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The Flooding of Urban Communities in Accra, Ghana: Assessing Population at Risk, Behavioral Response, and Fecal Contamination

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B.S.
Allegheny College
2011

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An abstract of
A thesis submitted to the Faculty of the
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Purpose: As the world becomes more urbanized, there is an increased risk of exposure to natural hazards such as flooding due to impervious surface areas without adequate parallel increases in the number of drainage networks. Flooding may also increase an individual's risk of exposure to fecal contamination containing an enteric pathogen. This study was performed to gather data to identify how many people in urban neighborhoods of Accra are at risk for exposure to flooding, why the flooding occurs, document the behaviors that could cause exposure to floodwater, and determine whether people living in a flood zone are at risk for exposure to increased fecal contamination.

Methods: Four different data collection procedures were used: 1) GIS mapping of flood areas, 2) Calculating the population at risk in each community by using census boundaries, 3) Household questionnaire on behavioral practices in response to flooding, and 4) Microbiological testing of water and soil samples for general *E. coli* and enteric viruses that indicate human fecal contamination.

Results: The percentage of area that flooded in Alajo, Bukom, Old Fadama, and Shiabu were 28.98%, 33.02%, 87.36%, and 48.51%, respectively. Soil, drain, and floodwater samples had high concentrations of *E. coli* and only a few detected norovirus contamination. In a linear regression model for *E. coli* concentration of soil samples both the community Old Fadama and distance to the latrine were significant. For Old Fadama the *E. coli* concentration increased by $4.8*10^{3}$ CFU per gram and within 20 meters of a latrine it increased by $8.5*10^{5}$ CFU per gram of soil.

Discussion: A resident's contact to drain water is more likely to be sporadic compared to floodwater where exposure is almost guaranteed. There are potential risk factors such as distance to a latrine and differences between communities, which influence the amount of fecal contamination. However, a resident's behavioral response to flooding can put them at an increased or decreased risk for *E. coli* or norovirus exposure. Short-term preventive factors such as bucketing out water during flooding could potentially increase the risk of exposure to fecal-contaminated floodwater compared to long-term preventive factors such as cement walls.

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Chapter 1: Introduction

Flooding is a common disaster in both industrialized and developing countries, accounting for 40% of all natural disasters worldwide (Noji, 2000). Flooding occurs annually in many of these countries, and appears to be increasing in severity and frequency with urbanization. Flooding causes a broad range of physical, economic, social, and agricultural damage (*Pakistan Economic Survey 2011-2012: Flood Impact Assessment*, 2012; Haefner, 1996; Kolva, 2002). The physical destruction of homes can displace a large number of people, who move into crowded and unsanitary temporary housing conditions ("Action Plan for National Recover and Development of Haiti", 2010). The loss of businesses and city infrastructure, such as roads and bridges, impacts the economic stability of the population through loss of commerce and high unemployment ("Action Plan for National Recover and Development of Haiti", 2010). Individuals affected by flooding are at higher risk for depression and anxiety (Bennet, 1970; Phifer et al., 1990). On a larger scale, the loss of crops can result in food insecurity (*Pakistan Economic Survey 2011-2012: Flood Impact Assessment*, 2012).

Flooding also threatens public health by spreading pathogens that cause enteric and vector-borne diseases (McCarthy et al., 1994; Schwartz et al., 2006). Diarrheal disease, malaria, and respiratory illnesses are the most common population health problems that increase as a consequence of flooding (Kondo et al., 2002; Siddique et al., 1991). Epidemiological studies in India, Bangladesh, Brazil, Indonesia, Mozambique, South Africa, Sudan, Germany, Haiti, and United States have demonstrated that diarrheal disease rates increase after major flood events and that the increase in disease is associated with increased exposure to fecal contamination (Kondo et al., 2002; Siddique et al. 1991; Schwartz et al., 2006; Luby et al., 2008). One study in Mozambique found that the incidence of diarrhea increased by 2-4 times during and after a severe flood in 2000, compared to previous years (Kondo, et al., 2002). Household surveys in Mozambique indicated that drinking water in the flood area was consumed without treatment. Microbial analyses of drinking water collected from these sources confirmed there was *Escherichia coli* (Kondo, et al., 2002).

Another study in Bangladesh analyzed disease outcomes following three major floods during 1988, 1998, and 2004 (Schwartz et al., 2006). Enterotoxigenic *E. coli* (ETEC) were included in the surveillance system in 1998, and were the fourth most commonly identified pathogen in patients. Between 1997-1999, the number of pathogenic *E. coli* cases in flooded areas (18%) was significantly higher than in non-flooded areas (9%, $p<0.001$) (Schwartz et al., 2006). *E. coli* contamination was detected in drinking water in Bangladesh after flooding. Of those 186 wells with a history of inundation 15% of them had *E. coli* contamination compared to none of the 21 tube wells that were never inundated (Luby et al., 2008). Therefore, flooding plays a role in assisting the spread of feces containing enteric pathogens in the environment and increasing the risks of exposure.

The rainy season can increase the likelihood that enteric pathogens, such as *E. coli, Cryptosporidium,* and norovirus will survive in floodwater and soil (Nagels et al., 2002). These enteric pathogens can persist in homes or communities for days, months, or even year around (Anderson et al., 2005; Karim et al., 2004). The frequency, severity, and also duration of flooding affect the risk of exposure to enteric pathogens and disease.

Urban populations are particularly vulnerable to flooding. The occurrence and severity of flooding can be exacerbated by urbanization and improper construction techniques (Noji, 2002). Rapid population growth has resulted in increased land development and impervious surface areas (Afeku, 2005). The impervious surface area decreases the amount of soil capable of absorbing water and increases water run-off, resulting in overloading of wastewater drainage channels. Rapid urbanization can also outpace city infrastructure development, leading to undersized or improperly channeled drainage networks (Rain et al., 2011).

Drainage can be affected by limited garbage collection. In areas that lack formal trash management services, residents will use drains for disposal of household waste such as plastics, canned drink containers, food waste, and bags of feces (Acheampong, 2010; Afeku, 2005). The solid waste clogs the drains, forcing the drain to overflow when it rains (Acheampong, 2010). As a result, wastewater consisting of domestic effluent, industrial sources, and urban runoff can spread fecal-contaminated water over a wide geographic area (Obuobie et al, 2006). Additionally, the untreated drain water flows directly into local surface waters and eventually the ocean. This increases the probability of high concentrations of fecal contamination in areas frequently used for recreational or fishing purposes. Thus, seasonal flooding can increase the amount of fecal matter in wastewater and its geographic spread, increasing the risk of exposure to enteric pathogens for city residents.

The behavioral response of individuals to flooding is a very important factor that influences the risk of exposure to fecal contamination. There is very limited information describing the behavioral responses to floods in developing countries and the actual risk of exposure to fecal contamination. Many communities subject to frequent flood events have developed strategies to prevent floodwater from reaching the households. In Accra, Ghana, residents have used blocks, stones, and furniture to create blockades (Douglas et al., 2008). In Nairobi, Kenya, the strategies used to prevent water from entering homes included digging trenches around houses before flooding, constructing dykes or trenches to divert water away from houses, and using sandbags at the entrance to a house (Douglas et al., 2008; Mendel, 2006). Similar behavioral responses to flooding were observed in Lagos, Nigeria; Accra, Ghana; and Nairobi, Kenya (Douglas et al., 2008). However, these strategies are typically only effective for decreasing the severity of flooding, rather than the probability of exposure of individuals to fecal-contaminated floodwater. When houses flood, fecal contamination of pathogens can last for long periods of time depending on the housing structure and area (Taylor et al., 2013). Some people leave their homes in order to avoid the floodwater, thereby decreasing their risk of exposure to contaminated water. However, many others tend to stay in their home throughout the flood event to protect their valuables and property (Douglas et al., 2008). Adults, in particular, can also experience extremely high exposure when bailing contaminated water out of their homes (Hollis, 1975; Douglas et al. 2008).

This study will address some of the knowledge gaps about the risks posed to residents living in flood areas in Accra, Ghana. Accra was selected as the model for the study because it is an urban city that experiences annual flooding that causes damage. Accra is a rapidly developing, coastal capital city of approximately four million people (Rain et al., 2011). The climate is classified as a tropical savannah, and includes a dry and rainy season (“Climate", 2013). The primary rainy season lasts from April until mid-July, followed by a second shorter season in October. The monthly rainfall in April, May, June, July, and October is 88.9 mm, 134.62 mm, 198.12 mm, 50.8 mm, and 63.5 mm, respectively (“Climate", 2013). Each year, the heavy rainfall in Accra causes floods that result in significant property damage as well as 40-145 deaths in Ghana per year (Douglas et al., 2008; “Ghana Country Profile: Natural Disasters”, 2013). We will explore how many people are likely to be exposed, why flooding occurs, how do victims respond, and whether people living in a flood zone are actually exposed to greater concentrations of fecal contamination compared to others in their communities who do not live in a flood area.

Chapter 2: Literature Review

Definition and causes of flooding

Floods are defined as the overflow of water into areas not usually submerged with water (Gunn, 1990). The cause and severity of floods can be influenced by natural and human factors (Noji, 2000). Natural factors include seasonal variation in rainfall and geological conditions, such as topography (Noji, 2000). Over the last century, climate change has increased temperatures and the frequency of heavy rainfall, which has led to more frequent flooding (Groisman et al., 2004). Populations in many cities around the world are particularly at risk for flooding caused by natural factors because the cities were developed in highly vulnerable sites. Those with the strongest population growth have been in coastal areas with greater risk from floods, cyclones, and tidal waves. Much of the remaining land available for urban growth is also risk-prone, for example flood plains or steep slopes prone to landslides. As climate change continues, populations will face increased exposure to flood-related disasters (Nicholls, 1995).

Human actions that alter the environment, such as increased land use caused by rapid urbanization and poor planning of where drains and houses are built, can also make areas more vulnerable to flooding (Noji, 2000). Urbanization, i.e. the growth of cities, has always been a major source of economic growth, innovation, and employment. Historically, many cities grew because they increased access to natural resources and raw supplies (Cohen, 2006). At the beginning of the 20th century, there were 16 cities worldwide with more than a million people. As of 2005 there were 400 cities greater than 1 million inhabitants, with 70% located in developing countries (Cohen, 2006). Cities are currently home to about half of the world's population, and within the next 30 years the population is expected to increase by two billion, primarily within urban communities (Cohen, 2006).

In Africa alone, the population of some cities is estimated to increase by up to 85%, almost doubling the current population by 2025 ("The State of African Cities 2010: Governance, Inequality, and Urban Land Markets", 2010). Some of the most populous cities in Africa that will have to deal with significant growth include Dar Es Salaam, Addis Ababa, Lagos, and Accra ("The State of African Cities 2010: Governance, Inequality, and Urban Land Markets", 2010). The rapid growth of cities in developing countries is problematic, in that it can outpace the capacity of most cities to provide citizens with adequate services (Cohen, 2006). Municipal governments will have to address major issues, including shortages of food and water, poor infrastructure, and lack of housing during this urbanization process ("The Urbanization of Africa: Growth Areas", 2010). Each year the cities also attract new migrants, which results in more squatter settlements or shantytowns. These informal settlements impede attempts to improve infrastructure and deliver essential services (Cohen, 2006).

Rapid and uncontrolled urbanization can clearly increase the risk of flooding. When urbanization was accelerating in the 1970s, Hollis et al. noted that changes in land use, such as increased road pavement, could increase the frequency of small floods (1975). Rapid population growth increases land development, which typically means paving surface areas with impervious materials like concrete (Afeku, 2005). The increase in impervious surface area decreases the amount of soil capable of absorbing water and increases water run-off, resulting in overloading of wastewater drainage channels. Infrastructure development, particularly in resource-poor countries, is frequently outpaced by the rate of urbanization, leading to undersized or improperly channeled drainage networks (Rain et al., 2011).

The effectiveness of drainage networks can be compromised both by increased water volume and limited garbage collection. In cities lacking garbage collection services, many residents use the drains for disposal of household waste (Acheampong, 2010; Afeku, 2005). The improperly managed solid waste clogs drains, forcing the drains to overflow when it rains (Acheampong, 2010). As a result, liquid wastewater, consisting of domestic effluent, industrial waste, and urban runoff, can spread contamination over a wide geographic area (Obuobie et al, 2006). Additionally, the untreated drain water flows directly into local surface waters and eventually the ocean. If the drains are used for disposal of human sewage, this increases the probability of high concentrations of fecal contamination in areas frequently used for recreational or fishing purposes. Thus, seasonal flooding can increase the amount of fecal matter in wastewater and its geographic spread, increasing the risk of exposure to human sewage for city residents.

Flooding in Accra, Ghana

Accra, Ghana is an excellent example of how urbanization can exacerbate flood exposure. Accra is a rapidly-developing, coastal capital city of approximately four million people (Rain et al., 2011). The climate is considered a tropical savanna, consisting of a dry and rainy season (“Climate", 2013). The primary rainy season lasts from April until mid-July, followed by a second, shorter season in October. The monthly rainfall in April, May, June, July, and October is 88.9 mm, 134.62 mm, 198.12 mm, 50.8 mm, and 63.5 mm, respectively (“Climate", 2013). The heavy rainfall causes annual floods that result in loss of human life and property damage, such as loss of valuables or housing (Douglas et al., 2008).

The seasonal rainfall comes in high volumes of water in a short period of time on developed surface area soil with poor absorptive capacity (Afeku, 2005; Arnold et al., 1996). In addition, drainage systems are lacking in many areas. Where drains do exist, limited garbage collection has resulted in residents using the drains for disposal of household waste, such as plastics, canned drink containers, sugar cane, and bags of feces (“flying toilets”) (Afeku, 2005; Acheampong, 2010). These factors exacerbate flooding caused by high rainfall, inadequate containment of water run-off, and overdevelopment. Floodwater is then forced to flow horizontally, instead of into the soil, and come into people’s houses. If residents of flood zones remain in the area during flood events they may face an increased risk of exposure to water and soil carrying feces with enteric pathogens (Afeku, 2005; Acheampong, 2010).

Historical examples of the impact of flooding

Flooding is a common disaster in both industrialized and developing countries, accounting for 40% of all natural disasters worldwide (Noji, 2000). Throughout history, flooding has caused a broad array of damage in China, United States, and Pakistan, among other countries. Flooding in China demonstrates how much destruction can be caused by repeated disasters. In September and October of 1887, the rising of the Yellow River due to heavy rainfall caused massive flooding that killed between 900,000 to 2,000,000 people ("Huang He Floods," 2012). The next, and most destructive, flood occurred in 1931 when 88,000 square kilometers were flooded and another 22,000 square kilometers were partially inundated ("Huang He Floods," 2012). The number of people killed was between 850,000 to 4,000,000, mainly due to disease and famine caused by the destruction of farmlands rather than by injuries from the actual flood ("Huang He Floods," 2012). The last devastating flood in recent history occurred in 1938. The Chinese destroyed the dikes on the river in an effort to halt advancing Japanese troops during the Japanese-Sino War in 1938 ("Huang He Floods," 2012). The flooding that occurred as a result caused the deaths of between 500,000 and 900,000 people ("Huang He Floods," 2012). The multiple floods that occurred in China demonstrate repetition of disasters within an area ("Huang He Floods," 2012).

Flooding continues to be a severe problem for many nations. In the United States, the Great Flood of 1993 covered 9 states (1,035,995 square kilometers), damaged 1,000 levees, and left residual floodwater in some places for up to 200 days (Larson, 1996). The flood devastated crops and transportation systems and destroyed over 50,000 homes. Consequently 20 billion dollars was spent to rebuild homes and repair railways (Haefner, 1996; Kolva, 2002). Furthermore, the damage to soybean and corn crops caused a total loss of 1.22 billion dollars in revenue in seven states (Espy, 1993).

In 2011, a flood occurred in Pakistan during the monsoon season that brought about a variety of damage to crops, public infrastructure, human settlements, and the national economy (*Pakistan Economic Survey 2011-2012: Flood Impact Assessment*, 2012). The destruction of essential infrastructure, like roads, bridges, and markets made the immediate delivery of aid impossible (*Pakistan Economic Survey 2011-2012: Flood Impact Assessment*, 2012). Significant reconstruction was required in many sectors, including housing, transportation and communication, as well as in the agriculture, livestock, and fisheries food industries. Also in desperate need of reconstruction were facilities for energy, education, and healthcare. Pakistan has since undertaken steps to improve the health and safety of the environment to lessen the effects of this, and future floods. They have added new irrigation systems, renovated their national policy on flood management, and constructed sanitation facilities (*Pakistan Economic Survey 2011-2012: Flood Impact Assessment*, 2012).

The environmental damage caused in the 2011 floods included accumulation of solid waste and debris, and contamination of drinking water and other domestic resources (*Pakistan Economic Survey 2011-2012: Flood Impact Assessment*, 2012). Damage to solid waste and contamination of drinking water led to typhoid and diarrheal disease (*Pakistan Economic Survey 2011-2012: Flood Impact Assessment*, 2012). Floods and their effects on human infrastructure, the environment, and health devastate nations all over the world.

Health Outcomes of Flooding

The ramifications of flooding include significant health impacts on individuals living or working in these areas. Rates of mortality, injury, toxin exposure, mental health trauma, rodent-borne disease, vector-borne disease, and enteric diseases are all increased among individuals exposed to floods (Ahern et al., 2005).

Mortality

Deaths occur frequently in areas that flood, regardless of whether the country is of high or low income. The number of casualties is usually influenced by the characteristics of the flood, with flash flooding being more hazardous than one of slower onset (Ahern et al., 2005). With no time to prepare or escape, many people drown or sustain traumatic injuries (Ahern, Kovats, Wilkinson, Few, & Matthies, 2005). The number of fatalities also depends on cultural, environmental, and socio-economic factors. Fatalities are particularly high in resource-poor settings that have an increased vulnerability to disasters (Ahern, et al., 2005). The Center for Research on Epidemiology of Disasters estimated that in 2002-2011 the ratio of deaths worldwide in low vs. high resource settings was almost 23:1 (Database, 2011).

Injuries

Injuries from flooding can occur before, during, and after a disaster. In the 1993 flood in the Midwest, the emergency departments created a standardized questionnaire to record daily information about flood related illness and injury ("MMWR Morbidity Surveillance following the Midwest Flood --- Missouri, 1993," 1993). From July 16, 1993 to September 4, 1993, 524 flood-related conditions were reported ("MMWR Morbidity Surveillance following the Midwest Flood --- Missouri, 1993," 1993). Of these 250 (47.7%) were injuries. Out of these 250 patients, the most common injuries were sprains/strains (34%), lacerations (24%), abrasions/contusions (11%), and “other injuries” (11%) ("MMWR Morbidity Surveillance following the Midwest Flood --- Missouri, 1993," 1993).

Toxic Exposure

Floods can trigger a release of chemicals stored within an environment, especially in areas used for agriculture or industry. However, the casual pathway between floods and the spread of toxic contaminants has not been proven (Haines, Kovats, Campbell-Lendrum, & Corvalan, 2006). Prior to hurricanes Katrina and Rita, elevated levels of lead and arsenic contamination were recorded in soil samples in New Orleans. However, the level of these contaminants did not change after the storm and flooding, suggesting that there was no change that could be attributed to the flooding (Schwab et al., 2007).

Mental Health

The World Health Organization (WHO) recognizes that mental health consequences from flooding have been studied very little, and people in developing countries are particularly vulnerable due to limited access to treatment ("The World Health Report 2001--- Mental Health: New Understanding, New Hope," 2001). Mental health issues related to flooding include common disorders (anxiety, depression), posttraumatic stress disorder (PTSD), and suicide (Ahern, et al., 2005). Risk factors that influence the development of these mental disorders include degree of exposure, age, gender, previous experience, and socioeconomic status (Alderman, Turner, & Tong, 2012). Most publications come from studies within middle or high incomes countries (Ahern, et al., 2005). A longitudinal study in the state of Iowa after the U.S. Midwest floods of 1993 compared symptoms of depression in pre-flood and post-flood diagnosis records (Ginexi, Weihs, Simmens, & Hoyt, 2000). The diagnosis of common mental disorders significantly increased by 8.5 fold after the flood (OR=8.5; 95% CI: 5.54-13.2) (Ginexi, et al., 2000). Studies of the 1996 flood in Quebec, Canada also suggested an increase in PTSD and emotional distress after floods (Ahern, et al., 2005; Maltais et al., 2000).

Posttraumatic stress disorder symptoms are characterized by avoidance of association with anything related to the stressor and intrusive memories ("The World Health Report 2001--- Mental Health: New Understanding, New Hope," 2001). In the Midwest flood of 1993, McMillen et al. found that 60 subjects (38%) met the criteria for posttraumatic stress disorder (Ahern, et al., 2005; McMillen, North, Mosley, & Smith, 2002). However, limitations of the study included retrospective data collection and the absence of a control group (Ahern, et al., 2005; McMillen, et al., 2002). Information about suicide rates related to flooding is also very limited, and of the two articles written on this subject, one was retracted and the other had no direct epidemiological evidence of association between flooding and suicide (Ahern, et al., 2005).

Rodent-borne Disease

Altered patterns of contact with rodents produced by flooding can increase disease transmission risk. Leptospirosis outbreaks have been associated with flooding in a wide range of countries, including Argentina, Brazil, Cuba, India, Korea, Mexico, Nicaragua, and Portugal (Ahern, et al., 2005). In Brazil, during the summer of 1996, an outbreak occurred in the Rio de Janeiro Western region (Barcellos & Sabroza, 2001). Geographic Information System (GIS) was used to georeference cases in the area and map the flood zones (Barcellos & Sabroza, 2001). The difference in leptospirosis case rates between flood and non-flood areas was statistically significant ($\alpha < 0.05$). The incidence rate of leptospirosis in flooded areas was twice that observed outside of the flooded areas (Barcellos & Sabroza, 2001).

Vector-borne Disease

Vector-borne disease and flooding have a complex relationship; floodwaters can have dual effects on vector-borne diseases. (Ahern, et al., 2005). For example, floodwaters can wash away the breeding sites for the mosquito vector for malaria, lowering mosquito-borne transmission (Sidley, 2000). However, floodwaters could also increase disease transmission by creating stagnant water breeding sites in blocked drains, especially in urban settings. There have been numerous reports of this situation in Africa, Asia, and Latin America (Ahern, et al., 2005; "International Notes Health Assessment of the Population Affected by Flood Conditions -- Khartoum, Sudan," 1989).

Malaria was one of two major concerns among public health officials after the flood in Mozambique in 2000; the other concern was diarrheal disease due to fecal contamination of water. A Japanese medical team diagnosed 30% of the patients and found that the incidence of malaria increased by 1.5-2 fold, and accounted for 5% of the deaths ("International Notes Health Assessment of the Population Affected by Flood Conditions -- Khartoum, Sudan," 1989). The number of patients that consulted the medical clinic increased by four to five times that of previous years, the population also increased by three fold ("International Notes Health Assessment of the Population Affected by Flood Conditions -- Khartoum, Sudan," 1989). The risk factors for malaria infection post-flooding included destruction of living environment, creation of favorable breeding environments for mosquitoes, and population migration ("International Notes Health Assessment of the Population Affected by Flood Conditions -- Khartoum, Sudan," 1989).

Enteric Disease

Enteric disease is caused by the oral ingestion of fecal contamination via food, water, soil or contact with surfaces or unclean hands, and is one of the most common, if not the most common health issue in flooding. Various studies in India, Bangladesh, Brazil, Indonesia, Mozambique, South Africa, Sudan, Germany, and United States have demonstrated the worldwide influence of flooding on enteric disease ("Health

Assessment for the Population Affected by Flood Conditions," 1989; Kondo et al., 2002; Siddique, Baqui, Eusof, & Zaman, 1991).

Bangladesh 1988

During the 1988 floods in Bangladesh, diarrhea was the most common symptom (34.7%) and cause of death among all age groups, except for those > 45 years of age, in 46,470 treated patients in 72 affected sub-districts (Siddique, et al., 1991). The second most frequent cause of illness was respiratory infection (Siddique, et al., 1991). A separate community-based survey in two of the affected flood districts in the 1988 flood found that, besides fever (n=329, 63.6%) and respiratory problems (n=242,46.8%), diarrhea (n=229, 44.3%) was the third major reported disease (Kunii, Nakamura, Abdur, & Wakai, 2002). When respondent's families were also included, diarrhea (n=162, 26.6%) became the second highest health problem after fever (n=261, 42.8%) (Kunii, et al., 2002). Those with lower socioeconomic status, poor sanitary conditions, and hygiene practices were more likely to experience a diarrheal outbreak (Kunii, et al., 2002). However, the researchers expressed concern about selection bias due to the high rate of male respondents compared to female respondents. More accurate data characterizing food preparation exposures, and the overall health status of children, would have been collected from female respondents (Kunii, et al., 2002).

Another study in Bangladesh analyzed causes of diarrhea after three major floods during 1988, 1998, and 2004 (Schwartz et al., 2006). The mean number of cases per day of enterotoxigenic *E. coli* pathogen attributed diarrhea was significantly lower in non-flood areas compared to flooded areas. *E. coli* surveillance was only initiated in 1998, but was the fourth most commonly identified pathogen in that year. The mean number of *E.*

coli cases in flooded areas was significantly greater than in non-flooded areas (18% flood vs. 9% non-flood, $p<0.001$) (Schwartz et al., 2006). Pathogenic *E. coli* were also found in drinking water in Bangladesh after flooding. The wells with a history of inundation had a higher occurrence of *E. coli* contamination (Luby et al., 2008). Of those wells inundated, 15% of the 186 wells had *E. coli* contamination compared to none of the 21 tube wells never inundated (Luby et al., 2008). Therefore, flooding plays a role in spreading human exposure to enteric pathogens.

Khartoum Sudan 1988

Khartoum, the capital of Sudan, is located at the junction of the White and Blue Nile rivers and has a population of approximately 4.5 million ("Health Assessment for the Population Affected by Flood Conditions," 1989). Within 24 hours on August 4th 1988, Khartoum received double the amount of its usual annual rainfall, 210mm, followed by heavy rainfall on the 11th and 13th ("Health Assessment for the Population Affected by Flood Conditions," 1989). The accumulation of rainfall caused displacement of 750,000 inhabitants and destroyed 127,000 dwellings ("Health Assessment for the Population Affected by Flood Conditions," 1989). The flooding disrupted food and water supplies, sanitation, transportation, and communication throughout the country ("Health Assessment for the Population Affected by Flood Conditions," 1989). The aftermath of the flood affected nutritional status among children 1-5 years of age, and rates of vector-borne and diarrheal disease.

Immediately after the flood, the Center of Disease Control (CDC), Sudanese Ministry of Health, World Health Organization (WHO), and USAID set up a disease surveillance system in three urban districts using 24 health facilities and three hospitals

("Health Assessment for the Population Affected by Flood Conditions," 1989). The selected sites were based on locations where a large number of displaced people had settled. Data was collected on rates of watery diarrhea, dysentery, jaundice, malaria, measles, acute respiratory infections, and "other diseases”. Additionally, stool samples were collected from those who were suspected to have dysentery or cholera ("Health Assessment for the Population Affected by Flood Conditions," 1989).

Between August 21st-31st, there were 15 suspected individual outbreaks of diarrheal diseases, although no cases of typhoid or cholera were microbiologically confirmed ("Health Assessment for the Population Affected by Flood Conditions," 1989). Studies in Khartoum suggested that flooding did increase diarrheal rates; however, this may have been due to an increase in population numbers, and some of the studies lacked a control population ("Health Assessment for the Population Affected by Flood Conditions," 1989; McCarthy et al., 1996; McCarthy et al., 1994). Diarrhea was the most common cause of morbidity in 9,217 of the 29,526 (31%) reported visits to health facilities and hospitals ("Health Assessment for the Population Affected by Flood Conditions," 1989). A supplemental case-control study, in October and November of 1988, enrolled 200 cases of febrile illness and 100 controls of afebrile illness from Omdurman Hospital. The researchers found that 7% of cases and 1% of controls were infected with *Salmonella typhi* or *paratyphi*, 5% of cases and 1% of controls with *Shigella*, and 2% of cases and controls with *Campylobacter* (McCarthy, et al., 1996). *Salmonella typhi or paratyphi*, *Shigella*, and *Campylobacter* disease may have already been endemic in the region, but floodwater was probably an important influence on their further spread to other areas and between people.

Hepatitis E outbreaks were also reported (McCarthy, et al., 1994). IgG and IgM samples were taken from 55 patients at Omdurman Military Hospital, and 32 patients (58%) had IgM anti-HEV (McCarthy, et al., 1994). These patients did not significantly differ in their age, number of days of jaundice, prior history of jaundice, use of sources of drinking water, symptoms, and physical examination (McCarthy, et al., 1994). The findings indicate that hepatitis E was an important cause of epidemic jaundice after the flooding in Khartoum, although insufficient information was collected for identifying the potential exposures that could have led to infection (McCarthy, et al., 1994). Also, these studies were limited to one hospital, so generalization of these results to the population is not possible.

Mozambique 2000

In Mozambique, roughly one third of the land is a floodplain, or is at least below 100m (Roger, 2006). Heavy rains in December of 1999 and early January of 2000 caused the Incomati, Maputo, and Umbeluzi rivers to flood (Roger, 2006). When Cyclone Connie hit in early February, it brought record rainfalls to southern Mozambique causing the Incomati river to flood again (Roger, 2006). Another cyclone occurred at the end of February, caused severe flooding and the highest number of internally displaced people in the Gaza province (Roger, 2006). The district within Gaza that had the highest number of victims was Chokwe. A survey found that 90% of those interviewed reported a decline in general health since the flooding (Kondo, et al., 2002). The most commonly detected illnesses were respiratory tract infections, diarrheal disease, and malaria (Kondo, et al., 2002).

Diarrheal disease was analyzed by a clinic that was opened by a Japanese Medical Team in Chokwe (Kondo, et al., 2002). The clinic operated for nine days and received 2,611 patients, which included children between 0-14 years of age (41.7%), young adults between 15-44 years of age (40.7%), and patients > 44 years of age (17.6%) (Kondo, et al., 2002). The study collected health information from those who used the health facilities following the floods (Kondo, et al., 2002). Diarrheal disease was diagnosed in 15% of patients that came into the health clinic following the flood (Kondo, et al., 2002). The number of patients with diarrhea increased 5-10-fold during the post-flood period compared to diarrheal cases from the year before, and the incidence of diarrhea was 2-4 times greater compared to the same period in other years (Kondo, et al., 2002). There were no cases of cholera or dysentery discovered in this particular area of Mozambique. However, in other districts where cholera was already endemic, approximately 17,000 new cases were diagnosed after the flood in 2000, suggesting an increased vulnerability of the population (Naidoo & Patric, 2002; "Weekly Epidemiological Record," 2001).

The impact of flooding on microbial exposure

There is substantial evidence that flooding can increase the risk of diarrheal disease and other diseases. However, only a limited number of these studies have tried to identify the exposures that could have led to infection. There is a large gap in knowledge about flood-related exposure and associated contamination of the environment with fecal-transmitted pathogens such as norovirus, *Cryptosporidium*, adenovirus, and *Escherichia coli.* The risk of exposure during flooding can be defined as the probability that an individual will be exposed to an infectious agent or toxin due to a flood event versus the probability that they will be exposed in the absence of exposure to a flood. This requires characterizing not only the concentration of contamination in flood and non-flood zones, but also the persistence of enteric pathogens and the behavioral practices of people that bring them into contact with flooding.

Evidence of increased exposure to diarrheal pathogens from floodwater

There is some evidence that suggests that increased exposure to fecal-contaminated water increases the risk of disease and that fecal contamination of water, including floodwater, increases after flooding. This evidence of contamination and exposure is derived from observational epidemiological modeling and microbial analysis.

An observational study in Salzburg, Austria suggested that contaminated floodwater with raw sewage caused a norovirus outbreak. This outbreak involved people who helped clean out a hotel that had flooded from heavy rainfall. Over 77% of the 64 tourists that helped clean the hotel became infected with norovirus (Schmid, Lederer, Much, Pichler, & Allerberger, 2005). Before the group was switched to another accommodation, they were heavily exposed to feces while cleaning the hotel sanitation system and there were reports of visible pieces of toilet paper and feces in the floodwater (Schmid et al., 2005). Along with the tourists, 60% of a group of 10 firefighters who pumped the floodwater out of the hotel also became infected (Schmid et al., 2005). The connection between the firefighters and tourist' illness with observations of toilet paper and feces strongly suggested that norovirus exposure occurred from the floodwater.

In Surabaya, Indonesia, hospital- and community-based studies investigated the prevalence, and mode of transmission of *Cryptosporidium* through questionnaires administered to patients experiencing diarrhea and controls with no gastrointestinal symptoms (Katsumata et al., 1998). Of the 917 cases with diarrhea, 2.8% were shedding

Cryptosporidium oocysts while 1.4% of 1,043 controls were shedding oocysts (Katsumata, et al., 1998). Logistic regression was used to model putative risk factors, such as rainy season, flood, and crowding, on the risk of infection with *Cryptosporidium* (Katsumata, et al., 1998). Both flooding (OR=3.083, 95% CI 1.935-4.912) and rainy season (OR= 10.655, 95% CI 1.382-82.177) were determined to be significant, although the confidence interval for rainy season was very wide (Katsumata, et al., 1998). Although drinking boiled water is common practice in Indonesia, exposure could have also occurred through the use of unboiled water in food preparation, washing hands, and taking baths (Katsumata, et al., 1998). The spread of *Cryptosporidium* by floodwater can be particularly hazardous due to a protective outer shell that allows the protozoan to live outside the body for long periods of time and to be resistant to chlorine disinfectants ("Parasites - Cryptosporidium (also known as "Crypto")," 2010). Because it is so environmentally durable, the risk of exposure for susceptible hosts can be prolonged for many months after contamination has occurred.

Experimental microbiological studies have confirmed that fecal contamination of water is increased after flooding. In New Zealand, water samples were collected during a natural flood event and an artificially created one to determine if flooding during rainfall causes an increase of *E. coli* in the streams (Nagels et al., 2002). The study area was surrounded by agricultural pastures used to pen warm-blooded animals, and contained significant quantities of animal feces. After both the natural and artificial flooding event, *E. coli* concentrations increased from 10^2 cfu/100 mL before the floods to 10^4 cfu /100 mL after flooding (Nagels et al., 2002). This suggests that fecal bacteria, such as *E. coli*, can be mobilized in floodwaters at high concentrations.

Similar conclusions were drawn after flooding in 2005 in Jakarta, the capital city of Indonesia. Jakarta lacks an adequate sewage system and regularly floods because of low elevation (Phanuwan et al., 2006). Following the 2005 flood in January, floodwater and river samples were collected for bacterial and viral analysis (Phanuwan, et al., 2006). Both river and floodwater samples contained high concentrations of norovirus, adenovirus, and *E. coli* contamination, but the floodwater had the highest levels of contamination (Phanuwan, et al., 2006). This evidence revealed that the floodwaters in Indonesia were spreading contamination and creating exposure risks for populations living in the impacted area. These studies demonstrate that flooding does increase fecal contamination of water.

The exposure of an individual to fecal-contaminated water depends on the contamination of the water as described above, duration of exposure, and frequency of exposure. Floodwaters not only spread water containing enteric pathogens, but they also spread sediments and soils (Solo-Gabriele, 2000). Die-off rates for enteric pathogens tend to be lower in sediments compared to water (Karim et al., 2004). Additionally, gravity causes microorganisms to settle and concentrate into sediments on the bottom of water bodies or containers. A study comparing wastewater and sediment samples determined that *Cryptosporidium* concentrations were two to three orders greater in sediment than in wastewater (Karim et al., 2004). The survival of fecal pathogens depends on the microorganism; some only live minutes to hours in the environment, while others, such as *Cryptosporidium,* can persist for months. The duration of exposure to enteric pathogens in the environment for an individual living in a previously flooded area can depend in part on how long the organisms persist in the environment. Some bacteria, such as *E. coli*, have the potential to not only persist, but multiply in environmental waters, sediments, and soils (Anderson et al., 2005; Karim et al., 2004).

Behavioral Response to Flooding

When flooding occurs, the behavioral response by residents living and working in an impacted area is an important factor that can either increase or decrease an individual's risk of exposure to fecal contamination. There is very limited information about human behavior during floods in developing countries, and most studies to date have been performed in Africa. Due to the frequency and regularity of flood events in many areas, residents have developed various strategies to prevent floodwater from reaching their households. In Accra, Ghana they use blocks, stones, and furniture to create barricades against high water levels (Douglas et al., 2008). In Nairobi, Kenya, households employed preventive factors, such as digging trenches around houses before flooding, constructing dykes or trenches to divert water away from house, securing structures with waterproof material, and using sandbags at the entrance of a house (Douglas et al., 2008; Mendel, 2006).

Most of the time, these preventative factors are only effective for decreasing the severity of flooding, but not the amount of exposure of individuals to fecal-contaminated floodwater. There is a similarity in behavioral response between residents of Accra, Ghana, and Nairobi, Kenya. When floodwaters start to rise, some people leave their homes in order to avoid it. Therefore, they have a decreased risk of exposure to fecal-contaminated water. However, many others tend to stay in their homes to protect their valuables and property (Douglas et al., 2008). Children have been placed onto high tables to avoid their exposure to the contaminated floodwater. However, adults experience significant contact with floodwater while bailing water out of their homes with buckets and digging trenches to channel the water elsewhere (Hollis, 1975; Douglas et al. 2008). The removal of floodwater by adults could directly increase their exposure to potentially-contaminated water and indirectly expose their children through hand contact.

As the literature reveals, limited evidence suggests that flooding can increase the amount of contamination in the environment and its geographic spread. This increases the number of individuals that could be exposed to the contamination in the floodwaters. Behavioral evidence from several African countries suggests that, in these developing countries, exposure is likely as flood victims frequently stay in their homes throughout and after flooding. Additionally, floodwaters can spread persistent enteric pathogens throughout the environment, which increase the geographic area where exposure can occur. This exposure can increase the risk of infection with an enteric pathogen.

In the future, flooding will become more severe due to climate change and urbanization of cities. There are very few studies that have systematically measured exposure by determining the population at risk, whether they are exposed, and whether living in a flood zone affects the concentration of feces and enteric pathogens in water and soil in the environment. Therefore, it is essential to collect data related to these exposure pathways in order to obtain a better understanding of who is at risk in the population.

Chapter 3: Research Objectives and Rationale

Research Objectives

1. To identify areas where flooding occurs in Shiabu, Bukom, Old Fadama, and Alajo in Accra, Ghana and estimate how many people are affected by flooding.
2. To describe the causes of flooding, the duration, the frequency, and the behavioral response to a flood in these communities.
3. Test whether soil, drain water, or floodwater samples collected during the rainy season from flood areas in the four study communities contain increased concentrations of fecal indicator bacteria and pathogens compared to soil and drain water collected from non-flood areas and explore the factors that might influence the risk of contamination.

Rationale

Changes in land use, such as road pavement and urban development may increase the frequency of small floods by up to 10 times per year. Severe floods that occur every 100 years could also double in size. These urban areas tend to be located in hazard-prone locations, typically in low elevation coastal areas such as Accra, Ghana.

Diarrheal diseases, vector-borne disease, and respiratory illness are the top three health issues reported after a flood event. Epidemiological studies in India, Bangladesh, Brazil, Indonesia, Mozambique, South Africa, Sudan, Germany, and United States have demonstrated that diarrheal disease rates soar after major flood events ("Health Assessment for the Population Affected by Flood Conditions," 1989; Kondo et al., 2002; Siddique, Baqui, Eusof, & Zaman, 1991). However, limited studies have been done to determine if there are differences from where the flood occurs and other areas.

The behavioral response to flooding is also an important factor that influences the risk of exposure to fecal contamination. There is very limited information describing the behavioral responses of people to floods in developing countries and the actual risk of exposure to fecal contamination. Many communities subject to frequent flood events have developed strategies to prevent floodwater from reaching the households. In Accra, Ghana they use blocks, stones, and furniture to create high places (Douglas et al., 2008). In Nairobi, Kenya, the main preventive factors used to decrease the entrance of water into homes included digging trenches around houses before flooding, constructing dykes or trenches to divert water away from house, and secure structures with waterproof material at the entrance of the house (Douglas et al., 2008).

Moist conditions in the rainy season increase the likelihood that enteric pathogens, such as pathogenic *E. coli* and norovirus will persist in floodwater, drain water, and soil. These floodwaters can remain in homes or communities for days, months, or even year-around. Thus, the risks of exposure and disease are impacted not just by the frequency and severity of flooding, but also by the duration that flood-related contamination persists in the environment. Accra was selected as the setting for this because it is an urban area that experiences annual flooding that causes damage. We will explore who is at risk, why, how do they respond, and do the people living in a flood zone experience increased risk of exposure compared to others in their communities.

Contribution of Student

I was involved in the development of the flood behavioral survey and microbiological data collection form. I traveled to Accra, Ghana to supplement the SaniPath study by collecting flood samples, doing behavioral data surveys, and mapping flood areas. The drain density information came from Stephanie Gretsch's data collection the summer of 2012. I carried out a two-week pilot study to see what needed to be adjusted in sampling and the behavioral surveys. After completion of the survey, I added the data in Microsoft Access, and transferred it to SAS 9.3 for analysis. The lab samples were partially processed by me and handed over to the lab team of SaniPath to do the membrane filtration for *E. coli* and RNA/DNA analysis. The data were added into the environmental sample database for SaniPath. I drafted the manuscript, including the figures and tables, which were edited by my thesis advisor and committee member.

Chapter 4: Manuscript

METHODS AND MATERIALS

Study sites. This study was conducted as a part of a more comprehensive, Gates Foundation-funded exposure assessment study called "SaniPath" based in Accra, Ghana. Accra is an excellent model for studying the impact of flooding in rapidly growing cities that suffer from annual flooding events. A list of potential study communities in Accra was generated, along with a basic description of their demographic characteristics, such as: formal/informal settlements, religion, sanitation coverage, and coastal/inland geography. Communities where other water, sanitation, and hygiene (WASH) related projects were currently in progress were excluded due to concerns about potential confounding. Four communities of Alajo, Bukom, Shiabu, and Old Fadama were chosen based upon the primary goal of diversity in physical and socio-demographic characteristics.

SaniPath microbiological data. SaniPath collected soil and drain water samples in dispersed areas in each community between March and December of 2012 for microbial analysis. This nested study supplemented data collection efforts, specifically in flood zones, to ensure adequate microbial data was available for analysis. *E. coli* and norovirus GI/GII concentration in soil and drain water samples were compiled from the entire dataset for each community.

GIS mapping. *Flood areas.* A community liaison in each of the four communities was asked to identify areas that typically flooded after rainfall. A flood area was defined as an area that experienced standing water for more than two hours after a rainfall event. Perceived flood areas were mapped by walking the boundaries using the “tracking” option on a Garmin Etrex Venture HC unit with 1-meter resolution was used to collect Global Positioning System (GPS) points. A brief survey was administered to a resident living within the identified area to corroborate the classification of the area as a flood zone. The Garmin points and tracking option were uploaded to the Garmin application on the computer, then plotted in Google Earth, and then transferred to Geographic Information System (ArcGIS). Once the flood areas were mapped in GIS, each flood area was formed into a polygon to determine the total area in square meters that flooded within the communities.

Drain density in each flood area. Drain information was collected by GPS points in the field, and like the flood data, was transferred to GIS in order to map the drains within each community. The drains were clipped to the flood areas to determine drain density of those areas. Drain density (1/m) was calculated as the total length of drains in a specific flood area (m) divided by the total area of that specific flood area (m^2) ("Calculating Geometry and Drainage Density", 2008).

Distance of environmental samples from public latrine. GPS points were collected for all public latrines within the four communities by SaniPath staff and were converted into shapefiles for GIS. The public latrine shapefile was used to determine the distance between the soil, drain water, and floodwater samples and the nearest public latrine. A distance of less than 20 meters was chosen as criteria for increased environmental contamination risk based on the World Health Organization (WHO) recommendation for safe distance from a latrine. In GIS the “select by distance option” was used on the public latrine shapefile to determine whether environmental samples were collected within 20 meters of a public latrine.

Determination of population at risk for flooding. Alajo, Bukom, and Shiabu census data was used to calculate the population in each area. The community boundary was overlaid on the census data and used LandScan to apportion the population of each community (LandScan). For Old Fadama, a census of the population within the community in 2009 was available (Housing the Masses, 2010). The percentage of area within each community that flooded was calculated by summing the square area within each mapped flood boundary. The estimated population density was multiplied by the total area within a flood zone in each community to approximate the number of people at risk for exposure to floodwater.

Survey methods. At least one resident was randomly identified in almost every flood area to participate in a survey. The survey contained ten questions about the frequency, duration, cause, preventive factors, and management of flooding within the area (Appendix A and B). The questions were asked open-ended in order to not influence the resident's response, and to discover other answers that were not already considered in preparation of the survey. Data were recorded in Microsoft Access and then transferred to Statistical Analysis System (SAS) 9.3 for descriptive analysis.

Cause of flooding. There were seven hypothetical causes of flooding included in the survey questions (Appendix A). The selected causes of flooding for the survey were 1) "Overflowing of drains", which occurred when water would rise above the drain and run onto the surrounding land (Appendix A; Figure 1). 2) "Water cannot reach a drain" was defined as situations where drains were present but were distant from the flooded area or were at a higher incline (Appendix A). Therefore, standing water remains until it dries up or someone removes it by bucket. 3) "No drains" means that there were no drains in the area sufficient for removing floodwater. This response also included situations where there was insufficient change in slope for the water to flow to a distant drain (Appendix A). Therefore, the water dries in the sun or is removed by buckets. The only difference between "water cannot reach the drain" and "no drain" is purely the presence or absence of a drain within the vicinity. For 4) "low lying areas" the ground was already saturated and damp (Appendix A). Rainfall easily causes the area to flood due to its low elevation. These areas tended to be close to another water source, such as a large drain or beach (Figure 1). 5) "High volume rainfall" indicates a heavy amount of rainfall that triggers immediate overflowing of drainage canals (Appendix A). 6) "No planned structures" were defined as an area where houses were built on top of, or near drains and subsequently prevented proper drainage (Appendix A; Figure 1). 7) "Unfinished drains" were defined when construction of a formal drain would abruptly end in the middle of an area and water would flow into the surrounding area (Appendix A).

Figure 1. Causes of Flooding in the Four Communities.

Preventive measures in response to flooding. There were eight preventive measures included on the survey (Appendix A). Digging drains, raising building structures, and bailing water out of houses were noted through literature on flooding in communities of Africa and were added to the survey (Douglas et al., 2008). “Digging drains” meant that residents used knives or other tools available to create a drain with dirt or concrete to channel water elsewhere (Appendix A; Figure 2). “Raised building structures” included any structures built on stilts to prevent water infiltration (Appendix A; Figure 2). Options not considered that came up in the “Other” section during interviews included cement walls, crushed cement, bucketing out water, guiding water out onto pavement, removal of drain blockage, and covering cracks in doors with rags. Cement walls were used to prevent the water from drains or standing water from being able to reach the house (Appendix A; Figure 2). Crushed cement also was placed in a layer around the house to help absorb water. Another method was bailing out standing water in order to decrease the amount that came into homes. Other methods included guiding water out onto the pavement or removing blockages from the drains to make the water flow. Rags were used to cover cracks in the doors to prevent the water from getting in until the water stopped rising.

Figure 2. Preventive Factors Used in the Four Communities.

Sample collection and microbial analysis. *Field collection.* Flood-related samples were collected in order to supplement the soil and drain water samples already collected by the SaniPath project. The GPS coordinates of each soil, drain water, and floodwater sample were recorded using a Garmin Etrex Venture HC with 1-meter resolution. When a sample was taken, observations of specific characteristics of flooding in that area were recorded (Appendix B). Before sample collection, clean gloves were sprayed and rubbed with 70% ethanol. Soil samples were collected by using a sterile spatula to scoop up soil sediment at a depth of 5 cm from up to seven areas at the location. Composite samples were placed in one sterile 100 mL Whirl-Pak bag. Drain water and floodwater samples were collected by lowering a sterilized bailer into the water with a rope, and then pouring the water into a 500 mL Whirl-Pak bag. Afterwards, the spatula and bailer were re-sterilized by ethanol and flaming. The Whirl-Pak bags were placed on ice packs and taken to the lab for processing within 6 hours of collection.

Processing of soil samples. The 100 mL Whirl-Pak Bag was rotated five times to mix the dry sample. Clean gloves were sprayed and rubbed with 70% ethanol. On a weighing scale, 10 grams of sample were measured into a sterile 50 mL tube and 20 mL of sterile 1x PBS (phosphate-buffered saline, pH 7.2) was added. The sample was shaken vigorously on a rotator or shaker for 30 minutes at room temperature. The sample was allowed to settle for 15 minutes and then a 10 mL volume was transferred by pipet into a new sterile tube. Samples were serially diluted with sterile PBS and 1 mL, 0.1 mL, and 0.01 mL volumes of floodwater were reserved for *Escherichia coli* (*E. coli*) assays. A 1.5 mL sample was aliquoted into a 1.7 mL Eppendorf tube for DNA extraction, and stored at 4°C. Another 1.0 mL sample was aliquoted into a 1.7 mL Eppendorf tube and mixed with 0.12 grams of PEG (Polyethylene glycol) for RNA extraction, and stored at 4°C.

Processing of drain water and floodwater samples. The 500 mL Whirl-Pak bag was rotated five times to mix the sample. Clean gloves were sprayed and rubbed with 70% ethanol. Samples were serially diluted to 10^{-1}, 10^{-2}, 10^{-3}, 10^{-4}, 10^{-5}, 10^{-6}, and 10^{-7} volumes by mixing 900 µl of 1x PBS with 100 ul of raw sample and vortexing for 10 seconds. The 10^{-5}, 10^{-6}, and 10^{-7} serial dilutions of drain water were reserved for fecal *E. coli* assays. A volume of raw sample was reserved for DNA (1.5 mL) and RNA (1.0 mL plus 0.12 g PEG) extraction.

E. coli membrane filtration for samples. BBL MI agar was prepared by mixing 36.5 grams of BBL MI powder in 1L of purified water and autoclaving it at 121°C for 15 minutes. Prior to pouring plates, 5 mL of 1 mg/mL cefsulodin was added per liter of tempered agar medium. These were dispensed in 5-7 mL amounts in 15x60 mm plates and allowed to solidify and dry, and then stored in 4°C until use. Membrane filtration for *E. coli* assays was performed by vacuum filtering either 1x PBS (negative control) or prepared dilutions of a sample (MI Medium - U.S. EPA Method 1064, 2009). The filter was then rolled onto the MI agar plate and incubated at 37°C for 20 to 24 hours. *E. coli* colonies were enumerated by counting the blue or indigo colonies for each sample dilution. If the colony counts were greater than 200, the dilution was labeled as "too numerous to count" and the next lowest dilution was counted instead. If the concave blue and indigo colonies could not be clearly distinguished from background filth, then they were labeled as "too dirty to count". The goal was to identify plates with 20-80 colonies for enumeration. Total coliforms were identified under normal/ambient light by counting all blue/green fluorescent bacteria (*E. coli*), blue/white fluorescence (total coliforms other than *E. coli*), and blue/green with fluorescent edges (also *E. coli*).

RNA and DNA extraction. RNA/DNA was extracted from soil, drain water, and floodwater using the Qiagen Viral RNA kit/FastSoil DNA extraction kit. Viral Extraction: RNA extraction Buffer AVE-carrier mix was mixed with calculated Buffer AVL solution in order to create a lysis buffer; then vortexed for 30 seconds. Afterwards 560 uL of lysis buffer was added into each RNA extraction tube with the PEG concentrated sample. After incubation for 10 minutes at room temperature, the sample was centrifuged to remove any top liquid. Then 560 ul of ethanol was pulse vortexed for 15 seconds to pellet any remaining particles. All of the supernatant was transferred to the column in the vacuum. The column was washed with AW1 buffer (750 ul) and AW2 buffer (750 ul), followed by centrifuging for 1 minute at 13,200 rpm at 4°C. After transferring the dry column to a sterile microcentrifuge tube, the RNA was eluted with 50 ul of elution buffer. The tube was incubated at room temperature for 5 minutes and centrifuged to elute the viral RNA for 1 minute at 9,400 rpm at 4°C.

Quantitative PCR for Norovirus GI and GII. Reverse Transcription Polymerase Chain Reaction (RT-PCR) was used for norovirus to determine the concentration in each sample. A 15.0 uL master mix was prepared with molecular H_2O (5 uL), 5x buffer (5.0 uL), dNTP (10mM, 1.0 uL), COG2 F (10uM, 1.0 uL), COG2 R (10uM, 1.0 uL), RING2-TP (10uM, 0.5 uL), RNAse inhibitor (0.25 uL), and Qiagen enzyme (1.0 uL). The 15.0 uL of master mix was aliquoted into the 0.2 mL PCR tubes of either a 96 well plate or individual tubes. The PCR negative control contained 10 uL of molecular water. For the test samples, 10 uL of RNA was added to each PCR tube. The PCR conditions were 50°C for 32 minutes, 95°C for 15 minutes, 95°C for 15 seconds, and 56°C for 1 minute for a total of 45 cycles. Concentrations of samples were determined by comparison to a standard curve, obtained by plotting the fluorescent signal detected over 40 consecutive cycles of amplification of four serially diluted Norovirus standard concentrations.

Data management. Before the project was conducted, a small pilot study of the GPS point collection, survey, and lab protocols was used for 2-3 weeks in order to test the tools and make any necessary changes. Each sample collected was coded with a barcode, and was double entered into the SaniPath database. The hardcopy forms were checked by SaniPath personnel as a third measure to identify any inconsistencies in the data.

Analytical methods. *Descriptive analysis*. Maps of flood vs. non-flood area, drain density, and less than 20 meters from a latrine were created in ArcGIS 10.1. The flood vs. non-flood areas were derived from the kmz file drawn into Google Earth using GPS points (0=Non-flood area, 1= Flood area). The drain densities for all samples were classified into 3 categories: low, medium, or high density tertiles. Those of low density were less than or equal to 0.016 linear meter of drain per m^2 of flood area, medium density was between 0.016 and 0.031 linear meter of drain per m^2 of flood area, and the highest percentile of areas contained greater than or equal to 0.031 linear meter of drain per m^2 of flood area. A binary variable for distance to a public latrine was also created (0= Further than 20 meters from a latrine, 1= Within 20 meters from a latrine).

The presence, absence, and concentration of *E. coli* and norovirus GI/GII in soil, drain water, and floodwater samples were compared for flood and non-flood zones, categorical drain density, and less than 20 meters distance to a public latrine using SAS 9.3. The number of samples, and percentage, median, and range of the positive samples were complied into separate tables for *E. coli* and norovirus GI and GII. *E. coli* samples were calculated per gram and the drain water and floodwater were calculated per 100 mL after multiplying the number of colonies by the proper dilution. Weighted boxplots were used to display the distribution of log concentrations of *E. coli* for each of the three variables (flooding, drain density, and distance to a latrine). *E. coli* was used as indicators of all types of feces, and norovirus were used to quantify the presence of human feces in the sample.

Norovirus drain and floodwater samples were extracted from 1 mL of undiluted and unconcentrated sample and recovered in 50 uL of sterile water. For soil, 1 mL of soil elute (equivalent to 0.5 grams recovered by washing 10 grams in 20 mLs of buffer) was extracted and eluted with 50 uL of sterile water. A 5 uL volume of each sample extract was run in duplicate for norovirus GI and GII. The quantity of genomic equivalent copies (GEC) of norovirus was calculated by comparison of strength of the amplification fluorescent signal to the standard curve for norovirus standards. If duplicate GEC values were obtained, the average GEC for each duplicate was used as the final GEC for each sample. We then multiplied the estimated GEC of virus per 5ul by 1000 to reach the reported concentration of norovirus per 100 mL. The norovirus concentration per gram of soil was calculated by multiplying the average GEC per 5 ul by 2.

Linear regression models. Linear regression was used to model the association between flood zone, categorical drain density, community, and distance from a latrine less than 20 meters on the log concentration of *E. coli* in soil and drain water samples. Interaction and confounders were examined against the primary independent variable of interest, flood vs. non flood areas. The community variable was expressed as three dummy variables with Shiabu as the reference and chunkwise method applied to communities with flood vs. non-flood areas. Four interaction variables were formed with flood vs. non-flood, which were communities, distance from a latrine, or drain density to determine if there was effect modification ($\propto < 0.05$). Each interaction term was removed from the model one-by-one starting with the highest p-values. Only variables with a p-value of less than 0.05 were left in. Three independent variables were analyzed for whether each was a confounder for association between flood vs. non-flood areas and log concentration of *E. coli* contamination. Confounders were removed one-by-one, starting with the highest p-value. If the removal of one variable caused the flood vs. non-flood area beta to change by more than +/- 10%, then it was considered a significant confounder and kept in the model. If not, the variable was permanently removed from the model. An all possible regression model was run to determine the R^2, C(p), AIC, BIC, and MSE. The model of *E. coli* concentration in soil included the following variables: flood areas, Old Fadama, distance to a latrine, and drain density. The model of *E. coli* concentration in drain water included the following variables: flood areas, drain density, and distance to a latrine.

RESULTS

Mapping of flood areas

The primary criterion that defined a flood zone in the four communities was based on the liaison's judgment. The liaisons were local residents who were highly familiar with all areas in the community and who were most likely to communicate with other residents about community level issues. Residents who were survey participants in a flood zone were also asked to confirm the report of flooding (Figure 3). There was good agreement between the liaison and resident's opinion. Only at one point in Alajo did a resident's perception of an area being a flood zone differ from that of the liaison. The liaison thought it was a flood zone; however, the resident claimed it was not because the water would only last 5-10 minutes after rainfall.

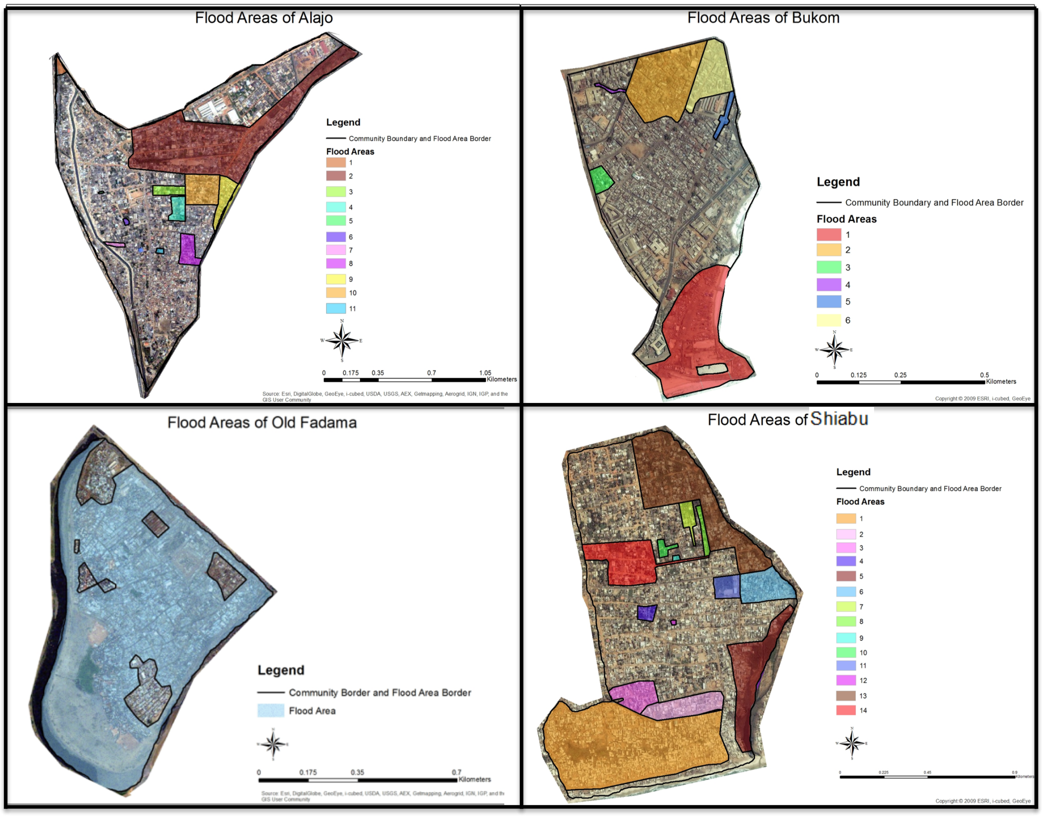

Figure 3. Numbered Flood Areas in Each of the Four Study Communities.

Percentage of area that floods and number of residents affected

The communities with the largest total flood area were Alajo, followed by Shiabu, Old Fadama, and Bukom (Table 1). The communities with the highest percentage of flooded area and number of residents affected by flooding were: Old Fadama (87.36%, 69,612), Shiabu (48.51%, 5,871), Bukom (33.02%, 2,800), and Alajo (28.98%, 4,104) (Table 1; Figure 3). The individual flood areas are shaded, and a black border indicates boundaries. Adjacent flood areas with a black border represent different zones divided by a road that does not flood (Figure 3).

Table 1. Proportion of Area Affected by Flooding and Estimated Number of Residents Affected by Flooding in Each Community.

	Total Area of Community (m^2)	Total Flood Area (m^2)	Percentage of Flooded Area in Community (%)	Population	Number of Residents Affected by Flooding
Alajo	1,632,003	472,990	28.98	14,161	4,104
Bukom	369,875	116,129	31.40	8,917	2,800
Old Fadama	561,886	490,887	87.36	79,684	69,612
Shiabu	1,540,786	747,507	48.51	12,103	5,871

$$\text{Percentage of Flooded Area in Community} = \frac{\text{Total Flood Area}}{\text{Total Area of the Community}}$$

Estimated Number of Residents Affected by Flooding = Percentage of Flooded Area in the Community * Population

Causes of flooding

The liaison and residents' perception of the main cause of flooding overlapped and differed for each area (Table 2). For those that did not overlap, this is most likely due to there being more than one potential cause of flooding identified in the area (Table 2). For example, in flood area #8 in Alajo, the liaison said it was due to high volume rainfall, and the resident claimed it was due to overflooding of the drain because it was clogged (Table 2). However, when there is high volume rainfall, this causes trash to move into the drains and clog the drain; hence both factors play a role in flooding.

Table 2. Perceptions of Liaisons and Residents on the Causes of Flooding in the Four Study Communities of Accra.

	Liaison	Liaison's Opinion on Cause of Flooding	Resident	Resident's Opinion on Cause of Flooding	Observation Conducted
Alajo Flood Area					
1	X	Water cannot reach the drain			
2	X	Water cannot reach the drain	X	Low lying area	X
3	X		X	Overflowing of drain because it is clogged	
4	X		X	High volume rainfall	
5	X				
6	X	Overflowing of drain because it is clogged			
7	X		X	Overflowing of drain because drain capacity inadequate for rainfall	
8	X	Overflowing of drain because drain capacity inadequate for rainfall	X	Overflowing of drain because drain capacity inadequate for rainfall	
9	X	High volume rainfall	X	Overflowing of drain because it is clogged	
10	X		X	Overflowing of drain because it is clogged	
11	X	No drains	X	No layout	
Bukom Flood Area					
1	X	Low lying area	X	Low lying area	X
2	X	No drains	X	No drains and low lying area	X
3	X	Low lying area due to erosion			X
4	X	Overflowing of drain because it is clogged			X
5	X	Overflowing of drain because it is clogged		Overflowing of drain because it is clogged	
6	X		X	Overflowing of drain because it is clogged	X
Old Fadama Flood Area					
1	X	Low lying area, no layout, and no drains	X	No drains and low lying area	X
Shiabu Flood Area					
1	X		X	Overflowing of drain because of incline	X
2	X	Overflowing of drain because of incline		No drains and low lying area	X
3	X	Overflowing of drain because of incline			
4	X	Drains do not connect	X	Low lying area	X
5	X	Low lying area, drains do no connect, and high volume rainfall	X	Drains do not connect	X
6	X	No drains	X	High volume rainfall	X
7	X	No drains			
8	X	Low lying area	X	Low lying area	X
9	X	Poorly constructed			
10	X				
11	X	No drains			
12	X	Low lying area			
13	X	Drain does not connect and lack of drains	X	Drain does not connect and water cannot reach the drain	X
14	X	Lack of drains	X	Overflowing of drain because it is clogged	X

In total, 30 households were interviewed about the causes of flooding, and a more extensive interview about flooding and behavioral response was administered in 20 of those households. Of the 20 extensive interviews, 8 took place in Alajo, 3 in Bukom, 2 in Old Fadama, and 7 in Shiabu. There were some differences in the causes of flooding in each community (Table 2; Table 3; Figure 3). In Alajo, there were many different flood areas; the main cause of flooding was overflowing drains, followed by low lying areas, high volume rainfall, and no planned structure (Table 3). The biggest flood area in Alajo was flood area #2, which was caused by low lying areas and poor drainage (Table 2; Figure 3). In Bukom, the two major causes of flooding were overflowing of drains and low lying areas (Table 3). Flood area #1 was the largest, and the primary cause of flooding was low lying areas and having only one drain that came from the higher elevation of the community (Table 2; Figure 3). Old Fadama was one large connected flood area due to overflowing drains, poor drainage, and low lying areas (Table 3, Figure 3). All of the causes of flooding contributed to substantial new flood events throughout the rainy season and persistence of standing water in the dry season for Old Fadama. In Shiabu, there were a variety of causes of flooding (Table 3). Shiabu was unique in one respect because flooding was caused by recent construction of drains in the area. However, the drains were not completed, so the area floods from water that pours out of the end of an unfinished drain. Overall, the major causes of flooding in the four communities were overflowing of clogged drains or inadequate drainage capacity and heavy rainfall, followed by low lying areas as the second major cause (Table 3).

Table 3. Reported Causes of Flooding in Each Study Community.

	Alajo n(%)		Bukom n(%)		Old Fadama n(%)		Shiabu n(%)		Overall N(%)	
What Causes Flooding in Your Area?	9	100	5	100	7	100	9	100	30	100
Overflowing of Drain	6	67	2	40	1	14	2	22	11	36
Water Cannot Reach the Drain	0	0	0	0	2	29	0	0	2	7
No Drain	0	0	1	20	1	14	1	11	3	10
Low Lying Area	1	11	2	40	3	43	3	34	9	30
High Volume Rainfall	1	11	0	0	0	0	1	11	2	7
No Planned Structure	1	11	0	0	0	0	0	0	1	3
Unfinished Drains	0	0	0	0	0	0	2	22	2	7
If Drain Overflows, Why?	6	100	2	100	1	100	2	100	11	100
Clogged Drain	4	67	2	100	0	0	1	50	7	64
Drain Capacity Inadequate for Rainfall	2	33	0	0	1	100	0	0	3	27
Drain is on an Incline	0	0	0	0	0	0	1	50	1	9

Observations were conducted in flood areas where microbiological samples were taken (Table 2). The main observed indicators in a flood zone were watermarks (93%), presence of standing water (87%), and preventive factors (80%) (Table 4). Lack of drains (40%) and observation of clogged drains (33%) were not reliable indicators (Table 4).

Table 4. Observation of Flood Indicators in Areas Reported as a Flood Zone.

	Observational Notes				
	Watermarks	Presence of Standing Water	Preventive Factors	Lack of Drain	Clogged Drain
Alajo Flood Area					
2	X		X		
Bukom Flood Area					
1	X	X		X	
2	X	X	X	X	
3	X	X	X	X	
4	X	X	X		X
6	X	X		X	
Old Fadama Flood Area					
1	X	X	X	X	
Shiabu Flood Area					
1	X	X	X		X
2	X	X	X		
4	X				
5	X	X	X		
6	X	X	X	X	
8	X	X	X		X
13	X	X	X		
14		X	X		
Total	14	13	12	6	3

X=Yes, [1]Clogged drain can only be present, if drain present

Reported duration of flooding

Flooding duration was variable depending on the community (Table 5). Flooding in Alajo generally lasted the shortest amount of time and was usually gone within a few hours to a few days (Table 5). In Bukom, flooding reportedly lasted one to two weeks. In the flood zone of Old Fadama, some floodwater was present throughout the year, including the dry season (Table 5; Figure 4). In Shiabu, flood duration was as little as a one week up to six weeks (Table 5). The largest flood area in Shiabu, zone #1, reported that flooding could last up to six weeks (Figure 3). This was an area where residents reported overflowing of drains that surrounded the border of the flood area (Figure 4). Then, the water would flow into smaller residential streets where there was a lack of drains and then remain stagnant for weeks.

Table 5. Reported Flooding Duration by Study Community.

	Alajo n(%)		Bukom n(%)		Old Fadama n(%)		Shiabu n(%)		Overall N(%)	
Number of Weeks the Flooding Lasts in Your Area?	8	100	3	100	2	100	7	100	20	100
0 Days	5	63	0	0	0	0	0	0	5	25
1 Week	3	37	1	33	0	0	2	29	6	30
2 Weeks	0	0	2	67	0	0	3	43	5	25
3 Weeks	0	0	0	0	0	0	0	0	0	0
4 Weeks	0	0	0	0	1	50	1	14	2	10
5 Weeks	0	0	0	0	0	0	0	0	0	0
6 Weeks	0	0	0	0	0	0	1	14	1	5
All Year	0	0	0	0	1	50	0	0	1	5

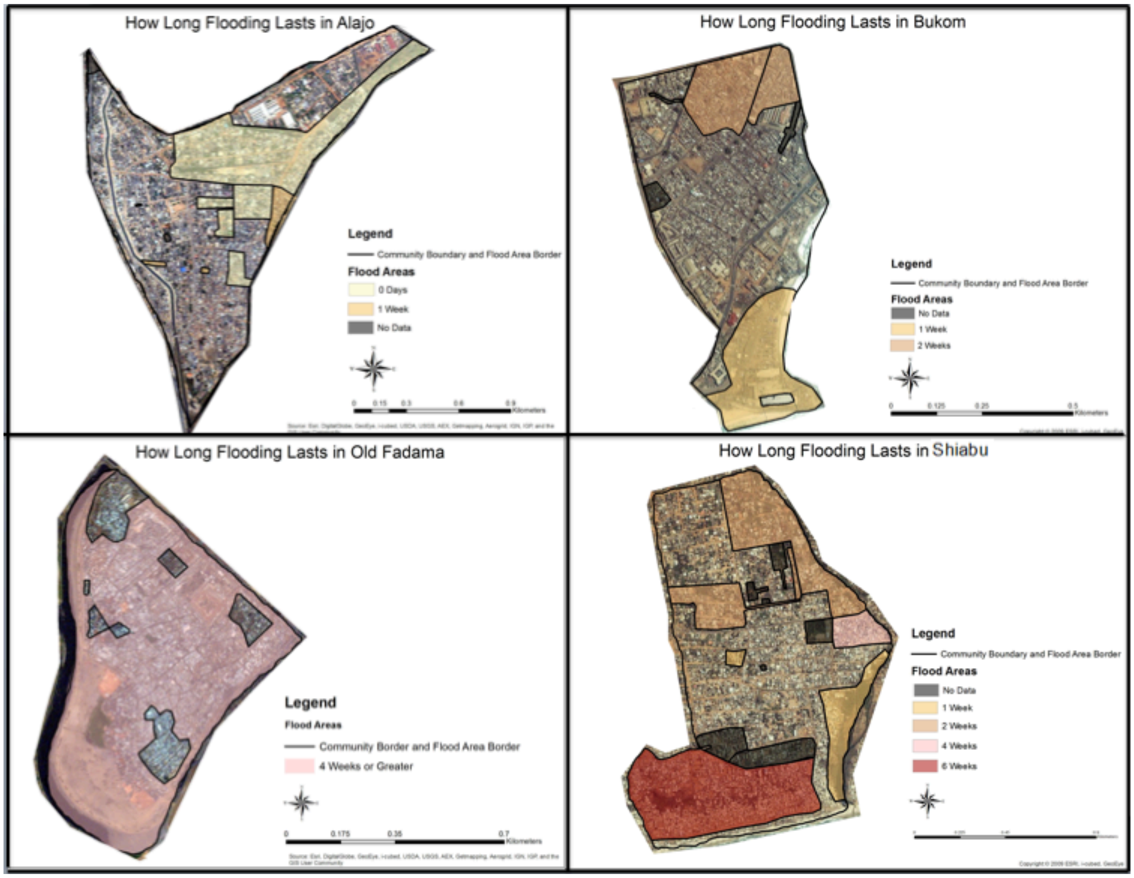

Figure 4. Flood Duration in Each Community of Accra.

Behavioral responses to flooding

Prevention of flooding in homes

Most residents reported that they tried to prevent flooding in their home; however, those that did not try to prevent flooding indicated that they had no way to prevent it

(Table 6). In Alajo survey respondents reported a range of ways to try to prevent flooding (Table 6). In general, heavy rainfall once or twice a year caused flash floods that lasted only 2-3 hours, so residents responded with simple, quick solutions such as rags to prevent water entry into the house (Table 6). In Shiabu, more permanent long-term preventive factors were used, including digging of drains, raising building structures, and constructing cement walls in areas where flooding lasts from a few weeks to a month (Table 6). The most frequently used preventive structures were raised building structures, cement walls, and bucketing out water (Table 6).

Table 6. Reported Practices to Prevent Household Flooding in Flood Zones in Four Study Communities of Accra.

	Alajo n(%)*		Bukom n(%)		Old Fadama n(%)		Shiabu n(%)		Overall N(%)	
Do You Try to Prevent Flooding in Your Home?	8	100	3	100	2	100	7	100	20	100
Yes	7	88	3	100	1	50	5	71	16	80
No	1	12	0	0	1	50	2	29	4	20
If Yes, How?	7	98	2	100	1	100	5	100	15	100
Digging of Drains	0	0	0	0	0	0	1	20	1	7
Raise Building Structure	1	14	0	0	1	100	2	40	4	27
Cement Walls	1	14	0	0	0	0	2	40	3	19
Crushed Cement to Absorb Water	1	14	0	0	0	0	0	0	1	7
Bucket out Water	1	14	2	100	0	0	0	0	3	19
Guide it Out to Pavement	1	14	0	0	0	0	0	0	1	7
Move What is Blocking the Drain	1	14	0	0	0	0	0	0	1	7
Rags to Cover Cracks in Door	1	14	0	0	0	0	0	0	1	7
If Not, Why?	1	100	1	100	1	100	1	100	4	100
Does Not Enter	1	100	0	0	0	0	0	0	1	25
No Way to Prevent, Wait to Dry	0	0	1	100	1	100	1	100	3	75

*Alajo Total for “If, Yes How?” was 98%

<u>Behavioral practices for leaving the home during flooding</u>

The only two areas where people would leave their homes during a flood event were in Alajo and Old Fadama (Table 7). Residents in Alajo tend to have more resources and wealth than those of the other communities and may have been able to better secure their houses before leaving behind their belongings. Those that remained in their homes generally did so in order to protect possessions, or had nowhere else to go to. Children stayed in houses with adults, except for one household in Alajo that sent their children away during flooding (Table 7). When the children were kept in the house during the flooding, they were put on top of a high object like a table to protect them from exposure to the floodwater. Those in Old Fadama explained that when their houses flood, they sleep on their mattress, which floats on top of the floodwater that may have fecal contamination.

Table 7. Number of Adults and Children that Stay or Leave their Houses during Flooding.

	Alajo n(%)		Bukom n(%)		Old Fadama n(%)		Shiabu n(%)		Overall N(%)	
Do You Stay in Your Home After Flooding?	8	100	3	100	2	100	7	100	20	100
Yes	4	50	3	100	1	50	7	100	15	75
No	3	37	0	0	1	50	0	0	4	20
Sometimes	1	13	0	0	0	0	0	0	1	5
Do Your Children Stay in Your Home After Flooding?	8	100	3	100	2	100	7	100	20	100
Yes	3	37	3	100	1	50	7	100	14	70
No	4	50	0	0	1	50	0	0	5	25
Sometimes	0	0	0	0	0	0	0	0	0	0
Not Applicable	1	13	0	0	0	0	0	0	1	5

Behavioral patterns for removing floodwaters from the home

Three-fifths of residents indicated that they actively removed floodwaters from their homes (Table 8). For those with flooding, residents reported that they left until the area dried out or put their property on high tables. Among the residents that did remove floodwater, all responded that water removal was performed with buckets (Table 8).

Table 8. Reported Practices for Removing Floodwater from Flooded Homes in Four Study Communities.

	Alajo n(%)		Bukom n(%)		Old Fadama n(%)		Shiabu n(%)		Overall N(%)	
Do You Remove Floodwaters from Your Home?	7	100	2	100	2	100	5	100	16	100
Yes	4	57	2	100	2	100	4	80	12	75
No	3	43	0	0	0	0	1	20	4	25
If Yes, How?	4	100	2	100	2	100	4	100	12	100
Buckets Out Water	4	100	2	100	2	100	4	100	12	100
If No, Why?*	3	99	0	0	0	0	1	100	4	100
Wait Until Water is Gone	1	33	0	0	0	0	1	100	2	50
Put Property on Table	1	33	0	0	0	0	0	0	1	25
Leave Short Term During Flooding	1	33	0	0	0	0	0	0	1	25

*Alajo Total for "If No, Why?" was 99%

*Among residents who indicated their houses flooded

Effect of season on feces disposal in community drains

When drains become filled during heavy rainfall, flooding becomes a potential concern, as does the potential for fecal contamination in the water. The sources of potential fecal contamination are important to identify for future mitigation efforts to decrease the resident's risk of exposure. The response to the question about feces disposal in community drains was evenly divided between daily disposal of feces in the drains and never disposing of feces in the drains (Table 9). This practice differed by neighborhood and whether there were drains within the vicinity. In Bukom and Shiabu, the question was not applicable for some residents because there were no drains in the area (Table 9). The residents indicated that feces disposal in drains occurred with the same frequency, or more in the rainy season than in the dry season (Table 9).

Table 9. Disposal of Feces in Drains by Study Community.

	Alajo n(%)		Bukom n(%)		Old Fadama n(%)		Shiabu n(%)		Overall N(%)	
How Often Do You See Feces Dumped in Drains in Your Neighborhood Every Week?	8	100	3	100	2	100	7	100	20	100
Always (Everyday)	4	50	1	33	1	50	2	29	8	40
Often (Every Other Day)	0	0	0	0	0	0	0	0	0	0
Sometimes (Once A Week)	1	13	0	0	0	0	1	14	2	10
Never	3	37	0	0	1	50	3	43	7	35
Not Applicable	0	0	2	67	0	0	1	14	3	15
Do You See This More, Less, or the Same Amount in the Rainy vs. Dry Season?	8	100	3	100	2	100	7	100	20	100
More Often	3	37	1	33	0	0	2	29	6	30
Less Often	0	0	0	0	0	0	0	0	0	0
Same	2	25	0	0	1	50	1	14	4	20
Never	3	38	2	67	1	50	4	57	10	50

E. coli concentration in environmental samples from the four study communities

Most soil, drain water, and floodwater samples had *E. coli* contamination (Table 10). More than 88% of soil and drain water samples were positive for *E. coli*, regardless of whether they were collected from flooded areas, different density of drains in the neighborhood, or distance from latrines (Table 10).

Table 10. Percentage of Positive *E. coli* Samples for Soil, Drain Water, and Floodwater for all Four Communities.

	N (% positive)					
	Soil		Drain Water		Floodwater	
Flooding	286		98		10	
Flood	150	(92.0)	50	(92.0)	10	(70.0)
Non-flood	136	(93.4)	48	(89.6)	0	(0.0)
Drain Density*	286		98		10	
Low	106	(91.5)	26	(88.5)	2	(100.0)
Medium	135	(94.1)	50	(88.0)	5	(40.0)
High	45	(91.1)	22	(100.0)	3	(100.0)
Latrine	286		98		10	
Within 20 meters	43	(86.1)	11	(100.0)	1	(0.0)
Further than 20 meters	243	(93.8)	87	(89.7)	9	(77.8)

*Drain density was separated into tertiles of low (≤0.016 linear meter of drain per m^2 of flood area), medium, (>0.16 and ≤0.031 linear meter of drain per m^2 of flood area), and high (>0.032 linear meter of drain per m^2 of flood area)

E. coli concentrations in environmental samples ranged from $1.4*10^{-2}$ to $1.6*10^{5}$ CFU/gram in soil, $7.1*10^{-1}$ to $1.5*10^{11}$ CFU/100 mL in drain water, and $7.1*10^{-1}$ to $1.0*10^{9}$ CFU/100 mL in floodwater samples (Table 11). *E. coli* concentrations in soil, drain water, and floodwater samples in flood versus non-flood areas were not visually different (Table 11). The drain water samples had the highest concentration of *E. coli*, followed by floodwater samples and soil samples (Table 11). *E. coli* concentrations in soil and drain water samples were both similar in flood and non-flood areas (Table 11, Figure 5). *E. coli* concentrations in soil, drain water, and floodwater in low, medium, and high density drain areas did not significantly differ (Table 11, Figure 6). Drain water and floodwater samples were similar with high, low, and than medium drain density having the highest concentration of *E. coli*, respectively (Table 11). *E. coli* concentrations in soil, drain water, and floodwater samples collected within 20 meters of a latrine versus those collected more than 20 meters away from a latrine were not significantly different (Table 11, Figure 7).

Table 11. *E. coli* Concentrations (CFU) in Soil, Drain Water, and Floodwater Samples from Four Study Communities.

	CFU of *E. coli* per gram in Soil Samples			CFU of *E. coli* per 100 mL in Drain Water Samples			CFU of *E. coli* per 100 mL in Floodwater Samples		
	n	Median	Range	n	Median	Range	n	Median	Range
Flooding	286			98			10		
Flood	150	$3.4 *10^{3}$	$1.4*10^{-2}$ - $1.6*10^{5}$	50	$1.9*10^{8}$	$7.1*10^{-1}$ - $1.5*10^{11}$	10	$5.3*10^{5}$	$7.1*10^{-1}$ - $1.0*10^{9}$
Non-flood	136	$9.6*10^{2}$	$1.4*10^{-2}$ - $1.6*10^{5}$	48	$3.3*10^{8}$	$7.1*10^{-1}$ - $7.2*10^{10}$	0	0.00	0.00
Drain Density	286			98			10		
Low	106	$6.3*10^{2}$	$1.4*10^{-2}$ - $1.6*10^{5}$	26	$2.4*10^{8}$	$7.1*10^{-1}$ - $1.5*10^{11}$	2	$3.2*10^{7}$	$2.0*10^{4}$ - $6.4*10^{7}$
Medium	135	$3.3*10^{3}$	$1.4*10^{-2}$ - $1.6*10^{5}$	50	$1.5*10^{8}$	$7.1*10^{-1}$ - $1.5*10^{10}$	5	$7.1*10^{-1}$	$7.1*10^{-1}$ - $1.0*10^{6}$
High	45	$5.2*10^{3}$	$1.4*10^{-2}$ - $8.0*10^{4}$	22	$1.2*10^{9}$	$1.0*10^{7}$ - $7.2*10^{10}$	3	$9.1*10^{7}$	$1.3*10^{5}$ - $1.0*10^{9}$
Latrine	286			98			10		
Within 20 meters	43	$7.3*10^{2}$	$1.4*10^{-2}$ - $1.6*10^{5}$	11	$5.2*10^{8}$	$1.0*10^{7}$ - $1.8*10^{10}$	1	$7.1*10^{-1}$	$7.1*10^{-1}$
Further than 20 meters	243	$2.2*10^{3}$	$1.4*10^{-2}$ - $1.6*10^{5}$	87	$2.4*10^{8}$	$7.1*10^{-1}$ - $1.5*10^{11}$	9	$9.3*10^{5}$	$7.1*10^{-1}$ - $1.0*10^{9}$

* $1.4*10^{-2}$ and * $7.1*10^{-1}$ represents negative samples at the lower limit of detection

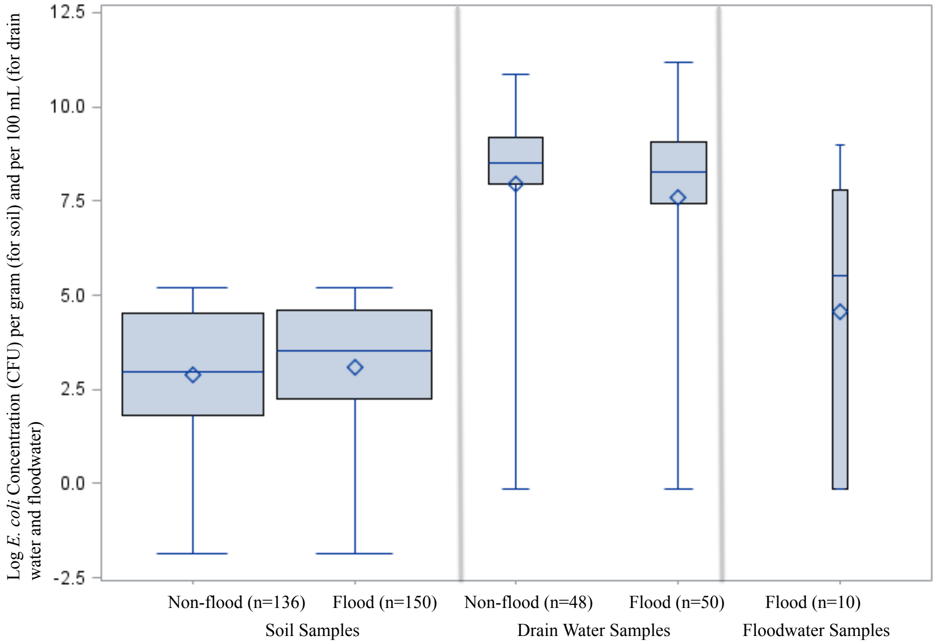

Figure 5. Weighted Boxplots of Log *E. coli* Concentration (CFU) in Soil, Drains, and Floodwater Samples by Flood vs. Non-flood Areas.

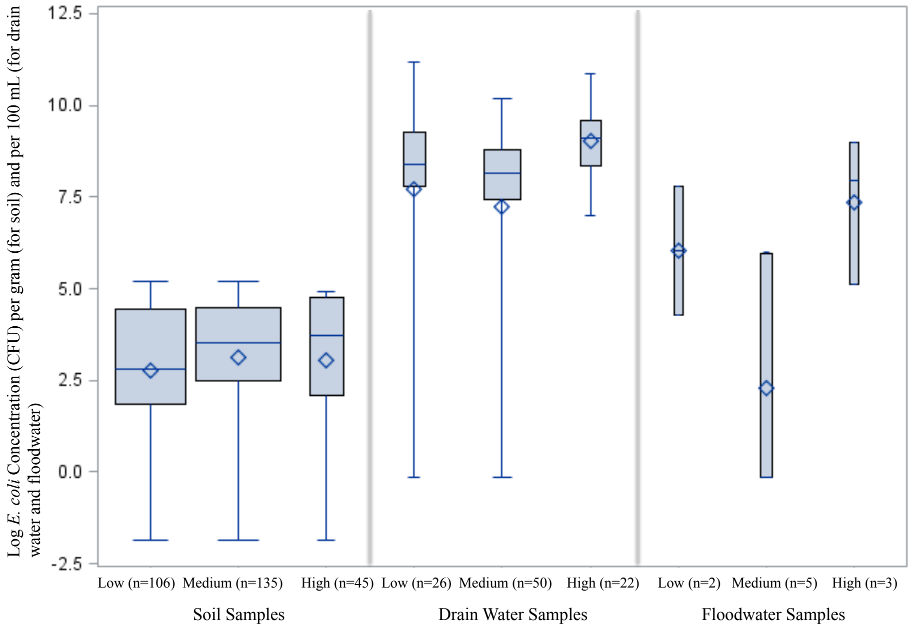

Figure 6. Weighted Boxplots of Log *E. coli* Concentration (CFU) by Drain Density.

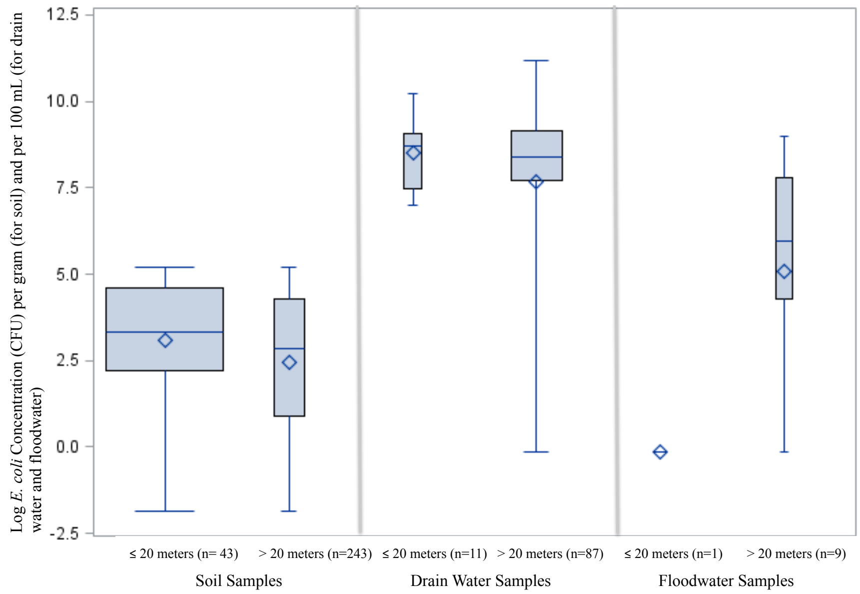

Figure 7. Weighted Boxplots of Log *E. coli* Concentration (CFU) by Latrine Distance.

Multivariable linear regression model

A linear regression model was used to model the impact of flooding, drain density, neighborhood, and proximity to a latrine on log *E. coli* concentration in soil samples (Table 12). The soil regression model had an adjusted coefficient of determination (R^2) of 0.0641, Mallows' Criterion (C(p)) of 5.00, Akaike Information Criterion (AIC) 333.1518, Bayesian Information Criterion (BIC) of 335.3356, and residual mean square (MSE) of 3.28420. The variables included in the model were flood areas, the community of Old Fadama, less than 20 meters to a latrine, and drain density. Drain density was a confounder of *E. coli* concentration and flood areas. Samples collected in Old Fadama and less than 20 meters to a latrine were associated with higher *E. coli* concentrations (Table 12).

Table 12. Predictors of *E. coli* Concentration (CFU/gram) in Soil Samples.

Variables	Beta Coefficient	P-value	Potential Confounders for Flood vs. Nonflood Areas
Flood Area	-0.15059	0.5422	----
Old Fadama	1.16409	<0.0001*	No
Less than 20 meters to a Latrine	3.41529	0.0263*	No
Drain Density	-0.69285	0.6993	Yes
*Significant values by Linear Regression α<0.05			

Best-Fit Model: $\hat{y}$= 2.51391 - 0.15059(Flood Area) + 1.16409(Old Fadama) + 3.41529(Less than 20 meters to a Latrine) -0.69285(Drain Density)

A linear regression model was used to model the affect of flooding, drain density, neighborhood, and proximity to a latrine on log *E. coli* concentration in drain water (Table 13). All the variables left in the model were confounders. The drain water regression model has an adjusted R^2 of 0.0052, C(p) of 6.00, AIC of 196.5759, BIC of 199.3670, and MSE of 7.29511. There were no significant predictors in the drain water model (Table 13).

Table 13. Predictors of *E. coli* Concentration (CFU/100 mL) in Drain Water Samples.

Variables	Beta Coefficient	P-value	Potential Confounders for Flood vs. Nonflood Areas
Flood Area	-0.33198	0.6141	----
Drain Density	40.50902	0.1191	Yes
Less than 20 meters to a Latrine	1.05238	0.2342	Yes
Alajo	-0.2496	0.7204	Yes
Old Fadama	-0.97992	0.1884	Yes
*Significant values by Linear Regression α<0.05			

Best-Fit Model: $\hat{y}$=7.14340 - 0.33198(Flood Area) + 40.50902(Drain Density) + 1.05238(Less than 20 meters to a Latrine) - 0.2496(Alajo) - 0.97992(Old Fadama)

Norovirus concentration in environmental samples collected from the four study communities

A total of 307 environmental samples were tested for GI and GII noroviruses. Only 1 soil sample was positive for norovirus GI and no floodwater samples were positive (Table 14). There were 3 positive drain water samples (Table 14). There were a total of 30 samples that were positive for norovirus GII. Soil, drain water, and floodwater samples were positive for norovirus GII in 13, 15, and 2 samples, respectively (Table 14).

Table 14. Number and Percentage of Norovirus Positive Soil, Drain Water, and Floodwater Samples.

	N (% positive samples)			N (% positive samples)		
	Norovirus GI Soil Samples	Norovirus GI Drain Water Samples	Norovirus GI Floodwater Samples	Norovirus GII Soil Samples	Norovirus GII Drain Water Samples	Norovirus GII Floodwater Samples
Flooding	223	74	10	223	75	9
Flood	112 (0.0)	34 (8.8)	10 (0.0)	112 (7.1)	34 (20.6)	9 (22.2)
Non-flood	111 (0.9)	40 (0.0)	0 (0.0)	111 (4.5)	41 (19.5)	
Drain Density	223	74	10	223	75	9
Low	80 (1.3)	20 (0.0)	2 (0.0)	80 (7.5)	20 (25.0)	2 (0.0)
Medium	101 (0.0)	35 (5.7)	5 (0.0)	100 (6.0)	34 (17.7)	4 (25.0)
High	42 (0.0)	19 (5.3)	3 (0.0)	43 (2.3)	21 (19.1)	3 (33.3)
Latrine	223	74	10	223	75	9
Within 20 meters	25 (0.0)	6 (0.0)	1 (0.0)	25 (8.0)	7 (42.9)	0 (0.0)
Further than 20 meters	198 (0.5)	68 (4.4)	9 (0.0)	198 (5.6)	68 (17.7)	9 (22.2)

Norovirus concentrations (genome-equivalent copies) in environmental sample ranged from $3.5*10^6$ - $7.9*10^6$ per 100 mL for drain water and a single soil sample had $1.1*10^4$ GEC per gram (Table 14; Table 15). Concentrations were also higher in areas with medium drain density (Table 15). There was no norovirus GI drain water samples within 20 meters of a latrine, hence it is difficult to tell if there is visually a difference (Table 15).

Table 15. The Number, Median, and Range of Norovirus GI Concentrations (GEC) in Soil, Drain Water, and Floodwater Samples.

	GEC of Norovirus GI per gram in Soil Samples			GEC of Norovirus GI per 100 mL in Drain Water Samples			GEC of Norovirus GI per 100 mL in Floodwater Samples		
	n	Median	Range	n	Median	Range	n	Median	Range
Flooding	1			3			0		
Flood	0	0.0	0.0	3	$5.0*10^6$	$3.5*10^6$ - $7.9*10^6$	0	0.0	0.0
Non-flood	1	$1.1*10^4$	$1.1*10^4$	0	0.0	0.0	0	0.0	0.0
Drain Density	1			3					
Low	1	$1.1*10^4$	$1.1*10^4$	0	0.0	0.0	0	0.0	0.0
Medium	0	0.0	0.0	2	$6.5*10^6$	$5.0*10^6$ - $7.9*10^6$	0	0.0	0.0
High	0	0.0	0.0	1	$3.5*10^6$	$3.5*10^6$	0	0.0	0.0
Latrine	1			3			0		
Within 20 meters	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
Further than 20 meters	1	$1.1*10^4$	$1.1*10^4$	3	$5.0*10^6$	$3.5*10^6$ - $7.9*10^6$	0	0.0	0.0

Soil, drain water, and floodwater samples were positive for norovirus GII in 13, 15, and 2 samples, respectively (Table 16). Norovirus GII concentrations ranged from $1.8*10^5$ - $1.3*10^6$ GEC/gram in soil, $2.1*10^5$ - $6.7*10^6$ CFU/100 mL in drain water, and $1.3*10^5$ - $6.9*10^5$ CFU/100 mL in floodwaters (Table 16).

Table 16. The Number, Median, and Range of Norovirus GII Concentrations (GEC) in Soil, Drain Water, and Floodwater Samples.

	GEC of Norovirus GII per gram in Soil Samples			GEC of Norovirus GII per 100 mL in Drain Water Samples			GEC of Norovirus GII per 100 mL in Floodwater Samples		
	n	Median	Range	n	Median	Range	n	Median	Range
Flooding	13			15			2		
Flood	8	$3.5*10^5$	$7.7*10^2$ - $1.3*10^6$	7	$6.1*10^5$	$2.1*10^5$ - $1.9*10^6$	2	$4.1*10^5$	$1.3*10^5$ - $6.9*10^5$
Non-flood	5	$5.9*10^5$	$1.8*10^5$ - $1.1*10^6$	8	$2.4*10^6$	$7.6*10^5$ - $6.7*10^6$	0	0.0	0.0
Drain Density	13			15			2		
Low	6	$5.5*10^5$	$1.8*10^5$ - $1.1*10^6$	5	$2.0*10^6$	$7.6*10^5$ - $4.9*10^6$	0	0.0	0.0
Medium	6	$3.0*10^5$	$7.7*10^2$ - $6.3*10^5$	6	$5.2*10^5$	$2.1*10^5$ - $1.2*10^6$	1	$6.9*10^5$	$6.9*10^5$
High	1	$1.3*10^6$	$1.3*10^6$	4	$2.4*10^6$	$1.2*10^6$ - $6.7*10^6$	1	$1.3*10^5$	$1.3*10^5$
Latrine	13			15			2		
Within 20 meters	2	$4.7*10^5$	$3.2*10^5$ - $6.3*10^5$	3	$4.9*10^6$	$2.4*10^5$ - $6.7*10^6$	0	0.0	0.0
Further than 20 meters	11	$3.8*10^5$	$7.7*10^2$ - $1.3*10^6$	12	$1.1*10^6$	$2.1*10^5$ - $2.9*10^6$	2	$4.1*10^5$	$1.3*10^5$ - $6.9*10^5$

DISCUSSION

After flooding or any type of natural disaster, it is difficult to connect the source of contamination, the population exposed to hazardous substances, and disease. Flooding is a risk factor for illness based upon evidence of increased numbers of individuals seeking medical treatment in the aftermath of flooding events. Diarrheal diseases from enteric pathogens are one of the top three health issues after a flood, along with malaria and respiratory illness ("Health Assessment for the Population Affected by Flood Conditions", 1989; Siddique et al, 1991). However, few research efforts have focused on the magnitude and duration of health risks associated with flooding. The purpose of this study was to identify potential sources of contamination and describe the behavioral responses to flooding that could lead to greater or lesser exposure to floodwater. This was accomplished using multiple methods including spatial mapping, household surveys and interviews, environmental sampling, and microbiological analyses.

Community liaison as an effective way to determine flooding

The use of a liaison to determine flood areas was an extremely effective method for identifying and mapping flood areas. Each of the four community liaisons was able to identify the flood areas accurately except for one area. If possible cross-validation should be conducted to confirm that the area meets the criteria of flooding. Interviewing residents also gave the opportunity to talk about the severity of flooding in the area, causes, how long it lasts, and the number of people affected. One potential difficulty with using a liaison is that the area they live in may not be affected by flooding, so they may underestimate the severity of flooding in other areas. Observing watermarks, evidence of prevention practices, and presence of standing water were all consistent indicators of a potential flooding area.

Number of people affected by floodwater

Estimating how many people are at risk of exposure to fecal-contaminated floodwater is important for identifying populations at risk of enteric disease and for prioritizing response efforts. The number of people affected by flooding in each of the four communities was 4,104 in Alajo, 2,800 in Bukom, 69,612 in Old Fadama, and 5,871 in Shiabu. Residents of Old Fadama had a greater risk of exposure to floodwater because 87.4% of the community flooded and the floodwater would remain for long periods of time. In Shiabu, 48.5% of the community flooded and water would remain for a few weeks to a month. Residents in communities, such as Old Fadama and Shiabu, where exposure to floodwater is prolonged may be at greater risk of exposure to fecal contamination. If individuals in these areas vacated their houses, then there would be less opportunity for exposure. Identifying the populations at risk from flooding is one of many important factors that need to be understood in order to evaluate the risk of flood-associated exposures (Schwartz et al., 2006; Luby et al., 2008; Katsumata et al., 1998).

Behavioral response and increase risk of exposure to floodwater

Individual responses to prevent flooding, such as removal of floodwater from home, or choosing to leave the home could also play an important role in mitigating exposure to fecal-contaminated water. Some preventive responses, such as raised building structures and cement walls, were more long-term solutions to prevent water from reaching or entering homes. These were frequently observed in Accra. Short-term practices included unblocking drains and using rags to block cracks in a door. Our sample size was too small to adequately measure and report how often these preventive measures were used. The preliminary results from this study suggest that these short-term prevention methods are likely to expose individuals to contaminated floodwaters. Because all survey respondents that had floodwater enter their homes reported that they remove it by buckets, it is likely that their arms, hands, and legs come into contact with fecal-contaminated floodwater and place them at risk of enteric exposure.

Very few studies have examined behavioral responses to flooding. In many cities across Africa, the flood response is similar to that reported by residents of Accra. Studies in Kampala, Uganda reported short-term efforts to open up drainage channels, construct barriers at the entrance of homes, and create outlets at the rear of homes to remove water quickly (Douglas et al., 2008). In Lagos, Nigeria, the main response to floodwater was to bail it out and use pieces of cloth to reduce the amount of water coming into the house (Douglas et al., 2008). Even though these behavioral responses to flooding have been documented it is unknown how these different short-term preventive factors influence the risk of exposure to fecal contamination and illness.

It is difficult to determine the range of exposure to fecal contaminated floodwater in the communities of Accra caused by an individual's choice to either leave or stay within the area. Three-fourths of the respondents in this study reported that they stayed in their homes after flooding. However, a small percentage did leave and were most likely not exposed to fecal-contaminated water. In Kampala, Uganda previous studies have reported that some people seek refuge in churches or mosques until the floodwaters subside (Douglas et al., 2008). Understanding the different factors that determine behavioral response to flooding is important for QMRA (quantitative microbial risk assessment) models that estimate risks of exposure to fecal contamination and infection associated with flood events.

Drain contamination with fecal matter and exposure risk posed after flooding

Almost half of those surveyed in the four study communities in Accra, Ghana reported that feces were disposed of in neighborhood drains every day. Improper disposal of feces in drains increases risk of exposure to enteric pathogens when there is contact with drain water. Residents also responded that they observed more feces disposed of in the drains during the rainy season compared to the dry season. During the rainy season, increased runoff moves the trash and feces in the drains. Therefore, it may be easier to more inconspicuously dispose of garbage in the drains. However, the increased use of drains for garbage disposal results in drain clogging and overflow into the community. This can cause increased exposure to fecal-contaminated to fecal-contaminated water with enteric pathogens. This increased mobility of fecal contamination can spread enteric pathogens to soil and other objects. The enteric pathogens in drain water and soil can persist from minutes to months depending on the pathogen and environment (Karim et al., 2004; Taylor et al., 2013).

Exposure to fecal-contaminated water has been linked to illness (Schmid et al., 2005; Katsumata, et al., 1998). The longer the floodwater remains in a community, the more opportunities there are for people to be exposed. In communities such as Old

Fadama and Shiabu, fecal-contaminated water may remain on the ground from a few days to year around. Sometimes the standing floodwater in these areas forced people out of their homes due to health concerns or inhabitable conditions. Therefore, persistence of enteric pathogens in floodwater, along with exposure behavior are important factors to consider in a model of exposure.

E. coli and norovirus concentration in soil, drain water, and floodwater

Overall almost all samples had *E. coli* contamination indicating that there was fecal contamination in soil, drain water, and floodwater. Analyses of the samples for noroviruses were performed to determine if the fecal contamination indicated by the *E. coli* concentrations was due to humans or other animals. A positive norovirus sample indicates that the fecal contamination in that soil, drain water, or floodwater sample is due at least in part to human feces. The median concentrations of both *E. coli* and norovirus were higher in soil and drain water samples collected within 20 meters of a latrine, but the number of norovirus-positive samples was small, so it is not possible to draw conclusions about areas at greater risk of human fecal contamination. There was a higher number of norovirus-positive drain water samples compared to soil samples, which may be due to higher human fecal contamination of the drains. Analysis for other human enteric pathogens could be done in the future in order to improve our ability to identify areas in the environment that are contaminated with human feces.

Linear regression modeling of *E. coli* concentration in soil samples

In the linear regression model of *E. coli* concentration in soil, samples collected from the neighborhood of Old Fadama, less than 20 meters from a latrine, and drain density were included in the model. Old Fadama and less than 20 meters from a latrine were significant ($\propto < 0.05$) predictors of *E. coli* concentration. When the soil sample was from Old Fadama, *E. coli* concentration increased by $4.8*10^3$ CFU per gram compared to the other neighborhoods. Old Fadama is the community with the lowest socioeconomic status in our study and is not formally recognized by the government; therefore, it has no formal drains or trash pickup. Increased fecal contamination in soils could be caused by trash piling up and floodwater stagnating for prolonged periods of time. When a sample is within 20 meters of a latrine, the *E. coli* concentration was higher by $8.5*10^5$ CFU per gram of soil. Our data supports the WHO assumption that areas less than 20 meters from a latrine are at risk factor of fecal contamination. Fecal contamination from latrines could spread if latrine pits are inundated and the water runs off into the surrounding area. Studies in Jakarta, Indonesia and New Zealand have suggested that floodwater plays a significant role in mobilizing fecal contamination after a rainfall event (Phanuwan et al., 2006; Nagels et al., 2002). These contaminated areas within close vicinity to a latrine may only place people at risk of exposure if floodwater then spreads that contamination to a larger area with more people. However, in this model distance to a latrine was a significant predictor of *E. coli* contamination in soil, but whether the sample was from a flooded area or not was not associated with *E. coli* concentration.

Drain density was a confounder on the relationship between flood zones and log of CFU of *E. coli* concentration, but ultimately *E. coli* concentrations were not significantly associated with either flood areas or drain density. This model explained only a small part of the *E. coli* concentration since the R-adjusted value was only 0.0641. This may have been due to sample size or the use of only binary and categorical variables in the model. This could also mean that there are other non-measured factors, such as the practice of open defecation, that play a bigger role in *E. coli* concentration in soil.

Strengths and Limitations:

Strengths:

This research study was conducted using multiple methods in order to perform a more comprehensive examination of the extent on flooding and associated risk factors. Other studies generally focus on one specific area, such as where the source of contamination occurred or the proportion of the population that were affected by flood-related health outcomes. While assessing these relationships are important, many fail to look at the bigger picture or to compare risks in different sites or times. This study attempted to measure both microbiological contamination in flood and non-flood areas and to collect some preliminary behavioral data to characterize the factors that may influence when and how people are at risk of exposure to microbiological contamination associated with flood events. As a result, the information can be used as a guide for future studies that attempt to better characterize behavioral responses to flooding and incorporate those into a model estimating risk of exposure to enteric pathogens after flooding. Spatial analysis was another strength in the study.

Limitations:

There are always limitations to any study. In this study, sample size was a major limitation for the surveys, hence only descriptive analyses were performed. A larger sample size would be necessary to draw definitive conclusions about causes and duration of the flooding and the behavioral practices by people in response to flooding. Another limitation was the time frame; only one household was interviewed per flood area, and due to logistics and time constraints some flood areas were missed. Interview bias was another potential limitation of this study since participants were interviewed in the presence of the community liaison, which may have introduced bias to the responses.

The environmental samples may be affected by convenience bias, and may not be generalizable to the whole neighborhood. Samples were collected when it was possible to get to the area within a particular time frame. Some geographic areas lacked drain water and soil samples while others had a large number of samples.

Summary and Conclusions

This study attempts to provide a comprehensive overview of the risks associated with flooding in terms of potential sources of fecal contamination and ways that people may be exposed to flood-associated contamination in the four communities. There are many factors that may contribute to exposure of individuals to enteric pathogens in flood events such as short-term preventative factors. All individuals within the neighborhood also bucketed out floodwater from their homes, which may put them at increased risk. This project collected information on contamination of soil and drain water along with behavior in order to determine what may put some individuals in communities more at risk and to determine whether flooding and other factors increase that risk. *E. coli* concentration in soil samples are higher in the community of Old Fadama and when the distance to a latrine is less than 20 meters, but living in a flood zone alone was not a risk factor.

Although the overall distribution of *E. coli* contamination was not different when comparing areas in flood and non-flood zones, and with low to high density, Old Fadama appears to be unique. It has fewer drains that the other neighborhoods, fewer latrines, of which most are unimproved, and nearly the entire area experiences flooding of prolonged duration. Thus the neighborhood itself being a risk factor could reflect additive effects for all of these factors. Future investigations can use this information to follow up on specific aspects of this research. Specific areas for follow up include:

1) Further research on the behavioral response of people during flooding with a larger sample size.
2) Collection of additional floodwater samples in order to determine how much fecal contamination is spread by the floodwater compared to soil or drain water.
3) Eventual design of community-specific recommendations for flooding based on behavioral and microbial data.

Chapter 5: Lessons Learned and Recommendations

- Floodwater is logistically difficult to collect when rain is sporadic in the city. It could rain in one community one morning, but not in any of the others. To systematically analyze floodwater, it is necessary to collect samples over multiple rainy seasons due to the difficulty in capturing these samples at the appropriate time and place.
- Collecting floodwater can be dangerous and potentially hazardous to the safety of the personnel.
- More time was needed in the field to conduct the survey among individuals living in the flood areas. Due to logistical constraints and limited time, we did not collect large enough number of surveys for meaningful interpretation of results.
- The one question on the survey that was not useful was "How often does it flood in your house?" This open-ended question led to many answers, including "whenever it rained" or "all the time during the rainy season" and could not reliably be used as a quantitative value.

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Appendices

Appendix A: Flood Survey Form

Flood ID _________ Date_________ Interviewer_________ Location ID__________

Time_________ Interviewee_________ Select the Neighborhood___________

1a) What causes the flooding in your area?

1. Overflowing of Drain
2. Water Cannot Reach Drain
3. No Drain
4. Low Lying Area
5. Other

1b) If other, please specify: ___________

1c) Notes: ___________

2a) If drain overflows, why?

1. Clogged Drain
2. Too Much Water
3. Other

2b) If other, please specify: ___________

3a) Do you try to prevent flooding in your home?

1. Yes
2. No

3b) If yes, how?

1. Digging of Drains
2. Placement of Sandbags

3. Placement of Tires
4. Placement of Sawdust
5. Raise Building Structures
6. Other

   If other, please specify: ___________

3c) If not, why? ___________

4) Number of days the flooding lasts in your area? ___________

Notes: ___________

5a) Do you remove floodwaters from your home?

1. Yes
2. No

5b) If yes, how?

1. Scoop Water Out of the Home
2. Other

If other, please specify: ___________

5c) If no, why not? ___________

6) How often does it flood in your house per year? ___________

Notes: ___________

7) Do you stay in your home after flooding?

1. Yes
2. No
3. Sometimes
4. No Answer

8) Do your children stay in your home after flooding?

1. Yes
2. No
3. Sometimes
4. No Answer
5. Not Applicable

9) How often do you see feces dumped in drains in your neighborhood every week?

1. Always (Everyday)
2. Often (Every Other Day)
3. Sometimes (Once A Week)
4. Never
5. Not Applicable

10) Do you see this more, less, or the same amount in the rainy vs. the dry season?

1. More Often
2. Less Often
3. Same
4. Never
5. Not Applicable

Notes: ___________________________________

Appendix B: Flood Sample Collection Form

Flood ID _________ GPS Latitude________ GPS Longitude________ Date_________

Select the Neighborhood___________ Picture ID__________ Barcode__________

Location ID___________ Sample Type___________

1) Impervious Surface:
    1. All Concrete (0% Dirt)
    2. Mostly Concrete (25% Dirt)
    3. Half Concrete (50% Dirt)
    4. Mostly Dirt (75% Dirt)
    5. All Dirt (100% Dirt)
    6. Sand
2) Water Marks?
    1. Yes
    2. No
3) Presence of Standing Water?
    1. Yes
    2. No
4) Preventive Factors?
    1. Digging of Drains
    2. Placement of Sandbags
    3. Placement of Tires
    4. Placement of Sawdust
    5. Raise Building Structures

6. Other

If other, please specify: ___________

5) Presence of Drains?

1. Yes

2. No

6) If there is a drain, is the drain obviously clogged?

1. Yes

2. No

3. Not Applicable

7) Are there children in the area?

1. Yes

2. No

Notes: _____________________

If the place has standing water and is flooded, answer the following questions:

8) Are there people working to remove the floodwater?

1. Yes

2. No

9) Are there people eating in the floodwater?

1. Yes

2. No

10) Are businesses open as usual?

1. Yes

2. No

11) What other activities are people doing in the flood area? (such as removing clothes from drying line): ____

12) Observation of dumping trash in drains.

   1. Yes
   2. No
   3. Not Applicable

13) Observation of dumping trash in floodwater.

   1. Yes
   2. No

14) Observation of open defecation.

   1. Yes
   2. No

Notes: ___________________