Title	Health Effects of Flooding in Rural Bangladesh
Author(s)	Milojevic, Ai; Armstrong, Ben; Hashizume, Masahiro; McAllister, Katherine; Faruque, Asg; Yunus, Md; Kim Streatfield, Peter; Moji, Kazuhiko; Wilkinson, Paul
Citation	Epidemiology, 23(1), pp.107-115; 2012
Issue Date	2012-01
URL	http://hdl.handle.net/10069/35070
Right	© 2012 Lippincott Williams & Wilkins, Inc.; This is a non-final version of an article published in final form in Epidemiology, 23(1), pp.107-115; 2012

Manuscript number: #11-379

Flood effects on mortality, diarrhea and acute respiratory infection in rural Bangladesh: controlled interrupted time-series analysis

Ai Milojevic[1]

Ben Armstrong[1]

Masahiro Hashizume[2]

Katherine McAllister[1]

ASG Faruque[3]

Md Yunus[3]

Peter Kim Streatfield[3]

Kazuhiko Moji[4]

Paul Wilkinson[1]

1 London School of Hygiene and Tropical Medicine, 15-17 Tavistock Place, London WC1H 9SH, UK

2 Department of International Health, Institute of Tropical Medicine, Nagasaki University, 1-12-4, Sakamoto, Nagasaki 852-8523, Japan.

3 International Centre for Diarrhoeal Disease Research, Bangladesh. Mohakhali (GPO Box 128, Dhaka 1000) Dhaka 1212, Bangladesh

4 Research Institute for Humanity and Nature, 457-4 Motoyama, Kamigamo, Kita-ku, Kyoto 603-8047, Japan

Word counts:

Abstract	250
Main body text	3997
References	27
Tables	5
Figures	2

Corresponding author: Dr. Masahiro Hashizume, Department of International Health, Institute of Tropical Medicine, Nagasaki University, 1-12-4, Sakamoto, Nagasaki 852-8523, Japan.

Email: hashizum@nagasaki-u.ac.jp

RUNNING TITLE: Health effects of flooding in rural Bangladesh

GRANT INFORMATION:

This work was partly supported by Ecohealth project, Research Institute for Humanity and Nature, Kyoto, Japan, and Health and Labour Sciences Research Grant. The views expressed in this paper are those of the authors, and do not necessarily reflect those of the contributing agencies.

ACKNOWLEDGEMENTS: None

Date submitted: June 23, 2011. Date accepted: September 16 2011.

ABSTRACT

Background

There is little information regarding non-traumatic 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 flood 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 non-flooded in 2004. Ratios of mortality, diarrhea and acute respiratory infection rates in flooded compared with non-flooded 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 non-flooded 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 eighteen 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 two years after flooding. Apparent excesses for mortality and diarrhea reported in other situatinos, using less-controlled estimates, emphasize the importance of stringent confounder control.

Floods are the most frequent natural disaster. They have affected more than 2.8 billion people over the last 30 years,[1] and killed more than 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 disease (especially among children in low-income countries),[4] and acute respiratory infections in children (particularly under 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 of people in Bristol forced from their homes by flooding in 1968 was found to have 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 psychological 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 compare with nearby non-flooded 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 two parts, one of which remains vulnerable to seasonal flooding and one which is mostly protected against it (Figure 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 two 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 living 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 analysed 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 8,378 cases of diarrhea admitted to Centre facilities from 2001 to 2007 that could be linked with flood exposure and socio-economic data defined below.

Exposure to flooding was ascertained from an interview survey of the heads of 9,524 *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 (Figure

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 Diarrhoeal Disease research, Bangladesh, the Research Institute for Humanity and Nature, Japan and the London School of Hygiene and Tropical Medicine.

Definition of flood, pre- and post-flood 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 non-flooded 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 pre-monsoon 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 over-spill 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 "pre-flood period" as the three years before week 29 of 2004 and the "post-flood period" as the three 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 yearly blocks thereafter. Note that the pre-flood 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 non-flooded areas by week (mortality and diarrhea) or month (acute respiratory infection) for the years 2001-2007 (2001 through 2006 for acute respiratory infection). To control for any pre-existing differences in health outcomes between the flooded and non-flooded 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 post-flood periods with the rate ratio for the pre-flood period as a whole (RRs "controlled for pre-flood 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 pre-flood period and seasonality"). Modelled seasonality in RRs for each outcome, adjusting for the 2004 flood effect, is shown in the eAppendix (eFigure 1, http://links.lww.com).

In additional analyses, we stratified by age (0-15, 15-60, 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 chi-squared test.[17] We performed all statistical analyses using Stata 11 (Stata Corporation, College Station, Texas).

RESULTS

Analyses were based on 66,777 residents in the flood areas and 144,362 in the non-flood areas. Characteristics of the study population at the time of flood onset are described in Table

1. The populations in flood and non-flood 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 5,280 deaths from all causes in the non-flooded area and 2,388 in the flooded area among persons for whom we had all information necessary for analyses. Mortality rates in the flooded and non-flooded areas were broadly similar, although, there were some differences in the seasonal/annual variation (Figure 2A). Rate ratios (flooded vs non-flooded) were close to 1.0 (Figure 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 non-flooded areas (35 and 70 deaths, respectively). The ratio of those rates (flooded to non-flooded areas) was 1.11 (95% confidence interval [CI]= 0.74-1.66), and 1.14 (0.76-1.72) when additionally controlled for the pre-flood RR; it was 1.10 (0.71-1.73) when further controlled for season (Table 2). In the post-flood 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 sub-groups examined (Table 3).

Diarrhea

We identified 4,250 diarrhea cases from non-flooded area and 2,852 from the flooded area who met our study criteria (Figure 2C and Table 4). Figure 2C shows that there is usually a higher risk of diarrhea in the flooded area compared with the non-flooded area during the monsoon season (June – September). Seasonality in the RRs was apparent after controlling for the rates in non-flooded areas.

During the flood period, the rate of diarrhea per 1,000 person-weeks at risk was 0.22 in the flooded area and 0.10 in the non-flooded areas, giving a rate ratio of risk in flooded to non-flooded 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 5 to 1 weeks 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 non-flooded areas, adjusted RRs were still elevated in the flood period (RR=1.55, 95%CI: 1.12-2.15) but not in the post-flood period. An exception to this was during the second year after the flood whenan 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) 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 afterwards (1.54 [0.79-3.00]). A salmonella outbreak in weeks 26-27 of 2006 was centered in the two 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 non-flooded and flooded areas, respectively, in children under 5 years. Figure 2E shows marked peaks of acute respiratory infection morbidity in July–August of the pre-flood years of 2002 and 2003, in both flooded and non-flooded 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 non-flooded 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 are unclear.

In the flood period, the rate of children's acute respiratory infection was 14 per 1000 person months at risk in the flooded area (227 cases) and 14.6 in the non-flooded 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 pre-flood differences in RRs and seasonality.

The RR of flooded to non-flooded 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 post-flood period (Table 5). However, by adjusting for pre-flood 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 non-severe acute respiratory infection (eFigure 4, http://links.lww.com).

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 six months post-flood relative to pre-flood 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) (see also eFigure 5).

DISCUSSION

This study provides detailed quantitative evidence on the flood-related risk of mortality, diarrhea, and acute respiratory 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 afterwards, once analyses were controlling for pre-flood rate differences between flood and non-flood areas and seasonality.[18] This was true also for cause-specific forms of diarrheal illness (cholera, non-cholera 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 more than 22% above the pre-flood rate is unlikely for the 6 months after flooding, and an excess of more than 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 six months and longer after flooding the rate ratios showed higher risks in the flooded populations even after adjustment for both pre-flood rate differences and seasonality. The difficulty of interpretation here arises from two 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 non-flood 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 post-flood) 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 non-flooded populations were not considered. A limitation of many previous published studies of flood-related diarrhea was that they lacked outcome data in the pre-flood period or for control areas. In our analyses, adjustment for pre-flood 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 with regard to 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 two months, while in 2004, although much heavier rainfall occurred, the water level remained high for only one 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 problem 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 post-flood 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.

A number of 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, up until the date of the interview, the longtime interval could cause recall bias. If our flooded *baris* are more likely than non-flooded *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 three year pre- and post-flood 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 pre-flood rate differences and seasonality. We can exclude a relative excess of more than 74% in diarrheal illness for the flood period itself, and of more than 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 two years after the flood, although questions remain about the interpretation of this as a direct causal effect of flooding.

REFERENCES

1. Centre for Research on the Epidemiology of Disasters. EM-DAT: the OFDA/CRED International Disaster Database. http://www.em-dat.net/ Accessed May 5, 2011.
2. Milly PC, Wetherald RT, Dunne KA, Delworth TL. Increasing risk of great floods in a changing climate. *Nature* 2002; **415:**514-517.
3. Easterling DR, Meehl GA, Parmesan C, et al. Climate extremes: observations, modeling, and impacts. *Science* 2000; **289:**2068-2074.
4. Kosek M, Bern C, Guerrant RL. The global burden of diarrhoeal disease, as estimated from studies published between 1992 and 2000. *Bull World Health Organ* 2003; **81**:197-204.
5. Watson JT, Gayer M, Connolly MA. Epidemics after natural disasters. *Emerg Infect Dis* 2007; **13**:1-5.
6. Parker DJ, Thompson PM. Floods in Africa: vulnerability, impacts and mitigation. Floods. London: Routledge, 2000.
7. Lipp EK, Huq A, Colwell RR. Effects of global climate on infectious disease: the cholera model. *Clin Microbiol Rev* 2002;**15**:757-770.
8. Bennet G. Bristol floods 1968. Controlled survey of effects on health of local community disaster. *Br Med J* 1970;**3**:454-458.

9. Abrahams MJ, Price J, Whitlock FA, Williams G. The Brisbane floods, January 1974: their impact on health. *Med J Aust* 1976;**2**:936-939.

10. ICDDR B. Flood relief update an appeal for further funds http://www.icddrb.org/news_detail.cfm?ID=377 Accessed April 11, 2011.

11. Rayhan MI. Assessing poverty, risk and vulnerability: a study on flooded households in rural Bangladesh. *Journal of Flood Risk Management* 2009; **3**:18-24.

12. ICDDR B. ICDDR,B's hospitals face new flooding crisis. http://www.icddrb.org/news_detail.cfm?ID=376 Accessed April 11, 2011.

13. Qadri F, Khan AI, Faruque AS, et al. Enterotoxigenic Escherichia coli and Vibrio cholerae diarrhea, Bangladesh, 2004. *Emerg Infect Dis* 2005; **11**:1104-1107.

14. ICDDR,B. Health and demographic surveillance system–Matlab, Vol. 41. Registration of health and demographic events 2007. Scientific Report, No. 106. 2009.

15. Fauveau V, Wojtyniak B, Chowdhury HR, Sadar AM. Assessment of cause of death in the Matlab Demographic Surveillance System. In: Fauveau V, ed. Matlab: Women, Children and Health. Dhaka: International Centre for Diarrhoeal Research, 1991.

16. Bangladesh Disaster & Emergency Response DER Sub-Group. Monsoon Floods 2004, Post-Flood Needs Assessment Summary Report. Dhaka, 2004. http://www.lcgbangladesh.org/flood2k4/index.php Accessed April 5, 2011.

17. DerSimonian R, Laird N. Meta-analysis in clinical trials. *Control Clin Trials* 1986; **7**:177-188.

18. Ahsan Karar Z, Alam N, Kim Streatfield P. Epidemiological transition in rural Bangladesh, 1986-2006. *Glob Health Action* 2009; **2**. doi: 10.3402/gha.v2i0.1904.

19. Hashizume M, Wagatsuma Y, Faruque AS, et al. Factors determining vulnerability to diarrhoea during and after severe floods in Bangladesh. *J Water Health* 2008; **6**:323-332.

20. Kunii O, Nakamura S, Abdur R, Wakai S. The impact on health and risk factors of the diarrhoea epidemics in the 1998 Bangladesh floods. *Public Health* 2002; **116**:68-74.

21. Ahern M, Kovats RS, Wilkinson P, Few R, Matthies F. Global health impacts of floods: epidemiologic evidence. *Epidemiol Rev* 2005; **27**:36-46.

22. Siddique AK, Baqui AH, Eusof A, Zaman K. 1988 floods in Bangladesh: pattern of illness and causes of death. *J Diarrhoeal Dis Res* 1991; **9**:310-314.

23. Campanella N. Infectious diseases and natural disasters: the effects of Hurricane Mitch over Villanueva municipal area, Nicaragua. *Public Health Rev* 1999; **27**:311-319.

24. World Health Organization. Epidemic-prone disease surveillance and response after the tsunami in Aceh Province, Indonesia. *Wkly Epidemiol Rec* 2005; **80**:160-164.

25. Luby SP, Gupta SK, Sheikh MA, et al. Tubewell water quality and predictors of contamination in three flood-prone areas in Bangladesh. *J Appl Microbiol* 2008; **105**:1002-1008.

26. Emch M. Diarrheal disease risk in Matlab, Bangladesh. *Soc Sci Med* 1999; **49**:519-530.

27. Ali M, Emch M, Donnay JP, Yunus M, Sack RB. Identifying environmental risk factors for endemic cholera: a raster GIS approach. *Health Place* 2002; **8**:201-210.

FIGURE LEGENDS:

Figure 1. Flooded villages in the monsoon flood 2004 in Matlab.

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

Table 1. Characteristics of the study population in Matlab at the time of flood onset (15 July 2004)

		Non-flooded area		Flooded area	
		n=144,362	(%)	n=66,777	(%)
Age (years)					
	0-15	49,323	(34)	23,488	(35)
	15-60	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	4,620	(3)	6,396	(9)
	Filtered water	5,930	(4)	3,085	(4)
	Tube well	133,159	(92)	56,549	(84)
	Others/unknown	653	(0)	747	(1)
Latrine type					
	Non-sanitary	117,113	(81)	55,461	(83)
	Sanitary	24,847	(17)	10,317	(15)
	Unknown	2,402	(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)	1,367	(2)
	Unprotected	81,630	(56)	65,376	(97)
	Unknown	50	(0)	34	(0)

Table 2. Mortality: pre- and post-flood[a] mortality in the flooded and non-flooded areas. Rate ratios of flooded compared with non-flooded areas.

	No. Deaths		**Rate per 1000**		**Crude RR (95%CI)**		**RR controlled for pre-flood period (95%CI)**		**RR controlled for pre-flood period and seasonality[b] (95%CI)**	
	Non-flooded	Flooded	Non-flooded	Flooded						
			Pre-flood							
-3 year	796	361	0.11	0.11	1.00	(0.89–1.14)				
-2 year	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)
			Post-flood							
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 29-33 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 six.

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 pre-flood period[a]

Possible modifier of flood impact	Death		Diarrhea		Acute respiratory infection	
	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)						
0-15	0.71 (0.25–1.99)	0.98 (0.59–1.65)	1.05 (0.68–1.63)	0.84 (0.66–1.08)	-	-
15-60	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						
Non-sanitary	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 Vs. non-flood area, controlling for the analogous ratio in the pre-flood 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 post flood[a] episodes in the flooded and non-flooded areas

	No. Diarrhea		Rate per 1000		Crude RR (95%CI)		RR controlled for pre-flood period (95%CI)		RR controlled for pre-flood period and seasonality[b] (95%CI)	
	Non-flooded	Flooded	Non-flooded	Flooded						
Pre-flood										
-3 year	619	371	0.09	0.12	1.32	(1.16–1.51)				
-2 year	786	479	0.11	0.14	1.33	(1.19–1.49)				
-1 year 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)
Post-flood										
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 year	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 29-33 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 six.

Table 5. Acute respiratory infection (ARI): pre and post flood[a] episodes in the flooded and non-flooded areas

	No. ARI		Rate per 1000		Crude RR (95%CI)		RR controlled for pre-flood period (95%CI)		RR controlled for pre-flood period and seasonality[b] (95%CI)	
	Non-flooded	Flooded	Non-flooded	Flooded						
Pre-flood										
-2 year	10646	4729	54.20	50.17	0.93	(0.89–0.96)				
-1 year to -7 month	5036	2483	49.99	52.01	1.04	(0.99–1.09)				
-6 month	633	306	37.57	38.51	1.02	(0.89–1.17)				
-5 month	599	320	35.35	40.13	1.14	(0.99–1.30)				
-4 month	684	343	40.38	42.89	1.06	(0.93–1.21)				
-3 month	546	270	32.20	33.56	1.04	(0.90–1.21)				
-2 month	398	193	23.41	23.91	1.02	(0.86–1.21)				
-1 month	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)
Post-flood										
+1 month	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 month	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 month	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 month	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 month	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 month	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 month 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 year	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-August in 2004

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

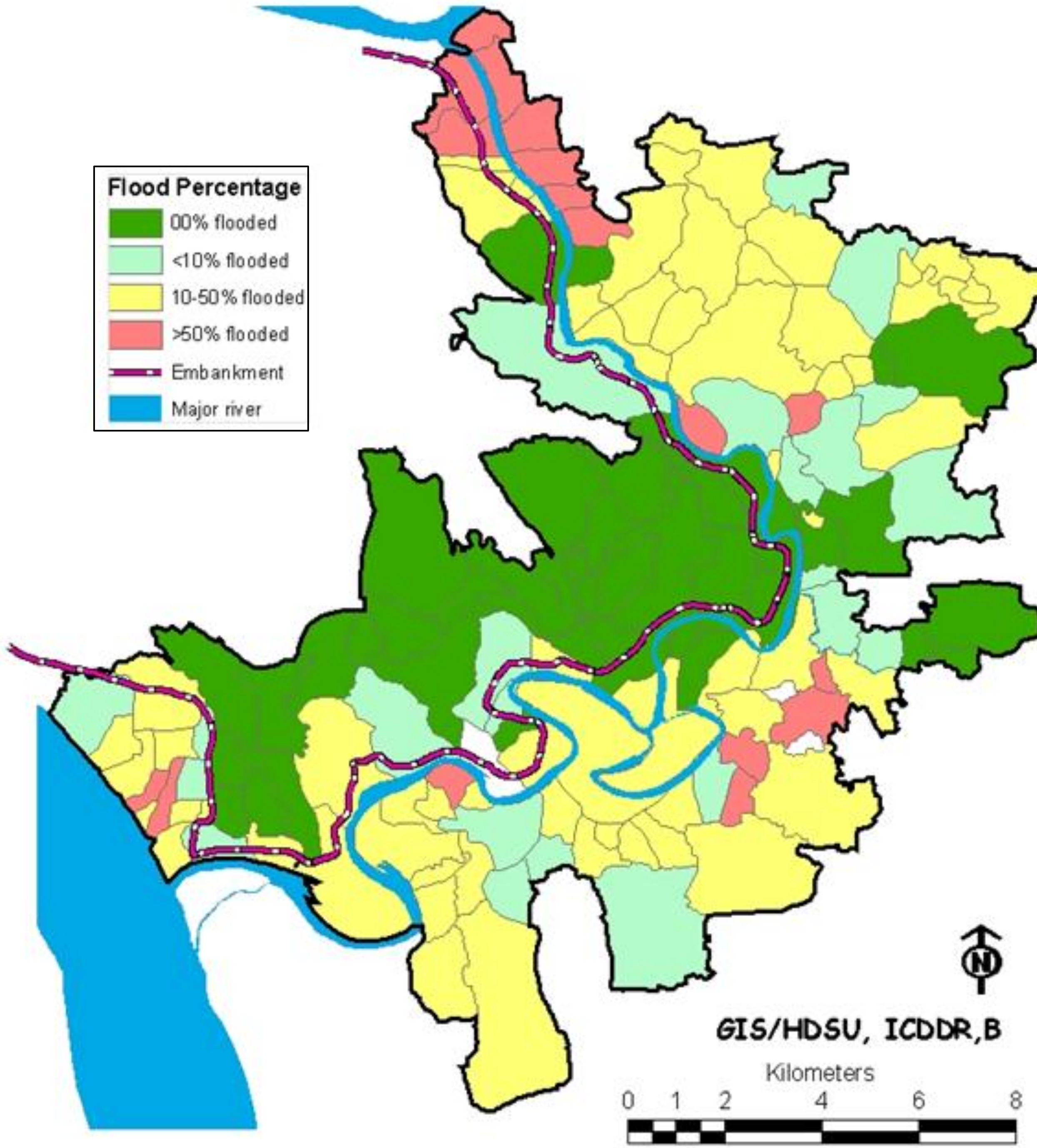
Flood Percentage
00% flooded
<10% flooded
10-50% flooded
>50% flooded
Embankment
Major river
N
GIS/HDSU, ICDDR,B
Kilometers
0 1 2 4 6 8

Figure 1

Figure 2a left

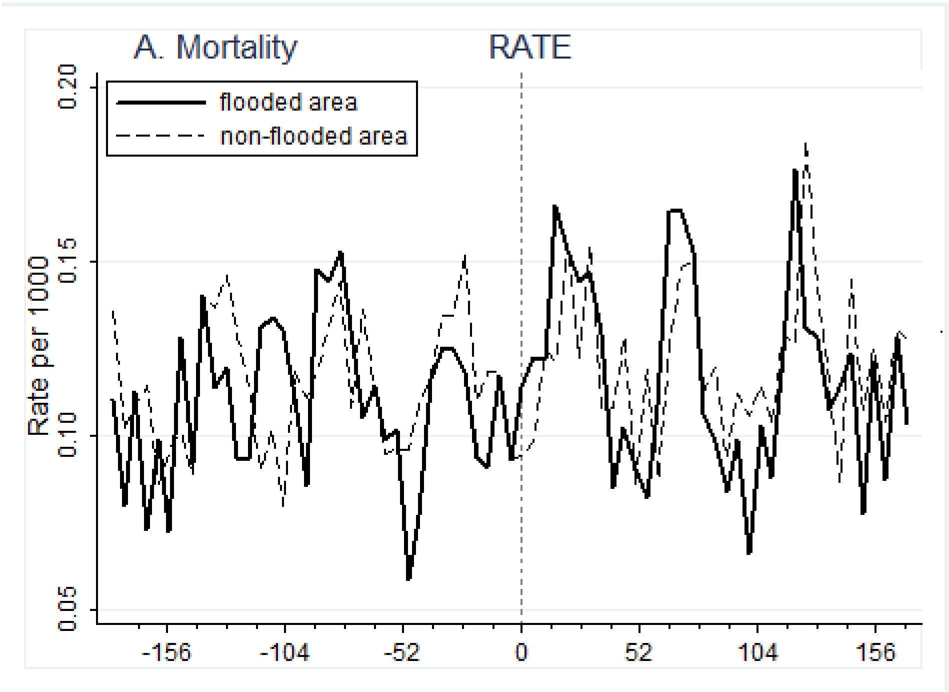

Figure 2a right

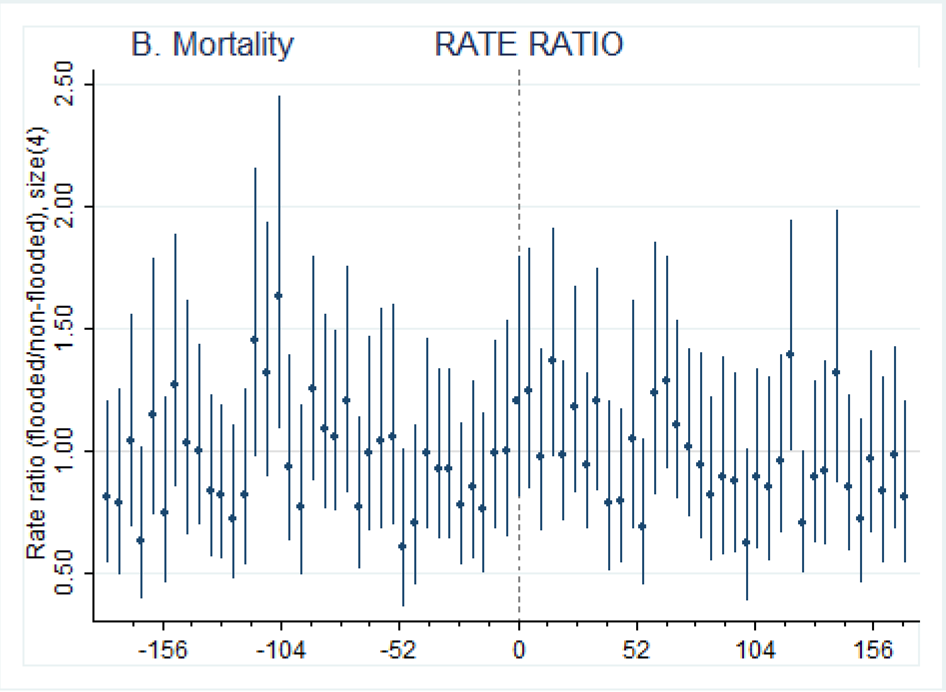

Figure 2b left

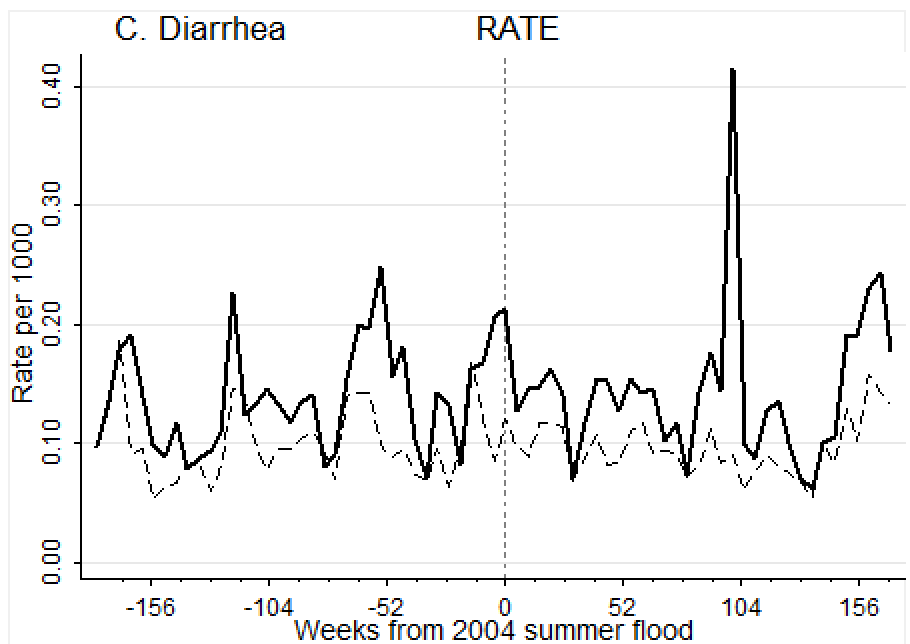

Figure 2b right

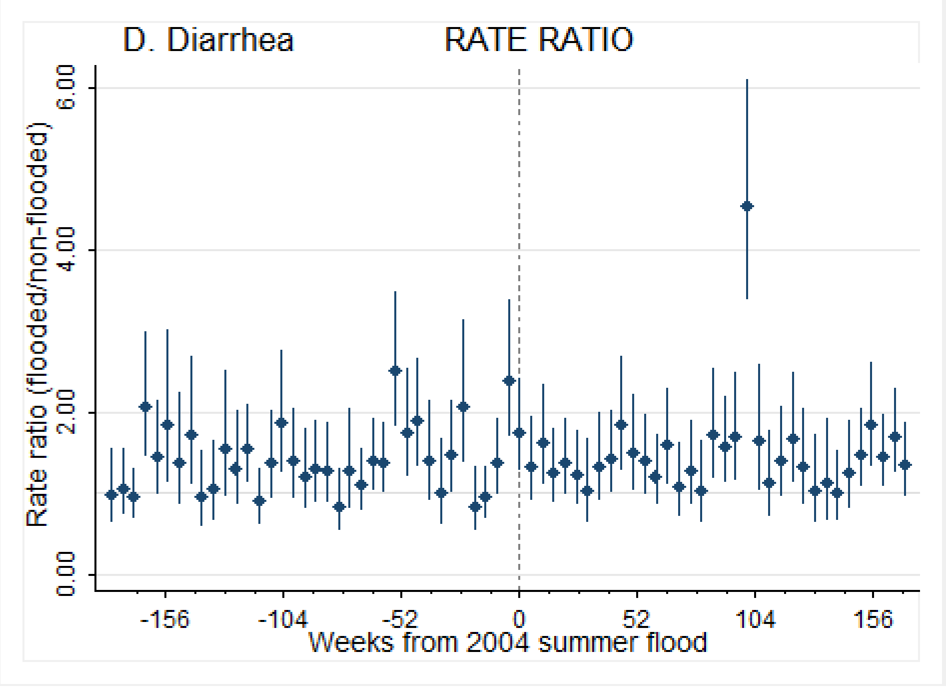

Figure 2c left

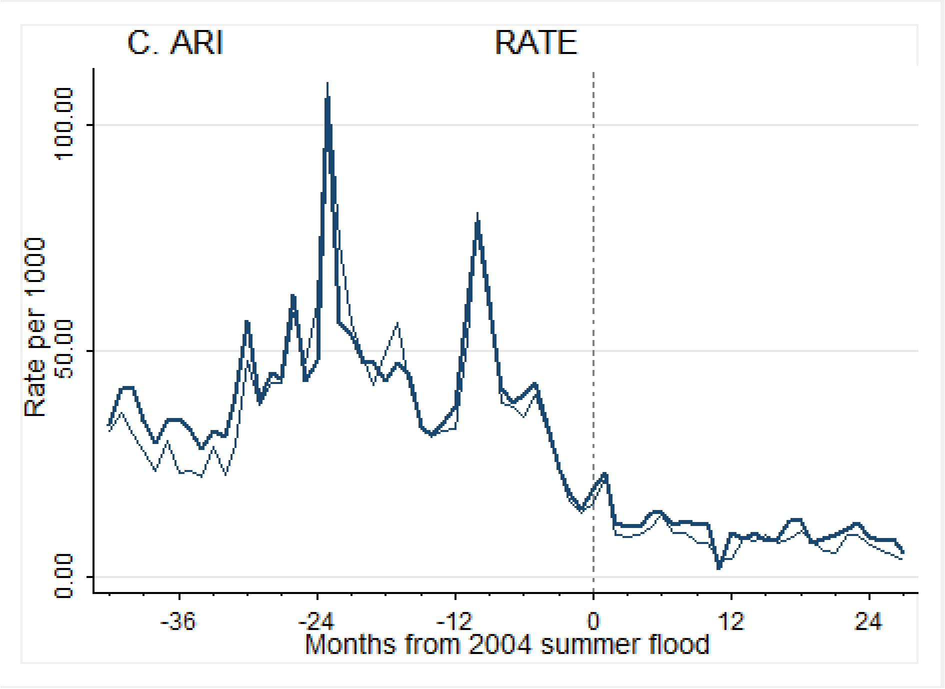

Figure 2c right