

# **Association between Annual River Flood Pulse and Paediatric Hospital Admissions in the Mekong Delta Area**

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## **Abstract**

The Mekong Delta is the most vulnerable region to extreme climate and hydrological conditions however the association between these conditions and children's health has been little studied. We examine the association between annual river flood pulse and paediatric hospital admissions in a Vietnam Mekong Delta city.

Daily paediatric hospital admissions (PHA) were collected from the City Paediatric Hospital, and daily river water level (RWL) and meteorological data were retrieved from the Southern Regional Hydro-Meteorological Centre from 2008 to 2011. We evaluated the association between annual river flood pulse ( $\geq 90^{\text{th}}$  percentile of RWL) and PHA using the Poisson distributed lag model, controlling for temperature, relative humidity, day of week, seasonal and long-term trends. The seasonal pattern of PHA was examined using harmonic and polynomial regression models.

The cumulative risk ratios estimated for a 15-day period following an extreme RWL was 1.26 (95%CI, 1.2-1.38) for all age groups, 1.27 (95%CI, 1.23-1.30) for under five-years and 1.15 (95%CI, 1.07-1.20) for school-aged children, 1.24 (95%CI, 1.21-1.27) for all-causes, 1.18 (95%CI, 1.12-1.21) for communicable infection, 1.66 (95%CI, 1.57-1.74) for respiratory infection and 1.06 (95%CI, 1.01-1.1) for other diseases. The peak PHA risk is in the September-October period corresponding to the highest RWL, and the PHA-RWL association was modified by temperature.

An increase in PHA is significantly associated with annual river flood, and the pattern of PHA is seasonally correspondent to the RWL. These findings combined with projected changes in climate conditions suggest important implications of climate change for human health in the Mekong Delta region.

## 1. Introduction

The flooding events, which have become more frequent in recent years and have become a great public health concern (Prudhomme et al. (2003), were believed to have a significant impact on children in both high- and low-income areas (Alderman et al. 2012;Yeo and Blong 2010). The potential direct and indirect adverse health effects of floods included drowning and acute trauma (Jonkman et al. 2009;Pradhan et al. 2007;Yeo and Blong 2010), injuries (Ahern et al. 2005;Abaya et al. 2009;Diaz 2004;Sullivent et al. 2006), toxic exposure (Euripidou and Murray 2004;Fox et al. 2009), water- and vector-borne diseases (World Health Organization 2011) such as diarrhoea (Abaya et al. 2009;Schwartz et al. 2006;Vollaard et al. 2004), respiratory and skin infections (Diaz 2004;Caroll et al. 2010;Reacher et al. 2004), dengue fever and malaria (World Health Organization 2011;Sidley 2008;Abaya et al. 2009), and non-communicable diseases such as malnutrition and mental health disorders (Berry et al. 2008;Nino and Lundberg 2005;Goudet et al. 2011).

Besides the effects of climate change, urbanization, which has rapidly shifted of rural to urban land use in developing countries recently, also leads to increased risk of flooding and its association with human health effects. Urbanization significantly causes rigorous changes of land cover, resulting elevated risk of flooding as more population and property are being placed in the newly developed lands (Dewan and Yamaguchi 2008). In addition, urbanization results to the reduction of surface roughness, shortens the runoff travel time, and increase peak discharges which makes flood hazard susceptibility distinctly higher in urbanized areas (Nirupama and Simonovic 2007). Nevertheless, cities in developing areas in Asia are not capable enough to deal with increased flood-related health problems because of their high rates of population and poverty as well as their poor adaptive capacity (Tol 2008;Adger 2006;Dewan 2013). Moreover, health consequences of floods depend greatly on geographic and socio-economic factors as well as the characteristics of the population affected (Ahern et

al. 2005;Du et al. 2010). Therefore, understanding the pattern of flood-health effect relationship should be addressed ideally in the specific location and for the specific vulnerable groups in terms of public health preparedness and prevention (Hunter Health 2003).

The Mekong River Delta (MRD) is considered as the most vulnerable region to extreme climate and hydrological events in Southeast Asia (Yusuf and Francisco 2009). The study (Vastila et al. 2010) indicated that the projected flood duration in the MRD highly likely increase in all the simulated scenarios. The flood start and end dates are projected to occur earlier and later respectively. Besides the flood pulse, which occurs annually, other studies (Delgado et al. 2010;Eastham et al. 2008) also predicted an increasing likelihood of extreme floods. It was estimated that 74% of all victims of the extreme flood events in MDR were children under six years old (CFSC [Committee for Flood and Storm Control 2004]). Nevertheless, the previous investigation only focused on surveys fatality and injury but not on hospitalized morbidity. Moreover, besides the extreme flood events due to intense or prolonged rainfall and tidal extremes (Birkmann et al. 2010), the effects of the usual river flood pulse have been neglected in the previous studies.

The objectives of this study were (i) to investigate the short-term association between paediatric hospital admission and annual river flood pulse which is represented by the high river water level, and (ii) to examine the seasonal pattern of paediatric hospital admissions in Can Tho city, the Vietnam Mekong Delta area.

## **2. Materials and Methods**

### **2.1 Study location**

The study was conducted in Can Tho city, a city in Mekong Delta in Vietnam (Figure 1). Can Tho is the fourth most populous city in Vietnam with a total area of 1,411.49 km<sup>2</sup> and

a population of 1,188,390 people, and a population density of 842 people/km<sup>2</sup> (Huyen 2012). Located in the heart of the Mekong Delta, Can Tho residential life is strongly affected by the meteorological and hydrological factors. The annual river flood pulses usually occur from May to November due to increased flows from upstream, tidal surges and intense local rainfall in Can Tho. The extent and depth of flooding varies depending on meteorological and hydrological factors and infrastructure construction, with an estimated area of 9,700ha-36,000ha under 1 metre of water (Neumann et al. 2013). These higher water levels and runoff increase the mobilisation of pathogens, pesticides, dissolved and absorbed pollutants and heavy metal, potentially resulting in negative impacts on residential health in Mekong Delta (Bates et al. 2008).

## 2.2 Data collection

### 2.2.1 Hospital admissions data

Daily paediatric hospital admissions (PHA) data from 1<sup>st</sup> January 2008 to 30<sup>th</sup> December 2011 were collected from the Can Tho City Paediatric Hospital which is the sole public hospital for children in Can Tho city, and hence represents a strong majority of paediatric patients in the research location. The data comprise: date of birth, date of admission, diagnosis as per International Classification of Disease (ICD10), and date of hospital discharge. These data were cleaned to exclude patients who are not Can Tho residents and to collapse data by date of admission, age ( $\leq 5$  and 5-15 year-olds), disease groups comprising: communicable infectious diseases [A00-A99, excluding infections with a predominantly sexual mode of transmission; B00-B99, excluding human immunodeficiency virus (HIV)], respiratory infection (J00-J22), and the rest including all other diseases with the exclusion of malignant neoplasms and *other* neoplasms (C00-97, D00-49) and external causes of morbidity and mortality (V01-Y98). The data collection was permitted by Vietnam Health Environment Management Agency (VHEMA), Ministry of Health in Vietnam that is

the leading agency responsible for climate change and health among health sectors in Vietnam, and the permission and supports were also provided by Can Tho Health Department, the leading health management agency in the local area.

### 2.2.2 Meteorological and river water level data

Daily meteorological and river level data, monitored at the Can Tho Hydro-Meteorological Station and available from the Southern Regional Hydro-Meteorological Centre, were also collected for the period January 2008- December 2011. The parameters comprises of daily average temperature ( $^{\circ}\text{C}$ ), daily relative humidity (%), and the maximum river water level (RWL) in the Tien River, a section of the Mekong Delta River which runs through Can Tho city. As classified by Can Tho Committee for Flood and Storm Control (CCFSC), the warning levels for the river flood correspond to the specific river water level, of which flood warning level 1 is 170 cm, level 2 is 180 cm, and level 3 is 190 cm. These warning levels were used to urge local authorities and inhabitants to prepare for flood risk reduction and mitigation.

### 2.3 Data analysis

Initially, a restricted cubic spline function was used to control for seasonal and long-term trends of dependent variable (PHA) and to take account for potential non-linear effects of exposure variables (RWL, and meteorological parameters). We first estimated the spline term based on the entire time series using all days and single unadjusted Poisson regression models, and then incorporates the spline estimates as an offset in the full models. The predicted values of the outcome and exposure variables were then calculated from the fitted spline function models. The restricted cubic spline was applied because splines are possibly more flexible than fractional polynomial function, so it may be suitable for modelling complex functions (Royston and Sauerbrei 2007). In addition, it is an easy way of including explanatory variables in a smooth non-linear way in a wide variety of models. The number

of knots was set at 7 in this analysis, since 7 per year has been considered as a balance between providing adequate control for seasonality and other confounding by trend in time, while leaving sufficient information from which to estimate exposure effects (Dominici et al. 2000).

We hypothesized that the highest level of RWL, representing an occurrence of annual river flood pulse, would be associated with an increased risk of paediatric hospital admission, so the 90<sup>th</sup> percentile was chosen as the cut-off point (<90<sup>th</sup> percentile: reference category, and ≥90<sup>th</sup> percentile: examined category). This hypothesis is based on previous studies which indicated that a majority of waterborne disease outbreaks were preceded by extreme meteorological and hydrological parameters (Harper et al. 2011; Curriero et al. 2001; Rose et al. 2000). In the following step, the Poisson distributed lag model (*Equation 1*) was used to examine the lag effects between exposure to increase of RWL and subsequent occurrence of PHA, and the time lags for this variability were taken at a 15-day lag.

$$\ln[E(PHA)] = \beta_0 + \beta_1 RWL_{t-q} + \beta_2 AT_t + \beta_3 RH_t + \beta_4 DOW_t + s(time) \quad \text{Equation 1}$$

where *PHA* is the count of daily paediatric hospital admissions, *RWL* is the daily river water level, *t* represents the day of hospitalization, *q* denotes single-day lags 1-15 days before the day of hospital admission ( $q = 1, 2, \dots, 15$ ), *AT* is daily average temperature, *RH* is daily relative humidity, *DOW* is day of week, and *s(time)* is a penalized spline using calendar time with smoothing parameters at 7 knots.

In order to examine the association between extreme RWL and PHA, the Poisson models (*Equation 2*) were fit with daily counts of PHA as the dependent variable and categorical daily RWL as the independent variable, adjusted for potential confounding factors, including AT, RH, and DOW. The previous studies illustrated that temperature, humidity, or a combination of these meteorological factors are associated with the replication, persistence, and transmission of pathogens in the environment (Checkly et al. 2000; Fleury et

al. 2006; Namouva et al. 2007; Singh et al. 2001). All models included AT and RH as continuous variables. The cumulative effect over a 15-day period following an extreme RWL event was computed from the model using a quadratic distributed lag function in order to reduce collinearity resulting from correlated RWL on days that are close lags. This function allows us to model the cumulative effects of RWL over the entire lag period and simultaneously compute the nonlinear and delayed effects (Bush et al. 2014).

$$\ln[E(PHA)] = \beta_0 + \sum_{q=1}^{15} \delta_q RWL_{t-q} + \beta_2 AT_t + \beta_3 RH_t + \beta_4 DOW_t + s(time) \quad \text{Equation 2}$$

where  $\delta_q$  is the effect of extreme RWL ( $\geq 90^{\text{th}}$  percentile)  $q$  days before the day of hospitalization. The cumulative summary of risk ratio estimates corresponding to extreme RWL is given as  $\sum_{q=1}^{15} \delta_q$ .

We conducted 2 sensitivity analyses. First, the association between PHA and RWL was conducted by specifying exposure variable, RWL in a different way. A categorized RWL using an ordinal scales (50-80, 80-110, 110-140, 140-170, 170-200,  $>200$  cm) was examined. This scale was used to examine the linear relationship between RWL and risk of PHA after adjusting for meteorological factors and day of week. We hypothesized that age and disease group could be modifying factors for the RWL-PHA relationship, so the sensitivity analyses were also conducted for separate groups queried by age ( $\leq 5$  and 5-15 year-olds) and diseases (communicable infection, respiratory infection, and others). Second, we performed a sensitivity analysis to test the impact of number of knots (7, 6, 5, and 4) on the regression results to determine the optimal number of knots to control for long-term and seasonal trend in the models.

Finally, the seasonal pattern of PHA was examined. Consultation with local hydrologists and analysis in the seasonal pattern of RWL confirmed that the annual river flood pulse usually occurs from August to October. We developed a harmonic regression model (Equation 3) from January to June, one month before the peak period of RWL because



the previous study found that water contamination and illness could be elevated a month prior to the flood event due to the run off as a result of heavy rainfall (CCDR 2000). We then used the developed regression model to predict expected admissions for the period of July – December. The risk ratios were calculated by comparing observed and expected admissions over time. The seasonal pattern of PHA risk ratio was examined using a fitted polynomial regression model, and this was evaluated by the levels of temperature and humidity (high, >mean; normal, <= mean). All data analyses were conducted using Stata version 11.0 (Stata Corporation, College Station, TX, USA).

$$\ln[E(PHA)] = \beta_0 + \beta_1 \sin(2\pi\omega t) + \beta_2 \cos(2\pi\omega t) + \varepsilon_t \quad \text{Equation 3}$$

where *PHA* is the count of paediatric hospital admissions, *t* is time in days,  $\omega$  is frequency ( $\omega = 1/30.25$ ),  $\varepsilon$  is the error term.

### 3. Results

#### 3.1 Descriptive analysis

Daily river water level (RWL) during the study period ranged from 40 to 215 cm with a daily mean of 125 cm (95%CI, 123-126). RWL at 166 cm (the 90<sup>th</sup> percentile), which is approximate to the 1<sup>st</sup> flood warning level (170 cm), was used as the cut-off point for extreme RWL in this analysis. The total number of annual river flood pulses with RWL above 166 cm was 149 (Table 1). The year 2011 had 10 to 21 more days of extreme RWL than the other years. The seasonal RWL was significantly higher in the wet season, which ranged from 65 to 215 cm, than in the dry season, which ranged from 40 to 184 cm. The number of days with extreme RWL in the wet season was 8 times as many as that in the dry season (132 versus 17 days). The histogram, Q-Q plots, and Shapiro-Wilk test ( $p < 0.01$ ) showed a slightly left skewed distribution of RWL (mean, 125 cm; median, 122 cm); out of the total of 1458 days, 653 days (43%) had a RWL greater than the mean. During the study period, daily AT ranged from 21.5 to 31.4°C with a daily mean of 27.2°C (95% CI, 27.1-27.3). The temperature was

relatively consistent at around 27°C across the years and seasons (Table 1). Distributional tests showed a normal distribution of the daily AH (mean, 27.2; median, 27.3°C). RH ranged from 65-97% with the mean of 82% (81.7-82.3) and a normal distribution (mean, 82; median, 82). This parameter was a bit higher in the wet season (mean, 84.5%) than in the dry season (mean, 82%). Across the years, the RH seems to have decreased from 2008 to 2011.

The total number of PHA from all causes recorded during 2008-2011 was 44,542, of which 77.5% were for under-5 year-olds at the date of admission, and 64% were infectious diseases (Table 2). The number of PHA in the wet season was nearly 3 times as high as that in the dry season for all age and disease groups. The PHA caused by infectious diseases seems to have increased in 2009-2010 with children less than 5 year-olds whereas the admissions caused by other diseases were more numerous in 2011. The seasonality of PHA started increasing from Week 27 (July) and peaked at Week 40-44 (October), then went down from Week 50 (early December) each year (Figure 1). The increase of PHA appears to correspond with the increase on RWL and RH at the same month lag while there seems to be a delayed response with a several month lag for admissions and temperature (Figure 3). However, this study only examined the short-term association within 15 day lags only.

### 3.2 Association between paediatric hospital admission and river water level

The results of the multivariate Poisson distributed lag model using a quadratic distributed lag function, extreme RWL was significantly associated with increased PHA with a cumulative risk ratio of 1.26 (95%CI, 1.2-1.38) after a 15-day lag following an extreme RWL event (Table 3). Among the young children ( $\leq 5$  year-olds), the risk ratio of PHA was 1.27 (95%CI, 1.23-1.30) for cumulative 15-day lag following an extreme RWL compared with a 15-day period with moderate RWL. Among the school-age children (5-15 year-old), the risk ratio was also significantly positive but on a smaller scale: the risk ratio was 1.15 (95%CI, 1.07-1.20). In terms of disease groups, the risk ratio of PHA was 1.24 (95%CI, 1.21-

1.27) for all causes, 1.18 (95%CI, 1.13-1.22) for communicable infectious diseases, 1.66 (95%CI, 1.57-1.74) for respiratory infectious diseases, and 1.06 (95%CI, 1.01-1.1) for other diseases after 15-day period following an extreme RWL.

The sensitivity analysis, which categorized RWL in different ways as described in Section 2.3, demonstrated a linear-trend relationship between PHA and RWL. Compared with the RWL of 50-80 cm, at the level of 80-110cm the risk ratio of PHA increased by 2% (RR, 1.02, 95%CI, 0.96-1.08), and at a RWL of 110-140cm it rose by 5% (RR, 1.05, 95%CI, 0.98-1.11), but these increases were not statistically significant ( $p>0.1$ ). In fact, the risk ratio of PHA statistically increased by 14% (RR, 1.14, 95%CI, 1.07-1.20) when RWL was at the level of 140-170cm, by 20% (RR, 1.2, 95%CI, 1.12-1.28) when RWL was at the level of 170-200 cm, and by 28% when RWL was more than 200 cm. The cumulative risk ratio increased by 16% (RR, 1.16, 95%CI, 1.14-1.17) following a 15-day period of 30 cm increase in RWL above the level of 80-110 cm. The sensitivity analysis, which used lower number of knots in the regression models, revealed that change in number of knots per year for the time trend did not substantially affect the estimated effects of RLW on PHA, indicating that our findings were relatively robust in this regards. For example, the risk ratio of PHA statistically increased by 22% (RR, 1.22, 95%CI, 1.18-1.24) for all causes, and that increased by 25% (RR, 1.25, 95%CI, 1.20-1.27) for less than 5 year-old if the number of knots was 5 per year.

### 3.3 Seasonal pattern of paediatric hospital admissions

The risk ratios of PHA, which were computed using the harmonic regression model, illustrate that the risk of PHA among children in Can Tho city starts increasing in May, with a statistically the significant increase found from July (Figure 4). The peak in risk ratio is within September-October which corresponds with the highest RWL in the year, and the risk ratio of PHA starts declining from November-December. The seasonal pattern of PHA was significantly influenced by the variation in daily average temperature during and after the

annual flood season. Figure 4 shows that the peak of risk ratio was about 10% higher in the days with temperature  $> 27^{\circ}\text{C}$  (mean level) compared with the risk ratio in the days with temperature  $\leq 27^{\circ}\text{C}$ , and the declining stage of risk ratio for the hot days was much slower than that for the normal temperature days. However the seasonal pattern of PHA was not influenced by the change in humidity, since the peak and declining stages of risk ratio showed no difference between the high humid days ( $>82\%$ ) and moderate humid days ( $\leq 82\%$ ) (Figure 4).

#### **4. Discussion**

This is the first study of the association between annual river flood pulse, which was represented by river water level, and hospital admissions among children in the Mekong Delta area. The study results indicate a significantly positive association between PHA and extreme RWL ( $\geq 90^{\text{th}}$  percentile) over a 15-day lag. The threshold of sensitivity for RWL associated with increase of PHA is found at the level of 170 cm. Young children (under-five year-olds) and respiratory infection are more sensitive to extreme RWL than school-age (5-15 year-olds) and other diseases.

The plausible explanation for the flood-disease association is the presence of contaminated water due to flood and related factors. Floods interacted with climate variability undermine clean water supplies and cause significant risk of water-related diseases among children, especially in less developed areas. For instance, flooding causes expansion of river channel, increase in water velocity, overland flow, and occurrence of shallow subsurface flow, resulting in high water turbidity and potentially transporting pathogens, so that drinking water sources are contaminated (Harper et al. 2011). Moreover, high turbidity levels can protect pathogens from natural disinfection, as well as hinder other disinfection techniques (Aramini et al. 2000). Therefore, the risk of exposure to waterborne pathogens is increased as

a result of run-off and increased turbidity (Curriero et al. 2001;Schuster et al. 2005;Thomas et al. 2006). In addition, children must consume more water per body mass than adults while their immune systems are less developed than those of adults, resulting in less effective in fighting pathogens (Bunyavanich et al. 2003). The low-income inhabitants which live close to water bodies may have elevated risk of infection during the flooding season, since they frequently use contaminated surface water for cooking, bathing etc. (Dewan 2013;Corner et al. 2013).

The finding of this current study was consistent with previous studies of the association between climate factors which cause elevation of river water level and human health adverse effects. There were a few studies (Kien et al. 2010;Few et al. 2009;Kelly-Hope et al. 2008) investigated the relationship between climate-related conditions and water-borne diseases in Vietnam Mekong Delta, and these studies indicated that enteric infections among general populations were associated with annual floods. For example, the study by Kien et al (2005) typhoid fever is endemic for the Mekong River Delta and rates correspond to increase in annual floods, and that was more serious when the floods interacted with high temperature. Another study by Kelly-Hope et al (2008) found that significant increase of shigellosis/dysentery, cholera, and typhoid associated with high precipitation periods. However these studies did not evaluate the effects of annual floods on children health impacts separately.

The findings are also relevant to that from previous studies which have been conducted in somewhere else worldwide. Daily paediatric hospital admissions for diarrhoea in Peru increased 200% over baseline after the flooding and high temperature triggered by 1997-98 El Nino (Checkly et al. 2000). A study based in Chennai India indicated that extreme precipitation was associated with 2.72 times increase in the number of gastrointestinal-related illness among young children ( $\leq 5$  year) (Bush et al. 2014). The

studies also found that an interquartile range in drinking-water turbidity likely caused by extreme precipitation caused an elevated risk of hospital admission among children 0-15 year-olds (Schwartz et al. 1997); a 10-cm river-level rise above threshold was associated with a 5.5% increase in cases of rotavirus diarrhoea (Hashizume et al. 2007b), and a 10 mm increase above threshold of 52 mm of average rainfall was associated with a 5.1% increase in non-cholera diarrhoea cases (Hashizume et al. 2007a). Among water-borne infections, the typhoid incidence associated with river water levels was highest among young children (0-4 years) and elderly people (60+), and a statistically significant inverse association was found between typhoid incidence and distance to major water bodies (Dewan et al. 2013; Corner et al. 2013). The vector-borne disease such as dengue fever was also found elevated with high river level at shorter lags with the highest at a lag of six weeks (Hashizume et al. 2012). However the positive effect of lower level was also found at the longer lags and this study did not analysed age-specific effects for children separately. The study by Milojevic et al (2012) found the moderate increase in risk of acute respiratory infection among 0-15 year-old children during the six months after the flood but no positive relationship found during the flood. That finding is different from the finding from this study that the increased risk of respiratory infections among young children within 0-15 day of flooding events.

The seasonal analysis revealed a significant association between the annual river flood pulse and PHA among children during the wet season: the seasonal peak of PHA corresponded to the annual peak of RWL (September-October). Although this study did not evaluate the association between extreme low RWL and PHA because there were very few days (2 observations) with RWL lower than 50 cm during the study period, its finding is consistent with the previous studies which indicated that admission rates are elevated during both the high and low water level periods and related factors (Hashizume et al. 2007a; Nichols et al. 2009). It is noteworthy that the magnitude and time-length of increase in PHA during-

and post-flood are found to be modified by temperature, in which the bigger magnitude and longer period of increase in hospital admissions during high temperature were found in this study. The plausible mechanism for the modifying effects of temperature may relate to the obvious link between waterborne disease and the temperature-induced blooms of various planktonic species that are directly or indirectly hazardous to children's health. For example, high temperature can lead to blooms of *Cyanobacteriae* (Blue-green algae), *Dinoflagellates*, *Pfiesteria piscicida* which can cause dermatitis, respiratory problems, neurotoxic reactions, diarrhoea, or eye irritation (Hunter 1998;Hungerford 2001;Morris 1999). Moreover, it has also been suggested that higher water temperature will cause prolonged survival of pathogens in the environment (Chief Medical Officer 2001). The previous work also indicates that the effects of temperature on waterborne diseases such as diarrhoea is also related to the socio-economic status of a vulnerable population, so that people with lower educational attainment, living in households with non-concrete roof, and users of unsanitary toilets are more vulnerable to waterborne disease during high temperature periods (Hashizume et al. 2007a).

An understanding of the association between the annual flood pulse represented by RWL and PHA will have important implications for preventive medicine, hospital preparedness, and for water-resource professionals in the Mekong Delta region where a low-income and weak environmental hygiene conditions, where there is a high burden of waterborne diseases. Besides the extreme flood events, which are unpredictable, an annual river flood pulse can be considered as a predictable health hazard that continues to lead to health issues for vulnerable residents along the river delta, so health prevention and preparedness corresponding to the usual variability of RWL should be considered as important as unpredictable extreme flood events. For preventive medicine, appropriate water resource management, sanitation, access to clean water supplies, and piped sewage connections are necessary to reduce the risk of hospital admission for waterborne diseases.

The study also suggests that raising the awareness of residents about the link between a river flood pulse and related diseases, and developing a model for an early-warning system using weather prediction could be considered as a part of the solution (Bush et al. 2014). Similarly, preparedness such as enhanced drug stock and hospital bed availability should be enhanced if the seasonal pattern of risk of hospital admissions is considered to be important data for the planning process among the local hospitals. This study may be the good start for this purpose in Mekong Delta region, since it uses a cost-effective design, time-series, to examine association between meteorological/hydrological data and seasonal pattern of risk of hospital admission. The data collected for the study uses existing data from highly reliable sources: meteorological centres and hospital record systems.

The primary limitation of this current study is that PHA remains under-reported because we did not consider minor cases that were admitted and treated in the lower-level hospitals in Can Tho such as district hospitals and commune health clinics. Therefore, the PHA in the study is more representative for moderate and severe cases. However, Can Tho paediatric hospital is the sole paediatric hospital in Can Tho city, so the hospital admissions are still highly representative of children's admissions in the research location. In addition, moderate and severe cases of hospital admissions are more precisely classified for ICD than the minor cases in the lower-level hospitals because a more reliable and consistent health record system is found in the higher level hospitals in Vietnam. The second limitation found in this study is that the potential influence of redistribution of districts conducted in 2008 in Can Tho, in which more districts were split from the original districts, was not evaluated. This redistribution might change land use, urban and rural population, development of infrastructure, or water and sanitation systems, which potentially have effects on the risk of disease among residents. Any future study should take these factors into account for data collection and analysis.



## 5. Conclusions

This current study revealed a positive association between annual river flood pulse, which is represented by the threshold of river water level at 170 cm, and the increase of paediatric hospital admissions in the typical Mekong Delta area, Can Tho city. The seasonal pattern of increased paediatric hospital admission corresponds to the seasonal pattern of elevated river water level, and this relationship pattern is modified by the change in temperature. Young children are more sensitive to the annual river flood pulse and climate factors than the school-aged children, and the most concerned disease group is respiratory infection. These results indicate important implications of the projected local changes in climate on human health impacts in Mekong Delta region (MDR), which has been considered to be one of the most vulnerable areas to climate change in Southeast Asia. This work may make a significant contribution to local health prevention and hospital preparedness for children's health in Can Tho city. However, for more comprehensive solutions of disease prevention, the further studies should be conducted to better understanding the interaction between flooding effects and some potentially modified factors, including: genders, age-specific (0-2, 3-5, and  $\geq 5$  which corresponding to home-care, kindergarten-care, and school-age children), cause-specific for individual disease, socioeconomic status, infrastructural factors, and identifications of the most cost-effective mitigation and adaptation from children's health perspective.

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**Competing Financial Interest**

The authors declare they have no actual or potential competing financial interests

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**Table 1.** Daily average river water level (RWL) and meteorological conditions categorized by year and by season in Can Tho city 2008-2011 [minimum, maximum, mean, and (95% Confidence Interval)] and number of extreme events of RWL.

Variable	River water level		Temperature (°C)	Humidity (%)
	Level (cm)	Extreme events (n)		
By year				
2008	65; 200; 125 (122-128)	37	22.2; 29.7; 26.8 (26.7-27.0)	66; 97; 83.1 (82.5-83.7)
2009	45; 193; 121 (118-124)	35	21.5; 29.9; 27.2 (27.0-27.4)	67; 96; 82.4 (81.8-82.9)
2010	40; 194; 125 (119-125)	28	22.8; 31.4; 27.6 (27.4-27.8)	65; 97; 81.7 (81.1-82.5)
2011	67; 215; 132 (128-135)	49	23.5; 30.2; 27.2 (27.0-27.3)	66; 96; 81 (80.4-81.5)
By season				
Dry (December-April)	40; 184; 120 (119.4-122.4)	17	21.5; 30.2; 27.3 (27.2-27.4)	65; 96; 82 (81.8-82.4)
Wet (May-November)	65; 215; 130 (126.4-130.7)	132	23.9; 31.4; 27.4 (27.3-27.5)	67; 97; 84.5 (84.1-84.8)
Entire period (2008-2011)	40; 215; 125 (123-126)	149	21.5; 31.4; 27.2 (27.1-27.3)	65; 97; 82 (81.7-82.3)

The 90<sup>th</sup> percentile of the RWL for the entire study period (166 cm) was used as the cut-off point to define extreme RWL.

**Table 2.** Daily paediatric hospital admission (PHA, total counts & %) by year, season, age, and cause from Can Tho Paediatric Hospital, 2008-2011.

Variable	Age		Disease group			
	<=5	5-15	All cause	Communicable infection	Respiratory infection	Others
<i>By year</i>						
2008	7,890 (23)	1,969 (20)	9,859 (22)	3,744 (21)	2,345 (22)	3,770 (24)
2009	8,593 (25)	2,940 (29)	11,533 (26)	4,636 (26)	2,760 (26)	4,137 (26)
2010	8,920 (26)	2,962 (30)	11,882 (27)	5,176 (29)	3,057 (28)	3,649 (23)
2011	8,957 (26)	2,131 (21)	11,088 (25)	4,160 (23)	2,463 (23)	4,465 (27)
<i>By season</i>						
Dry (December-April)	12,694 (37)	3,421 (34)	12,741 (27)	4,805 (27)	2,934 (28)	5,002 (31%)
Wet (May-November)	21,666 (63)	6,581 (66)	31,621 (73)	12,911 (73)	7,691 (72)	11,019 (69%)
<i>Entire period (2008-2011)</i>	34,360 (77.5)	10,002 (22.5)	44,362	17,716 (40)	10,625 (24)	16,021 (36)

180 admissions, which were external causes and missing values, were excluded from the analysis.



**Table 3.** Cumulative risk ratio effects of paediatric hospital admissions associated with extreme river water level (RWL) by disease group and age category

Category	Cumulative Risk Ratio	95% CI	p-value
Age groups			
<i>All ages</i>	1.26	1.20-1.38	<0.01
<i>&lt;=5 years</i>	1.27	1.23-1.30	<0.01
<i>&gt;5 years</i>	1.15	1.07-1.20	<0.01
Disease groups			
<i>All causes</i>	1.24	1.21-1.27	<0.01
<i>Communicable infection</i>	1.18	1.13-1.22	<0.01
<i>Respiratory infection</i>	1.66	1.57-1.74	<0.01
<i>Others</i>	1.06	1.01-1.1	0.01

The cumulative RR was computed from the multivariate Poisson distributed lag model adjusted for daily average temperature, relative humidity, day of week, seasonal and long-term trend, and a quadratic distributed lag function was added into the model.

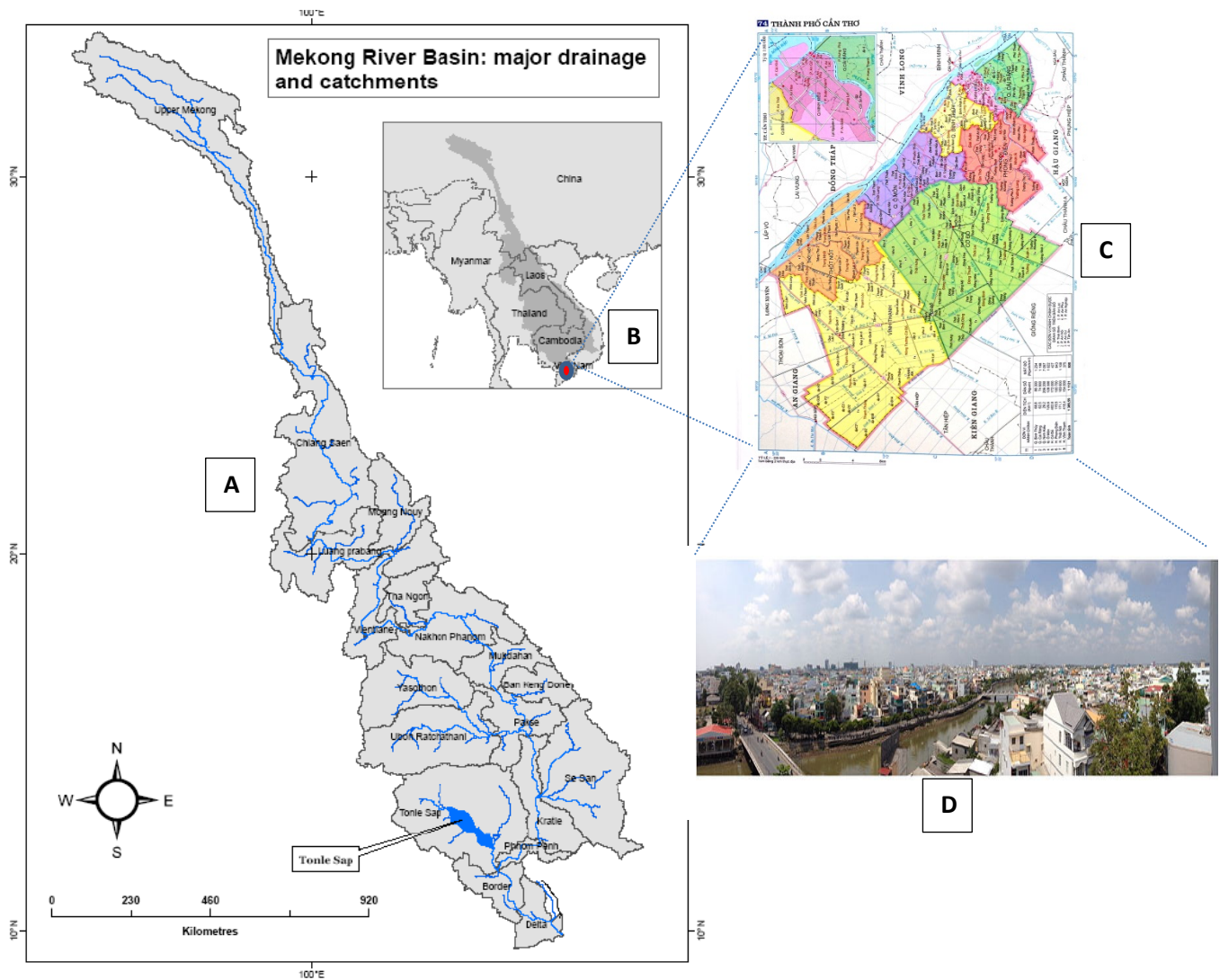


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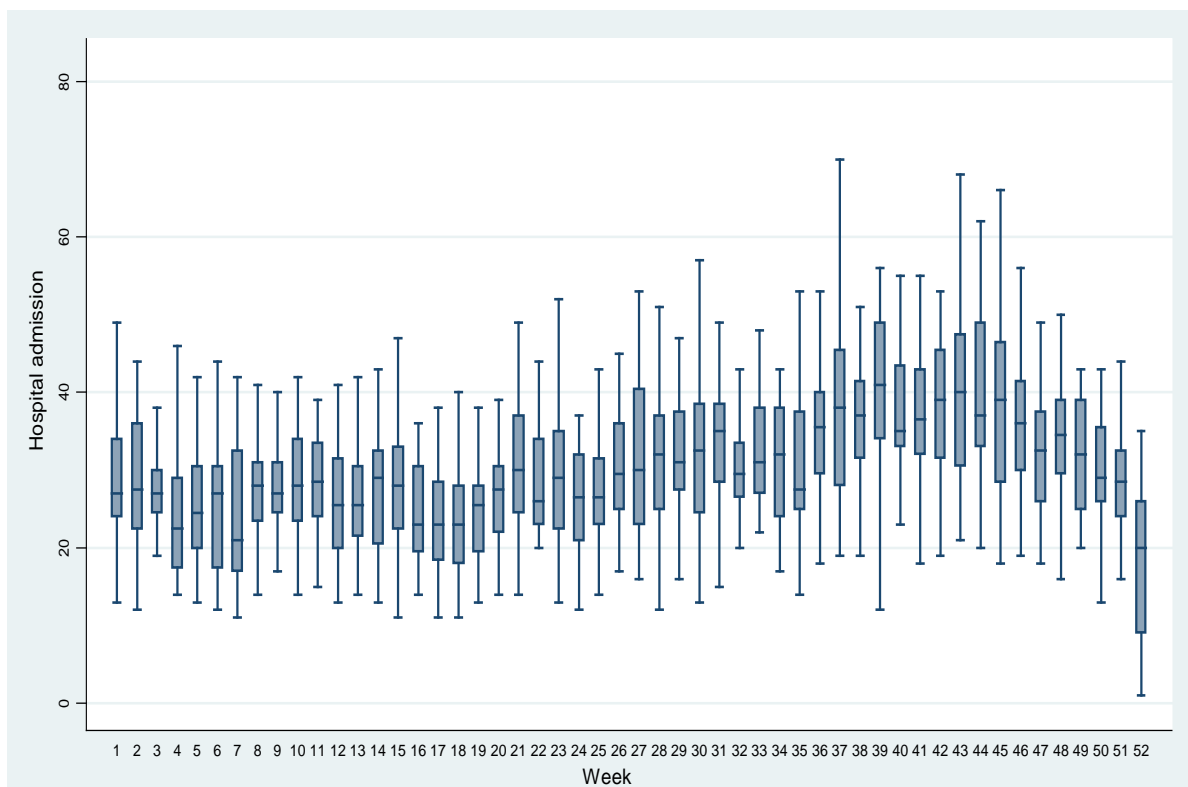
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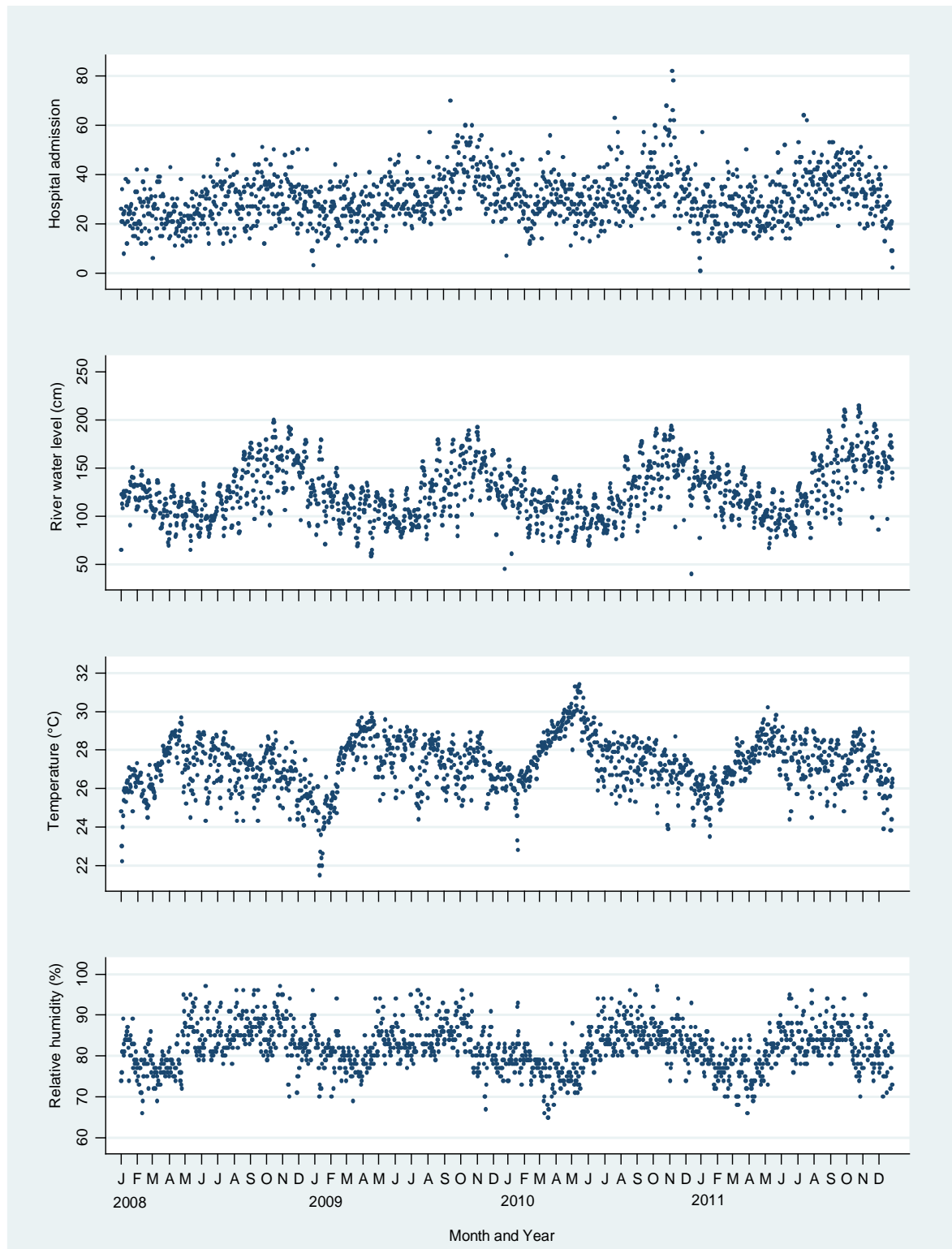


**Figure 1.** (A) Mekong Delta Basin; (B) Vietnam; (C) Can Tho City; (D) Can Tho panorama  
(Source: Estham, 2008; Google maps; and Wikipedia)

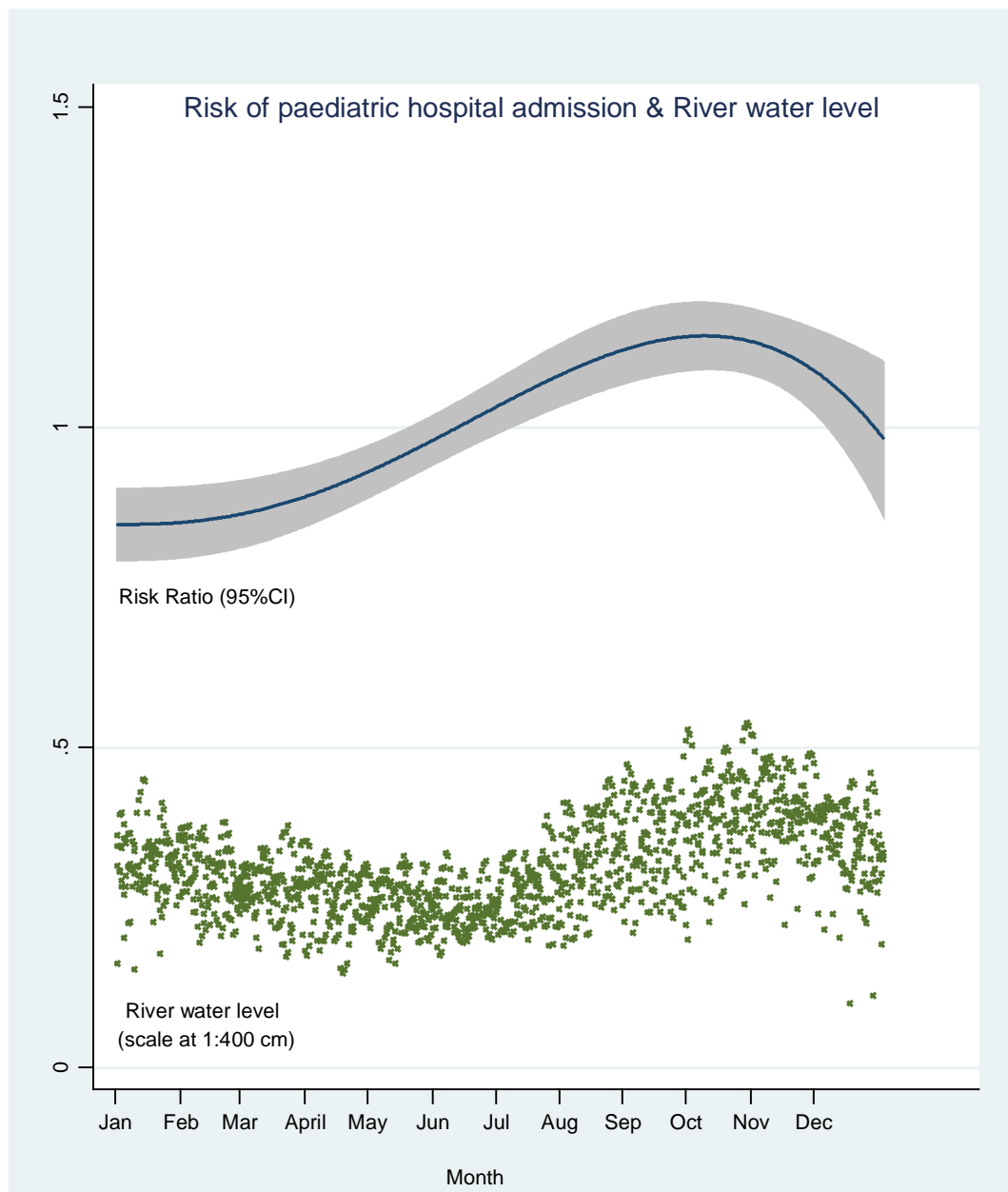


**Figure 2.** Weekly paediatric hospital admissions (minimum, 25<sup>th</sup>, 50<sup>th</sup>, 75<sup>th</sup>, maximum) in a year

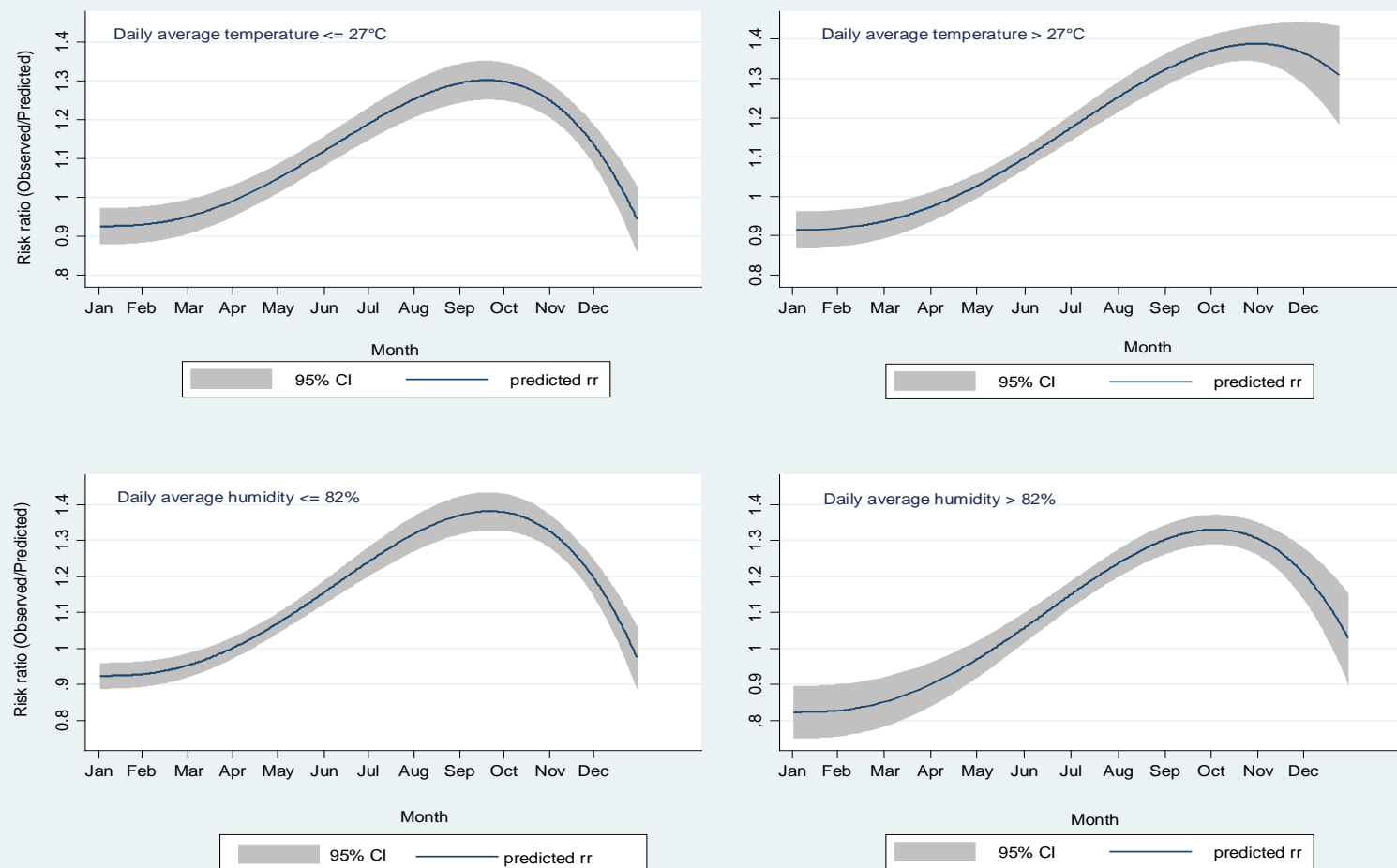




**Figure 3.** Daily time series between 2008 to 2011, for paediatric hospital admissions, river water level, average temperature and relative humidity in Can Tho city, Vietnam.



**Figure 4.** Seasonal pattern of risk ratio of paediatric hospital admission and river water level.



**Figure 5.** Seasonal pattern of risk ratio of paediatric hospital admission by temperature and humidity.