Title: Factors determining vulnerability to diarrhoea during and after severe floods in Bangladesh

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Short title: Factors determining vulnerability to diarrhoea after floods in Bangladesh

Abstract

Background: This paper identifies groups vulnerable to the effect of flooding on the number of hospital visits due to diarrhoea during and after a flood event in 1998 in Dhaka, Bangladesh.

Methods: The number of observed cases of cholera and non-cholera diarrhoea per week was compared to expected normal numbers during the flood and post-flood periods, obtained as the season-specific average over the two preceding and subsequent years using Poisson generalised linear models. The expected number of diarrhoea cases was estimated in separate models for each category of potential modifying factors: sex, age, socio-economic status and hygiene and sanitation practices.

Results: During the flood, the number of cholera and non-cholera diarrhoea cases was almost six and two times higher than expected, respectively. In the post-flood period, the risk of non-cholera diarrhoea was significantly higher for those with lower educational level, living in a household with a non-concrete roof, drinking tube-well water (vs. tap water), using a distant water source and unsanitary toilets. The risk for cholera was significantly higher for those drinking tube-well water and those using unsanitary toilets.

Conclusions: This study confirms that low socio-economic groups and poor hygiene and sanitation groups were most vulnerable to flood-related diarrhoea.

Key words: Bangladesh, cholera, diarrhoea, episode analysis, floods, vulnerable population

Background

Floods are the most frequent natural disasters affecting over 2.5 billion people during the last 30 years (Centre for Research on the Epidemiology of Disasters 2007). Recently floods have tended to intensify, and this trend could increase with climate change (Easterling et al. 2000; Milly et al. 2002). The effects of floods on diarrhoeal diseases may be of significant public health concern, since diarrhoeal disease is one of the leading causes of morbidity and mortality, especially among children in low-income countries (Kosek et al. 2003).

There is a potential for increased transmission of diarrhoeal diseases during flood and post-flood conditions. In high-income countries, the risk of diarrhoea due to flood is considered to be low (Hajat et al. 2003; Hunter 2003; Ahern et al. 2005), although a study in the United Kingdom reported an increase in the risk of gastroenteritis for individuals exposed to flooding (Reacher et al. 2004). Another study in the United States found that flooding in the house or yard was associated with an increased risk of gastrointestinal illness (Wade et al. 2004). Self-reported diarrhoea was used as an outcome measure in these studies.

In low-income countries, where the water supply and sanitation system and the causative agents of diarrhoea are likely to be different from those in high-income countries, post-flood increases in cholera (Sur et al. 2000), rotavirus diarrhoea (Ahmed et al. 1991; Fun et al. 1991), cryptosporidiosis (Katsumata et al. 1998) and non-specific diarrhoea (Woodruff BA et al. 1990; Siddique et al. 1991; Biswas et al. 1999; Mondal et al. 2001; Kondo et al. 2002; Kunii et al. 2002) have been reported. Most of these studies had methodological limitations, in particular lack of pre-flood data, lack of comparison groups and potential recall bias. A recent rigorous study in Bangladesh reported flood-related diarrhoeal epidemics which were primarily explained by cholera (Schwartz et al. 2006). However, neither this nor the other papers provided much evidence on what factors determine vulnerability to the effects of flooding on the transmission of diarrhoeal diseases. Identification of the most vulnerable

group will be a basis to develop effective public health policies that reduce adverse health effects of flooding on the population.

In 1998, one of the most severe floods in recent history was observed in Dhaka, Bangladesh following high rainfall in the country and in the upper catchment areas. It was estimated that about 56% of the city was inundated (Huq & Alam 2003). The flood caused damage to over 30% of the 860 000 shelter units in the Dhaka Metropolitan Area and affected more than 4 million people (Huq & Alam 2003). The objective of this study was to identify potential vulnerable groups to the effects of flooding on the number of laboratory-confirmed cholera and other (non-cholera) diarrhoea during and after the 1998 flood in Dhaka, Bangladesh.

Methods

Data

The International Centre for Diarrhoeal Disease Research, Bangladesh (ICDDR,B), Dhaka hospital serves an urban population of approximately 10 million individuals and provides free treatment to more than 100 000 cases of diarrhoea each year. The Centre maintains a surveillance system in which data from every 50th patient presenting to the hospital for treatment of diarrhoea is collected, including the patient's characteristics and microbiological examination of stool or rectal swab sample for identifying enteric pathogens. We abstracted individual information on age, sex, socio-economic status, hygiene and sanitation practices and pathogens identified from stool specimen during a six-year period (January 1996 to December 2001) including the severe flood year. The patient was classified as having cholera when *Vibrio cholerae* was identified from the stool specimen. All other patients including those with culture negative stool samples, were categorised as non-cholera diarrhoea. We analysed weekly counts of cases.

Meteorological data (daily rainfall and maximum temperature) for the six-year period were provided by the Bangladesh Meteorological Department. Daily time-series of rainfall and maximum temperature were converted into weekly amounts of rainfall and weekly average maximum temperature, respectively. Daily river level data (five measurements a day) were recorded by the Bangladesh Water Development Board. We analysed the daily maximum values averaged by week.

Definition of flood and post-flood periods

The period of flood was defined as the period that the river level (Brigonga river at Mill Barrack in Dhaka) exceeded the danger level (6.0 m) defined by the Bangladesh Water Development Board. The flood period was identified from week 30 to 38 (July to September) in 1998. The river level data were missing from April 1997 to March 1998, but no severe floods were reported in Dhaka during this period (Centre for Research on the Epidemiology of Disasters 2007). Although the duration of the effects of flooding on diarrhoea is not clearly understood, the potential effects of large-scale flooding on water, sanitation and health infrastructure has been estimated to last up to six months (McCluskey J 2001). Thus, the post-flood period was defined as up to week 14 in 1999 (approximately six months after the end of the flood).

Statistical analysis

Expected normal numbers of cholera and non-cholera diarrhoea for each week during the flood year and for the rest of the post-flood period in the following year were obtained as the season-specific average over the two preceding (1996−97) and subsequent years (2000−01). This season-specific average was obtained by fitting a Poisson generalised linear model with

sine and cosine functions with annual cycle and harmonics up to an order of six to the non-flood four years.

The ratios of the observed against the expected number of cases during the flood and post-flood periods were calculated separately. The observed/expected ratio was also calculated for the pre-flood period in 1998 so that any excess in that period could be discounted in the interpretation of the flood and post-flood results. Confidence intervals (CIs) for the ratios were estimated from standard Poisson assumptions augmented by a refinement to take account of variability in the expected number of cases from four years data (1996−97 and 2000−01) as well as variability in the cases observed in the flood year itself. Specifically, 95% CIs for the ratios were calculated by the following formula:

$$\frac{O}{E}\times\exp(-1.96\times\sqrt{\frac{1}{O}+\frac{1}{(E\times 4)}})<\frac{O}{E}<\frac{O}{E}\times\exp(1.96\times\sqrt{\frac{1}{O}+\frac{1}{(E\times 4)}})$$

where, O: Observed number of cases, and E: Expected number of cases.

Cases were stratified by factors that could potentially modify flood effects: sex, age, socio-economic status (educational level and roof structure of the house) and hygiene and sanitation practices (drinking water source, distance to the water source and type of toilet). The expected number of cases of diarrhoea was estimated in separate models for each category of potential modifying factors. The same core model used for estimating the effect on all cases was used for this purpose. The difference in ratios within each category was tested by using the chi-squared statistic proposed by DerSimonian and Laird in the context of meta-analysis (DerSimonian & Laird 1986). To better identify the pattern of excessive risk in the post-flood period, the ratio of the observed against expected number of cases was also calculated in each four-week interval separately.

Expected normal river level and weather variables (rainfall and temperature) during the flood and post-flood periods were obtained using an identical seasonal model (though ordinary linear regression rather than Poisson regression). All analyses were carried out using the statistical package Stata 9.0 (Stata Corporation, College Station, Texas).

Results

During the flood period (week 30−38, 1998), the highest weekly average of daily maximum river level was recorded in week 37 at the level of 7.0 m (Figure 1 a). Rainfall well above expected normal values was observed just before (weeks 28 and 29) and during (week 33) the flood period (Figure 1 b). Temperature in the pre-flood, flood and post-flood periods was mostly close to normal (Figure 1 c).

The number of both cholera and non-cholera cases increased steeply from the beginning of the flood and peaked during the middle of the flood period (Figure 2). The number of cholera cases decreased almost to expected levels by seven weeks after the end of the flood, followed by a further increase 12 weeks after the end of the flood. The number of non-cholera diarrhoea cases decreased to expected levels by four weeks after the end of the flood. However, before the flood, the observed number of cholera cases was also slightly higher than the expected values.

During the flood, the number of cholera cases was almost six times higher than expected (Table 1). The ratio was still elevated, by approximately twofold, in the post-flood period. The number of non-cholera cases was also higher than expected both in the flood period (ratio = 1.8, 95% CI: 1.6, 1.9) and in the post-flood period (ratio = 1.2, 95% CI: 1.1, 1.3) (Table 2). However the ratio in the pre-flood period was also elevated for cholera (ratio = 1.8, 95% CI: 1.6, 2.0), while that for non-cholera diarrhoea was 1.0 (95% CI: 1.0, 1.1).

During the flood period, all subgroups examined had an approximately similar excess risk of both cholera and non-cholera diarrhoea (Tables 1 and 2), although two differences were close to statistical significance: for cholera, a higher excess risk was observed in those with tap water compared with those with tube wells, and for non-cholera diarrhoea a higher excess risk was noted in those with low education. In the post-flood period, the excess risk of non-cholera diarrhoea was strongly significantly higher for those with a lower educational level (vs higher educational level) and for those living in a household with a non-concrete roof (vs concrete roof), in contrast, this was not the case for cholera. During this period, the excess risks for both cholera and non-cholera diarrhoea were also significantly higher for those drinking water from tube wells (vs. tap water) and those using unsanitary toilets. For non-cholera diarrhoea the excess risk was also higher in those using a distant water source (five metres or more from the kitchen). There was little evidence for differences in excess risk by age or sex in either the flood or post-flood period.

The ratios of the observed against the expected number of cases in each four-week interval after the end of the flood are shown in Figure 3. The excess risk of cholera was highest in the flood period and decreased by eight weeks after the end of the flood followed by a slight increase between 12 and 16 weeks after the end of the flood. Evidence for an increased risk of infection was observed until 20 weeks after the end of the flood. An increased risk of non-cholera diarrhoea was observed by eight weeks after the end of the flood followed by a very slight increase thereafter. Although we have not calculated the expected numbers of each specific pathogen represented in the non-cholera patients, we show the distribution of these cases by pathogen (identified from stool specimens) in the pre-flood, flood and post-flood periods (Table 3). Rotavirus, *Escherichia coli*, *Campylobacter* and *Aeromonas* were the most common pathogens. The crude rates of all pathogens except *E. coli* were higher in the flood period than before, although numbers of rarer types of pathogens were small.

For simplicity, we have in the above analyses adjusted only for seasonality when estimating the expected values of diarrhoea. However, the incidence of diarrhoea could have been influenced by weather factors, in particular temperature (Checkley et al. 2000). An analysis adjusted additionally for temperature in the previous four weeks changed results very little (results not shown).

Discussion

This study provides evidence for higher risk of flood-related cholera and non-cholera diarrhoea in lower hygiene and sanitation groups in the post-flood period. Evidence for higher risk of flood-related non-cholera diarrhoea in lower socio-economic groups was also shown in the post-flood period, although this was not the case for cholera.

Although observational studies can never prove causality, the closeness of the timing of the hospital visits to the timing of the flood, the failure to explain the increase in hospital visits by either normal seasonality or temperature and the sheer number of hospital visits makes causality the most likely explanation. Although for cholera (but not non-cholera diarrhoea) there was also an increase in hospital visits before the flood, suggesting the possibility of an excess for 1998 caused by factors other than flooding, this excess was far smaller than that observed during the flood, and smaller than that observed up to 20 weeks after the flood.

There are several plausible causal mechanisms for the elevated risk of infection during the flood. Floods adversely affect water sources and supply systems as well as sewerage and waste disposal systems (Parker & Thompson 2000). The waste disposal system in Dhaka city was almost completely ineffective during the flood (Nishat et al. 2000). A number of tube wells were covered by the floodwaters and were contaminated (Rashid 2000). Many of the people affected by the flood became displaced and took refuge in temporary shelters(Karim

et al. 1999). Some of the shelters were extremely crowded (Karim et al. 1999), and a deterioration in environmental conditions were observed in shelters and slums (Ahmed et al. 1999). These observations suggest that personal hygiene and sanitation levels in the city were extremely disrupted, and that the transmission of enteric pathogens was likely to be increased during the flood.

Study findings showed the long-term persistence of the effects of flood on cholera and non-cholera diarrhoea. The consequences of communicable diseases have previously been believed to be limited to the period of flooding and soon after, and public health surveillance is usually carried out only for one month from the occurrence of flooding (Malilay 1997). Our findings suggest that this period may need to be lengthened. The long-term excess of infection in the post-flood period may be due to the persistence of low hygiene and sanitation status in the flood-affected communities. When people began returning home from shelters and other temporary accommodation, clean-up operations in the homesteads and slums as well as restoration of tube wells and sanitary latrines were suggested as priority tasks (Ahmed et al. 1999). However, it seems likely that these tasks would have taken longer than one month. This hypothesis may be supported by the findings of an increased risk (compared to normal years) for all-cause diarrhoea, particularly for lower hygiene and sanitation groups in the post-flood period, which suggests implications for public health policy in the recovery period. Advice on personal preventive measures in relation to sanitation and hygiene may need to be increased in such a severe flood event. Potential persistent poor nutrition in the flood-affected population may also be implicated in the post-flood excess of diarrhoea. In the presence of malnutrition, chronic or persistent diarrhoea could arise secondary to other infections (Thapar & Sanderson 2004). The long-term low nutritional status of children in flooded households compared to those in non-flooded households was reported in Bangladesh after the 1998 flood (del Ninno & Lundberg 2005). The lack of substantial observed differences in vulnerability to

cholera and non-cholera diarrhoea during the flood may be because the magnitude of the flood was so severe that most people were similarly affected during the flood.

The current study findings of flood-related excess of diarrhoea are broadly consistent with those of a recent study of several floods in Bangladesh, including the 1998 flood (Schwartz *et al.* 2006). The current study differs from the Schwartz study, however: (a) in investigating a wide range of societal and environmental factors determining vulnerability to the effects of flooding on diarrhoea, (b) considering a longer post-flood period, (c) using different statistical methodology.

Educational level can be a robust indicator of socio-economic status and is associated with incidence of diarrhoea in Bangladesh (Islam *et al.* 1984). Construction materials for roof structure are also used as an indicator of socio-economic status (ICDDR 2007). Lower socio-economic groups were more vulnerable to the effects of flood in developing non-cholera diarrhoea in this study. The pathways through which the influences of socio-economic status are mediated are not understood from the findings of this study. Poor groups in Dhaka suffered from a loss of possessions and separation from their social network during and after the prolonged flood (Rashid 2000). The flood also left most of the urban poor unemployed (Rashid 2000). These factors are likely to have resulted in a slower recovery of their original livelihood during the post-flood rehabilitation period, in addition to severe health problems including diarrhoea. Our study showed that the effects of the flood on non-cholera diarrhoea were influenced by socio-economic status, while cholera was not. This finding suggests that non-cholera diarrhoea may be more dependent on personal hygiene and sanitation practices which is closely related to socio-economic status.

Higher levels of vulnerability to the health impacts of flooding have been suggested in children and the elderly (Quarantelli 2003). In addition, during flooding, women may be more likely to be limited in their access to hygiene and sanitation facilities due to the socio-cultural

norms in Bangladesh (Rashid 2000). However, in our study, there was little evidence that any age or sex group was particularly affected in either the flood or post-flood period.

The magnitude of the increased incidence of cholera was greater than that of non-cholera diarrhoea. Cholera is primarily a waterborne disease and the occurrence of epidemics of cholera coincides with an increased prevalence of the causative *V. cholerae* strain in the aquatic environment (Lipp et al. 2002). The incidental ingestion of copepods, which carry a high concentration of *V. cholerae*, can initiate an infection especially when communities rely on untreated environmental water sources for bathing, cooking, and drinking water (Lipp et al. 2002). Thus, in Dhaka where there are many ponds and rivers in the communities, the transmission of *V. cholerae* from untreated environmental water sources to humans is more likely to happen during flooding. The increase in incidence during the flood was also high – at least according to a crude analysis – in *Aeromonas*, another water-borne organism. Another explanation may be possible under-representation of diarrhoeal cases depending on the severity. Considerable proportion of mild diarrhoea may have been treated by oral rehydration therapy at home to prevent them from visiting health facilities (Chowdhury *et al.* 1997). This discrepancy may be different between causal pathogens as the severity of clinical symptoms varies between pathogens (Cholera is characterised in its severe form by sudden onset). The number of cases due to pathogens causing less severe symptoms may only represent a small proportion of the actual number of cases.

Excess risk of cholera was higher for tap water users than those using tube well water in the flood period, though not quite significantly ($p=0.05$). This counterintuitive result may be due to people's temporal behavioural change in drinking water source during the flood, probably because wide spread alerts for drinking tube well or surface water were issued and clean water was provided by aid agencies and the government (Shahaduzzaman 1999). Moreover, faecal contamination of tap water was reported in Dhaka during the 2004 flood, and point of use

water treatment was recommended during and after floods (Islam *et al.* 2007). Investigations on detailed pathways of the flood-cholera relationship, particularly the role of drinking water quality are warranted.

The discrepancy between observed and expected values of cholera in the pre-flood period was little changed after adjusting temperature. The responsible factors are not clear, but they could be unmeasured environmental factors.

There are some limitations to this study which need to be considered. Firstly, if other health facilities in Dhaka city were considerably disrupted during the flood, this would have led to more people with diarrhoea than usual arriving at the ICDDR,B hospital This would have resulted in an overestimation of the estimated effects of the flood on the number of diarrhoea cases. However, this is unlikely to be a major problem as there was no observed difference in the geographic distribution patterns of patients between the flood year and non-flood years (Wagatsuma et al. 2001). Secondly, the results of this study may be dependent on the magnitude and type of flooding as well as local conditions regarding transmission of enteric pathogens such as hygiene and sanitary status. Therefore, these findings may not pertain to other regions.

Conclusions

With little other epidemiological evidence for the vulnerability of individuals to flooding this study confirms higher risk of flood-related diarrhoea in the post-flood period in groups with low socio-economic status and poor hygiene and sanitation. Since they would also likely be high-risk groups for general (flood-unrelated) diarrhoea, understanding of disease risk related to floods should also underscore the need for improving these conditions.

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References

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

Ahmed, M. U., S. Urasawa, K. Taniguchi, T. Urasawa, N. Kobayashi, F. Wakasugi, A. I. Islam & H. A. Sahikh. 1991 Analysis of human rotavirus strains prevailing in Bangladesh in relation to nationwide floods brought by the 1988 monsoon. *J Clin Microbiol* **29**(10), 2273-2279.

Ahmed, S. M., A. M. Husain, M. Sattar & A. Chowdhury 1999. A quick assessment of flood losses and post-flood rehabilitation needs in BRAC's programme areas. Experiences of deluge: flood 1998. Research Monograph Series Vol. 15. S. M. Ahmed & H. S. Ahmed. Dhaka, BRAC**:** 1-29.

Biswas, R., D. Pal & S. P. Mukhopadhyay. 1999 A community based study on health impact of flood in a vulnerable district of West Bengal. *Indian J Public Health* **43**(2), 89-90.

Centre for Research on the Epidemiology of Disasters. 2007. *EM-DAT: the OFDA/CRED International Disaster Database*. (http://www.em-dat.net/) Accessed 5 July 2007.

Checkley, W., L. D. Epstein, R. H. Gilman, D. Figueroa, R. I. Cama, J. A. Patz & R. E. Black. 2000 Effect of El Nino and ambient temperature on hospital admissions for diarrhoeal diseases in Peruvian children. *Lancet* **355**(9202), 442-450.

Chowdhury, A. M., F. Karim, S. K. Sarkar, R. A. Cash & A. Bhuiya. 1997 The status of ORT (oral rehydration therapy) in Bangladesh: how widely is it used? *Health Policy Plan* **12**(1), 58-66.

del Ninno, C. & M. Lundberg. 2005 Treading water. The long-term impact of the 1998 flood on nutrition in Bangladesh. *Econ Hum Biol* **3**(1), 67-96.

DerSimonian, R. & N. Laird. 1986 Meta-analysis in clinical trials. *Control Clin Trials* **7**(3), 177-188.

Easterling, D. R., G. A. Meehl, C. Parmesan, S. A. Changnon, T. R. Karl & L. O. Mearns. 2000 Climate extremes: observations, modeling, and impacts. *Science* **289**(5487), 2068-2074.

Fun, B. N., L. Unicomb, Z. Rahim, N. N. Banu, G. Podder, J. Clemens, F. P. Van Loon, M. R. Rao, A. Malek & S. Tzipori. 1991 Rotavirus-associated diarrhea in rural Bangladesh: two-year study of incidence and serotype distribution. *J Clin Microbiol* **29**(7), 1359-1363.

Hajat, S., K. L. Ebi, S. Kovats, B. Menne, S. Edwards & A. Haines. 2003 The human health consequences of flooding in Europe and the implications for public health: a review of the evidence. *Applied Environmental Science and Public Health* **1**(1), 13-21.

Hunter, P. R. 2003 Climate change and waterborne and vector-borne disease. *J Appl Microbiol* **94 Suppl**, 37S-46S.

Huq, S. & M. Alam 2003. Flood management and vulnerability of Dhaka city. Building safer cities: The future of disaster risk. A. Kreimer, M. Arnold & A. Carlin. Washington, D.C., The World Bank**:** 137-155.

ICDDR, B. 2007. Health and Demographic Surveillance System - Matlab: Volume 38. 2005 Socio-economic Census. Dhaka, ICDDR,B.

Islam, M. S., A. Bhuiya & M. Yunus. 1984 Socioeconomic differentials of diarrhoea morbidity and mortality in selected villages of Bangladesh. *J Diarrhoeal Dis Res* **2**(4), 232-237.

Islam, S. M., A. Brooks, M. S. Kabir, I. K. Jahid, M. Shafiqul Islam, D. Goswami, G. B. Nair, C. Larson, W. Yukiko & S. Luby. 2007 Faecal contamination of drinking water

sources of Dhaka city during the 2004 flood in Bangladesh and use of disinfectants for water treatment. *J Appl Microbiol* **103**(1), 80-87.

Karim, F., S. Sultan & A. Chowdhury 1999. A visit to a flood shelter in Dhaka city. Experiences of deluge: flood 1998. Research Monograph Series Vol. 15. S. M. Ahmed & H. S. Ahmed. Dhaka, BRAC**:** 40-45.

Katsumata, T., D. Hosea, E. B. Wasito, S. Kohno, K. Hara, P. Soeparto & I. G. Ranuh. 1998 Cryptosporidiosis in Indonesia: a hospital-based study and a community-based survey. *Am J Trop Med Hyg* **59**(4), 628-632.

Kondo, H., N. Seo, T. Yasuda, M. Hashizume, Y. Koido, N. Ninomiya & Y. Yamamoto. 2002 Post-flood--infectious diseases in Mozambique. *Prehospital Disaster Med* **17**(3), 126-133.

Kosek, M., C. Bern & R. L. Guerrant. 2003 The global burden of diarrhoeal disease, as estimated from studies published between 1992 and 2000. *Bull World Health Organ* **81**(3), 197-204.

Kunii, O., S. Nakamura, R. Abdur & S. Wakai. 2002 The impact on health and risk factors of the diarrhoea epidemics in the 1998 Bangladesh floods. *Public Health* **116**(2), 68-74.

Lipp, E. K., A. Huq & R. R. Colwell. 2002 Effects of global climate on infectious disease: the cholera model. *Clin Microbiol Rev* **15**(4), 757-770.

Malilay, J. 1997. Floods. The public health consequences of disasters. E. Noji. New York, Oxford University Press.

McCluskey J. 2001 Water supply, health and vulnerability in floods. *Waterlines* **19**(3), 14-17.

Milly, P. C., R. T. Wetherald, K. A. Dunne & T. L. Delworth. 2002 Increasing risk of great floods in a changing climate. *Nature* **415**(6871), 514-517.

Mondal, N. C., R. Biswas & A. Manna. 2001 Risk factors of diarrhoea among flood victims: a controlled epidemiological study. *Indian J Public Health* **45**(4), 122-127.

Nishat, A., M. Reazuddin, R. Amin & A. R. Khan. 2000 *The 1998 flood: impact on the environment of Dhaka city.* Department of Environment and IUCN Bangladesh, Dhaka.

Parker, D. J. & P. M. Thompson. 2000 *Floods in Africa: vulnerability, impacts and mitigation.* Routledge, London.

Quarantelli, E. L. 2003. Urban vulnerability to disasters in developing countries: Managing risks. Disaster Risk Management Series No3. A. Kreimer, M. Arnold & A. Carlin. Washington, DC., The World Bank Group**:** 211-232.

Rashid, S. F. 2000 The urban poor in Dhaka City: their struggles and coping strategies during the floods of 1998. *Disasters* **24**(3), 240-253.

Reacher, M., K. McKenzie, C. Lane, T. Nichols, I. Kedge, A. Iversen, P. Hepple, T. Walter, C. Laxton & J. Simpson. 2004 Health impacts of flooding in Lewes: a comparison of reported gastrointestinal and other illness and mental health in flooded and non-flooded households. *Commun Dis Public Health* **7**(1), 39-46.

Schwartz, B. S., J. B. Harris, A. I. Khan, R. C. Larocque, D. A. Sack, M. A. Malek, A. S. Faruque, F. Qadri, S. B. Calderwood, S. P. Luby & E. T. Ryan. 2006 Diarrheal epidemics in Dhaka, Bangladesh, during three consecutive floods: 1988, 1998, and 2004. *Am J Trop Med Hyg* **74**(6), 1067-1073.

Shahaduzzaman 1999. Health during disaster: sharing experiences with 1998 flood victims. Experiences of deluge: flood 1998. Research Monograph Series Vol. 15. S. M. Ahmed & H. S. Ahmed. Dhaka, BRAC**:** 46-56.

Siddique, A. K., A. H. Baqui, A. Eusof & K. Zaman. 1991 1988 floods in Bangladesh: pattern of illness and causes of death. *J Diarrhoeal Dis Res* **9**(4), 310-314.

Sur, D., P. Dutta, G. B. Nair & S. K. Bhattacharya. 2000 Severe cholera outbreak following floods in a northern district of West Bengal. *Indian J Med Res* **112**, 178-182.

Thapar, N. & I. R. Sanderson. 2004 Diarrhoea in children: an interface between developing and developed countries. *Lancet* **363**(9409), 641-653.

Wade, T. J., S. K. Sandhu, D. Levy, S. Lee, M. W. LeChevallier, L. Katz & J. M. Colford, Jr. 2004 Did a severe flood in the Midwest cause an increase in the incidence of gastrointestinal symptoms? *Am J Epidemiol* **159**(4), 398-405.

Wagatsuma, Y., M. Haq, A. Faruque & M. Malek 2001. *Defining the spacial risk for severe diarrhoeal cases in Dhaka city using geographical information system*. 9th Asian Conference on Diarrhoeal Disease and Nutrition, New Delhi, India.

Woodruff BA, Toole MJ, Rodrigue DC, Brink EW, MAahgoub ELS, Ahmed MM & Babikar A. 1990 Disease Surveillance and control after flood: Khartoum, Sudan, 1988. *Disasters* **14**(2), 151-163.

Figure legends

Figure 1 - Observed and expected normal (a) river level, (b) rainfall and (c) temperature in 1998-99 in Dhaka, Bangladesh

The vertical line shows the period of flood (weeks 30−38, 1998). Expected normal values were obtained as the season-specific average over the two preceding (1996−97) and subsequent (2000−01) years using ordinary multiple regression models.

Figure 2 - Observed and expected number of (a) cholera and (b) non-cholera diarrhoea in 1998-99 in Dhaka, Bangladesh

The vertical line shows the period of flood (weeks 30−38, 1998). Expected numbers of cases were obtained as the season-specific average over the two preceding (1996−97) and subsequent (2000−01) years using Poisson generalised linear models.

Figure 3 - The ratio of the observed and expected number of cases during the flood and each four-week interval in the post-flood period in Dhaka, Bangladesh

Flood period (0: weeks 30−38, 1998); Post-flood period (4: week 39−42, 8: week 43−46, 12: week 47−50, 16: week 51−2 in 1999, 20: week 3−6, 24: week 7−10 and 28: week 11−14). Expected numbers of cases were obtained as the season-specific average over the two preceding (1996−97) and subsequent (2000-01) years using Poisson generalised linear models.

TABLE 1: Excess risk of cholera during the flood (week 30−38) and post-flood (week 39, 1998− week 14, 1999) period in Dhaka.

	Flood period						Post-flood period					
	Observed (O)	Expected* (E)	O/E	95% CI		*p* value†	Observed (O)	Expected* (E)	O/E	95% CI		*p* value†
Total	350	59.3	5.9	5.0	7.0		422	199.1	2.1	1.9	2.4	
Characteristics												
Sex												
Female	174	26.0	6.7	5.2	8.5	0.17	179	93.0	1.9	1.6	2.3	0.15
Male	176	33.3	5.3	4.2	6.6		243	106.1	2.3	2.0	2.7	
Age (years)												
-15	171	25.7	6.7	5.2	8.5	0.15	200	108.1	1.8	1.6	2.2	0.07
15-29	104	16.8	6.2	4.6	8.4		114	45.1	2.5	2.0	3.2	
30+	75	16.8	4.5	3.2	6.2		108	45.9	2.4	1.9	3.0	
Socio-economic status												
Education‡												
No education	224	35.6	6.3	5.1	7.8	>0.2	248	118.1	2.1	1.8	2.4	>0.2
Informal or <6 yrs	37	7.6	4.9	3.0	7.9		77	34.8	2.2	1.7	2.9	
6 yrs or more	89	16.0	5.6	4.0	7.7		96	45.2	2.1	1.7	2.7	
Roof structure												
Non-concrete	262	48.6	5.4	4.5	6.5	0.08	347	164.1	2.1	1.9	2.4	>0.2
Concrete	73	9.1	8.0	5.4	11.9		57	27.5	2.1	1.5	2.9	
Hygiene and sanitation												
Drinking water source												
Tube well	108	22.9	4.7	3.6	6.2	0.05	260	97.2	2.7	2.3	3.1	<0.001
Tap water	241	36.1	6.7	5.4	8.2		162	100.8	1.6	1.3	1.9	
Distance to water source												
More than 5m	228	38.4	5.9	4.8	7.3	>0.2	303	141.6	2.1	1.9	2.5	>0.2
5m or less	122	20.8	5.9	4.4	7.8		118	56.8	2.1	1.7	2.6	
Type of toilet												
Unsanitary	136	24.5	5.6	4.3	7.2	>0.2	266	100.9	2.6	2.3	3.1	<0.001
Sanitary	214	34.8	6.1	5.0	7.6		156	98.2	1.6	1.3	1.9	

*The expected values were the season-specific average over the two preceding (1996-97) and subsequent (2000-01) years.

1 †Test for heterogeneity

2 ‡Mother's educational level for children under 15 years and self educational level for adult.

3

TABLE 2. Excess risk of non-cholera diarrhoea during the flood (week 30−38) and post-flood (week 39, 1998− week 14, 1999) period in Dhaka.

	Flood period						Post-flood period					
	Observed (O)	Expected* (E)	O/E	95% CI		*p* value†	Observed (O)	Expected* (E)	O/E	95% CI		*p* value†
Total	493	281.6	1.8	1.6	1.9		1052	859.2	1.2	1.1	1.3	
Characteristics												
Sex												
Female	196	115.3	1.7	1.4	2.0	>0.2	419	332.5	1.3	1.1	1.4	>0.2
Male	287	163.1	1.8	1.5	2.0		624	519.6	1.2	1.1	1.3	
Age (years)												
-15	331	196.0	1.7	1.5	1.9	>0.2	739	622.1	1.2	1.1	1.3	0.14
15-29	74	36.0	2.1	1.6	2.7		122	103.2	1.2	1.0	1.4	
30+	88	49.6	1.8	1.4	2.3		191	133.9	1.4	1.2	1.7	
Socio-economic status												
Education‡												
No education	254	129.9	2.0	1.7	2.3	0.06	508	374.1	1.4	1.2	1.5	0.004
Informal or <6 yrs	83	47.7	1.7	1.3	2.2		190	149.7	1.3	1.1	1.5	
6 yrs or more	145	99.1	1.5	1.2	1.8		343	327.3	1.0	0.9	1.2	
Roof structure												
Non-concrete	381	214.0	1.8	1.6	2.0	>0.2	827	647.3	1.3	1.2	1.4	0.002
Concrete	101	60.7	1.7	1.3	2.1		183	191.1	1.0	0.8	1.1	
Hygiene and sanitation												
Drinking water source												
Tube well	185	98.7	1.9	1.6	2.2	>0.2	501	363.8	1.4	1.2	1.5	0.002
Tap water	297	177.8	1.7	1.5	1.9		538	486.7	1.1	1.0	1.2	
Distance to water source												
More than 5m	302	170.9	1.8	1.5	2.0	>0.2	676	502.0	1.3	1.2	1.5	0.001
5m or less	179	107.1	1.7	1.4	2.0		364	349.0	1.0	0.9	1.2	
Type of toilet												
Unsanitary	195	111.3	1.8	1.5	2.1	>0.2	491	350.2	1.4	1.3	1.6	0.001
Sanitary	288	166.4	1.7	1.5	2.0		552	501.7	1.1	1.0	1.2	

*The expected values were the season-specific average over the two preceding (1996-97) and subsequent (2000-01) years.

1 †Test for heterogeneity

2 ‡Mother's educational level for children under 15 years and self educational level for adult.

3

TABLE 3: Average weekly number of non-cholera pathogens identified from stool specimens in the pre-flood, flood and post-flood periods in Dhaka.

	Pre-flood		Flood		Post-flood	
Pathogen	Mean	(%)	Mean	(%)	Mean	(%)
All non-cholera diarrhoea	35.6	(100)	54.8	(100)	37.6	(100)
Rotavirus	9.2	(26)	14.6	(27)	11.6	(31)
Escherichia. coli	9.9	(28)	8.3	(15)	6.0	(16)
Campylobacter	3.7	(10)	7.0	(13)	3.3	(9)
Aeromonas	3.1	(9)	6.9	(13)	4.9	(13)
Shigella	2.5	(7)	3.1	(6)	3.1	(8)
Salmonella	0.6	(2)	1.2	(2)	0.5	(1)
Other pathogens	0.8	(2)	1.2	(2)	1.3	(3)
No pathogen	13.2	(37)	22.3	(41)	13.2	(35)

Pre-flood: weeks 1−29, 1998; Flood: weeks 30−38, 1998; Post-flood: week 39, 1998−week 14, 1999

A patient was classified as non-cholera diarrhoea when *V. cholerae* was not identified from the stool specimen.

The cause of non-cholera diarrhoea was categorised as rotavirus, *Shigella, Salmonella, Campylobacter, E. coli* and *Aeromonas* when the respective pathogen was identified.

When two or more pathogens other than *V. cholerae* were identified from the same patient, the patient was classified as each pathogen of non-cholera.

The patient was classified as other pathogens when none of *V. cholerae, rotavirus, Shigella, Salmonella, Campylobacter* or *E. coli* was identified.

The patient was classified as "no pathogen" when no pathogen was identified from the stool

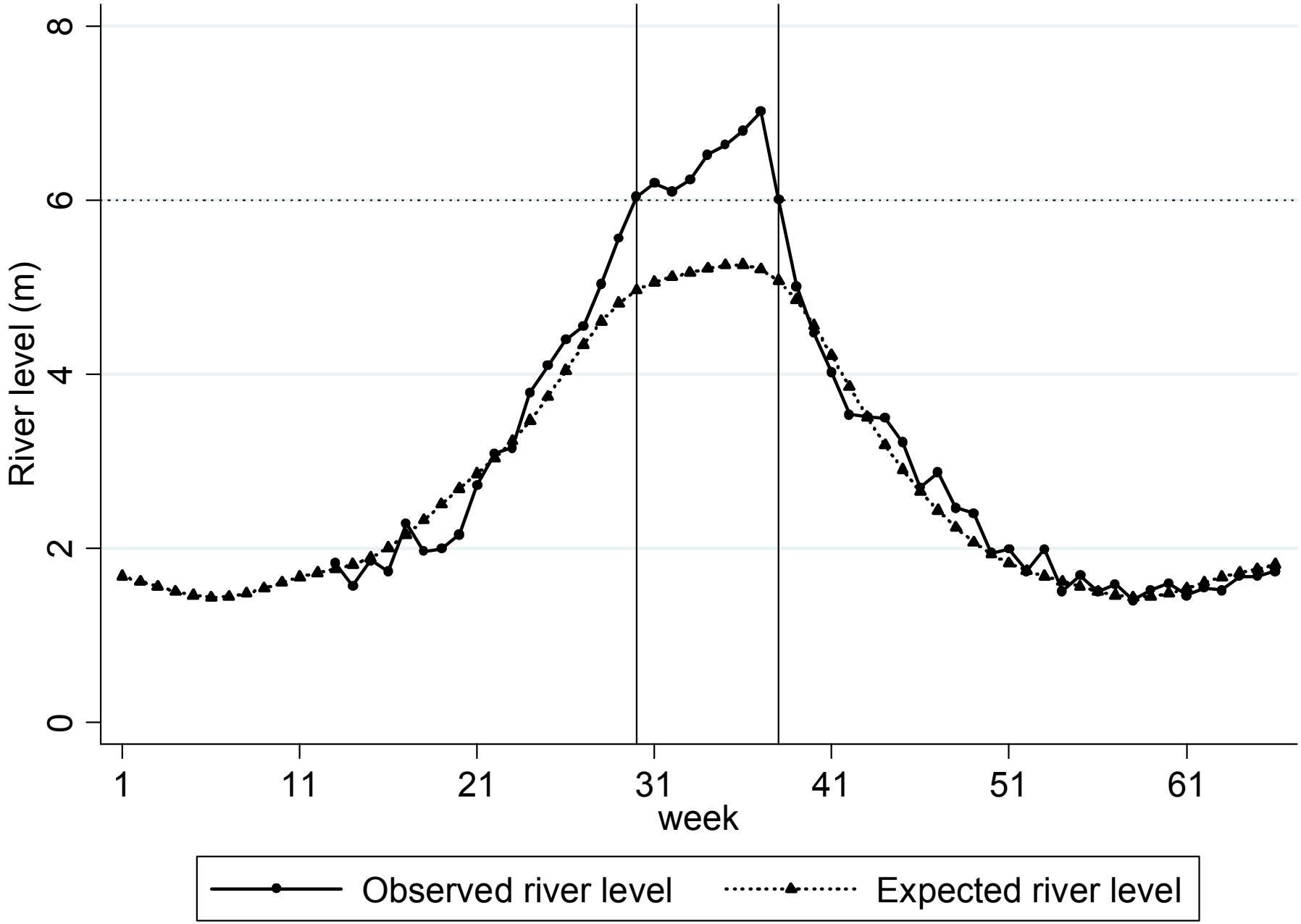
River level (m)
0
2
4
6
8
1
11
21
31
41
51
61
week
Observed river level
Expected river level

Figure 1 (a)

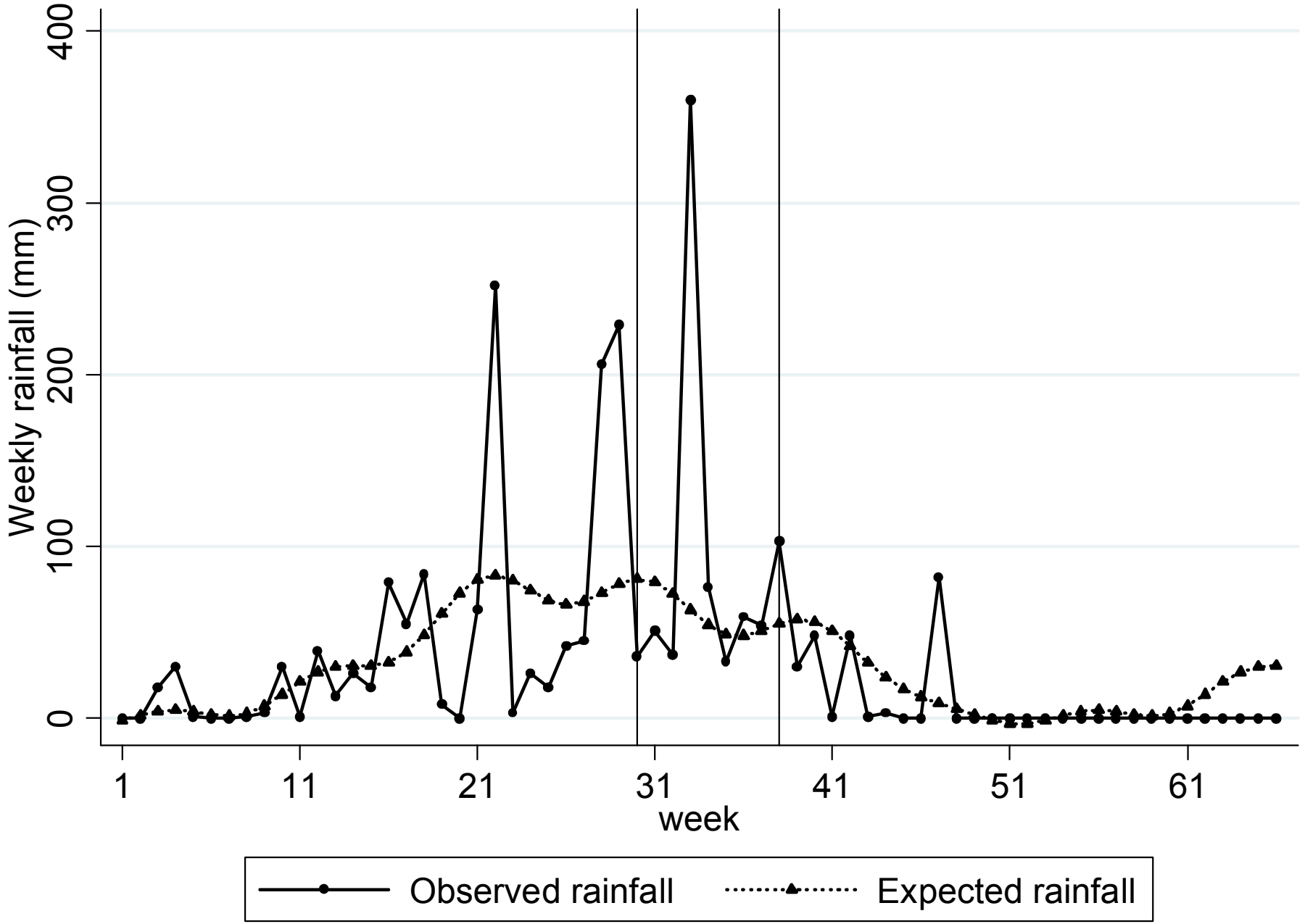
Weekly rainfall (mm)
0
100
200
300
400
1
11
21
31
41
51
61
week
Observed rainfall
Expected rainfall

Figure 1 (b)

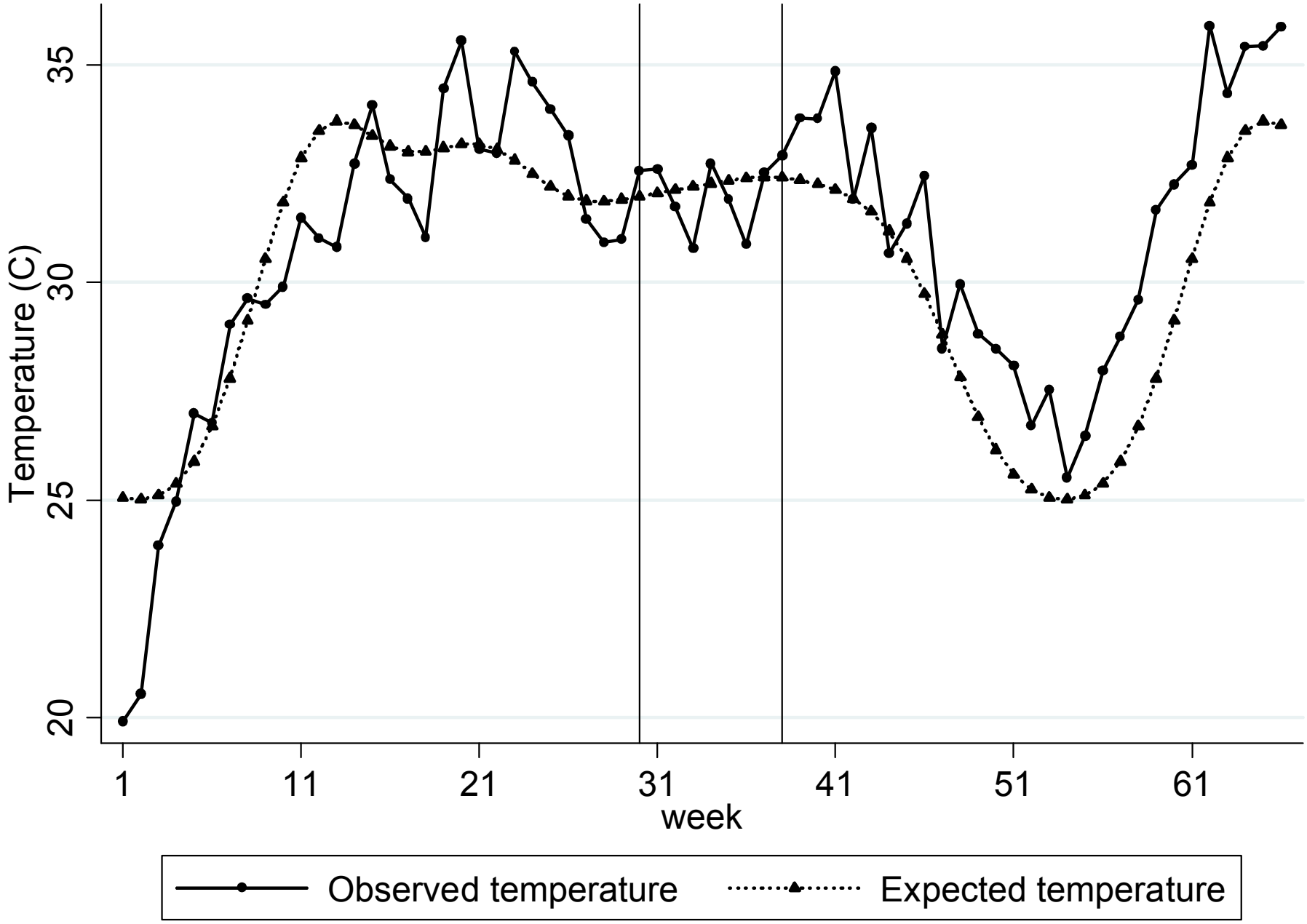
Temperature (C)
20
25
30
35
1
11
21
31
41
51
61
week
Observed temperature
Expected temperature

Figure 1 (c)

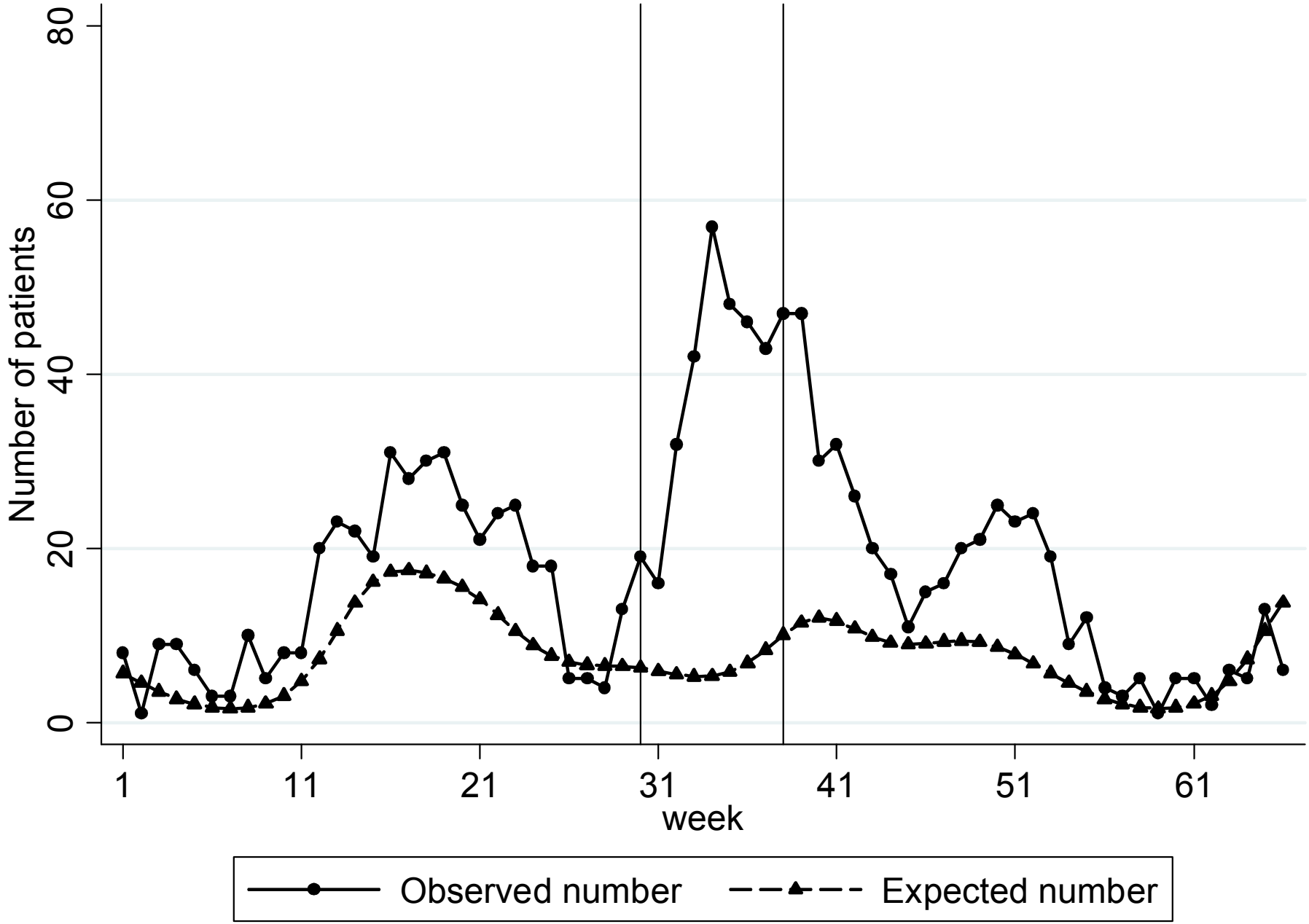
Number of patients
0
20
40
60
80
1
11
21
31
41
51
61
week
Observed number
Expected number

Figure 2 (a)

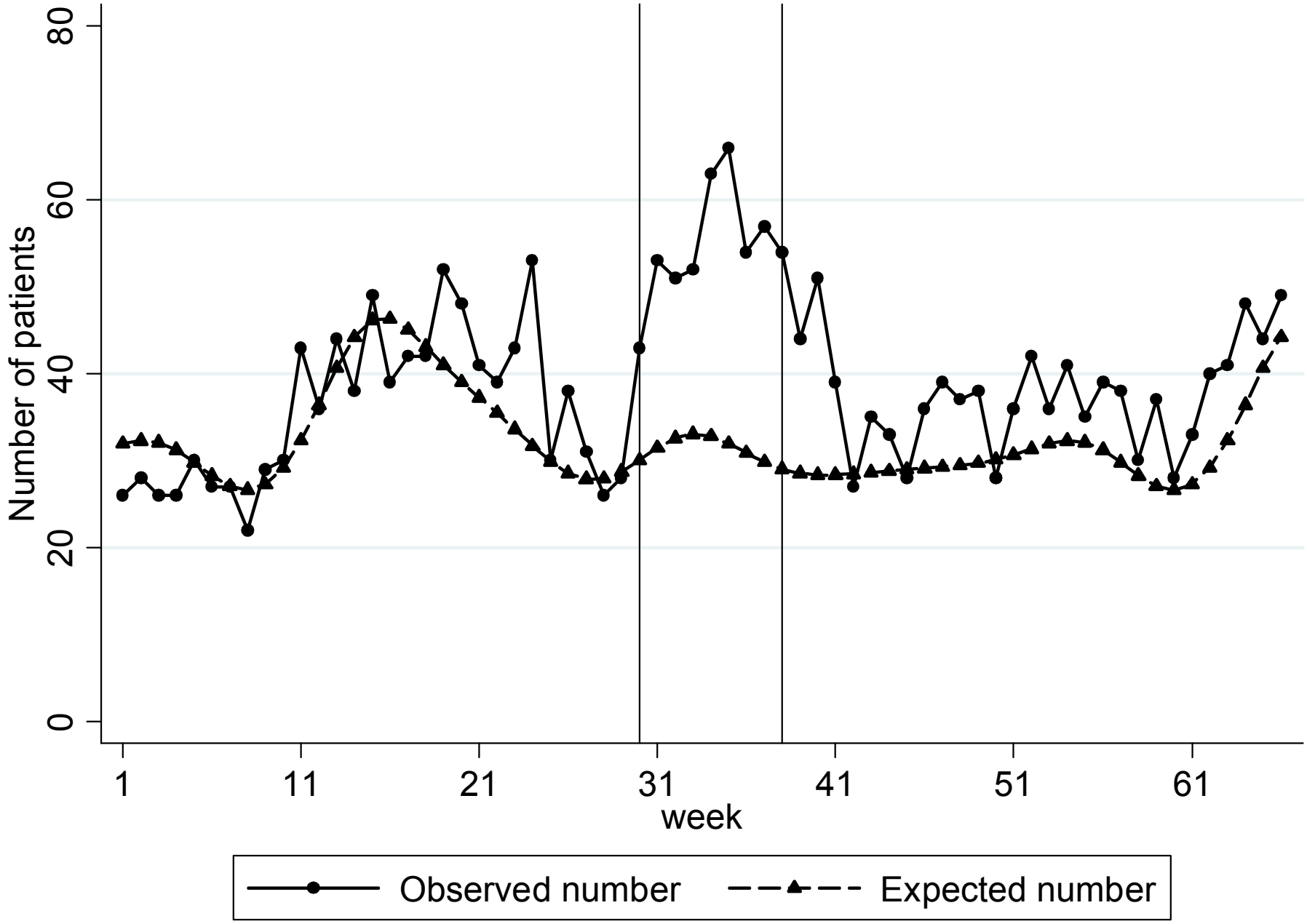
Number of patients
0
20
40
60
80
1
11
21
31
41
51
61
week
Observed number
Expected number

Figure 2 (b)

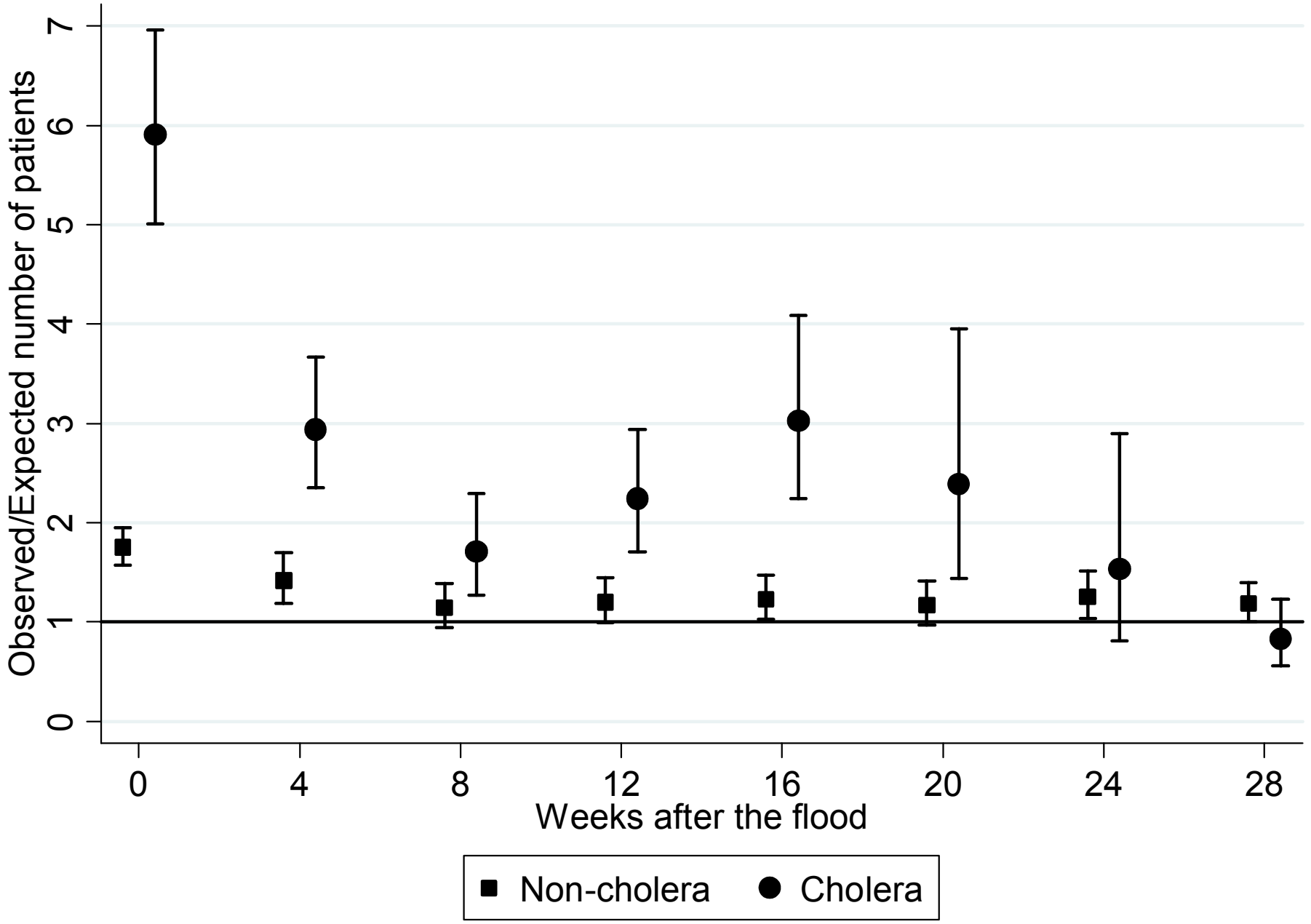
Observed/Expected number of patients
0
1
2
3
4
5
6
7
0
4
8
12
16
20
24
28
Weeks after the flood
Non-cholera
Cholera

Figure 3