，国内外でご協力頂いた方々に感謝申し上げます。また本研究のもととなる現地調査は，文部科学省科学研究費「バングラデシュ農村部における地下水ヒ素汚染除去装置の開発と普及に関する実証的研究」(基盤B，海外)及び厚生労働科学研究費補助金「水供給分野の国際協力における総合援助手法に関する研究」により実施したものである。この場をお借りしてお礼申し上げます。

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Summary：This survey's target is the selection methodology for economically feasible alternative water supply using the concept of appropriate technology. Groundwater has been polluted with arsenic in rural Bangladesh. Those who live in the rural, however, use the water for drinking and cooking purposes. Consequently cases of arsenicosis patients reached about 38,000 in 2008. Alternative drinking water sources have not fully been available in rural areas in Bangladesh. Therefore, ,chemical substances such as decontaminating chemical (bleaching powder) coagulant (Alum) and etc to be used for water purification as well as appropriate water supply equipment such as •Arsenic and Iron Removal Plant (AIRP) • is necessary for them. In this study, a mathematical formula has been developed to select most appropriate alternative water supply method for the villager in Bangladesh.
キーワード（Keywords）：ヒ素（Arsenic），代替水（Alternative water），経済的妥当性（Economically Feasible），経済ピラミッドの底辺層（Bottom of the pyramid），バングラデシュ農村部（Rural Bangladesh）

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GIS Mapping of Correlation between Arsenic and Iron Concentration of Ground Water of Bangladesh

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Abstract: High iron concentration in the groundwater of Bangladesh was observed long ago. Existence of high arsenic concentration was observed in early 1990s. Determining iron concentration is cheaper and some indigenous methods are applied locally for such a purpose. Determining concentration of arsenic is more expensive and a relatively new issue even though the measurement is very important from monitoring point. The correlation between these two will ensure the possibility of simple and cheaper option for monitoring arsenic concentration from that of the iron concentration. This made the correlation analysis between arsenic and iron concentration of ground water more rational. In this study, data of 4367 wells were categorized for analysis as per geographic location in 61 administrative districts of Bangladesh. Results were compared with the results of analysis performed without categorizing data as per geographic locations. It is evident from the study that correlation between arsenic and iron concentration of ground water is not constant nationwide, rather it is a zonal phenomenon. Geographic Information Sustem (GIS) maps were produced with the correlation analysis data which represents the correlation status of each individual district of Bangladesh. Outcome of this study reveals that a zone or belt of a region can be observed within a band of similar correlation coefficient. From the analysis and produced GIS (Geographic Information System) maps it was observed that 50.4% districts of Bangladesh showed correlation coefficient in excess of 0.4 and 37% districts show correlation coefficient in excess of 0.5. In the eastern part of Bangladesh a belt of very low correlation was observed. The produced GIS maps and the study results enable to predict tentatively or statistically the arsenic concentration of a well by only knowing the iron concentration of the same well. This will help in reducing the need and thus cost for frequent measurement of arsenic in many areas where high correlation of the two is observed and reported.

Key words: GIS mapping, correlation, arsenic, iron, contamination.

Introduction

In Bangladesh, water extracted from shallow aquifers is the primary source of drinking and cooking water for most of its over 150 million population. The rural water supply is almost entirely based on groundwater through use of hand pump tube wells; an estimated ten million domestic wells constitute the backbone of rural water supply in the country. The urban water supply is also heavily dependent on groundwater. The discovery of widespread arsenic contamination of groundwater in Bangladesh has led to a need for frequent monitoring of water quality. The national hydrogeochemical survey of groundwater conducted by the British Geological Survey

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(BGS) and the Department of Public Health Engineering (DPHE) have shown that large numbers of wells in Bangladesh also exceed permissible limits for iron (Fe) and arsenic (As) (BGS, DPHE, 2001). Arsenic contamination in groundwater has originated in the Indian state of West Bengal and neighbouring Bangladesh, particularly on the east side of the Ganges-Bhagirati contaminating ground water of Bangladesh (Karim Md. Masud, 2000). The eastern part (most of the deltaic region) of Bangladesh is affected by arsenic contamination. The aquifer of the contaminated zone in West Bengal and that of Bangladesh are hydro geologically connected. Arsenic occurrence in groundwater in some part of Bangladesh is so severe that it has caused a national problem. The World Health Organization (WHO) has set guideline value for arsenic in drinking water as 0.01 mg/L (WHO, 1993). Department of Environment (DoE) of Bangladesh has set the standard value of arsenic for Bangladesh as 0.05 mg/L (DoE, 1991). For drinking water allowable limit for iron is 0.3 to 1 mg/L. But in Bangladesh iron content is very high in ground water.

Measurement of arsenic concentration in water is very expensive wbich requires modern laboratory facility and expensive chemicals. Determination of iron concentration is relatively simpler and cheaper than that of determination of concentration of arsenic and also easily available in Bangladesh. GIS – one tool for decision making was used in the study to describe the geographical distribution of the correlation between arsenic and iron concentration in ground water. By using the regression analysis and GIS maps of correlation between the two parameters the presence of arsenic in a well can be tentatively predicted by testing the presence of iron of the same well only. This can save a lot of money if it is used in a large scale. This map will also show the population vulnerable due to high arsenic and iron content of ground water of Bangladesh.

The correlation is one of the most common and most useful statistics. A correlation is a single number that describes the degree of relationship between two variables. The measurement scales used should be at least interval scales but other correlation coefficients are available to handle other types of data. Correlation coefficients can range from –1.00 to +1.00. The value of –1.00 represents a perfect negative correlation while a value of +1.00 represents a perfect positive correlation. A value of 0.00 represents no correlation.

Data Collection

The national hydrochemical survey of groundwater conducted by the British Geological Survey (BGS) and the Department of Public Health Engineering (DPHE), Bangladesh in 2001 (BGS–DPHE, 2001) presented water quality data of 3364 wells. This data was a major source of the study. Data of another survey conducted by DPHE in 2007 for the second phase of DPHE–JICA project in the south-eastern part of Bangladesh was also used in this research. Those two data sets were compiled together to form a water quality data base of 4367 wells. Data of 61 administrative districts of Bangladesh was thus available for analysis. Data of Rangamati, Bandorban and Khagrachori are not available for analysis.

Methodology

Data base of 4367 wells was categorized as per geographical location of Bangladesh. Bangladesh has 64 administrative districts but data of 61 districts is available for analysis. This leads to separation of 61 sets of water quality data which includes arsenic and iron concentration of ground water. Initially correlation analysis was performed taking all the data together. Later, correlation analysis was performed for each district separately.

A comprehensive correlation map of different areas of Bangladesh was developed using GIS. Results of data analysis for different districts were used to prepare this correlation map. Regression models were also developed for each district so that the arsenic concentration in a well can be tentatively verified by testing the presence of iron of the same well in the same district.

Result and Discussion

Total 4367 number of data were used for analysis in this study. Data of 61 administrative districts of Bangladesh were available (Table 1) for analysis. Arsenic concentration in 38.2% of data exceeds the WHO guideline value of 10 μg/L. For Bangladesh, Department of Environment (DoE, 1997) sets the arsenic standard for drinking water to be 50 μg/L. 20.3% of data exceeds the standard value of 50 μg/L for drinking water.

Minimum number of samples (15 data) are available for Meherpur and maximum (250 data) for Jessore. Munshiganj, Chandpur, Noakhali, Meherpur, Gopalganj, Lakshmipur, Faridpur, Bagerhat, Satkhira, Comilla, Narail and Chuadanga are the 12 most arsenic contaminated districts. On the other hand Sirajganj, Sylhet,

Table 1: Distribution of data for 61 districts of Bangladesh

District	*Number of wells*	*% of wells exceeding As>50 µg/L*	*% of wells exceeding Fe>5 mg/L*	*District*	*Number of wells*	*% of wells exceeding As>50 µg/L*	*% of wells exceeding Fe>5 mg/L*
Bagerhat	78	47.4	43.6	Magura	62	9.7	8.1
Barguna	48	0.0	0.0	Manikganj	47	14.9	38.3
Barisal	92	30.4	15.2	Maulvibazar	60	10.0	48.3
Bhola	48	4.2	2.1	Meherpur	15	60.0	6.7
Bogra	94	8.5	16.0	Munshiganj	46	82.6	30.4
Brahamanbaria	93	22.6	9.7	Mymensingh	109	12.8	6.4
Chandpur	68	77.9	30.9	Naogaon	92	2.2	6.5
Chittagong	109	6.4	22.0	Narail	24	41.7	29.2
Chuadanga	34	41.2	11.8	Narayanganj	37	18.9	10.8
Comilla	173	42.2	11.0	Narsingdi	63	23.8	11.1
Cox's Bazar	62	1.6	27.4	Natore	51	0.0	2.0
Dhaka	57	24.6	29.8	Nawabganj	45	4.4	2.2
Dinajpur	94	2.1	8.5	Netrokona	76	27.6	25.0
Faridpur	74	55.4	28.4	Nilphamari	53	0.0	17.0
Feni	60	28.3	16.7	Noakhali	49	69.4	6.1
Gaibandha	71	7.0	40.8	Pabna	78	16.7	16.7
Gazipur	44	2.3	0.0	Panchagarh	39	0.0	7.7
Gopalganj	58	56.9	34.5	Patuakhali	61	0.0	1.6
Habiganj	82	7.3	41.5	Pirojpur	54	14.8	7.4
Jaipurhat	40	0.0	7.5	Rajbari	47	17.0	17.0
Jamalpur	63	6.3	33.3	Rajshahi	78	6.4	3.8
Jessore	250	13.2	8.0	Rangpur	86	1.2	34.9
Jhalakati	33	6.1	3.0	Satkhira	88	46.6	23.9
Jhenaidah	103	13.6	7.8	Shariatpur	81	39.5	17.3
Khulna	93	18.3	10.8	Sherpur	51	11.8	27.5
Kishoreganj	169	17.2	11.2	Sirajganj	89	23.6	51.7
Kurigram	77	9.1	44.2	Sunamganj	87	32.2	19.5
Kushtia	59	22.0	16.9	Sylhet	88	15.9	50.0
Lakshmipur	34	55.9	11.8	Tangail	91	8.8	45.1
Lalmonirhat	39	0.0	15.4	Thakurgaon	46	0.0	4.3
Madaripur	75	37.3	14.7				

Moulovibazar, Tangail, Kurigram, Bagerhat, Habiganj, Gaibandah, Manikganj, Rangpur, Gopalganj, Jamalpur, Chandpur and Munshiganj are the 14 most iron contaminated districts.

All available data were used to analyse (Table 2) the correlation between arsenic and iron concentration. The correlation coefficient is 0.195. Figure 1 represents the graphical variation.

Soil profile varies as the major part of Bangladesh is on the delta formed by the three major rivers Brahmaputra, Ganges and Meghna. This leads to an idea that correlation of arsenic and iron concentration of ground water may be a zonal phenomenon rather than a national phenomenon. When district-wise categorized data were analysed, correlation coefficient varied at different locations of Bangladesh. Results of correlation analysis as per geographical locations are provided in the Table 3.

Correlation analysis (Table 2) was performed using all available (4367 number) data without district wise categorization as per geographical locations, correlation coefficient which was found to be 0.192 is very insignificant. When all the data were reorganized as per their location, correlation coefficient improved in most of the districts drastically (Table 3). In Panchagar the value of the coefficient is 0.932 (Figure 4) which shows strong correlation. Significance level of this value is 0.0001 which shows that less than 0.01% chance that this correlation occurred by chance. Correlation coefficient of 23 districts exceeds 0.5 which is 38% of all the districts (Figure 2). On the other hand 50.4% districts show correlation coefficient in excess of 0.4 (Figure 3).

Munshiganj, Chandpur, Noakhali, Meherpur, Gopalganj, Lakshmipur, Faridpur, Bagerhat, Satkhira, Comilla, Narail and Chuadanga are the 12 most arsenic contaminated districts (Table 1). Arsenic contamination ranges from 40% to 80% of wells of these districts. Figure 5 shows the correlation coefficient of these 12 most arsenic contaminated districts.

Barguna, Jaipurhat, Lalmonirhat, Natore, Nilphamari, Panchagarh, Patuakhali, Thakurgaon, Rangpur, Cox's

Table 2: Correlation between arsenic and iron using all available data

Correlation coefficient	0.195
Number of Data	4367
Significance	0.0001

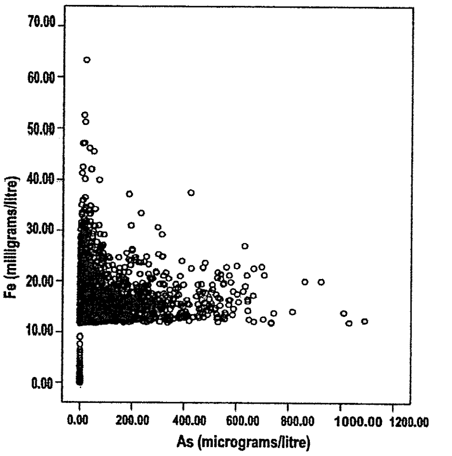

Figure 1: Variation of arsenic vs iron concentration of ground water of Bangladesh.

Table 3: Correlation coefficients of 61 districts of Bangladesh and the significance level of the result

District	*Correlation coefficient*	*Significance level*	*District*	*Correlation coefficient*	*Significance level*
Bagerhat	0.55	0.0001	Magura	0.61	0.0001
Barguna	0.36	0.011	Manikganj	0.44	0.002
Barisal	0.60	0.0001	Maulvibazar	0.02	0.871
Bhola	0.86	0.0001	Meherpur	0.69	0.004
Bogra	0.43	0.0001	Munshiganj	0.15	0.318
Brahamanbaria	0.19	0.069	Mymensingh	0.76	0.0001
Chandpur	0.11	0.381	Naogaon	0.20	0.051
Chittagong	–0.08	0.439	Narail	0.66	0.0001
Chuadanga	0.51	0.002	Narayanganj	0.43	0.008
Comilla	0.14	0.076	Narsingdi	0.53	0.0001
Cox's Bazar	–0.05	0.701	Natore	0.47	0.0001
Dhaka	0.44	0.001	Nawabganj	0.21	0.175
Dinajpur	0.72	0.0001	Netrokona	0.31	0.007
Faridpur	0.58	0.0001	Nilphamari	0.82	0.0001
Feni	–0.07	0.587	Noakhali	0.05	0.729
Gaibandha	0.10	0.394	Pabna	0.33	0.004
Gazipur	0.27	0.073	Panchagarh	0.93	0.0001
Gopalganj	0.58	0.0001	Patuakhali	0.30	0.021
Habiganj	0.09	0.428	Pirojpur	0.60	0.0001
Jaipurhat	0.21	0.193	Rajbari	0.56	0.0001
Jamalpur	0.45	0.0001	Rajshahi	0.53	0.0001
Jessore	0.39	0.0001	Rangpur	0.46	0.0001
Jhalakati	0.88	0.0001	Satkhira	0.48	0.0001
Jhenaidah	0.36	0.0001	Shariatpur	0.68	0.0001
Khulna	0.36	0.0001	Sherpur	0.17	0.233
Kishoreganj	0.62	0.0001	Sirajganj	0.19	0.071
Kurigram	0.19	0.105	Sunamganj	–0.16	0.139
Kushtia	0.07	0.579	Sylhet	0.11	0.289
Lakshmipur	0.06	0.752	Tangail	0.33	0.002
Lalmonirhat	0.67	0.0001	Thakurgaon	0.56	0.0001
Madaripur	0.74	0.0001			

Bazar, Dinajpur and Naogaon are the least arsenic contaminated districts. Figure 6 shows the correlation coefficient of these districts.

50% of these 12 most arsenic contaminated districts show correlation coefficient greater than 0.5. Similarly 50% of the 12 least arsenic contaminated districts show correlation coefficient greater than 0.5.

This district-wise correlation analysis of arsenic and iron reveals that correlation of arsenic and iron in ground water is a zonal phenomenon. Soil character is different in different parts of Bangladesh which leads to the difference in correlation. It is due to the difference in sediment characteristics throughout the country. Sediments are typical of alluvial and deltaic sediments with normal amounts of arsenic, mainly in the 1–10mg kg^{-1} range for total arsenic (BGS–DPHE, 2001). This normal amount of arsenic is sufficient to give excessive arsenic in the groundwater if dissolved or desorbed in sufficient quantity. Arsenic-rich ground water is tended to be found in areas with sediments containing relatively high concentrations of oxalate-extractable iron and arsenic (BGS–DPHE, 2001). Results of this correlation analysis also reveal the fact that zonal difference in sediment characteristic instigates the difference of correlation between arsenic and iron concentration of ground water.

GIS map (Figure 7) represents the zonal correlation status of Bangladesh. Data of 61 districts were separated as per their geographical locations. 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. Another similar type of belt is found around Rajshahi, Natore, Bogra and Jamalpur districts.

The total range of coefficient was divided into five groups for mapping. They are 0–0.2, 0.2–0.4, 0.4–0.6, 0.6–0.8 and 0.8–1. Districts falling in each of these groups are mapped with same colours. Figure 7 represents the zonal correlation status of Bangladesh. Data of 61

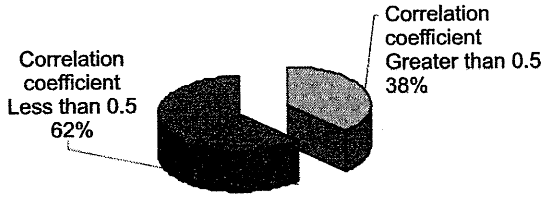

Figure 2: Percentage of districts showing correlation coefficient greater than 0.5.

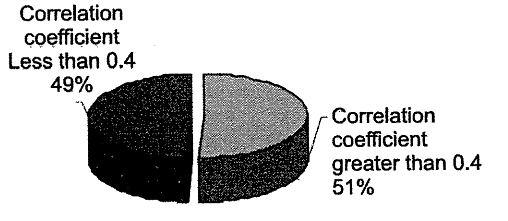

Figure 3: Percentage of districts showing correlation coefficient greater than 0.4.

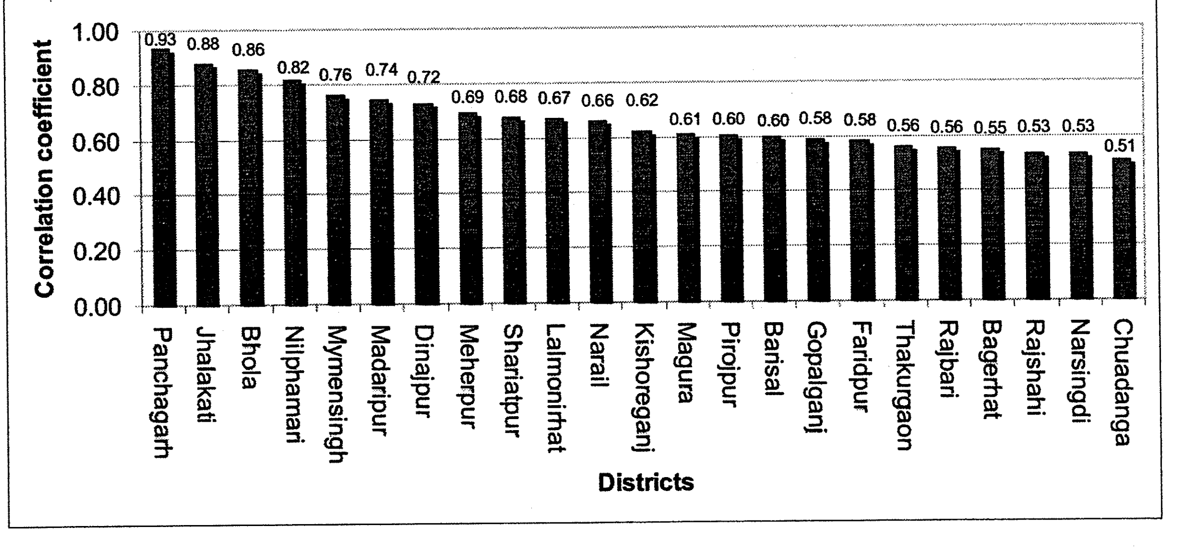

Figure 4: Districts showing correlation coefficient greater than 0.5.

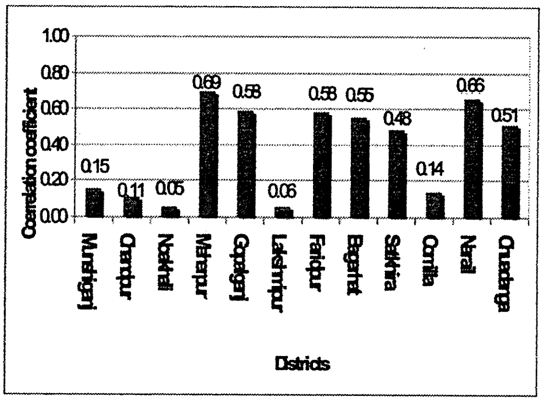

Figure 5: Correlation coefficient of 12 most arsenic contaminated districts.

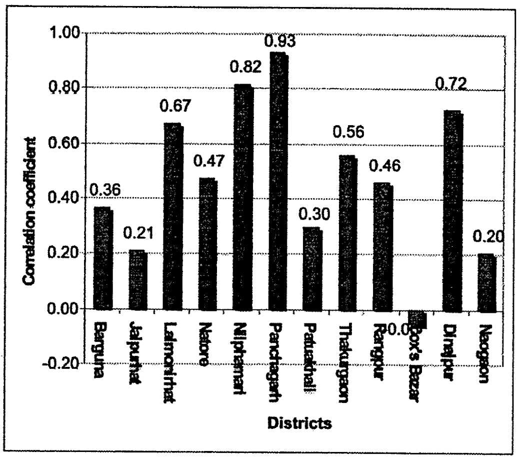

Figure 6: Correlation coefficient of 12 least arsenic contaminated districts.

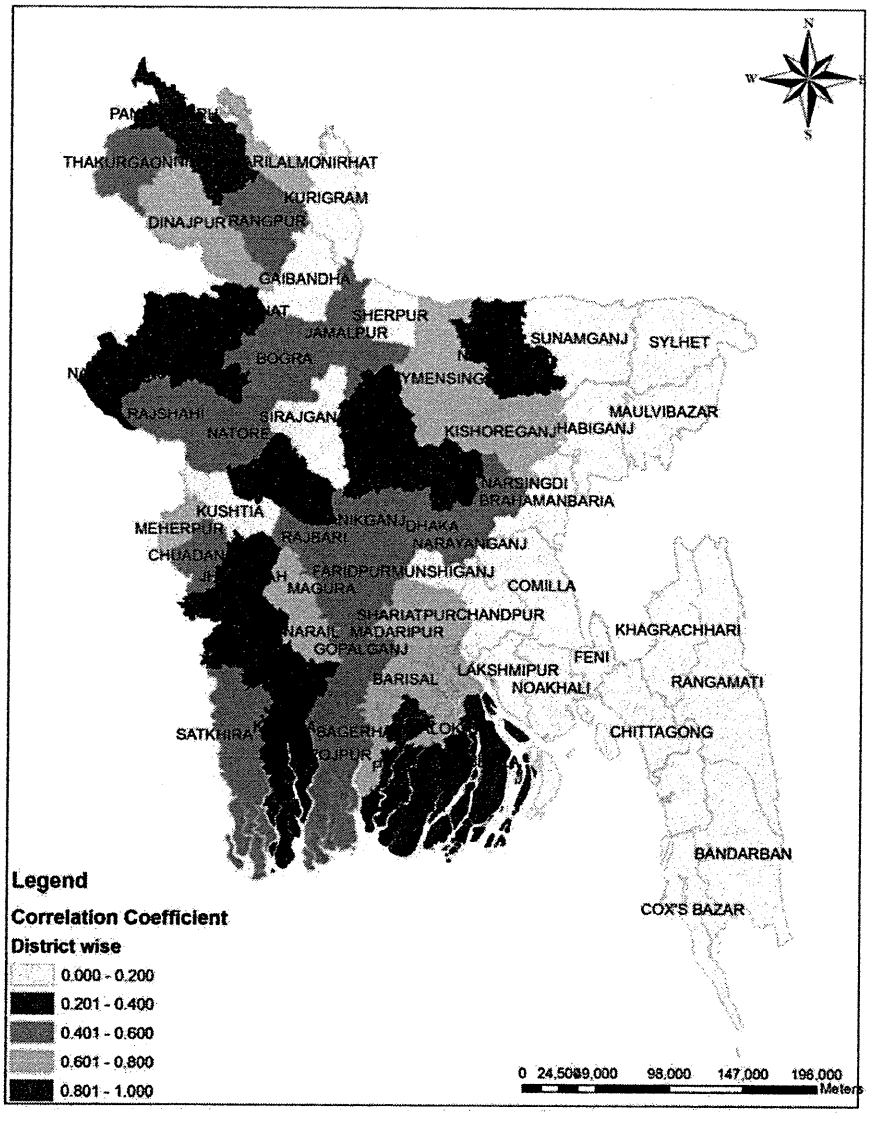

Figure 7: GIS map of correlation between arsenic and iron concentration of ground water of Bangladesh.

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,

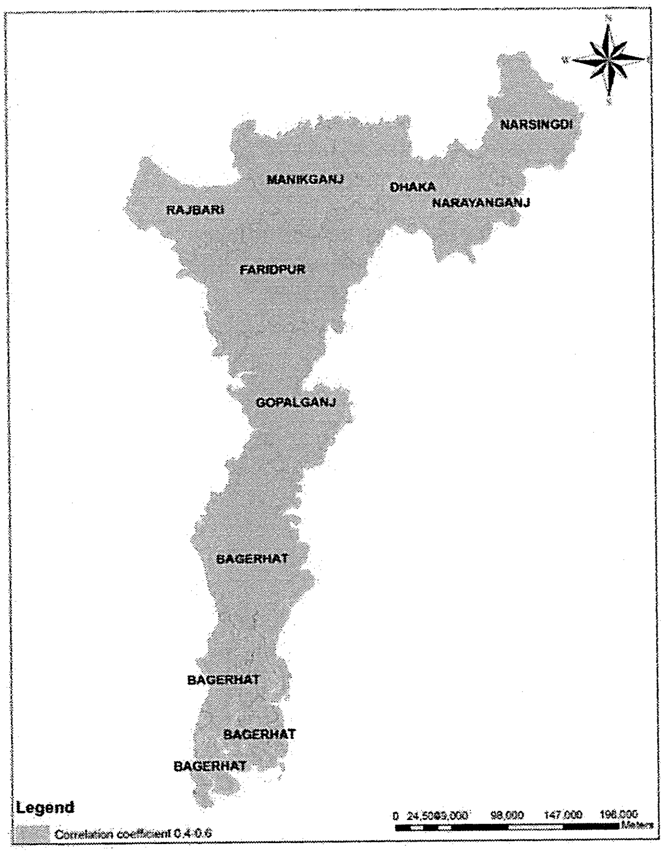

Figure 8: Districts showing correlation coefficient in the range between 0.4 and 0.6.

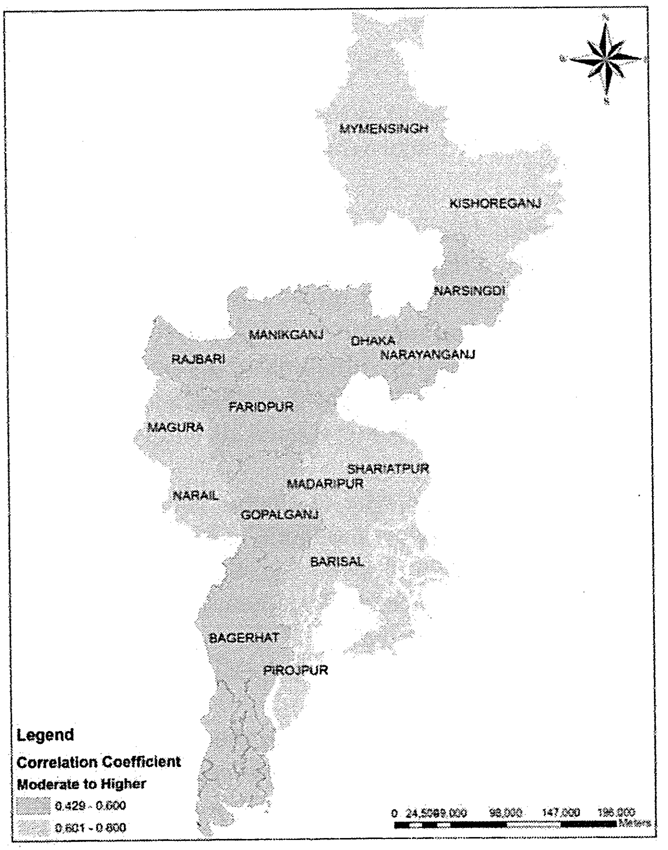

Figure 9: Districts showing correlation coefficient in the range between 0.4 and 0.8.

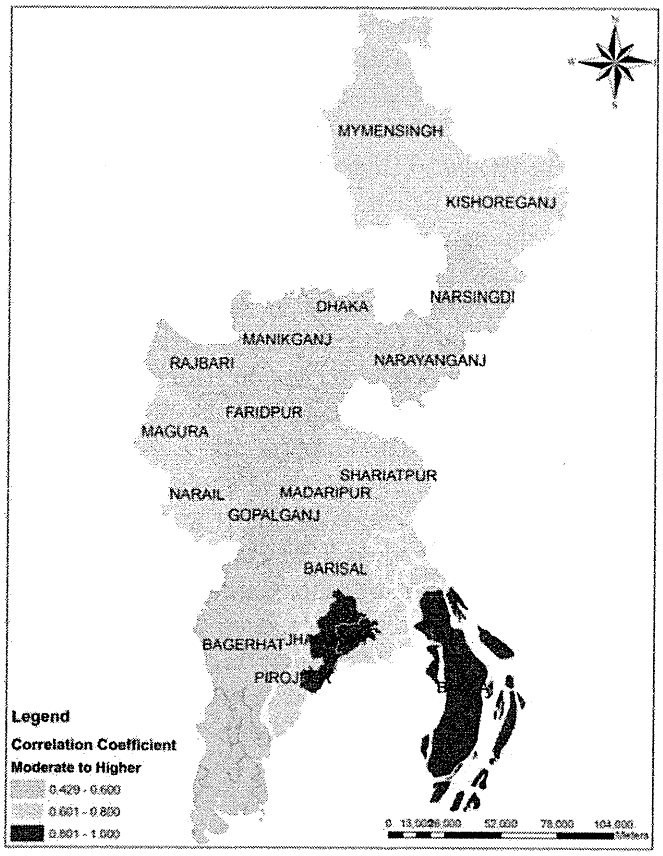

Figure 10: Districts showing correlation coefficient in the range between 0.4 and 1.

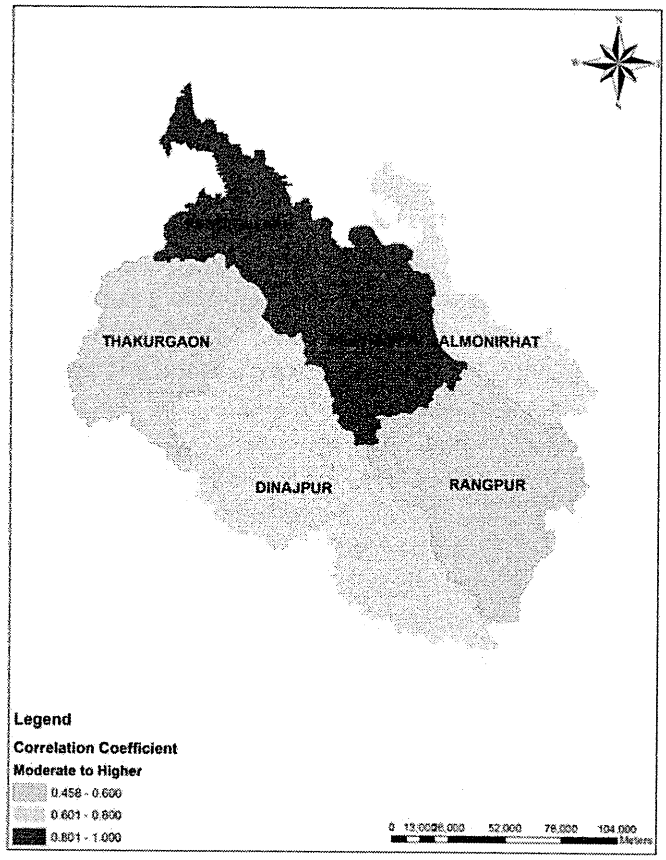

Figure 11: Districts in the northern part of Bangladesh showing correlation coefficient in the range between 0.4 and 1.

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

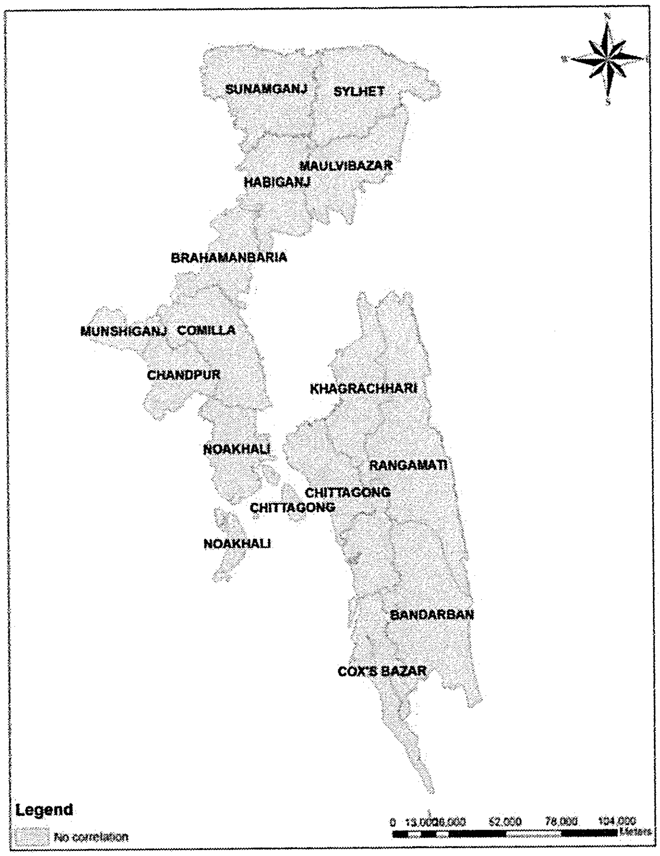

Figure 12: Districts in the eastern part of Bangladesh showing less or no correlation.

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.

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

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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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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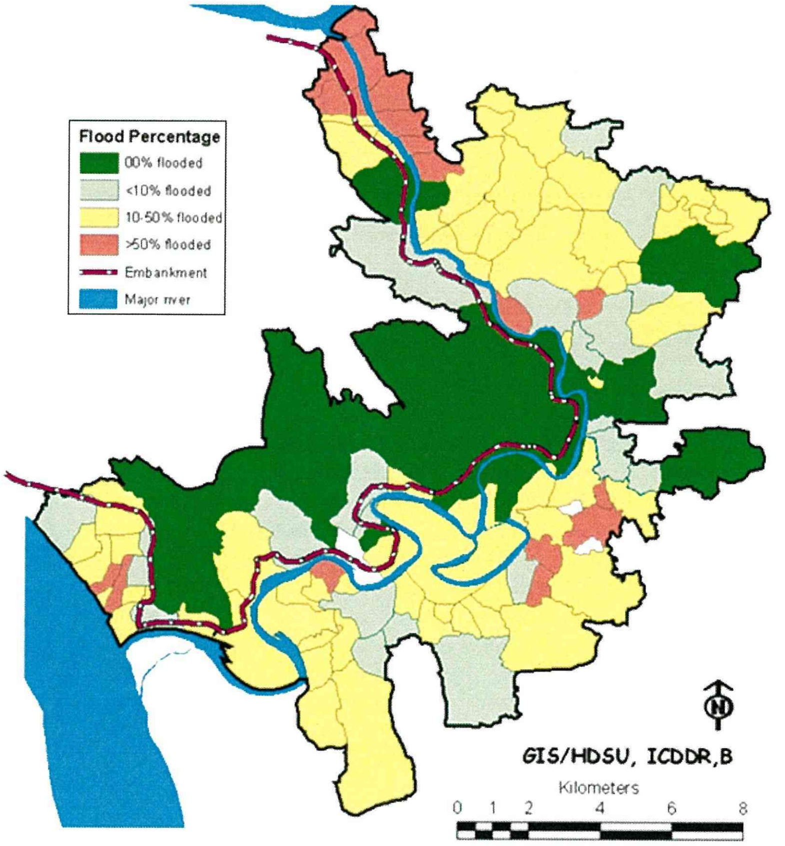

FIGURE 1. Percentage of flooded baris in villages in the monsoon flood 2004 in Matlab.

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).

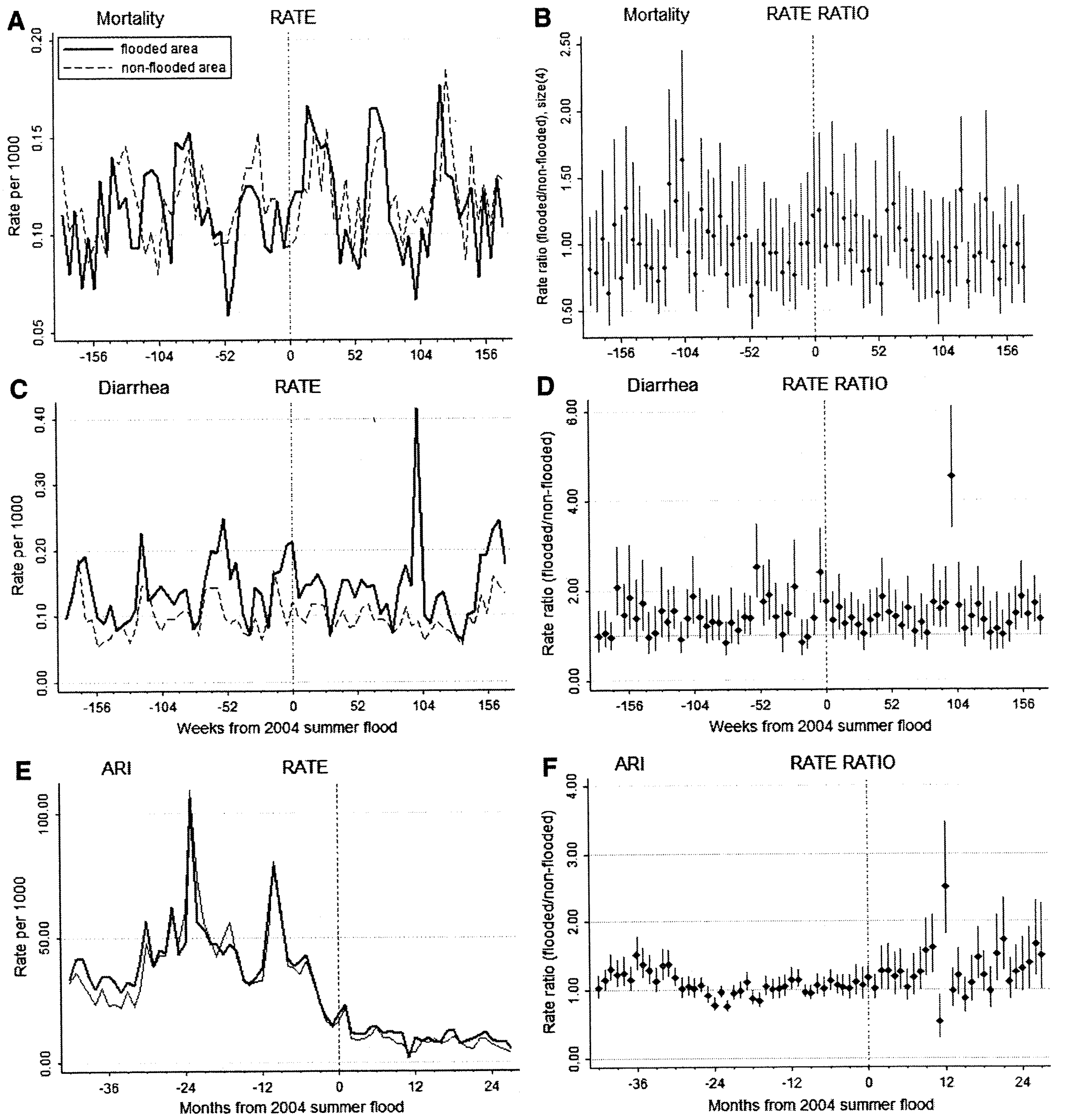

FIGURE 2. Rate (left) and rate ratio (right) of flooded to nonflooded area of outcomes. A and B, mortality; C and D, diarrhea; E and F, acute respiratory infection.

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-