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The Association between Heavy Rainfall Events and Diarrheal Disease: The Influence of Urban and Rural Geography

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By

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Bachelor of Science

Emory University

2012

Faculty Thesis Advisor: Karen Levy, Ph.D., M.P.H.

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Abstract

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Climate change is expected to impact health outcomes in the 21st century. Changes in precipitation are projected, with greater contrasts between wet and dry periods and increases in extreme weather events. Heavy rainfall events (HRE) have been shown to be associated with diarrheal diseases and waterborne disease outbreaks. Diarrhea remains an important cause of mortality amongst children under five years of age, causing over 700,000 deaths per year, and is also associated with long term health outcomes such as stunting. Differences in urban and rural settings could play an important role in driving the relationship between precipitation and diarrhea due to underlying differences in infrastructure and social factors. In this study we examine how urban versus rural contexts affects the relationship between HRE and diarrheal disease, using a dataset of daily case counts of diarrhea in all public hospitals and clinics from all 68 parishes in the Esmeraldas province of northwestern Ecuador from 2013-14. Our rainfall exposure measurements were taken from average daily precipitation estimates from the TRMM 3B42 satellite platform. HRE was defined as daily rainfall higher than the 90th percentile for the entire period, and antecedent rainfall conditions were defined as wet or dry depending on 8-week total prior rainfall. We carried out mixed effects Poisson regression on daily case count data, with heavy rainfall estimates and antecedent conditions lagged from 0 to 14 days. In rural areas, we found a positive association between HRE and daily case counts of diarrhea during the dry season, whereas a protective effect was observed in the wet season. In urban areas the expected counts of diarrhea were higher in all environmental conditions analyzed when compared to rural areas, and there was no protective effect in the wet season. Factors associated with urbanization, such as crowding or infrastructure, seem to dominate over climate related factors. Despite this, dry conditions appear to be highly associated with increased diarrhea in all areas. This study provides interesting insights into differences in mechanistic differences in how rainfall is associated with diarrhea in urban and rural areas.

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Manuscript

The Association between Heavy Rainfall Events and Diarrheal Disease: The Influence of Urban and Rural Geography

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Abstract

Climate change is expected to impact health outcomes in the 21st century. Changes in precipitation are projected, with greater contrasts between wet and dry periods and increases in extreme weather events. Heavy rainfall events (HRE) have been shown to be associated with diarrheal diseases and waterborne disease outbreaks. Diarrhea remains an important cause of mortality amongst children under five years of age, causing over 700,000 deaths per year, and is also associated with long term health outcomes such as stunting. Differences in urban and rural settings could play an important role in driving the relationship between precipitation and diarrhea due to underlying differences in infrastructure and social factors. In this study we examine how urban versus rural contexts affects the relationship between HRE and diarrheal disease, using a dataset of daily case counts of diarrhea in all public hospitals and clinics from all 68 parishes in the Esmeraldas province of northwestern Ecuador from 2013-14. Our rainfall exposure measurements were taken from average daily precipitation estimates from the TRMM 3B42 satellite platform. HRE was defined as daily rainfall higher than the 90th percentile for the entire period, and antecedent rainfall conditions were defined as wet or dry depending on 8-week total prior rainfall. We carried out mixed effects Poisson regression on daily case count data, with heavy rainfall estimates and antecedent conditions lagged from 0 to 14 days. In rural areas, we found a positive association between HRE and daily case counts of diarrhea during the dry

season, whereas a protective effect was observed in the wet season. In urban areas the expected counts of diarrhea were higher in all environmental conditions analyzed when compared to rural areas, and there was no protective effect in the wet season. Factors associated with urbanization, such as crowding or infrastructure, seem to dominate over climate related factors. Despite this, dry conditions appear to be highly associated with increased diarrhea in all areas. This study provides interesting insights into differences in mechanistic differences in how rainfall is associated with diarrhea in urban and rural areas.

Introduction

The Intergovernmental Panel on Climate Change (IPCC) predicts a change in the mean global surface temperature by 1.5 degrees Celsius by the end of the 21st century in comparison to the end of the 19th century. In the region of Latin America, it is predicted that the occurrence of extreme events will increase in frequency. Such changes in the climate can have downstream effects to change the hydrology of a region during periods of intense precipitation or dry season (24). Such changes in hydrology could result in changes of how the water supply interfaces with communities. Transmission patterns of diarrheal diseases could be altered due to these changes as contaminated water supplies have been associated with outbreaks of diarrheal disease (2, 3, 6, 17, 18, 20, 23, 27, 29, 30, 34, 45-48). Through such mechanisms and other effects of climate change such as rising temperature, global climate change could result in the increase in the burden of diarrheal disease (42).

Diarrheal disease is a major cause of mortality and morbidity for children under the ages of five. It is estimated that over 700,000 deaths occur annually and diarrheal disease is associated with long term health outcomes such as stunting (26, 28). Considering the large burden of diarrheal disease, a small proportional increase can result in a large number of children being affected. Rainfall has been shown to be associated with diarrheal disease (1, 4, 5, 8-11, 13, 14, 19, 21, 22, 24, 25, 31, 32, 35-42, 44). Rainfall may cause a flushing effect where contaminants and pathogens are flushed into the water supply and therefore result in outbreaks of diarrheal disease in the community (8). Evidence suggests diarrhea has been associated with high levels of rainfall as well as dry periods. Studies in Philippines (1), Bangladesh (11), and Ghana (40) have shown a positive association with an increase in diarrhea following periods of high rainfall. Alternatively studies in Philippines (1), Swaziland (14), the United Kingdom (32, 47) and the United States (45) have shown an increase in diarrhea to be associated with low levels of rainfall or dry period. A study in Ecuador has previously shown an increase in diarrheal disease following heavy rainfall events during dry periods whereas a protective effect of heavy rainfall events to lower diarrheal disease during wet periods. Therefore the evidence suggests an interaction between rainfall events, antecedent conditions, and diarrheal disease. Dry periods could allow for accumulation of pathogens on sanitation and water storage surfaces which would result in a large release of contamination following heavy rainfall events. There could be continuous flushing during wet periods due to periodic rainfall. Therefore during wet periods, heavy rainfall events maybe protective by further diluting the level of contamination in the water supply (8).

The association between climate and diarrheal disease may also be modified due to contextual factors in the community. Sanitation and water supply infrastructure has been associated with the impact of rainfall on diarrhea (5, 16). Bhavani et al., showed that the positive association between diarrheal disease and unimproved sanitation was strongest following low rainfall whereas the association between diarrheal disease and unimproved water sources was strongest following periods of high rainfall (5). Such differences in sanitation and water supply could be present in urban versus rural contexts. Urban areas may have improved sanitation present whereas rural areas may not. Similarly urban areas may also have improved water sources whereas rural areas may not. There may also be other differences in urban and rural areas that may affect the association between rainfall and diarrhea. The complex relationship presented between rainfall and diarrhea merits further investigation.

In this study, we examined the relationship between rainfall and diarrhea with a focus on differences between urban and rural areas. We examined whether the association between dry periods and diarrheal disease was consistent across rural and urban areas and if the protective effect of heavy rainfall events in wet periods is observed in rural and urban areas. Finally we tested the hypothesis whether the relationship between rainfall and diarrheal disease in the context of antecedent conditions is significantly modified depending on whether an urban or rural context is considered.

Methods

1. Study Area

The study area comprises of the Esmeraldas province of Ecuador. Ecuador is divided into three levels of administrative divisions. In order of decreasing size they are province, canton, and parish. Esmeraldas province is located in the coastal areas of northwestern Ecuador. It contains a tropical climate and is in the equatorial region. There are eight cantons that compose Esmeraldas province. Within each canton, there are numerous parishes. Each parish has been classified as urban or rural based on INEC (Ecuadorian census) data. Urban parishes correspond to the major metropolitan areas within the province such as the city of Esmeraldas. There are 68 total parishes in the province of Esmeraldas of which 8 are urban and 61 are rural (Figure 1, Table 2).

2. Case Definition and Counts of Diarrhea

Records of non-emergency patient visits to all public hospitals and clinics within the province of Esmeraldas, Ecuador were collected between January 1st, 2013 and December 31st, 2014. The records were obtained through a partnership with the Ministry of Health of Ecuador (IRB Study ID: IRB00086362). Primary, secondary, and tertiary ICD-10 diagnosis codes were used for case identification. Cases were identified with a diagnosis code of A09.X (Infectious gastroenteritis and colitis, unspecified). Cases with a secondary or tertiary ICD-10 diagnosis code of A09.X were further examined to ensure the primary diagnosis was related to a waterborne disease such as amoebiasis. All cases with a primary, secondary, or tertiary ICD-10 diagnosis code of A09.X were identified and retained for further analyses. Only cases with a parish of residence within Esmeraldas province were retained.

Ages associated with cases were recalculate using the date of care and birthdate provided in the dataset. Age was categorized to equal to or under five years and over five years. Race of patients was re-categorized to black, white/other, mestizo, and indigenous. Any cases that contained discrepancies regarding age such as having a date of care that preceded the date of birth were discarded. Finally only cases between January 8th, 2013 and December 31st, 2014 were considered for analyses since the analysis plan included using aggregate counts of cases from the previous 7 days in the modeling strategies. Therefore the first week of case data could not be used. Using this selection criteria there were 33,927 cases for analysis (Table 1).

Cases were aggregated into counts of diarrhea cases by parish of residence, age category, race category, and sex over time. In this manner 68 time series were generated – one for each parish within Esmeraldas province – which were categorized as either urban or rural.

3. Rainfall

Satellite Rainfall Data

Daily satellite rainfall estimates were obtained from the TRMM 3B42 platform by NASA. Data was obtained through the GIOVANNI data portal hosted by NASA. The rainfall estimates have a spatial resolution of 0.25 x 0.25 degrees and a daily temporal resolution.

The area of each parish was divided into equal sized squares that were each sized 0.25 x 0.25 degrees. This formed a grid overlay on the area of the parish. The coordinates of the extent of each individual square within the grid were calculated and used to obtain an area-averaged time series of daily rainfall estimates from the TRMM 3B42 platform. Weights were assigned to each time series of rainfall based on the percentage of area of the parish that overlapped with the corresponding square within the grid for the parish. The time series of all squares within each grid were averaged based on this weighting scheme to generate an overall time series of daily rainfall estimates for the entire parish. This process was repeated for all 68 parishes to obtain 68 overall time series of daily rainfall estimates corresponding to each parish within Esmeraldas province (see Figure 2).

Heavy Rainfall Events

The 90th percentile was calculated for each time series of rainfall. Therefore a 90th percentile value for daily rainfall was calculated for each parish in Esmeraldas province. Daily rainfall was re-categorized as a heavy rainfall event (HRE) or non-heavy rainfall event if the daily rainfall estimate exceeded the 90th percentile value for the corresponding parish.

Antecedent Conditions

Antecedent conditions for each parish were calculated by calculating rolling sums of the previous 56 days (8 weeks) of daily rainfall estimates for each parish. This generated a time-series of antecedent conditions for each parish. The 33rd and 67th percentiles were calculated for each time-series of antecedent conditions, and the antecedent conditions were categorized as "Wet" if greater than the 67th percentile, "Dry" if lower than the 33rd percentile, and "Medium" otherwise. In this manner, the antecedent conditions for each parish were categorized.

4. Regression Analyses

A Poisson mixed modeling approach was used to analyze the association between heavy rainfall events and counts of diarrhea. Additionally terms for age category, sex, race category, antecedent conditions, and urban-rural status of parish were included to control for confounding. Furthermore a term for time was included in the model to control any overarching temporal trends in the model. Interactions between heavy rainfall event and urban-rural status, antecedent conditions and urban-rural status, heavy rainfall events and antecedent conditions, and heavy rainfall events, urban-rural status, and antecedent conditions were assessed. The model included a random intercept with the parish as a clustering variable to control for spatial confounding. Additionally the model included a co-variate for the total number of cases over the previous 7 days to adjust for temporal autocorrelation.

The variables for heavy rainfall event and antecedent conditions were temporally lagged up to 14 days in concordance. Each model contained heavy rainfall event and antecedent condition lagged for a specific length of time. In this manner 15 models were specified, where the heavy rainfall event and antecedent condition variable were temporally lagged from 0 to 14 days.

Global Moran's I test for spatial autocorrelation were run on the standardized residuals of the model at each time-slice to test for spatial autocorrelation of diarrhea counts. Additionally partial autocorrelation functions were run on the residuals of each model for each parish to test for temporal autocorrelation of diarrhea counts at varying lags.

Results

1. Study Population

There were 33,927 cases of diarrhea between January 8th, 2013 and December 31st, 2014. There was an equal distribution of males and females. The majority of the cases were equal to or under five years (61.38%). In terms of racial distribution, the largest proportion of patients were mestizo (62.31%), followed by black (30.73%), and the other racial categories (Table 2). While there are more cases in the rural parishes than the urban parishes (59.8% vs. 40.2%), there are greater number of rural parishes. The urban parish of Esmeraldas has the highest case load in the entire region with 20.5% of all cases observed in that parish. The rural parishes of Eloy Alfaro and Quininde cantons also appear to be areas of high burden of diarrheal diseases (Table 2, Figure 3). Due to this spatial heterogeneity in incidence, many regions contain sparse data. For example, no cases were observed in the canton of La Concordia and 61.3% of all days analyzed had 0 cases in the urban parish of Atacames canton (Table 2). Most cases of diarrhea appear to occur in between the months of July and January. 2013 appears to have a higher peak in cases compared to 2014 during this period (Figure 4). The urban parish of Esmeraldas stands out as having a high case load and corresponds to the higher peak in 2013 in the latter half of the year (Figure 5).

2. Rainfall

Daily rainfall estimates and 8 week total rainfall for Esmeraldas province show that there is a strong seasonality to rainfall in the region. The wet period seems to comprise of months early in the year such as January to March whereas June to January appears to be the dry period (Figure 7). Figures 6-7 suggest no major differences in rainfall patterns amongst rural and urban parishes nor in-between them in terms of daily rainfall nor 8 week total rainfall.

3. Associations between Heavy Rainfall Events (HRE), Urban and Rural Geography, Antecedent Conditions

Dry antecedent conditions in rural parishes without heavy rainfall events, defined as total rainfall over previous 8-weeks for the parish below the 33^{rd} percentile, were significantly ($p < 0.05$) associated with increase in expected counts of cases of diarrhea compared to wet antecedent conditions (> 67^{th} percentile of previous 8-weeks' total rainfall for the parish) controlling for age, race, and sex. The effect appears to be relatively constant regardless of the lag between the defined antecedent conditions and the date of care (Figure 8).

Heavy rainfall events with wet antecedent conditions in rural areas were associated with lower expected counts of diarrhea for lags of 1 to 12 days controlling for age, race, and sex. Of these lags, only lags of 7 and 13 days was not statistically significantly ($p > 0.05$) with a lowered expected case counts of diarrhea. Lags of 0 and 14 days were associated with an increase in expected counts of diarrhea but these results were not statistically significant ($p > 0.05$) (Figure 9).

Heavy rainfall events with dry antecedent conditions in rural parishes were associated with higher expected case counts of diarrhea in contrast to HREs with wet antecedent conditions in rural parishes controlling for age, sex, and race. The positive association decreases as the lag of climate variable increases. The association is statistically significant ($p < 0.05$) at all lags tested except at lags of 8, 13, and 14 days (Figure 10).

Urban parishes during wet antecedent conditions without heavy rainfall events appear to have a consistently higher expected case counts of diarrhea compared to rural parishes controlling for age, race, and sex. This effect is consistent across all lags of climate variables tested. None of these effects are statistically significant ($p > 0.05$). The large standard errors may be driven by the discrepancy between the number of cases in urban areas versus rural areas in addition to the large number of days with no cases in the dataset (Figure 11). Similarly, there is a positive but statistically non-significant relationship between heavy rainfall events in urban parishes with wet antecedent conditions across all lags tested ($p > 0.05$). The estimate of the effect does not appear to significantly change across the various lags tested (Figure 12). The positive but statistically non-significant ($p > 0.05$) is also seen for the association between expected case counts of diarrhea and urban environments with dry antecedent conditions without heavy rainfall events at all lags tested (Figure 13).

Finally there seems to be a consistent positive association between expected counts of diarrheal disease and heavy rainfall events in urban areas with dry antecedent conditions compared to no-heavy rainfall events in rural areas with wet antecedent conditions. The positive association is consistent across all lags considered in the modeling strategy. The association is statistically significant at the 95% confidence level at all lags tested except lags of 6 and 13 days (Figure 14).

Discussion

1. Findings

There is a differential impact of heavy rainfall events based on whether the environment is urban or rural and antecedent rainfall conditions. In rural areas, heavy rainfall events appear to be protective in wet periods in most of the lags tested whereas damaging during dry periods in relation to the expected counts of diarrhea cases observed (Table 3; Figures 8, 17). Whereas in urban areas, the protective effect is not observed during wet periods. Similar to rural areas, the increase in expected counts of diarrhea cases is observed in association to heavy rainfall events in dry periods (Table 4; Figures 14, 18, 20).

This differential effect can have multiple mechanistic explanations. Rural areas may have poor sanitation and water supply infrastructure. This can increase the level of vulnerability of the population and water supply to environmental factors. There can be fecal contamination spreading to the drinking water supply in rural areas due to poor sanitation. During wet periods there can be constant flushing of contaminants which allows the concentration at any given time to not be overwhelmingly large. Heavy rainfall events in wet periods may serve to further dilute the level of contamination in the water supply by introducing large amounts of water into the supply and therefore resulting in the observed protective effect of heavy rainfall events with wet antecedent conditions in rural areas (8). This dilatory effect may take some time to affect the epidemiology of diarrhea which is why the protective effect of is observed in lags of 8 days (expected count ratio (ECR): 0.91; 95% confidence interval: (0.86, 0.98)) (Figure 17) but not in the 0 day lag model (expected count ratio: 1.04; 95% confidence interval: (0.98, 1.11)) (Figure

15). This effect may diminish as the temporal distance increases between transmission and the heavy rainfall event which is why the protective effect was not observed at longer lags tested such as lags of 14 days (expected count ratio: 1.04; 95% confidence interval: (0.98, 1.11)) (Figure 18).

Conversely, during dry periods contaminants and microbes can build up on surfaces in contact with the water supply since there is not a constant flushing from rainfall (8). This may lead to the observation of increased counts of diarrhea associated with dry antecedent conditions with ECRs ranging from 1.21 to 1.32 (Table 4, Figures 15, 17, 19). A heavy rainfall environment during such dry periods could act to flush out a built up concentration of microbes that is suddenly released in the greater water supply. This could act to cause a spike in the level of contamination in the water supply and therefore explain the increased expected counts of diarrhea associated with heavy rainfall events with dry antecedent conditions in rural areas. This effect was observed to be significant at all lags tested except lags of 8, 13, and 14 days with ECRs ranging from 1.01 to 1.33 (Table 4, Figures 15, 17, 19).

In urban areas the differences between the wet and dry season are attenuated for the association between heavy rainfall events and expected counts of diarrhea. This could be a result of better sanitation and water supply infrastructure that is more robust to environmental changes. Additionally the effects of urbanization such as increased population density may be dominant over the seasonal trends more clearly evident in the rural areas. Under all environmental conditions analyzed, there seems to an increase in expected counts of diarrhea compared to rural areas with no heavy rainfall events in wet periods (Figures 16, 18, 20). There is no protective effect observed as with heavy rainfall events in wet periods in rural areas. While dry antecedent conditions or heavy rainfall events alone may not be have a significant effect ($p > 0.05$) on the expected case counts of diarrhea when compared to rural areas with wet antecedent conditions and no heavy rainfall events, when both heavy rainfall events and dry antecedent conditions are present there is a significant ($p > 0.05$) positive association observed with case counts of diarrhea with ECRs ranging from 3.17 to 4.09. This suggests that urbanization is a very strong factor in determining the relationship between environmental variables and diarrheal disease epidemiology and that the harmful effects of heavy rainfall events following dry antecedent conditions is consistently observed in urban as well rural areas.

2. Limitations

Due to sparse data, the data was detected to be over dispersed. A model based on the negative binomial distribution or a fully Bayesian model would correct for this over dispersion of data. Over dispersion results in inflated standard errors associated with the estimates. Therefore while our results may lack precision it should not introduce bias in the estimates. Additionally there is persistent spatial and temporal autocorrelation in the residuals despite including a random intercept for parish and adjusting for previous week's case counts. This suggests there could be factors that maybe mechanistically driving this autocorrelation that may not be captured through the data. This provides opportunities for further investigation into the mechanism of the epidemiology of diarrheal disease with consideration of climate variables.

3. Conclusion

The epidemiology of diarrheal disease is varied depending on urban or rural contexts and the climate factors present. Potential factors mediating the difference between urban and rural contexts could be the level of sanitation, population density, and socio-contextual factors. This presents further opportunities for investigation using larger data sources and more robust modeling techniques such as Bayesian models. The differential impact of heavy rainfall events based on urban versus rural geography and antecedent conditions highlights the importance of consideration of climate factors when designing public health interventions to address diarrheal disease as well as further understanding the epidemiology of diarrheal disease.

References

1. Adkins, H. J., Escamilla, J., Santiago, L. T., Ranoa, C., Echeverria, P., & Cross, J. H. (1987). Two-year survey of etiologic agents of diarrheal disease at San Lazaro Hospital, Manila, Republic of the Philippines. *J Clin Microbiol, 25*(7), 1143-1147.
2. Anderson, A. D., Heryford, A. G., Sarisky, J. P., Higgins, C., Monroe, S. S., Beard, R. S., . . . Glass, R. I. (2003). A waterborne outbreak of Norwalk-like virus among snowmobilers-Wyoming, 2001. *J Infect Dis, 187*(2), 303-306. doi: 10.1086/346239
3. Atherton, F., Newman, C. P., & Casemore, D. P. (1995). An outbreak of waterborne cryptosporidiosis associated with a public water supply in the UK. *Epidemiol Infect, 115*(1), 123-131.
4. Auld, H., MacIver, D., & Klaassen, J. (2004). Heavy rainfall and waterborne disease outbreaks: the Walkerton example. *J Toxicol Environ Health A, 67*(20-22), 1879-1887. doi: 10.1080/15287390490493475
5. Bhavnani, Darlene, Goldstick, Jason E., Cevallos, William, Trueba, Gabriel, & Eisenberg, Joseph N. S. (2014). Impact of Rainfall on Diarrheal Disease Risk Associated with Unimproved Water and Sanitation. *The American Journal of Tropical Medicine and Hygiene, 90*(4), 705-711. doi: 10.4269/ajtmh.13-0371
6. Bridgman, S. A., Robertson, R. M., Syed, Q., Speed, N., Andrews, N., & Hunter, P. R. (1995). Outbreak of cryptosporidiosis associated with a disinfected groundwater supply. *Epidemiology and Infection, 115*(3), 555-566.
7. Cairncross, S., Blumenthal, U., Kolsky, P., Moraes, L., & Tayeh, A. (1996). The public and domestic domains in the transmission of disease. *Trop Med Int Health, 1*(1), 27-34.
8. Carlton, E. J., Eisenberg, J. N., Goldstick, J., Cevallos, W., Trostle, J., & Levy, K. (2014). Heavy rainfall events and diarrhea incidence: the role of social and environmental factors. *Am J Epidemiol, 179*(3), 344-352. doi: 10.1093/aje/kwt279
9. Chou, W. C., Wu, J. L., Wang, Y. C., Huang, H., Sung, F. C., & Chuang, C. Y. (2010). Modeling the impact of climate variability on diarrhea-associated diseases in Taiwan (1996-2007). *Sci Total Environ, 409*(1), 43-51. doi: 10.1016/j.scitotenv.2010.09.001
10. Curriero, F. C., Patz, J. A., Rose, J. B., & Lele, S. (2001). The association between extreme precipitation and waterborne disease outbreaks in the United States, 1948-1994. *Am J Public Health, 91*(8), 1194-1199.
11. Dewan, A. M., Corner, R., Hashizume, M., & Ongee, E. T. (2013). Typhoid Fever and its association with environmental factors in the Dhaka Metropolitan Area of Bangladesh: a spatial and time-series approach. *PLoS Negl Trop Dis, 7*(1), e1998. doi: 10.1371/journal.pntd.0001998
12. Doyle, A., Barataud, D., Gallay, A., Thiolet, J. M., Le Guyaguer, S., Kohli, E., & Vaillant, V. (2004). Norovirus foodborne outbreaks associated with the consumption of oysters from the Etang de Thau, France, December 2002. *Euro Surveill, 9*(3), 24-26.
13. Drayna, P., McLellan, S. L., Simpson, P., Li, S. H., & Gorelick, M. H. (2010). Association between rainfall and pediatric emergency department visits for acute gastrointestinal illness. *Environ Health Perspect, 118*(10), 1439-1443. doi: 10.1289/ehp.0901671
14. Effler, E., Isaäcson, M., Arntzen, L., Heenan, R., Canter, P., Barrett, T., . . . Griffin, P. M. (2001). Factors contributing to the emergence of Escherichia coli O157 in Africa. *Emerging Infectious Diseases, 7*(5), 812-819.
15. Fewtrell, L., Kaufmann, R. B., Kay, D., Enanoria, W., Haller, L., & Colford, J. M., Jr. (2005). Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis. *Lancet Infect Dis, 5*(1), 42-52. doi: 10.1016/s1473-3099(04)01253-8
16. Fink, G., Gunther, I., & Hill, K. (2011). The effect of water and sanitation on child health: evidence from the demographic and health surveys 1986-2007. *Int J Epidemiol, 40*(5), 1196-1204. doi: 10.1093/ije/dyr102

17. Fong, T. T., Mansfield, L. S., Wilson, D. L., Schwab, D. J., Molloy, S. L., & Rose, J. B. (2007). Massive microbiological groundwater contamination associated with a waterborne outbreak in Lake Erie, South Bass Island, Ohio. *Environ Health Perspect, 115*(6), 856-864. doi: 10.1289/ehp.9430
18. Gelting, R., Sarisky, J., Selman, C., Otto, C., Higgins, C., Bohan, P. O., . . . Meehan, P. J. (2005). Use of a systems-based approach to an environmental health assessment for a waterborne disease outbreak investigation at a snowmobile lodge in Wyoming. *Int J Hyg Environ Health, 208*(1-2), 67-73. doi: 10.1016/j.ijheh.2005.01.009
19. Glass, R. I., Becker, S., Huq, M. I., Stoll, B. J., Khan, M. U., Merson, M. H., . . . Black, R. E. (1982). Endemic cholera in rural Bangladesh, 1966-1980. *Am J Epidemiol, 116*(6), 959-970.
20. Goodman, R. A., Buehler, J. W., Greenberg, H. B., McKinley, T. W., & Smith, J. D. (1982). Norwalk gastroenteritis associated with a water system in a rural Georgia community. *Arch Environ Health, 37*(6), 358-360.
21. Hashizume, M., Armstrong, B., Hajat, S., Wagatsuma, Y., Faruque, A. S., Hayashi, T., & Sack, D. A. (2007). Association between climate variability and hospital visits for non-cholera diarrhoea in Bangladesh: effects and vulnerable groups. *Int J Epidemiol, 36*(5), 1030-1037. doi: 10.1093/ije/dym148
22. Hashizume, M., Armstrong, B., Hajat, S., Wagatsuma, Y., Faruque, A. S., Hayashi, T., & Sack, D. A. (2008). The effect of rainfall on the incidence of cholera in Bangladesh. *Epidemiology, 19*(1), 103-110. doi: 10.1097/EDE.0b013e31815c09ea
23. Ihekweazu, C., Barlow, M., Roberts, S., Christensen, H., Guttridge, B., Lewis, D., & Paynter, S. (2006). Outbreak of E. coli O157 infection in the south west of the UK: risks from streams crossing seaside beaches. *Euro Surveill, 11*(4), 128-130.
24. Intergovernmental Panel on Climate Change. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (2007). Cambridge, United Kingdom: Cambridge University Press.
25. Kolstad, Erik W., & Johansson, Kjell Arne. (2011). Uncertainties Associated with Quantifying Climate Change Impacts on Human Health: A Case Study for Diarrhea. *Environmental Health Perspectives, 119*(3), 299-305. doi: 10.1289/ehp.1002060
26. Kosek, M., Bern, C., & Guerrant, R. L. (2003). The global burden of diarrhoeal disease, as estimated from studies published between 1992 and 2000. *Bull World Health Organ, 81*(3), 197-204.
27. Levy, K., Woster, A. P., Goldstein, R. S., & Carlton, E. J. (2016). Untangling the impacts of climate change on waterborne diseases: A systematic review of relationships between diarrheal diseases and temperature, rainfall, flooding, and drought. *Environ Sci Technol*. doi: 10.1021/acs.est.5b06186
28. Liu, L., Johnson, H. L., Cousens, S., Perin, J., Scott, S., Lawn, J. E., . . . Black, R. E. (2012). Global, regional, and national causes of child mortality: an updated systematic analysis for 2010 with time trends since 2000. *Lancet, 379*(9832), 2151-2161. doi: 10.1016/s0140-6736(12)60560-1
29. Mac Kenzie, W. R., Hoxie, N. J., Proctor, M. E., Gradus, M. S., Blair, K. A., Peterson, D. E., . . . et al. (1994). A massive outbreak in Milwaukee of cryptosporidium infection transmitted through the public water supply. *N Engl J Med, 331*(3), 161-167. doi: 10.1056/nejm199407213310304
30. Millson, M., Bokhout, M., Carlson, J., Spielberg, L., Aldis, R., Borczyk, A., & Lior, H. (1991). An outbreak of Campylobacter jejuni gastroenteritis linked to meltwater contamination of a municipal well. *Can J Public Health, 82*(1), 27-31.
31. Milojevic, A., Armstrong, B., Hashizume, M., McAllister, K., Faruque, A., Yunus, M., . . . Wilkinson, P. (2012). Health effects of flooding in rural Bangladesh. *Epidemiology, 23*(1), 107-115. doi: 10.1097/EDE.0b013e31823ac606

32. Nichols, G., Lane, C., Asgari, N., Verlander, N. Q., & Charlett, A. (2009). Rainfall and outbreaks of drinking water related disease and in England and Wales. *J Water Health, 7*(1), 1-8. doi: 10.2166/wh.2009.143
33. Nmorsi, O. P., Agbozele, G., & Ukwandu, N. C. (2007). Some aspects of epidemiology of filth flies: Musca domestica, Musca domestica vicina, Drosophilia melanogaster and associated bacteria pathogens in Ekpoma, Nigeria. *Vector Borne Zoonotic Dis, 7*(2), 107-117. doi: 10.1089/vbz.2006.0539
34. O'Reilly, C. E., Bowen, A. B., Perez, N. E., Sarisky, J. P., Shepherd, C. A., Miller, M. D., . . . Lynch, M. F. (2007). A waterborne outbreak of gastroenteritis with multiple etiologies among resort island visitors and residents: Ohio, 2004. *Clin Infect Dis, 44*(4), 506-512. doi: 10.1086/511043
35. Patil, Sandip Bharat, Deshmukh, Durgesh, Dixit, J. V., & Damle, A. S. (2011). Epidemiological Investigation of an Outbreak of Acute Diarrheal Disease: A Shoe Leather Epidemiology. *Journal of Global Infectious Diseases, 3*(4), 361-365. doi: 10.4103/0974-777X.91060
36. Philipsborn, Rebecca, Ahmed, Sharia M., Brosi, Berry J., & Levy, Karen. (2016). Climatic Drivers of Diarrheagenic Escherichia coli Incidence: A Systematic Review and Meta-analysis. *Journal of Infectious Diseases*. doi: 10.1093/infdis/jiw081
37. Portier CJ, Thigpen Tart K, Carter SR, Dilworth CH, Grambsch AE, Gohlke J, Hess J, Howard SN…Whung P. (2010). A Human Health Perspective on Climate Change: A Report Outlining the Research Needs on the Human Health Effects of Climate Change. *Environmental Health Perspectives/National Institute of Environmental Health Sciences*.
38. Prüss, Annette, Kay, David, Fewtrell, Lorna, & Bartram, Jamie. (2002). Estimating the burden of disease from water, sanitation, and hygiene at a global level. *Environmental Health Perspectives, 110*(5), 537-542.
39. Said, B., Wright, F., Nichols, G. L., Reacher, M., & Rutter, M. (2003). Outbreaks of infectious disease associated with private drinking water supplies in England and Wales 1970-2000. *Epidemiology and Infection, 130*(3), 469-479.
40. Seidu, Razak, Stenström, Thor Axel, & Löfman, Owe. (2013). A comparative cohort study of the effect of rainfall and temperature on diarrhoeal disease in faecal sludge and non-faecal sludge applying communities, Northern Ghana. *Journal of Water and Climate Change, 4*(2), 90-102. doi: 10.2166/wcc.2013.032
41. Simon, J. Lloyd, Kovats, R. Sari, & Ben, G. Armstrong. (2007). Global diarrhoea morbidity, weather and climate. *Climate Research, 34*(2), 119-127.
42. Singh, R. B., Hales, S., de Wet, N., Raj, R., Hearnden, M., & Weinstein, P. (2001). The influence of climate variation and change on diarrheal disease in the Pacific Islands. *Environmental Health Perspectives, 109*(2), 155-159.
43. Smith, K. R.; Woodward, A.; Campbell-Lendrum, D.; Chadee, D. D.; Honda, Y.; Liu, Q.; Olwoch, J. M.; Revich, B.; Sauerborn, R., Human health: impacts, adaptation, and co-benefits. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Field, C. B.; Barros, V. R.; Dokken, D. J.; Mach, K. J.; Mastrandrea, M. D.; Bilir, T. E.; Chatterjee, M.; Ebi, K. L.; Estrada, Y. O.; Genova, R. C.; Girma, B.; Kissel, E. S.; Levy, A. N.; MacCracken, S.; Mastrandrea, P. R.; White, L. L., Eds.; Cambridge University Press: Cambridge and New York, 2014; pp 709-754.
44. Thomas, K. M., Charron, D. F., Waltner-Toews, D., Schuster, C., Maarouf, A. R., & Holt, J. D. (2006). A role of high impact weather events in waterborne disease outbreaks in Canada, 1975 - 2001. *Int J Environ Health Res, 16*(3), 167-180. doi: 10.1080/09603120600641326

45. Vogt, R. L., Sours, H. E., Barrett, T., Feldman, R. A., Dickinson, R. J., & Witherell, L. (1982). Campylobacter enteritis associated with contaminated water. *Ann Intern Med, 96*(3), 292-296.
46. Waterborne outbreak of gastroenteritis associated with a contaminated municipal water supply, Walkerton, Ontario, May-June 2000. (2000). *Can Commun Dis Rep, 26*(20), 170-173.
47. Willocks, L., Crampin, A., Milne, L., Seng, C., Susman, M., Gair, R., . . . Lightfoot, N. (1998). A large outbreak of cryptosporidiosis associated with a public water supply from a deep chalk borehole. Outbreak Investigation Team. *Commun Dis Public Health, 1*(4), 239-243.
48. Yamamoto, N., Urabe, K., Takaoka, M., Nakazawa, K., Gotoh, A., Haga, M., . . . Iseki, M. (2000). Outbreak of cryptosporidiosis after contamination of the public water supply in Saitama Prefecture, Japan, in 1996. *Kansenshogaku zasshi. The Journal of the Japanese Association for Infectious Diseases, 74*(6), 518-526. doi: 10.11150/kansenshogakuzasshi1970.74.518

Tables

Table 1

Distribution of Cases of Diarrhea by Co-Variates, Esmeraldas Province Ecuador, January 8th, 2013 – December 31st, 2014

Variable		**Number of Cases of Diarrhea (n (%))**
Overall		33,927 (100.00)
Age (years)		
	<= 5	20824 (61.38)
	> 5	13103 (38.62)
Sex		
	Male	16927 (49.89)
	Female	17000 (50.11)
Race		
	Black	10425 (30.73)
	Indigenous	1726 (5.09)
	Mestizo	21140 (62.31)
	White/Other	636 (1.87)

Table 2

Spatial Distribution of Cases of Diarrhea & Temporal Sparsity of Data by Canton and Urban/Rural Status, Esmeraldas Province Ecuador, January 8th, 2013 – December 31st, 2014

Urban/Rural Status	Canton	Number of Cases of Diarrhea (n (%))	Number of Parishes (n)	Number of Days with 0 Cases (n (%))
Urban		13638 (40.2)		
	Atacames	482 (1.4)	1	443 (61.3)
	Eloy Alfaro	822 (2.4)	1	371 (51.3)
	Esmeraldas	6964 (20.5)	1	162 (22.4)
	La Concordia	0 (0.0)	1	723 (100.0)
	Muisne	286 (0.8)	1	570 (78.8)
	Quininde	2833 (8.4)	1	114 (15.8)
	Rioverde	1138 (3.4)	1	270 (37.3)
	San Lorenzo	1113 (3.3)	1	365 (50.5)
Rural		20289 (59.8)		
	Atacames	1574 (4.6)	4	271 (37.5)
	Eloy Alfaro	3981 (11.7)	16	46 (6.4)
	Esmeraldas	3034 (8.9)	8	172 (23.8)
	La Concordia	0 (0.0)	3	723 (100.0)
	Muisne	2612 (7.7)	8	135 (18.7)
	Quininde	5484 (16.2)	5	72 (10.0)
	Rioverde	1957 (5.8)	5	195 (27.0)
	San Lorenzo	1647 (4.9)	12	224 (31.0)

Table 3

Adjusted Expected Count Ratios of Diarrheal Disease by Environmental Condition in Rural Parishes, Esmeraldas Province Ecuador, January 8th, 2013 – December 31st, 2014

	Environmental Condition		
Number of Days Climate Variables Lagged (n)	**No HRE, Rural, Dry AC**	**HRE, Rural, Wet AC**	**HRE, Rural, Dry AC**
0	1.32 (1.27, 1.37)	1.04 (0.98, 1.11)	1.31 (1.20, 1.42)
1	1.30 (1.26, 1.35)	0.96 (0.89, 1.02)	1.10 (1.01, 1.19)
2	1.29 (1.24, 1.33)	0.90 (0.85, 0.96)	1.21 (1.12, 1.31)
3	1.28 (1.23, 1.32)	0.91 (0.85, 0.97)	1.33 (1.23, 1.45)
4	1.26 (1.21, 1.30)	0.83 (0.78, 0.89)	1.15 (1.06, 1.24)
5	1.28 (1.23, 1.32)	0.92 (0.86, 0.98)	1.19 (1.10, 1.29)
6	1.28 (1.24, 1.33)	0.98 (0.92, 1.05)	1.14 (1.05, 1.23)
7	1.25 (1.21, 1.29)	0.87 (0.82, 0.93)	1.29 (1.19, 1.41)
8	1.26 (1.22, 1.31)	0.91 (0.86, 0.98)	1.06 (0.98, 1.15)
9	1.25 (1.21, 1.30)	0.92 (0.86, 0.98)	1.14 (1.05, 1.24)
10	1.24 (1.19, 1.28)	0.92 (0.86, 0.98)	1.22 (1.12, 1.32)
11	1.21 (1.17, 1.26)	0.80 (0.75, 0.86)	1.13 (1.04, 1.23)
12	1.21 (1.17, 1.26)	0.80 (0.75, 0.86)	1.13 (1.04, 1.23)
13	1.26 (1.22, 1.31)	0.98 (0.92, 1.05)	1.01 (0.93, 1.10)
14	1.26 (1.22, 1.30)	1.04 (0.98, 1.11)	1.08 (1.00, 1.17)

Abbreviations: HRE, heavy rainfall events. AC, antecedent conditions.

Table 4

Adjusted Expected Count Ratios of Diarrheal Disease by Environmental Condition, Esmeraldas Province Ecuador in Urban Parishes, January 8th, 2013 – December 31st, 2014

	Expected Count Ratios			
Number of Days Climate Variables Lagged	**No HRE, Urban, Wet AC**	**No HRE, Urban, Dry AC**	**HRE, Urban, Wet AC**	**HRE, Urban, Dry AC**
0	2.89 (0.93, 8.99)	3.44 (1.1, 10.70)	2.86 (0.92, 8.93)	3.82 (1.22, 11.92)
1	2.89 (0.93, 8.99)	3.38 (1.09, 10.54)	2.59 (0.83, 8.07)	3.59 (1.15, 11.20)
2	2.83 (0.91, 8.82)	3.34 (1.07, 10.41)	2.54 (0.81, 7.93)	3.97 (1.27, 12.38)
3	2.86 (0.92, 8.90)	3.32 (1.07, 10.34)	2.57 (0.82, 8.01)	3.53 (1.13, 11.02)
4	2.83 (0.91, 8.83)	3.21 (1.03, 10.00)	2.48 (0.80, 7.75)	3.17 (1.02, 9.90)
5	2.82 (0.91, 8.79)	3.28 (1.05, 10.22)	2.65 (0.85, 8.26)	3.26 (1.05, 10.18)
6	2.82 (0.90, 8.77)	3.29 (1.06, 10.25)	2.77 (0.89, 8.64)	3.02 (0.97, 9.41)
7	2.72 (0.87, 8.47)	3.19 (1.02, 9.92)	2.94 (0.94, 9.17)	3.89 (1.25, 12.15)
8	2.85 (0.91, 8.87)	3.22 (1.03, 10.02)	2.43 (0.78, 7.57)	3.44 (1.10, 10.73)
9	2.77 (0.89, 8.62)	3.19 (1.02, 9.92)	2.82 (0.90, 8.80)	3.93 (1.26, 12.27)
10	2.83 (0.91, 8.80)	3.13 (1.01, 9.75)	2.54 (0.81, 7.92)	4.09 (1.31, 12.76)
11	2.82 (0.90, 8.77)	3.07 (0.99, 9.57)	2.34 (0.75, 7.30)	3.39 (1.09, 10.59)
12	2.82 (0.90, 8.77)	3.07 (0.99, 9.57)	2.34 (0.75, 7.30)	3.39 (1.09, 10.59)
13	2.79 (0.90, 8.69)	3.18 (1.02, 9.89)	2.69 (0.86, 8.39)	3.08 (0.99, 9.60)
14	2.80 (0.90, 8.71)	3.12 (1.00, 9.70)	2.99 (0.96, 9.31)	3.99 (1.28, 12.46)

Abbreviations: HRE, heavy rainfall events. AC, antecedent conditions.

Figures

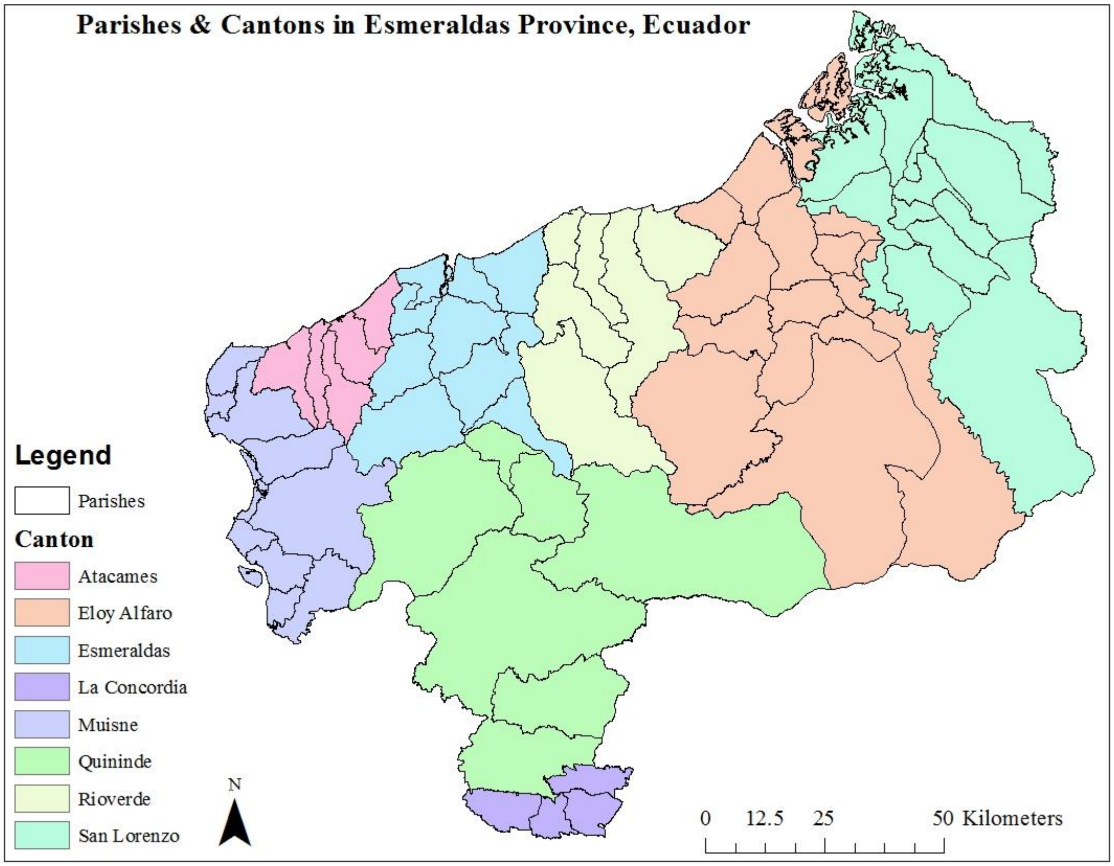


Figure 1. Overview of distribution of parishes in Esmeraldas province Ecuador by canton.

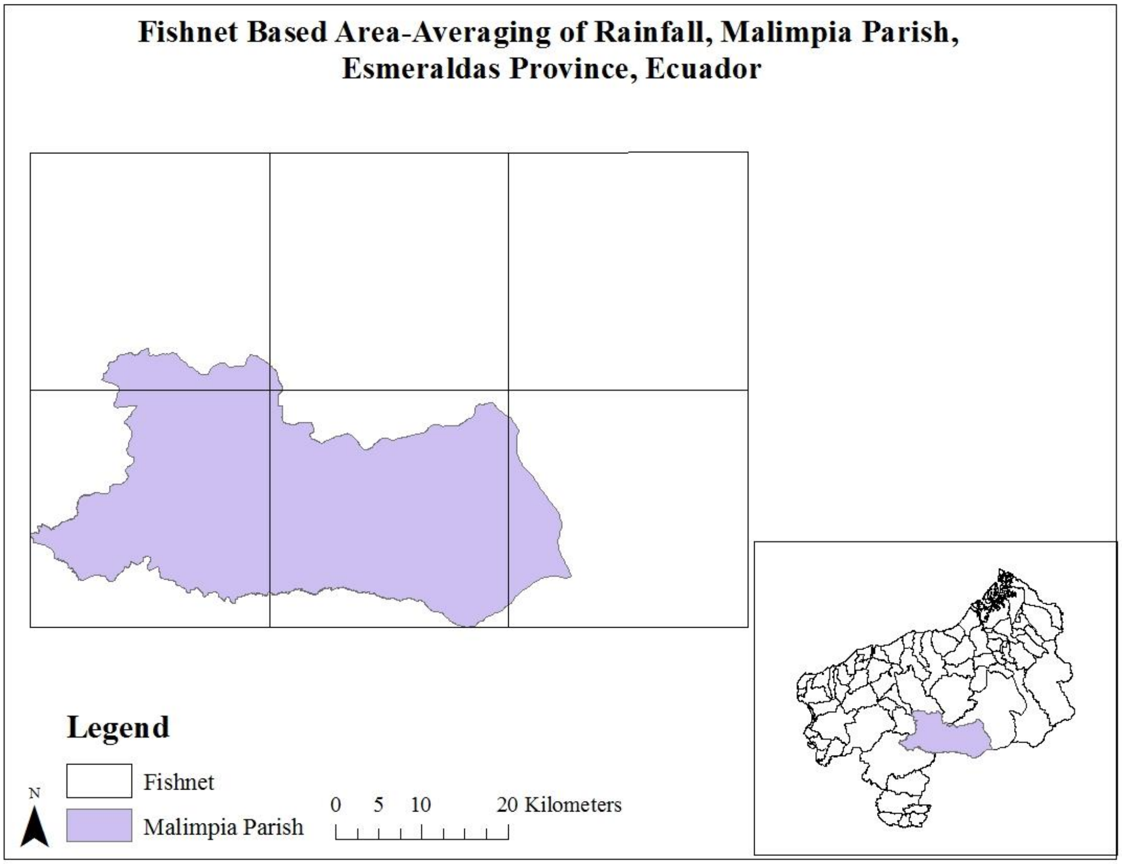


Figure 2. Example of fishnet based area-aggregation of satellite rainfall for each parish. A fishnet containing 0.25 x 0.25 degree squares (as shown above) divides each parish. The time series of daily rainfall estimates from the TRMM 3B42 satellite platform corresponding to each square is averaged together for each parish through a weighted scheme based on percentage of the parish area that overlaps with the corresponding square.

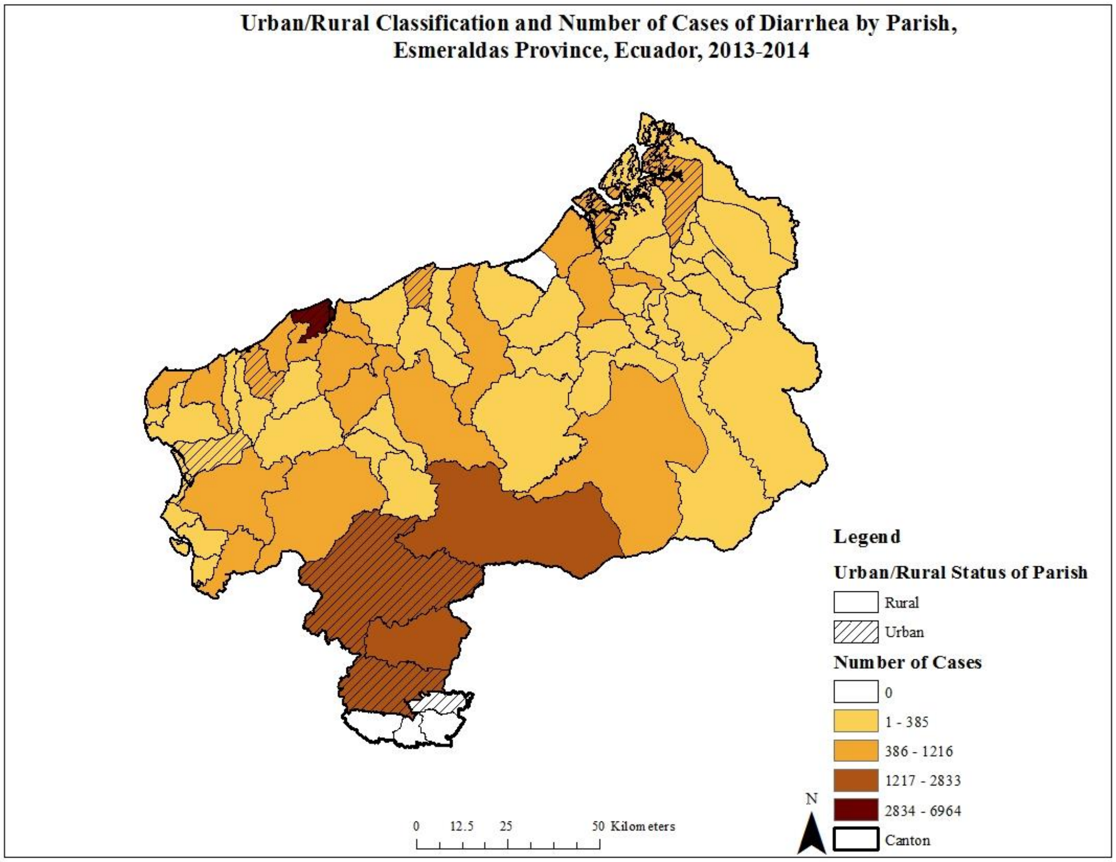


Figure 3. An overview of the spatial distribution of cases by parish, canton, and urban/rural status is shown. The canton of La Concordia in south contained no cases of diarrhea in the dataset in addition to the parish of Santa Lucia de las Penas in the Eloy Alfaro canton in the north of the region.

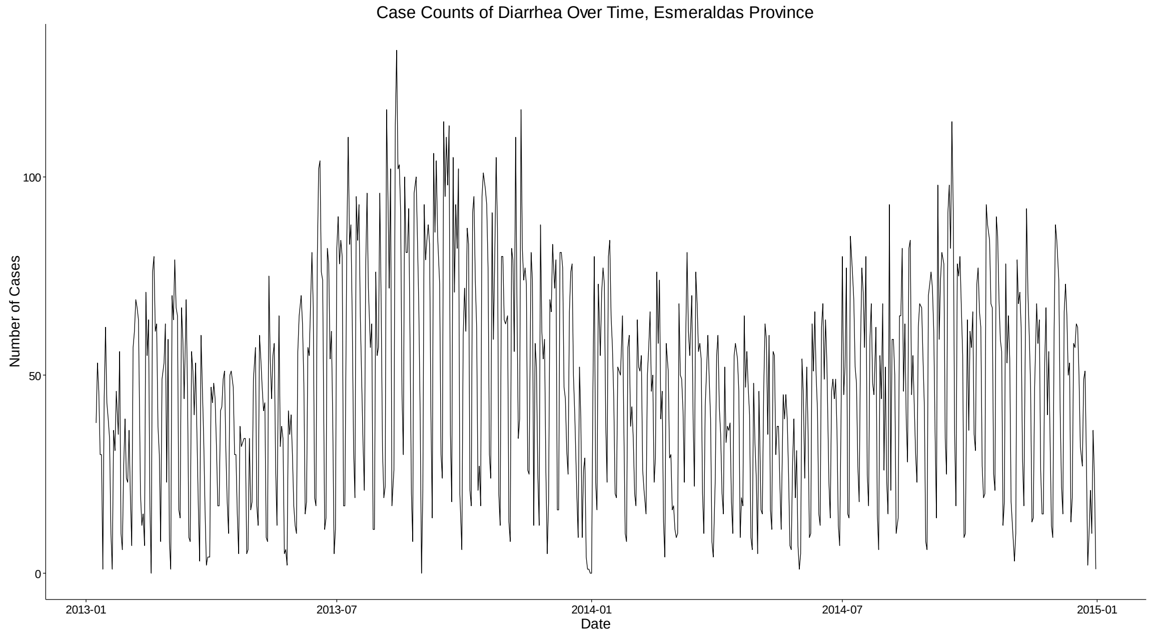


Figure 4. The temporal distribution of cases for Esmeraldas province is shown. There is a season trend observed in the cases of diarrhea with a rise in cases between the months of July and January in both years. The year of 2013 seems to have a higher peak in the number of cases of diarrhea compared to 2014.

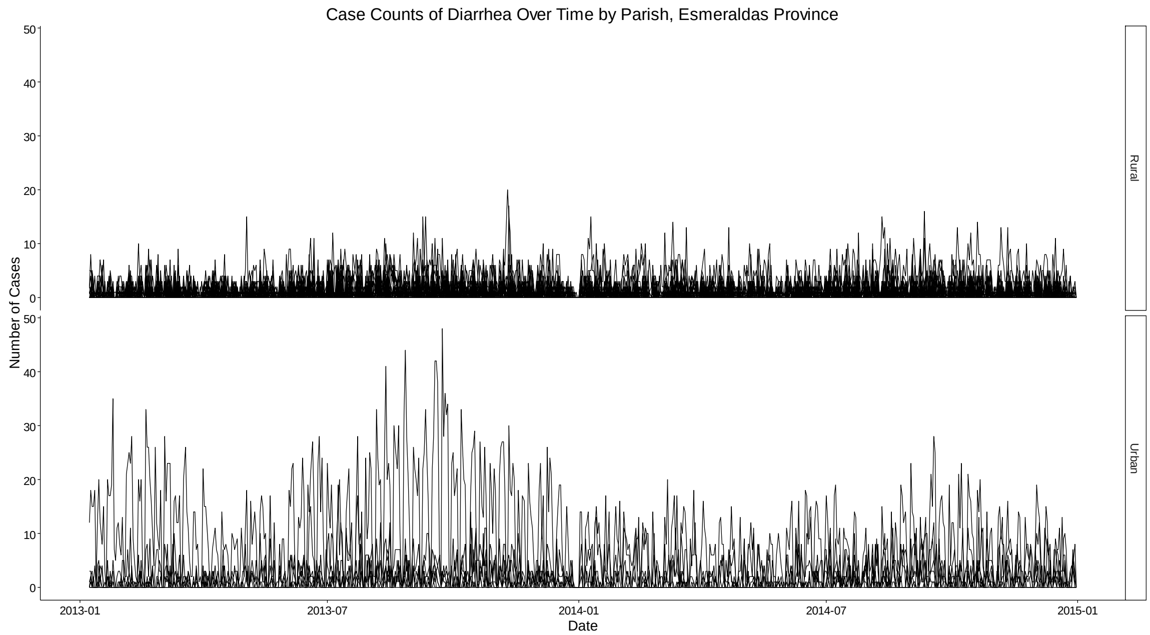


Figure 5. The temporal distribution of case counts of diarrhea by urban/rural parishes display a similar seasonal pattern of diarrhea with a peak between July to January. In the urban parishes, the parish of Esmeraldas in Esmeraldas canton appears to contain a large number of cases relative to other parishes. This could be since Esmeraldas is the major population center in the province.

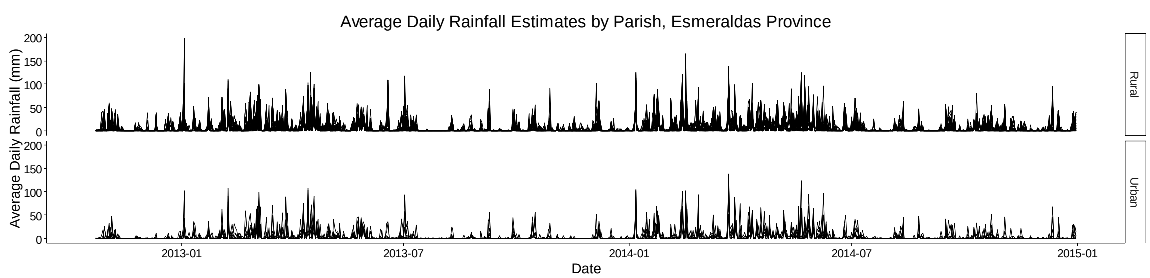


Figure 6. The temporal distribution of daily rainfall by urban/rural status of parish shows there is not an apparent difference in the rainfall patterns between the urban and rural areas of Esmeraldas province. Additionally there is a seasonality to the rainfall with dry season extending between July and January and the wet season in the other months.

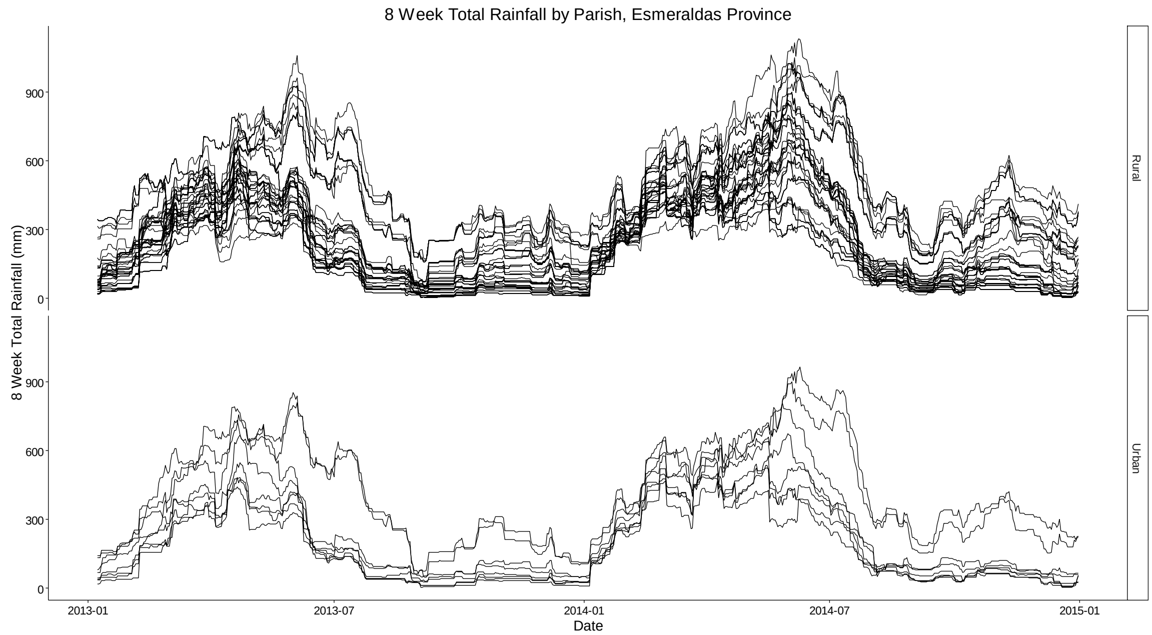


Figure 7. The eight week total rainfall corroborates the seasonal pattern and similarity between urban and rural parishes displayed by the daily rainfall estimates shown in Figure 6. These totals were used to define antecedent conditions as "dry antecedent conditions" below the 33rd percentile for the corresponding parish and "wet antecedent conditions" above the 67th percentile for the corresponding parish. Dry antecedent conditions appear to extend between the months of July and January whereas wet antecedent conditions appear to extend in the early months of both years (January – March).

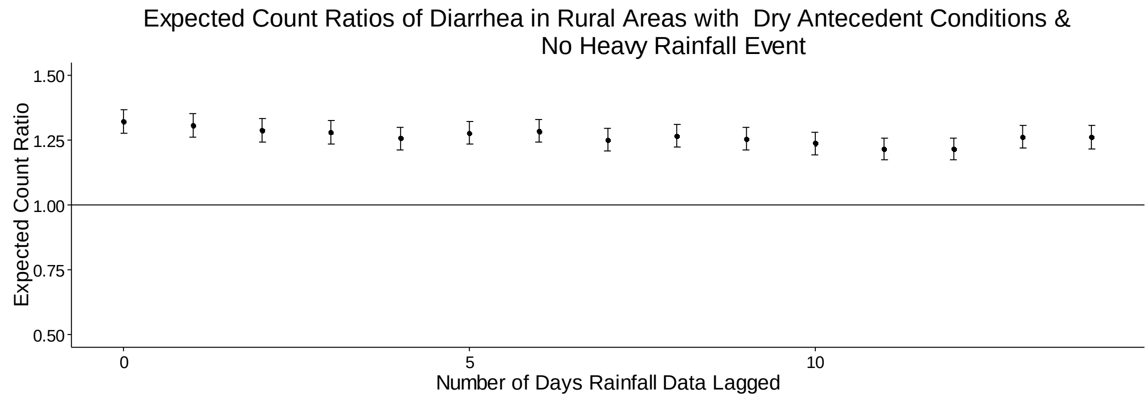


Figure 8. Expected count ratios of cases of diarrheal disease with dry antecedent conditions and no heavy rainfall events in comparison to wet antecedent conditions with no heavy rainfall events is shown. Dry antecedent conditions with no heavy rainfall events appear to be associated with increased counts of diarrhea controlling for age, sex, and race in rural areas.

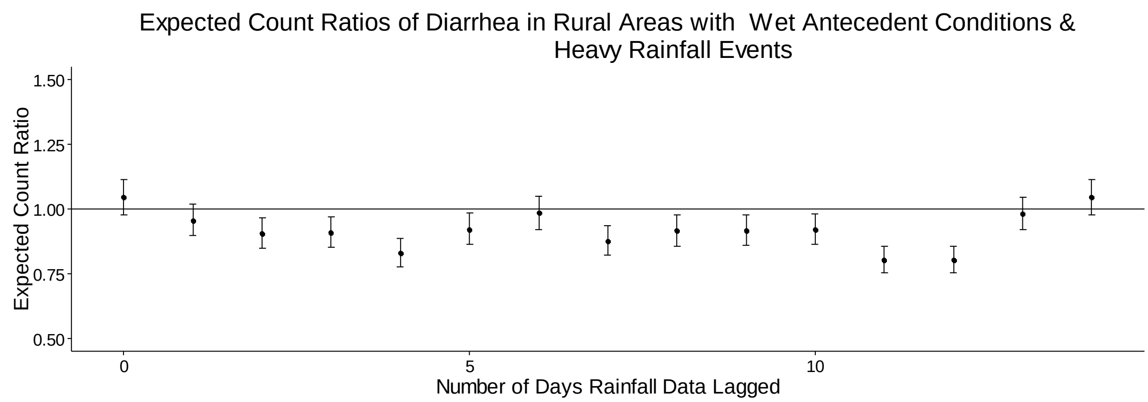


Figure 9. Expected count ratios of cases of diarrheal disease with wet antecedent conditions and heavy rainfall events in comparison to wet antecedent conditions with no heavy rainfall events is shown. Heavy rainfall events with wet antecedent conditions appear to be associated with decreased counts of diarrhea controlling for age, sex, and race in rural areas at most lags except for lags of 0, 1, 6, 13, and 14 days.

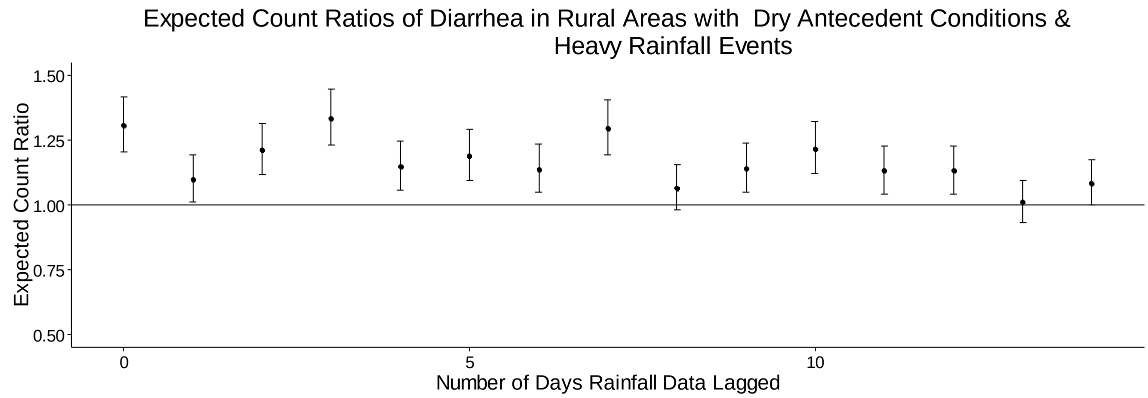


Figure 10. Expected count ratios of cases of diarrheal disease with dry antecedent conditions and heavy rainfall events in comparison to wet antecedent conditions with no heavy rainfall events is shown. Dry antecedent conditions with heavy rainfall events appear to be associated with increased counts of diarrhea controlling for age, sex, and race in rural areas. This association appears to decrease in strength as the lag tested increases.

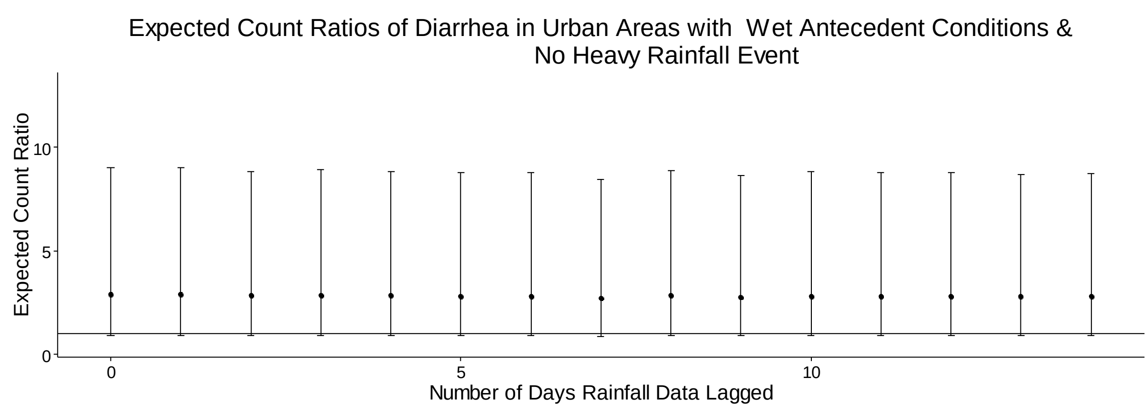


Figure 11. Expected count ratios of cases of diarrheal disease with wet antecedent conditions and no heavy rainfall events in urban areas compared to wet antecedent conditions with no heavy rainfall events in rural areas is shown. The measure of effect suggests urban areas are associated with increased counts of diarrhea controlling for age, sex, and race but our analyses do not suggest this is a significant difference from unity.

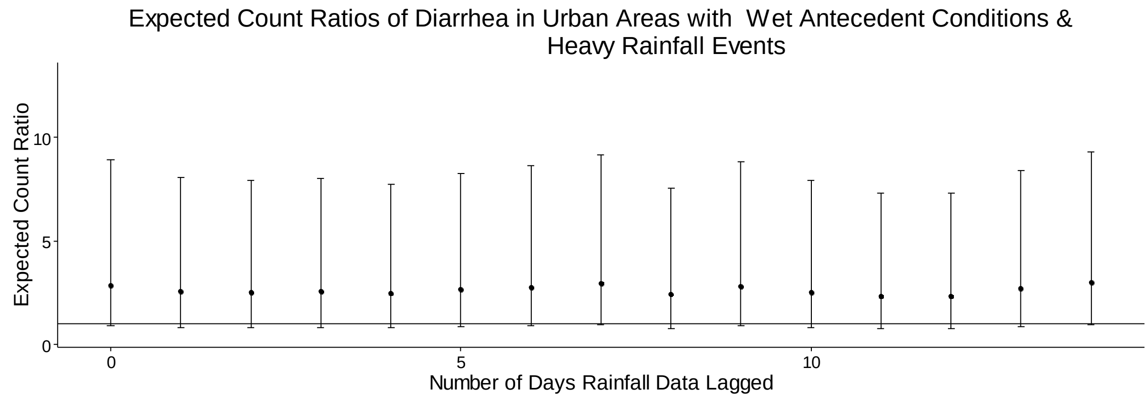


Figure 12. Expected count ratios of cases of diarrheal disease with wet antecedent conditions and heavy rainfall events in urban areas compared to wet antecedent conditions with no heavy rainfall events in rural areas is shown. The measure of effect suggests heavy rainfall events in urban areas are associated with increased counts of diarrhea controlling for age, sex, and race but our analyses do not suggest this is a significant difference from unity.

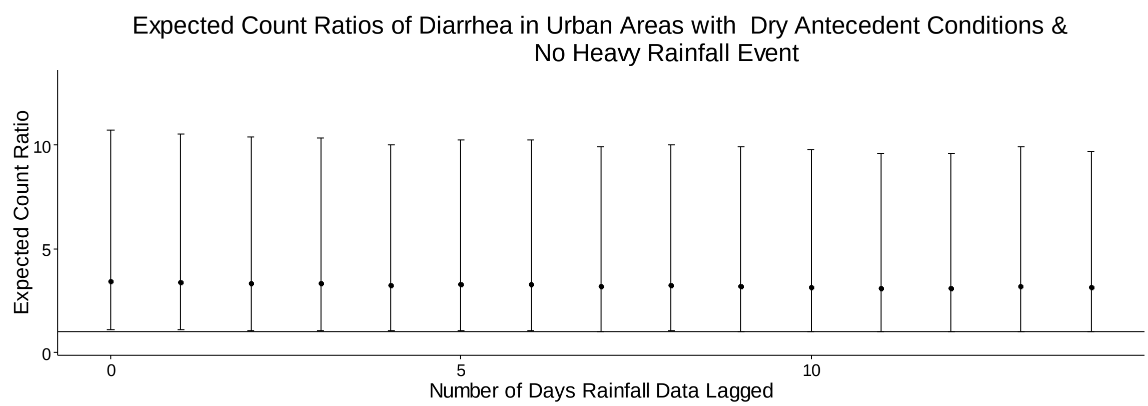


Figure 13. Expected count ratios of cases of diarrheal disease with dry antecedent conditions and no heavy rainfall events in urban areas compared to wet antecedent conditions with no heavy rainfall events in rural areas is shown. The measure of effect suggests dry antecedent conditions in urban areas are associated with increased counts of diarrhea controlling for age, sex, and race but our analyses do not suggest this is a significant difference from unity.

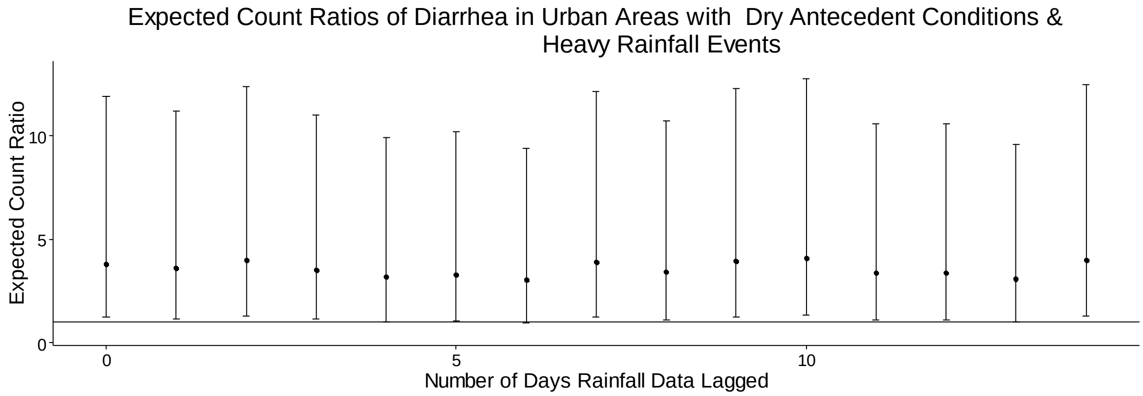


Figure 14. Expected count ratios of cases of diarrheal disease with dry antecedent conditions and heavy rainfall events in urban areas compared to wet antecedent conditions with no heavy rainfall events in rural areas is shown. The measure of effect suggests heavy rainfall events with dry antecedent conditions in urban areas are associated with increased counts of diarrhea controlling for age, sex, and race at lags of 6 and 13 days.

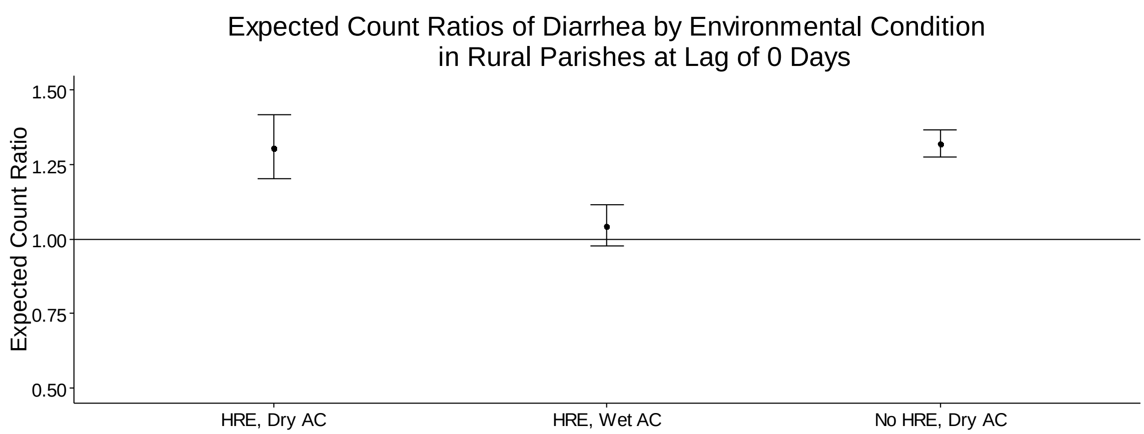


Figure 15. Abbreviations: HRE, heavy rainfall events; AC, antecedent conditions. Expected count ratios of diarrheal case counts by environmental condition compared to rural areas with wet antecedent conditions and no heavy rainfall events are shown. Dry antecedent conditions appear to be relatively strongly associated with increased counts of diarrhea cases in rural areas at a lag of 0 days.

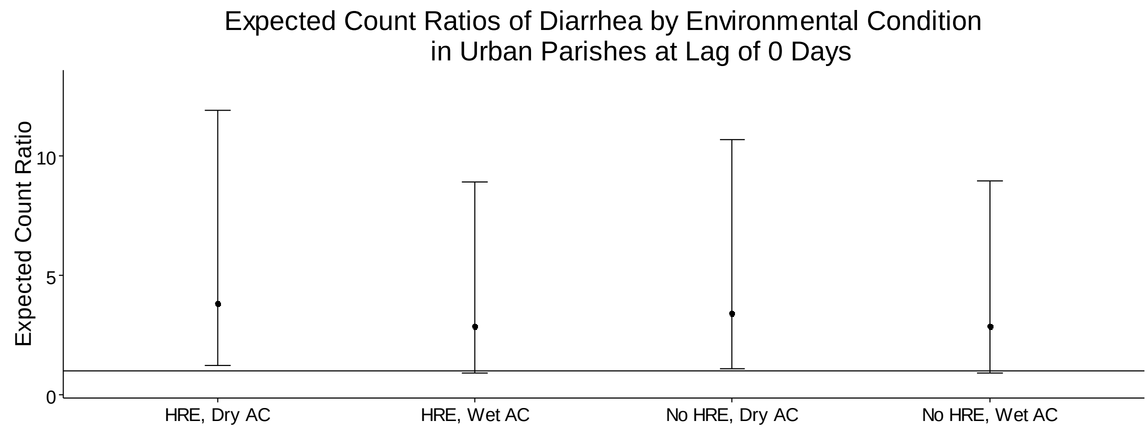


Figure 16. Abbreviations: HRE, heavy rainfall events; AC, antecedent conditions. Expected count ratios of diarrheal case counts by environmental condition compared to rural areas with wet antecedent conditions and no heavy rainfall events are shown. Dry antecedent conditions appear to be associated with increased counts of diarrhea cases in urban areas at a lag of 0 days.

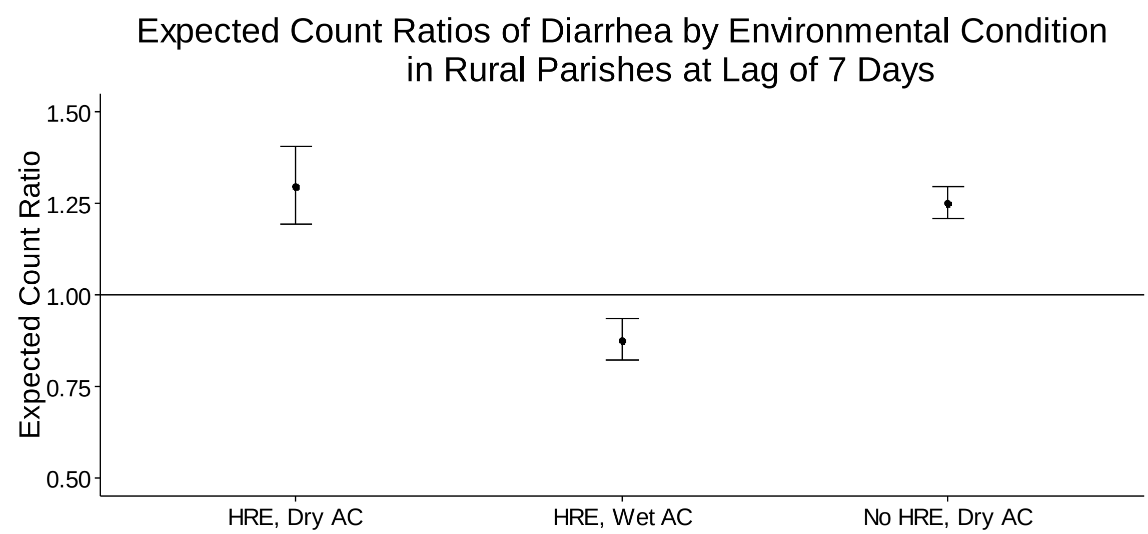


Figure 17. Abbreviations: HRE, heavy rainfall events; AC, antecedent conditions. Expected count ratios of diarrheal case counts by environmental condition compared to rural areas with wet antecedent conditions and no heavy rainfall events are shown. Dry antecedent conditions appear to be relatively strongly associated with increased counts of diarrhea cases in urban areas at a lag

of 7 days. Additionally heavy rainfall events appear to be protective with wet antecedent conditions but harmful with dry antecedent conditions at a lag of 7 days.

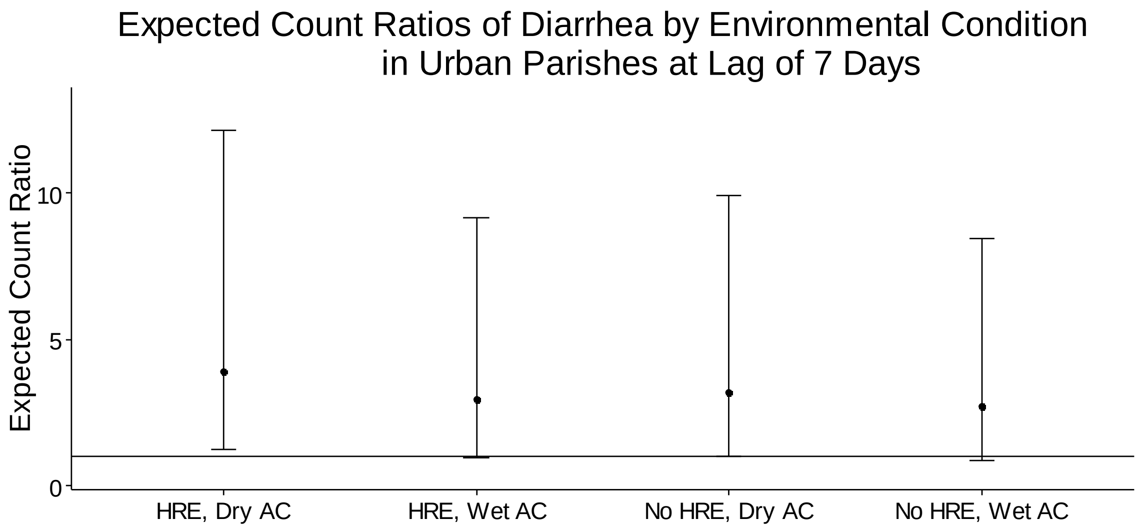


Figure 18. Abbreviations: HRE, heavy rainfall events; AC, antecedent conditions. Expected count ratios of diarrheal case counts by environmental condition compared to rural areas with wet antecedent conditions and no heavy rainfall events. Heavy rainfall events with dry antecedent conditions appear to be significantly associated with increased counts of diarrhea cases in urban areas at a lag of 7 days.

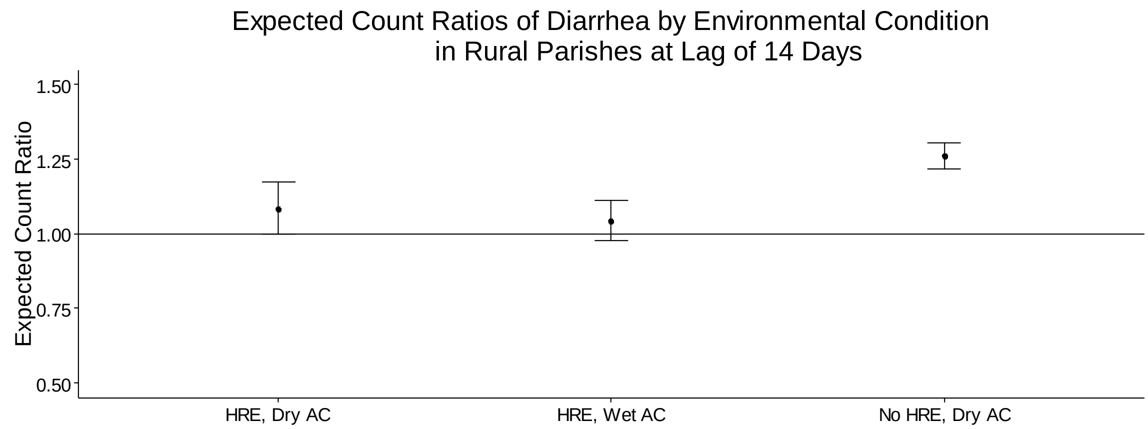


Figure 19. Abbreviations: HRE, heavy rainfall events; AC, antecedent conditions. Expected count ratios of diarrheal case counts by environmental condition compared to rural areas with wet antecedent conditions and no heavy rainfall events. Dry antecedent conditions appear to be relatively strongly associated with increased counts of diarrhea cases in urban areas at a lag of 14 days.

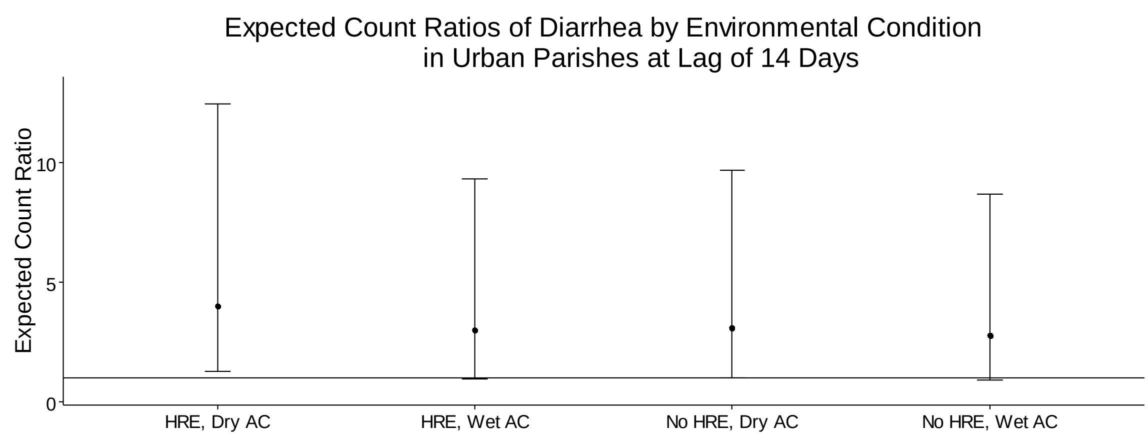


Figure 20. Abbreviations: HRE, heavy rainfall events; AC, antecedent conditions. Expected count ratios of diarrheal case counts by environmental condition compared to rural areas with wet antecedent conditions and no heavy rainfall events. Dry antecedent conditions appear to be relatively strongly associated with increased counts of diarrhea cases in urban areas at a lag of 14 days.

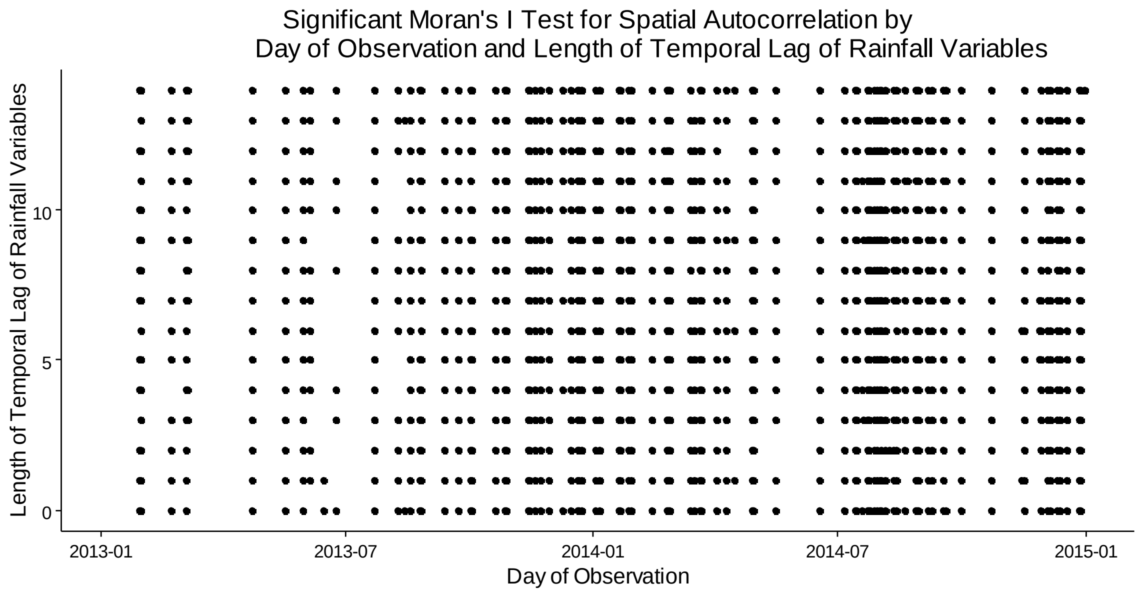
Summary

Climate change may result in increases in diarrheal diseases due to changes in water cycle affecting the transmission patterns of diarrheal diseases. This relationship between episodes of rainfall and diarrheal disease is further associated with antecedent rainfall conditions as well as contextual factors such as sanitation and water supply infrastructure. Studies show diarrhea to be associated with periods of low rainfall. Additionally heavy rainfall events are associated with increase in diarrhea during dry periods but a study in Ecuador shows there is a protective effect during wet periods.

Using case counts from all 68 parishes in the Esmeraldas province of Ecuador across 2013-14, the relationship between diarrhea and rainfall was analyzed within the context of urban and rural differences as well as antecedent conditions. In rural areas with wet conditions there was a protective effect observed between heavy rainfall events and diarrheal diseases at most lags tested except for lags of 0, 1, 6, 13, and 14 days. This protective effect was not observed in urban areas. Dry antecedent conditions were associated with an increase in diarrheal disease across all environments tested. In urban areas, it seemed the urban factor seemed to contribute heavily to driving the association with increased case counts of diarrhea. While the association between heavy rainfall and diarrhea was not significant under wet conditions in urban areas, the association between heavy rainfall and diarrhea with dry conditions had a significant association with an increase in case counts of diarrhea. This suggests that while dry conditions seem to be consistently associated with an increase in diarrheal disease in urban as well as rural areas, the association between heavy rainfall events and diarrhea seems to be modified by the antecedent conditions and the urban/rural context.

This has implications on further public health work to further explore the mechanistic factors driving the differential impact of rainfall in urban and rural contexts. Additionally it suggests that the urban/rural context merits consideration when planning to address diarrheal diseases through a climate change framework.

Appendix



Appendix I. The spatial autocorrelation of residuals of each model (one per lag tested) at each day is shown. Each dot indicates significant spatial autocorrelation present in the residuals as detected by the Global Moran's I test using 1000 Monte-Carlo iterations.