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Understanding Zoonotic Enteric Disease in Minnesota: A Spatio Temporal Analysis and Causal Theory Approach

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Abstract

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With 75 percent of diseases in humans having origin in animals or animal products, zoonotic diseases have an enormous impact on the global disease burden. A significant portion of this can be attributed to bacterial zoonotic enteric pathogens. This study was designed to locate clusters of bacterial zoonotic enteric outbreaks in the State of Minnesota and study the seasonality of these outbreaks. In addition to identifying hot spots for zoonotic enteric outbreaks in Minnesota, the study also aimed to design a causal model to improve understanding of risk factors. This thesis considered only the bacterial zoonotic pathogens with significant disease burden. Foodborne and non-foodborne zoonotic enteric outbreaks reported by Minnesota Department of Health (MDH) during the period 2000 to 2010 were analyzed in the study. A recent rise in trend of zoonotic enteric disease (ZED) outbreaks were confirmed through empirical analyses. The study also revealed increased bacterial ZED outbreaks in the summer months as compared to other months of the year. Hot spot analysis results indicated twin cities (Minneapolis and St. Paul) as the vulnerable area for ZED outbreaks. The study is especially important for health educators as it shines light on the right places and right time for tailoring interventions to reduce the disease burden.

Keywords: zoonotic enteric outbreaks, causal theory model, health program plan, hot spot analysis, spatio temporal analysis

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Chapter 1 - Statement of Problem

Introduction

Animals are an indispensable part of our life providing various benefits ranging from entertainment and companionship to food but with these interactions comes the risk of zoonotic diseases transmission to human beings. According to World Health Organization (WHO), complications associated with diarrhea, contributes to a significant estimate of 1.8 million deaths each year (World Health Organization [WHO], 2010). Many of these cases can be attributed to infections of zoonotic origin. Centers for Disease Control and Prevention (CDC) reports 76 million cases of foodborne diseases with 325,000 hospitalization and 5000 deaths each year in US (Krause & Hendrick, 2010). According to CDC, zoonotic enteric diseases (ZED) are the infections caused due to pathogens of animal origin that upsets the digestive system making people sick (Centers for Disease Control and Prevention [CDC], 2015c). Recent outbreaks of ZED in multiple states of US serve as a poignant reminder about the scope of animal to human diseases. "Transmission of zoonotic enteric pathogens at facilities where the public has direct contact with farm animals appears to be a growing public health threat" (Smith et al., 2004, p. 1098). In addition, bacterial foodborne zoonotic infection is the most common cause of human enteric disease. There are multiple routes of transmission of the zoonoses that can be broadly categorized under two headings 1) food borne zoonoses and 2) non-foodborne zoonoses. Consumption of contaminated animal foods and animal products is an important source of introducing zoonotic pathogens into the human body. While the disease burden of bacterial ZED is significant, current gaps in knowledge regarding its transmission and prevention leaves humans at greater risk (Stull, Peregrine, Sargeant, & Weese, 2012). The above scenario suggests bacterial ZED as an evolving public health challenge. It is of utmost importance to respond to this challenge through improving ZED awareness during the vulnerable season. While ZED is preventable, behavioral changes are suggested as immediate interim measures to mitigate the risks of infection (Pike et al., 2010).

Statement of Problem

Since the beginning of 21st century, ZED have significantly contributed to the burden of infectious diseases, both in human and financial terms. The recent reports of frequently occurring larger outbreaks has made it a major public health issue, beyond the population of livestock and pet owners. This is a challenge that needs comprehensive action in all its aspects. The National Association of State Public Health Veterinarians (NASPHV) and Healthy pets, Healthy People, CDC has outlined an extensive set of recommendations to prevent outbreak of ZED (National Association of State Public Health Veterinarians [NASPHV], 2011). This document suggests that the potential areas for outbreak of such zoonotic diseases are fairs and petting zoos, backyard poultry farming practices, animal venue operators, and reptile pets at home. Breakdowns in public health measures such as hygiene and sanitation increases the spread of these diseases (CDC, 2011a).

However, keeping in view the invaluable learning experiences that these environments offer, such visits should not be discouraged rather strategies be developed to minimize the risks. To our deception, most of the healthy looking animals often act as the asymptomatic carriers of the zoonotic pathogens that constantly shed into the environment and act as a source of infection. "Strong evidence exists for seasonal excretion and transmission, with periods of maximum numbers of shedding coinciding with peaks in human infection" (Schouten et al., 2005, p. 131). This suggests that there might be a seasonality and spatio temporal association with the outbreaks of ZED. Fortunately, enteric diseases attributed to animal contacts are preventable. Although the problem of zoonotic enteric illness is multifactorial, much can be done by education and increasing public awareness about zoonotic risks and threats posed from animal contacts. Studies emphasize behavioral approach as an immediate interim measures towards reducing the risks of zoonotic disease transmission in places of animal human contact (Pike et al., 2010). Outreach activities through constructive health program plans that aim to increase awareness, promote behavioral change, and encourage risk reduction measures must be attempted to decrease the disease burden.

Significance of the Problem

Various entertainment and educational opportunities achieved through animal human interactions are always accompanied with the unwanted risks of disease transmission from animals to humans. While public awareness of risks of ZED can be an effective protective strategy against illness, it is imperative from the public health perspective to address the problem at the time of the year when the public is most vulnerable. Therefore, this study will analyze archival data to identify the commonly occurring zoonotic enteric bacterial outbreaks in the State of Minnesota along with seasonality and geographical clustering from 2000 to 2010. According to CDC (2016a), zoonotic diseases are common, costly and completely preventable. Nevertheless, a constant effort is required to increase the level of awareness regarding zoonotic diseases and their transmission among public. Illuminating the importance of hand hygiene at public places with animal proximity and encouraging discussion through sharing of information to the vulnerable population is recommended. With a strong emphasis on the ZED vulnerability of fair visitors, this study established a causal theory model that could be used to educate and increase awareness. The causal theory model that was developed as part of the health program plan (HPP) considered several factors causing ZED at vulnerable settings.

Research Questions

1. What are the major zoonotic enteric bacterial pathogens prevalent in the State of Minnesota since 2000?
2. Is there a rise in the outbreaks of the enteric illnesses in the State of Minnesota attributed to zoonotic pathogens since 21st century? Is there a spatio temporal pattern for ZED outbreaks?
3. How to raise awareness and knowledge about zoonotic enteric diseases and promote prevention to reduce the risks of zoonotic transmission through a causal theory model?

Limitations

1. Due to possible HIPPA (Health Insurance Portability and Accountability Act) violations, primary data on the outbreaks could not be collected from the hospitals and clinics.
2. As most outbreaks of enteric diseases are self-limiting, under-diagnosis and under-reporting results in loss of cases affecting interpretation of data.

3. It is difficult to establish animal contact from the reports unless a detailed description of the outbreak is available.
4. Due to limited time and resources, utility of the developed health program plan could not be measured in an actual setting.

Delimitations

1. In broad terms, zoonoses are the diseases that are transmitted from animals to humans but this study will focus only on bacterial zoonotic enteric diseases.
2. While exploring data on foodborne outbreaks, the study will only consider foodborne illnesses due to direct or indirect animal origin.
3. In the process of developing causal theory model, the study will explore causal factors of only the ZED cases reported in the data source due to animal contacts.

Assumptions

1. All major outbreaks of ZED are reported and documented in the records.
2. Analyzing ten years period of data on ZED outbreaks will be sufficient for interpretation.

Definition of Terms

The following terms and definitions are included in this study for a better understanding of the content.

- Causal Theory Model **-** "The model of the health problem that brings together, in a visual display, the key factors that were identified from the community health assessment as being important to the health problem" (Issel, 2004, p. 153).

- Enteric Diseases - Gastrointestinal infections that enter the body through mouth and intestinal tract and are usually spread through contaminated food or water or by contact with vomit or feces (CDC, 2013).
- Health Program Plan (HPP) **-** It is a systematic process of providing attention and information on a health concern with an intention to have a positive effect on the health of the program participants or the program recipients (Issel, 2004).
- Pathogen **-** "A pathogen is usually defined as a microorganism that causes, or can cause, disease" (Pirofski & Casadevall, 2012). The bacterial enteric pathogen considered in this study are *Salmonella, E. coli, Campylobacter, Clostridium, Helicobacter and Yersinia.*
- Origin **-** The enteric disease outbreaks has been categorized into animal, non-animal and unknown origin depending on the source of outbreak.
- Outbreak **-** "A disease outbreak is the occurrence of cases of disease in excess of what would normally be expected in a defined community, geographical area or season" (WHO, 2016, para. 1).
- Spatio Temporal Analysis - Analysis of data across time and space.
- Zoonotic Enteric Disease (ZED) - Gastrointestinal diseases caused by germs from animals (CDC, 2015c).
- Zoonoses **-** Infections that are naturally transmitted between vertebrate animals and humans (WHO, 2015, para. 1). To be specific, a disease that usually exists in animals but can infect humans.

Chapter 2 - Literature Review

Introduction

This research primarily aims at improving public awareness about zoonotic enteric illness. It also developed a causal theory model to understand the key factors and associated causal factors of ZED outbreaks at potential settings. Realizing the grave impact that zoonotic enteric infections has on public health, a thorough literature review will help examine the various domains of these diseases. However, the review focusses on bacterial enteric diseases due to direct or indirect animal contacts as well as animal products. In addition, it briefly explores the literature on the common zoonotic enteric pathogens. It also includes a literature review of several government websites relating to the importance and examples of health programs focusing on health promotion.

Zoonoses

Rudolph Virchow, the Father of modern Pathology coined the term "Zoonosis." In 1959, World Health Organization (WHO) defined "Zoonoses" as "the diseases and infections that are naturally transmitted between vertebrate animals and humans" (WHO, 2015, para. 1). As stated by Stephen et al. (2004, p. 339), "zoonoses are the fundamental determinants of community health." Bacteria, virus, parasites, fungi, and prions can cause these diseases. The worldwide increase in incidences of zoonotic disease is mainly due to expansion of human settlement into animal habitat and increase in ownership of domesticated animals (Weiss, 2008). There are multiple routes of transmission of the zoonoses that can be broadly categorized under two headings 1) foodborne zoonoses and 2) non-foodborne zoonoses. Consumption of contaminated animal based food and food product is an important source of introducing zoonotic pathogens into the human body. Infections from *Salmonella*, *Campylobacter, E. coli,* and Bovine spongiform encephalopathy (BSE) are only a few of numerous foodborne zoonotic pathogens. Non-foodborne zoonotic infections can be transmitted from animals to humans in a number of ways including direct contact, being in close proximity, and through fomites and vectors. Zoonotic pathogens can be acquired during close contact with animals through inhalation, ingestion or other mechanisms resulting in the contamination of mucous membranes, damaged skin or intact skin (Kahn, Line, & Merck, 2010). Direct transmission occurs in diseases such as Rabies and Anthrax and indirect transmission through food, vector, environment, and contaminated fomites occurs in diseases like Salmonellosis, Plague, and Clostridia diseases. However, some diseases like brucellosis and mycobacteriosis also have multiple routes of infection.

As the inevitable interaction between animals and humans increases, zoonoses pose a genuine threat to health and survival for people, their livestock, companion animals, and wildlife (WHO, 2015). An increased incidence of most emerging diseases witnessed in the last two decades are zoonotic in origin. According to National Center for Emerging and Zoonotic Infectious Disease (NCEZID), emerging diseases refers to infections that have increased recently or have a potential to spike in near future like the newly discovered Bourbon virus in Kansas, Chikungunya virus new to Florida or bacteria that have become resistant to antibiotics, like MRSA (methicillin-resistant *Staphylococcus aureus*) (CDC, 2015a). Emerging zoonosis is defined as zoonotic disease that is newly recognized or evolved, or that has occurred previously but shows an increase in incidence or expansion in geographical, host, or vector range

(WHO, 2004). The WHO and most infectious disease experts agree that the source of next human pandemic is likely to be zoonotic, and wildlife is emerging as the primary source (Wang & Crameri, 2014). The twenty first century has already witnessed emerging zoonotic pathogens like Ebola, Avian Influenza, and SARS virus (Lashley, 2006). History of public health has globally recorded reluctance in accepting animals as a source of infection and attempts were made only to control the clinical cases (Bell & Palmer, 1983). Numerous factors influence the risk of acquiring zoonotic diseases including host susceptibility, routes of transmission and ability of pathogen to cross species barriers. Handling of infected wild and domestic animals increases the risk of zoonotic infections thereby increasing overall burden of infectious diseases. Although anyone with close proximity to animals can get zoonotic diseases but certain occupation and activities like livestock ownership, and human animal interaction significantly increases the risk of acquiring zoonotic disease. Of the numerous diseases that zoonotic infections can cause, zoonotic enteric illnesses contribute a significant proportion that cannot be underestimated.

Disease Burden due to Bacterial Zoonotic Enteric Diseases

Out of 1415 species of infectious organisms known to be pathogenic to humans, 868 (61%) are zoonotic, and 175 pathogenic species are considered to be emerging. An emerging pathogen is the causative agent of infectious diseases that shows increased incidences in a new or existing host population due to epidemiological changes (Woolhouse, 2002). Out of the emerging pathogens, 132 (75 %) are zoonotic in origin (Taylor, Latham, & Mark, 2001). Enteric pathogens like *Cryptosporidium spp*, non-typhoidal *Salmonella spp*, and Shiga toxin producing *Escherichia coli (STEC)* comprises a major category in the zoonotic diseases. "Although enteric zoonotic pathogens are commonly transmitted through food or water, recent outbreaks have highlighted direct or indirect contact with an animal reservoir (hereafter, animal contact) as another key route of transmission for these enteric pathogens, especially for young children and other populations at high risk" (Hale et al., 2012, p. 472). Pathogens like Shiga toxin–producing *Escherichia coli* O157:H7, *Salmonella, Campylobacter*, and *Cryptosporidium* species can be attributed to infection associated with animals in public settings (Minnesota Department of Health [MDH], 2005). A recent study estimated that of the overall domestic illness caused by seven major groups of enteric pathogens, 14 % of the burden was attributed to enteric infections caused by animal contact. Animal contact illness due to the above enteric pathogens is estimated to be 450,000 cases annually (Hale et al., 2012). According to Girard, Steele, Chaignat, & Kieny (2006), enteric pathogens are third leading cause of infectious diseases worldwide, and accounts for 2 million deaths every year. Enteric illness accounts for 150,000 hospitalizations and 3.7 million physician visits in the United States every year. This is approximately 10 % of hospitalization in children from one to five years of age. The financial burden of these illnesses is reflective from the estimated two billion dollars spent annually in caring for these patients in hospitals and outpatient settings (Colletti et al., 2010).

Both sick and apparently healthy animals can act as reservoirs of enteric pathogens suggesting that removing the ill animals is not enough to prevent environmental contamination and disease occurrence (Angulo, Steinmuller, Demma, Bender, & Eidson, 2006). Besides, intermittent fecal shedding of pathogens constantly contaminates the environment and is even more common during summer and fall

(Schouten et al., 2005; Williams, Avery, Killham, & Jones, 2005). In addition, different strains of the same pathogen have different shedding frequency. For example, strains S1 and S2 of *E. coli* O157:H7 were detected seven to eight times more often and 104 times larger than strain S3 (Gautam et al., 2012). Research findings suggests that seasonal variation in zoonotic enteric disease is present everywhere with regional variations highlighting environment-pathogen-host reaction (Lal, Hales, French, & Baker, 2012).

Furthermore, antimicrobial resistance among other zoonotic enteric pathogens pose genuine threats to human and animal health, and has severe clinical implications towards public health. Hence, antimicrobial resistance is a daunting public health task that adds to the significance of zoonotic enteric health concern. The use of antimicrobial agents in food animal results in resistance among pathogenic and commensal bacteria in these animals, and the resistant bacteria may then be transmitted to humans through food supply or direct contact with animals. Moreover, fecal-oral route is the most common way that humans get infected with zoonotic enteric pathogens (Angulo, Nunnery, & Bair, 2004). *Campylobacter* and *Salmonella* are the two most common bacterial cause of foodborne illness. Both these enteric pathogens show an increased concern of antibiotic resistance towards fluoroquinolones and third generation cephalosporin. For example, the resistance of *Campylobacter spp* to ciprofloxacin, a fluoroquinolone is statistically significant (95 % Confidence Interval). Reports of National Antimicrobial Resistance Monitoring System suggests that the prevalence of fluoroquinolone resistant *Campylobacter* shows a spike from 13 % in 1997 to 21 % in 2001 (CDC, 2013).

Routine administration of antibiotics to farm animals not to cure diseases but to boost growth is highly associated with subsequent multi drug resistant bacterial infections in humans (Drexler, 2010). There is enough research to emphasize that the severity of infection and increasing mortality due to various zoonotic enteric pathogens may be attributed to multidrug resistance among the pathogens (Angulo et al., 2004). Therefore, bacterial zoonotic enteric diseases requires a systematic surveillance and evaluation of a disease control program to control the outbreaks.

Factors Promoting Zoonotic Enteric Diseases in Minnesota

According to Minnesota Department of Health (MDH), the fair season starting every year from mid-June to Labor Day witnesses numerous enteric outbreaks. These outbreaks may be attributed either due to direct or indirect animal contacts (MDH, 2013). American Pet Products Manufacturers Association (2016) reports an increase in pet ownership of US households from 56 % in 1998 to 63 % in 2007-08. In addition, there is a rise in number of nontraditional pets like amphibians, rodents and reptiles. To magnify the problem, children encountering various animals at public settings yield in millions of animal human interactions, potentially raising the risks of enteric illness. Violation of recommended guidelines or lack of awareness leads to deleterious behavioral implications by the public in venues with animal display. A study related to practices and behaviors of visitors in 34 petting zoo areas in Ontario, Canada outlined the following observations (Figure 2.1).

Observation	No. (%) of events
Holding food or beverage in petting zoo	28 (82)
Unsupervised physical contact with animals by children estimated to be <6 years of age	12 (35)
Physical contact with animals by children estimated to be <6 years of age	34 (100)
Physical contact with animals by children estimated to be <1 year of age	28 (82)
Physical contact with animals by women appearing to be pregnant	14 (41)
Feeding animals by hand	22 (65)
Feeding animals using ice-cream cones	9 (26)
Entering animal pens without permission	1[a] (2.9)

[a] One individual.

Figure 2.1. Observations of behaviors of visitors in petting zoo areas at 34 petting zoos in Ontario, Canada. Adapted from "Observation of practices at petting zoos and the potential impact on zoonotic disease transmission" by Weese, McCarthy, Mossop, Martin, & Lefebvre, (2007), *Clinical Infectious Disease, 45*(1)*,* 10-15. Copyright 2007 by the Infectious Diseases Society of America. Reprinted with permission.

The above comprehensive study on behaviors and practices inside petting zoos identified deficiencies in following recommended guidelines in areas of education, animal access, hand hygiene, hand to mouth contact and supervision. In another research, pediatricians recommended:

> "parents need to be educated about the increased risks of exposure to nontraditional pets and animals in public settings for infants and for children younger than 5 years and for immunosuppressed people of all ages and should be made aware of the general recommendations for reduction of risks of infection, injury, and allergy" (Pickering, Marano, Bochini, & Angulo, 2008, p. 883).

Luckily, most of the zoonotic diseases including the enteric illness are preventable with practice of basic prophylactic zoonotic disease prevention measures. There exists a substantial knowledge gap in terms of lack of awareness about the zoonotic pathogens among the livestock keepers, pet owners, and the public. A deep insight into various literature reviewed suggests that much of the zoonotic enteric disease burden can be alleviated by illuminating prophylactic measures and bridging the existing gap in knowledge about the zoonotic diseases. Facilitating interdisciplinary collaboration by discussing information among veterinary, public and agricultural personnel and policy makers can also contribute towards easing the cause (Coulibaly & Yameogo, 2000). It is observed that increased industrialization of animal production as well as mishandling of animals creates an environment for entry of pathogens into the food chain. Therefore, ZED requires a systematic surveillance and evaluation of disease control program.

Overview of Common Bacterial Zoonotic Enteric Pathogens

As discussed above, the seven groups of enteric pathogens attributed for the majority of hospitalization and deaths due to enteric illness in United States are as follows 1) *Campylobacter* species, 2) *Cryptosporidium* species, 3) Shiga toxin–producing *Escherichia coli* (STEC) O157, 4) STEC non-O157, 5) *Listeria monocytogenes*, 6) Nontyphoidal *Salmonella* species, and 7) *Yersinia enterocolitica* (Hale et al., 2012). However, *Clostridium* and *Helicobacter* are also considered as bacterial pathogens with potential zoonotic risks.

Campylobacter.

These are groups of bacteria found worldwide with major zoonotic potential. Out of 18 *Campylobacter* species, *C. jejuni* and *C. coli* are the most important strains that cause enteritis in human and domestic animals (Humphrey, O'Brien, & Madsen, 2007). Direct contact with infected pets and livestock is the major cause of infections in humans. Apart from direct and indirect fecal-oral route, consumption of contaminated meat and milk also serve as transmission of the pathogens to humans from animal products (Callaghan, 2008). *Campylobacter* epidemiology is characterized by marked seasonality with peak incidences in late spring and early summer. A positive correlation in incidence has been suggested with the seasonality of canine births and as more puppies adopted as pets, particularly during summer (Evans, 1993).

Besides foodborne transmission, high risks of infection prevails from companion animals. *Campylobacter spp* are ubiquitously present and asymptomatically carried by many animals especially poultry as an important source of the pathogen. Thus, there is a prevalence of high risk of cross contamination when contaminated poultry is introduced to the kitchen. Apart from poultry, *C. coli* and *C. jejuni* are commonly present in cattle, sheep, and pigs but may not be a part of natural gut flora like *E. coli*. Presence of the bacteria in intestinal tract of dairy animals poses frequent risks of milk contamination if proper hygiene is not adopted during milking of cows.

Studies suggest that the infectious dose of the bacterium in humans is very low (less than 500) and to add to the problem a single live chicken can carry millions of human infectious dose. According to Humphrey et al. (2007, p. 243), "*Campylobacter* infection is a major public health problem with complex epidemiology, extensive animal and environmental reservoirs and multiple risk factors." Fecal contamination of carcasses in slaughter houses significantly contributes to the Campylobacteriosis outbreaks. The frequency of red meat contamination is relatively lower than white meat due to extensive chilling of the former carcass before its entry to food chain. Apart from the fact that general outbreaks are rarely recognized, the disease burden accounts to 2.5

million people each year in the United States. Further, one in 1000 cases may lead to complications like Gullian Barre Syndrome (Nachamkin, 2002).

E. coli.

E. coli are predominantly present as nonpathogenic flora in the gastro intestinal tract of human and animals. As such, many strains of *E. coli* remain in commensal relationship within the gastro intestinal tract but some strains can present itself as opportunistic pathogen causing infections in immunocompromised persons (Babcock, 2006). Literatures reviewed reveal a recent outbreak in April, 2015, that sickened 25 children in Whatcom County, Washington. Out of them, ten were hospitalized and six developed Hemolytic Uremic Syndrome (HUS). Investigations suggested manure bunker, hay maze area, and bleachers in the east and west wall of the fairground as the source of contamination (Whatcom County Health Department, 2015). Similarly, in September 2002, a county fair in Oregon witnessed the largest *E. coli* O157:H7 outbreak in its history. Research indicates that *E. coli* O157:H7 is prevalent even among the prize livestock exhibited at agricultural fairs. A study was conducted in 2003 on the prevalence of *E. coli* O157:H7 in livestock at 29 counties and three large state agricultural fairs in the United States. In this, it was found that *E.coli* O157:H7 could be isolated from 13.8 percent of beef cattle, 5.9 percent of dairy cattle, 3.6 percent of pigs, 5.2 percent of sheep, and 2.8 percent of goats (Babcock, 2006).

Due to abundant presence of the pathogen in animal and human feces more than any other ecological niche, they are considered as indicators of fecal contamination. Among all the animal vectors of the *E. coli* strains, cattle contributes significantly to human infections as symptomless excretor of human related strains to the environment and food chain (Shimshony, 2011). Majority research suggests the ubiquitous distribution of the pathogen in US cattle farms with peak shedding in warm months that coincides with the peak outbreaks of human cases (Hancock, Besser, LeJeune, Davis, & Rice, 2001). In addition, the food products obtained from supermarkets are also contaminated with *E. coli* O157:H7. Pathogenic strains of *E. coli* cause three main types of infections in humans 1) urinary tract 2) neonatal meningitis, and 3) gastro intestinal infections (Torres, 2010). Epidemiological reports suggests that these organisms contribute to the most common cause of pediatric diarrhea worldwide (Nataro & Kaper, 1998). Among all types of pathogenic *E. coli*, Shiga toxin producing *E. coli* is considered to be of zoonotic threat due to its widespread availability in human and animal species, and ability to produce disease in humans when transmitted from their animal reservoir. Self-recovery occurs within five to seven days in most cases although it can be life threatening in others leading to HUS and Thrombotic thrombocytopenic purpura (TTP). HUS leads to acute renal failure, and in majority of cases it follows a diarrheal illness in children. HUS can occur in people of any age, and is most common among children under five years and elderly over 65 years. CDC (2014) reports that overall HUS occurs in about 6% of patients of all ages with *E. coli* O157:H7 infection. Direct contact with animals and fecal contamination of the food, water sources are the major reasons of the *STEC* outbreak in humans (Wasteson, 2001). A report from Mayo Medical Laboratories indicates that around 73,000 people are known to be infected by O157 STEC alone each year, and when combined with non-O157 STEC, the number exceeds 100,000 cases, resulting in 3000 hospitalizations and 90 deaths (Grys, 2010). The common causes are attributed to consumption of undercooked ground beef or unpasteurized milk, or animal contact such as in petting zoos. From the zoonotic point of view, *STEC* is a serious public health issue that can be prevented by practicing proper hand hygiene after animal contacts in places like farms, fairs, petting zoos and backyards (Smith et al., 2004).

Salmonella.

Salmonella are rod shaped, non-spore forming bacteria ubiquitously found in the humans, environment and animals. Salmonellosis, the infection caused by the pathogen is clinically characterized into two categories. While few of the serotypes like *S. typhoid* and *S. paratyphoid* cause typhoid in few host species, the majority of them colonize in the gut of many hosts causing gastro enteric illness by entering into the human food chain. Some serovars gets transmitted efficiently into the food chain causing human diseases while others are prevalent in food producing animals but rarely appear in humans (Stevens, Humphrey, & Maskell, 2009). Literature suggests that bacterial foodborne zoonotic diseases are the major cause of gastrointestinal illness worldwide with *Salmonella* and *Campylobacter* accounting for 90 % of such food poisoning (Thorns, 2000). Diarrheal illness in humans is predominantly caused by the contamination of the food chain and the farm environment by selected non-typhoid serovars. They also possess the ability to contaminate the avian reproductive tract and eggs by virtue of colonization. *S. enteritidis* is a zoonotic pathogen causing pandemic through contaminated chickens and eggs in many countries including US (Thorns, 2000).

Besides the consumption of contaminated poultry and eggs, other food producing animals also pose a zoonotic threat. An interesting study by El-Tras, Tayel, & Samir (2010) outlines the major ways of the *S. enteritidis* contamination in the egg industry.

Eggshell contamination during handling by the packagers, shell-to-shell transmission during egg collection, and smoking during packing process increase the pathogen exposure through hand to mouth route (El-Tras et al., 2010). Foodborne infection, fecal-oral route, occupational and recreational exposure are the probable ways for the pathogen to spread to humans from animals (Kahn et al., 2010). Additionally, household pets like dogs and cats serve as a potential source for *Salmonella* infection among people. Specifically, natural pet treats and raw food diets produced with limited regulatory oversights are an indispensable source of Salmonellosis, and an emerging concern associated with the pathogen (Finley, Reid-Smith, Weese, & Angulo, 2006). Recent research indicates that rodents play an active role in transmission of zoonotic *Salmonella* through their biological materials (Antoniou et al., 2010). With the growing popularity of reptiles and amphibians as pets among families, there is an increased concern of *Salmonella* infection contracted from them. These pets include turtles, frogs, iguanas, snakes, and might have the pathogen on their body even if they appear clean and healthy (CDC, 2013). Additionally, CDC reports more than 40,000 cases of Salmonellosis each year in the United States whereas the actual total is much higher; around 1.4 million cases with many incidences remaining under reported. United States witnesses around 1000 deaths due to Salmonellosis complications each year (Hoyle, 2011).

Globalization of food supply, modern food processing methods, and attempts to import large range of food products to satisfy the consumers serve as the triggers for foodborne diseases. The increased burden of zoonotic foodborne diseases reflect the importance of establishing reliable detection and surveillance methods like Pulse Net, which is a molecular surveillance network for foodborne infections in United States

(Keusch, Pappaioanou, Gonzalez, Scott, & Tsai, 2009). In addition, it has been extremely difficult to treat *Salmonella* infection due to emergence of resistance to multiple antimicrobial drug. Fluoroquinolone and the third generation cephalosporins are the drug of choice to treat severe human *Salmonella* infections but there is increased antibiotic resistance over several decades (Acheson, & Hohmann, 2001). For example, of much concern is the recent drug resistance developed by *S. typhimurium* to five drugs namely ampicillin, chloramphenicol, streptomycin, sulfonamides, and tetracycline (Su, Chiu, Chu, & Ou, 2004). A detailed study over the four outbreaks related to multidrug resistant *S. typhimurium* caused in veterinary clinic and shelter house in United States during 1999 to 2000, including one in an animal shelter in Minnesota suggests the following facts about the pathogen (Wright et al., 2005).

1. Risks of occupational zoonotic transmission of *Salmonella spp* from sick animals to employees.
2. Risks of zoonotic transmission of the pathogen to pet owners.
3. *Salmonella* contaminated environment serves as an ongoing source of infections.
4. The possibility of nosocomial transmission.

Older adults, infants, immunocompromised people, and pregnant women are at the highest risk of infection (Lund & O'Brien, 2011). Immediate treatment with antibiotics may be required in some cases to prevent organ failure and death. Careful hand washing, appropriate preservation of foods, and optimum cooking procedures are some of the important ways to prevent the disease. Heat is the only way to kill the bacteria because freezing and drying are not effective on the pathogen.

Clostridium.

Clostridia are generally not considered as a zoonotic pathogen although they affect both human and animals. They are well adapted for host-to-host transmission but no evidence for transmission across the species has been noticed. Indirect transmission of infection through environmental contamination with the spores is the most common method of transmission from animals to human. However, the role of affected animals in the disease transmission is no more than multiplying hosts. *C. perfringens* is the common pathogen of new born domestic animals. Humans consuming meat contaminated with *C. perfringens Type C* may develop hemorrhagic enteritis (Songer, 2009). Among all the *Clostridium spp*, *C. difficile*, an emerging animal pathogen is suggested as a potential zoonotic enteric pathogen. Animal serves as a reservoir for the pathogen and food as the transmission routes from animals to human (Rupnik, Wilcox, & Gerding, 2009). Study indicates that approximately 20 % of retail ground meat samples and meat products contain *C. difficile* sometimes similar to those found among isolates of dogs, calves and human (Rupnik, et al., 2009). Although, facts suggests the transfer of *Clostridium difficille* strain from animals to human, it definitely needs further clarification.

Helicobacter pylori.

Helicobacter pylori is a spiral shape bacteria that causes variety of upper gastro intestinal disorders such as peptic ulcers, chronic gastritis, and gastric cancer. The prevalence of *H. pylori* in some populations and related socio economic factors confirm the man-to-man mode of transmission of the pathogen. Although human beings are the main reservoir, there still remains ambiguity about the zoonotic potential of the pathogen (Mach, 2000). However, recent reports of *H. pylori* in domestic cats has widespread zoonotic importance. A study by Handt and colleagues (1994), documented that *H. pylori* was cultured from six cats and organisms compatible in appearance with *H. pylori* observed in 15 additional cats by histologic examination. The isolation of *H. pylori* from the cats has zoonotic importance with transmission occurring from cats to humans (Handt et al., 1994). Due to the conflicting relationship depicted by epidemiological studies of *H. pylori* infections in animals and humans, it can be an example of reverse zoonoses with humans as the primary reservoir of the organism. "Reverse zoonoses" are infectious diseases, normally reservoired in humans, that can be transmitted to other vertebrates (Hubalek, 2003).

Yersinia.

Yersinia are a group of pathogens that has evolved with diverse clinical symptoms. *Y. enterocolitica (bio serotype 4/O:3)* is the major cause of human *Yersiniosis* worldwide with maximum winter incidences. Among various strains of *Y. enterocolitica* differentiated through serotyping, the highly pathogenic BT1B strain is predominant in United States. These emerging zoonotic entero pathogens use pigs as preferred reservoir hosts. The unique virulence properties of the pathogen favors improved colonization in the pig intestine (Batzilla, Heesemann, & Rakin, 2011).

These properties make pigs the asymptomatic carriers of the pathogen thereby increasing the risks of zoonotic transmission due to ignorance. However, *Y. pestis*, the causative agent of plague is an arthropod vectored zoonotic pathogen with rodents as the natural reservoir. Although, *Y. enterocolitica* are predominantly gastrointestinal pathogens, they can cause extra intestinal infections in humans with predisposing causes (Bottone, 1997). There are enough cases to establish the pathogen as a foodborne organism with infection acquired through oral route. Hand to mouth transmission, as a result of improper hand hygiene is also common. High prevalence of the pathogen in pig farms increases the risk of infecting the carcass, thus, enabling its transmission from farm to fork (Laukkanen et al., 2010). Preparation of raw pork intestine (chitterlings) and consumption of undercooked pork is particularly risky. Transmission to young children through contact with caregivers preparing chitterlings is a common way of transmission. Such cases reflect an indirect exposure to the contaminated vehicle as a major route of transmission. Reports of cases indicate rare possibilities of blood transfusion contaminated with the bacterial pathogen (CDC, 1997). However, based on the data from CDC and Food Net, Yersiniosis is relatively uncommon cause of enteric illness. Significant evidence exist to prove the decline of the disease incidences since 1996, possibly attributed due to educational and awareness efforts among the prevalent groups (Ong et al., 2012). Avoiding undercooked pork, proper hand washing, particularly after handling chitterlings, watching for cross contamination in kitchen, and sanitary disposal of animal feces in farms along with general awareness has been beneficial to control the outbreaks.

Listeria.

Listeria monocytogenes is a facultative anaerobic bacillus, which unlike most pathogens grow well in cold temperatures. It is an infrequent cause of sickness in general population. However, the illness is severe for older adults with immune suppressive conditions, pregnant women and fetuses and neonates. Listeriosis is a typical example of zoonotic pathogen in the food chain causing serious illness like meningitis and miscarriage along with sever enteric illness. Apart from sepsis, meningitis and meningoencephalitis, which are the typical clinical manifestations of Listeriosis, it also causes febrile gastroenteritis in otherwise healthy individuals (Ooi, & Lorber, 2005). Rarely, a cutaneous form of the disease is associated with occupational hazard and common among veterinarians, farmers (Zelenik et al., 2014). The bacteria is an enteroinvasive zoonotic pathogen, causing opportunistic foodborne infections. Recognition of the pathogen as a causative agent for various foodborne infection has remarkably raised its importance as a public health concern. Listeriosis was incorporated to the list of nationally notifiable diseases in the United States in 2001. *L. monocytogenes* as an adulterant in ready to eat (RTE) foods, requiring the absence of the pathogen in 25 gm of food, called zero tolerance (Kersting, 2008). Besides contaminated vegetables, healthy appearing animals can carry the pathogen thus contaminating foods of animal origin. Uncooked meats, and dairy products prepared from unpasteurized milk are the common source of infection. Persons at risk can prevent the infection by avoiding high risk food and practicing domestic hygiene. The burden of Listeriosis has been estimated as 1600 illness, 1400 hospitalizations, and 250 deaths each year in US (Topè, Rogers, & Hitter, 2014). An interesting research on the zoonotic exposure of the pathogen in rural residency indicates that pathogenic serotypes of the bacterium are more commonly isolated from households with ruminants on site than their counter parts with no ruminant holdings. Besides, the study showed that *L. monocytogenes* was transmitted into the home environment on the shoes and gloves of farmers. Consequently, zoonotic education among the farmers through physicians and health educator is important to improve outcome of the disease (Kersting, 2008).

Spatio Temporal Analysis

CDC has used spatio temporal analysis at several occasions to further the knowledge of the disease and its outbreaks (Groseth et al., 2015). In Geographic Information System (GIS), analysis of spatial and temporal data associated with reported cases of disease outbreaks can lead to effective prevention (Ward, 2006). GIS not only aids in understanding the distribution of disease, but also assist public health officials to emphasize their focus on vulnerable population (CDC, 2006). According to (Davis, Sevdali, & Drumright, 2014), spatio temporal examination of disease outbreaks can highlight clustering of cases over space and time. The knowledge of ZED outbreaks over time and space will help implement appropriate and effective disease prevention programs. The use of mapping and clustering of outbreaks to establish illness can be traced back to as early as John Snow's study of cholera in London in 1855 (Sasaki, Suzuki, Igarashi, Tambatamba, & Mulenga, 2008). Incorporation of spatial and temporal analysis into health-related research has gained importance with the availability of location based data of disease. One such application of spatial analysis is hot spot analysis, which help to identify vulnerable locations as hot spots for future control strategy (Sherman et al., 2014).

Causal Theory: The First Step to a Health Program Plan

The concept of public health planning started as early as Indus Valley civilization (Issel, 2004, p. 5). The goals of a health program plan (HPP) is to increase the rate of success, despite limited resources, through designed interventions (Issel, 2004). Current example of a HPP is the "Healthy People 2020", a national health promotion and disease prevention program aiming to improve the health of all (Healthy People 2020, 2014). It follows a framework of mobilize, assess, plan, implement, and track (MAP-IT) to achieve its vision. CDC strongly endorses the concept of "One Health Approach" that initially started as "a concept" became "an approach," and now "a movement." It recognizes that the health of human, animals, and environment are interconnected as they share the same interface (CDC, 2013). Keeping the health approach in view, CDC recently established National Center for Emerging and Zoonotic infectious Disease (NCEZID) strategic plan in 2010. The mission is to reduce illness and death associated with emerging and zoonotic infectious disease through implementation of high impact interventions (CDC, 2015a).

As each health problem has its unique sets of determinants, developing a health model gives a better understanding about the causal factors of the health issue (Issel, 2004). This determination of causal association has profound public health consequences, signaling the need to design programmatic intervention to address the issue (Glass, Goodman, Heman, & Samet, 2013). Public health interventions are defined as tailored actions oriented towards health promotion or protection in a community or population (Rychetnik, Frommer, Hawe, & Shiel, 2002). While interventions can be complex and context dependent, knowledge and research done on the topic shall aid in better tailoring of the interventions. Thus, the designed causal theory model will consider various factors attributed to the ZED outbreaks at public settings. A glance at the developed causal theory on ZED outbreaks, will position public health planners at a better stage in implementing the interventions and evaluating its outcomes. The health impact of such ZED has already been severe at several occasions. For example, some of the largest bacterial ZED outbreaks, like the 2004 State Fair at North Carolina and three other large public fairs in 2005 resulted in hundreds of illness and dozens suffering from complications with haemolytic uremic syndrome (HUS). The bacterial zoonotic pathogen identified in these outbreaks was *E. coli* O157:H7 (CDC, 2005).

A recent study has establish animal contact as the causal attribution of numerous enteric diseases (Angulo et al., 2006). According to LeJeune and Davis (2004), ZED outbreaks can be mitigated through proper communication of the risks to public. In addition, appropriate and effective signage is important to prevent the outbreaks (LeJeune & Davis, 2004). A survey of literature suggests that although there is sufficient risks to public visitors due to animal contacts only a few states have written guidelines towards its prevention in animal exhibition venues (Bender & Shulman, 2004).

Summary

Reducing public health risks from zoonotic diseases is becoming difficult considering the complexity in interaction among animals and humans (WHO, 2015). While the bond between humans and animals can bring much joy and happiness, it can pose significant disease burden on the society. The group of pathogens discussed in this chapter causes an important proportion of enteric illness with few of them contributing to leading cause of hospitalization and death. In conclusion, the substantial burden of disease transmission through animal contact emphasizes on the need to implement interventions and educational programs (Hale et al., 2012). Spatio temporal analyses of the outbreaks could provide better information on when and where to anticipate outbreaks as well as targeting intervention at appropriate location (Davis et al., 2014). Further, understanding the behavioral and environmental factors central to ZED outbreaks, will help in slowing down the outbreaks of these diseases. A causal theory model helps to understand the associated causative factors, in order to suggest preventive and programming measures to control the disease.

Chapter 3 - Methodology

Introduction

The purpose of this research was to conduct spatio temporal examination of the outbreaks of zoonotic enteric diseases including foodborne zoonotic infections, between the years 2000 to 2010. The research also investigated on clustering of ZED outbreaks in different counties of Minnesota over this time period. Disease clustering can be defined as unusually high incidences of outbreaks in close proximity over time and space. The literature suggests a seasonality associated with the outbreaks of ZED globally. An exploratory cross sectional data analysis was conducted for each time period to explore seasonality pattern in the ZED outbreaks in the State of Minnesota from 2000 to 2010 . This chapter describes the methods used to answer the following research questions:

1. What are the major zoonotic enteric bacterial pathogens prevalent in the state of Minnesota since 1999?
2. Is there a rise in the outbreaks of the enteric illnesses in the state of Minnesota attributed to zoonotic pathogens since 21^{st} century? Is there a spatio temporal pattern for ZED outbreaks?
3. How to raise awareness and knowledge about zoonotic enteric diseases and promote prevention to reduce the risks of zoonotic transmission through generating a causal theory?

Research Design

The design used in this research was a non-experimental type to ensure high validity. Information regarding outbreaks were acquired by detail review of newsletter published by Minnesota Department of Health, from 2000 to 2010 (MDH 2000; MDH 2001; MDH 2002; MDH 2003; MDH 2004; MDH 2005; MDH 2006; MDH 2007; MDH 2008; MDH 2009; MDH 2010). Prior to the decision of using this source of data, several health care providers were consulted. Local health care providers such as Mankato Clinic and Mayo Clinic Health System in Mankato did not reveal protected information on gastro enteric disease outbreaks because of the HIPPA rule. Besides, establishing animal contact in the infected cases were subjected to the extent of history taken by the concerned care provider. Therefore, archival data from the newsletter was used in order to get information about all possible ZED outbreaks.

Instrumentation

This study utilized ArcGIS 10.3 GIS software and IBM SPSS Statistics 20 software for exploratory data analysis. GIS was used as an effective tool for spatio temporal mapping of ZED outbreaks in various counties of Minnesota. This helped in understanding the occurrence of diseases at various locations in different months of the year. GIS tool was used for mapping frequency of ZED outbreaks and identifying hot spots of those outbreaks. Frequency and time series analyses of ZED outbreaks were carried out in IBM SPSS Statistics 20 software. Furthermore, whenever required Microsoft Excel was utilized to arrange data and prepare charts.

Reliability and Validity

In this research, reliability was ensured by using reliable data sources like published government newsletter. Reliability measures were integrated by accessing a constant resource for disease outbreak information throughout the study. In order to ensure validity the goals of the study were clearly described. Moreover, use of multiple data sets from the newsletter reduced significant threats to internal validity. External validity was achieved by keeping the population constant that is reviewing outbreaks only in the State of Minnesota.

Operationalization

This study focused on examining outbreaks of bacterial ZED in different counties of Minnesota. Bacterial ZED included zoonotic pathogens like *E. coli, Salmonella, Campylobacter, Clostridium, Yersinia,* and *Shigella*. The outbreaks of enteric disease due to direct and indirect animal contact as well as foodborne illness due to animal products was the dependent variable. Their occurrence in space (counties) and time (months of the year) were the independent variables.

Data Collection

After receiving permission from the Institutional Review Board, the data collection took place. Internet archiving was used for gaining access to the electronically published government newsletters. This study uses data from newsletters published by Minnesota Department of Health. The newsletters for each year were systematically reviewed and the source of outbreaks was categorized into animal and non-animal origin. Foodborne illnesses due to bacterial contamination of animal products were also considered as zoonotic origin. Information regarding outbreaks due to virus and parasites were also found in the newsletter, but not pertinent to this study. Disease outbreak information were organized yearly in an Microsoft Excel sheet under following headings like Pathogen, Origin, Contributing Factor, Vehicle, Setting, Month, and Place of Outbreaks. The information from Excel table were later utilized in ArcGIS 10.3 GIS software for spatio temporal mapping and analyses. The limitation of these data sets were that there were many outbreaks reported with unknown source of contamination. This created ambiguity in categorizing those outbreaks into animal and non-animal origin.

Data Analysis

IBM SPSS Statistics 20 software was used to prepare graphs to plot total number of zoonotic outbreaks over the study period. A time series graph was constructed to measure seasonality of ZED outbreaks in Minnesota. IBM SPSS Statistics 20 software was used to estimate county wise total number of zoonotic enteric outbreaks from 2000 to 2010.

In addition, centered moving average was calculated using IBM SPSS Statistics 20 software to get an idea of the overall trend on ZED in the study period. Also, charts were plotted to establish prevalent bacterial zoonotic enteric pathogens causing frequent enteric outbreaks in Minnesota. Furthermore, the top ten counties in Minnesota with bacterial ZED outbreaks were identified. Total number of outbreaks in each county of Minnesota was mapped using ArcGIS 10.3 GIS software. Hot spot analysis was carried out to find out disease clustering. The potential spatial cluster was identified in the State of Minnesota using Hot spot analysis tool. It calculates the Getis-Ord Gi* statistics for locating hot spots of ZED outbreaks in Minnesota counties. The resultant Z-scores tells where features with either high or low values cluster spatially. This tool works by calculating Z-score and P value for the data set. A higher Getis-Ord Gi* value indicates hot spot while low values indicates clusters of cold spot (CDC, 2016b). A statistically significant hot spot area should have high value of Getis-Ord Gi* and also surrounded by other neighboring counties with high values as well. The frequency of outbreaks aggregated over ten years period was plotted against months of the year. Using this graph, seasonality of the ZED outbreaks was analyzed and months of peak incidences were identified.

Developing a Causal Theory Model

In order to understand the health issue of ZED, the causal factors were organized in a conceptual model. The reported ZED outbreaks in the MDH newsletter, for the period 2000 to 2010, were carefully analyzed to identify several level of causal factors. While most of the factors were behavioral some were concluded to be due to gaps in policies and recommendations. The health impact and health outcome were then calculated from the data to show the significance of ZED in Minnesota. The generic model of a causal theory as described by Issel (2004) was followed during the process of developing the causal theory for ZED. The model describes antecedent factors, main causal or key factors, mediating factors, and moderating factors together contributing to the health impact and outcome of ZED health problem. According to Issel (2004), the antecedent factors are described as the pre-existing factors that can give birth to a certain health problem. The key factors are the elements that directly determines the expression of the health problem. Issel (2004) further explains mediating factors as those that facilitates the health outcomes by arbitrating between the cause and output. Finally, Issel (2004) explains moderating factors as those that might alleviate or aggravate the health outcomes depending on their nature. Based on the above model, a modified model was adopted for development of a causal theory in this thesis. The modified model (Figure 3.1) is based on the assumption that as causal factors accumulate, severity of the health problem and health outcome increases. The revised model is as follows.

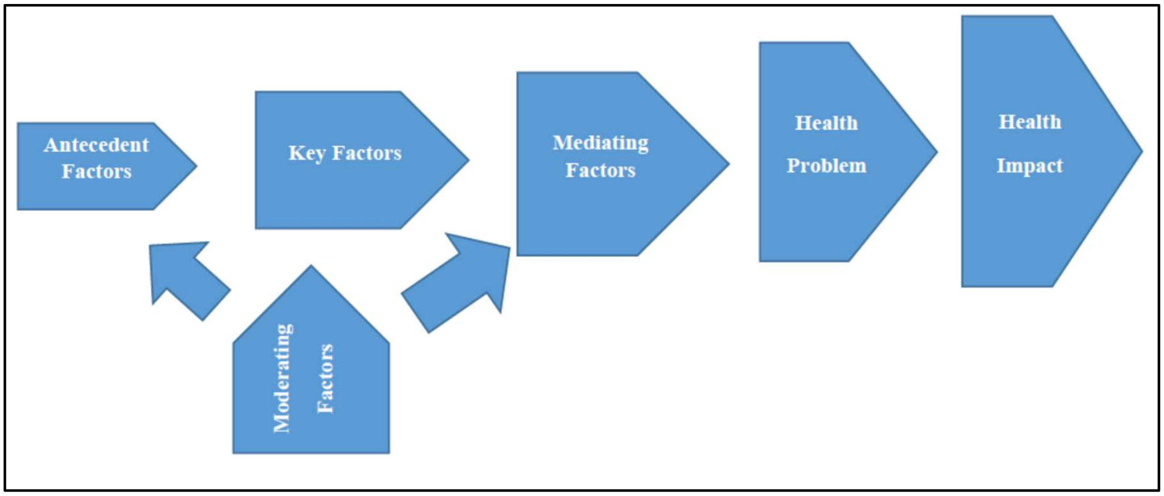

Figure 3.1. Modified proposed model of a causal theory.

The study organized various key and associated causal factors of ZED to write the causal theory statement for ZED in compliance to the following template (Issel, 2004, p. 163).

> "[*Health problem*] among [*population/community*], indicated in [*health outcome indicators*] is caused by [*causative factors*], but is mediated by *[mediating factors],* given that [*moderating factors*] moderate the causes and that [*required antecedent factors*] exists prior to the causes."

Chapter 4 - Results and Discussion

Introduction

The purpose of the study was to identify prevalent ZED pathogens in the State of Minnesota as well as analyze spatio temporal association of the pathogens. The collected archival data for the time period 2000 to 2010 was then thoroughly reviewed. The outbreak data was organized in a spread sheet according to year, pathogen, origin, settings, month, and affected counties. The data was graphed, plotted, and charted in order to make observations. Tables and graphs were created and used to report and analyze the data. The research questions were answered using descriptive statistics and GIS. Findings of the quantitative analysis of outbreaks are presented in this chapter.

Results and Research Questions

Out of all the bacterial enteric outbreaks from the period 2000 to 2010, those with zoonotic origin are presented below in Table 4.1. Prevalent zoonotic enteric pathogens in Minnesota was analyzed from this table. IBM SPSS Statistics 20 software was used to calculate the frequency of outbreaks for each zoonotic pathogen.

Research question 1: What are the major zoonotic enteric bacterial pathogens prevalent in the state of Minnesota since 2000?

Out of total number of enteric outbreaks (n= 202), those with zoonotic origin accounted for 55.94% (n= 113). Outbreaks with non-animal origin accounted for 14.85% (n= 30). Out of total number of outbreaks, 59 cases were of unknown origin. Due to uncertainty in their origin they were not considered in calculations and left as it is. As observed from Table 4.1, more than half of the bacterial enteric infections are zoonotic in nature.

Table 4.1

Total number of bacterial enteric outbreaks according to origin

Origin	Frequency (n)	Percent (%)
Animal	113	55.94
Non-Animal	30	14.85
Unknown	59	29.21
Total	202	100.0

Frequency of yearly outbreaks due to considered bacterial zoonotic pathogens was calculated by using IBM SPSS Statistics 20 software (Appendix A). Total number of zoonotic outbreaks were then calculated from the period 2000 to 2010. Descriptive analysis was used to examine the frequently occurring bacterial enteric pathogens in Minnesota. In Figure 4.1, the frequency table (see Appendix) was aggregated according to bacterial enteric pathogens to plot the chart for prevalent ones. IBM SPSS Statistics 20 software was used to calculate the frequency of outbreaks for each zoonotic pathogen. For comparison, total outbreaks due to pathogens considered in the study were also plotted in Figure 4.1. The six considered bacterial pathogens in the study were *E. coli, Campylobacter, Salmonella, Clostridium, Listeria,* and *Yersinia.* Out of the six considered bacterial pathogens, most of the ZED outbreaks were attributed to four pathogens such as *E. coli* O157: H7*, Campylobacter, Salmonella,* and *Clostridium.* Outbreaks due to *Listeria* and *Yersinia* was negligible. (*Listeria 1, Yersinia 0*). However, it is interesting to note that there were no outbreaks caused due to *Campylobacter* in the year 2003, 2004, 2005, and 2006.

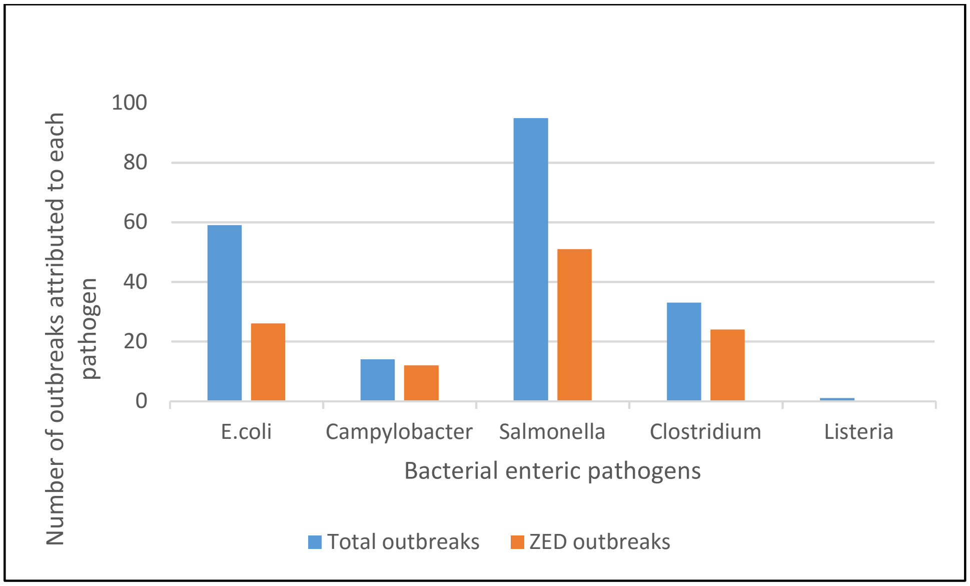

Figure 4.1. Prevalent enteric pathogens in Minnesota from 2000 to 2010.

Research Question 2: Is there a rise in the outbreaks of the enteric illnesses in the state of Minnesota attributed to zoonotic pathogens since 21st century? Is there a spatio temporal pattern for ZED outbreaks?

In Figure 4.2, total number of bacterial enteric outbreaks attributed to animal, non-animal, and unknown origin are plotted over ten years period from 2000 to 2010. Outbreaks attributed to the bacterial pathogens mentioned in the study were only considered. Figure 4.3 illustrated only ZED outbreaks over the specified time period. A comparison of both the bar charts helps to visualize the trends in enteric and ZED cases. It also explains the disease burden of the outbreaks attributed to enteric and zoonotic enteric illnesses every year for the specified time period. Although Figure 4.2 and 4.3 confirms the rise in outbreaks, it does not clearly reveal the increasing trend in recent years. Therefore, to evaluate the overall trend in the outbreaks center moving average technique was employed.

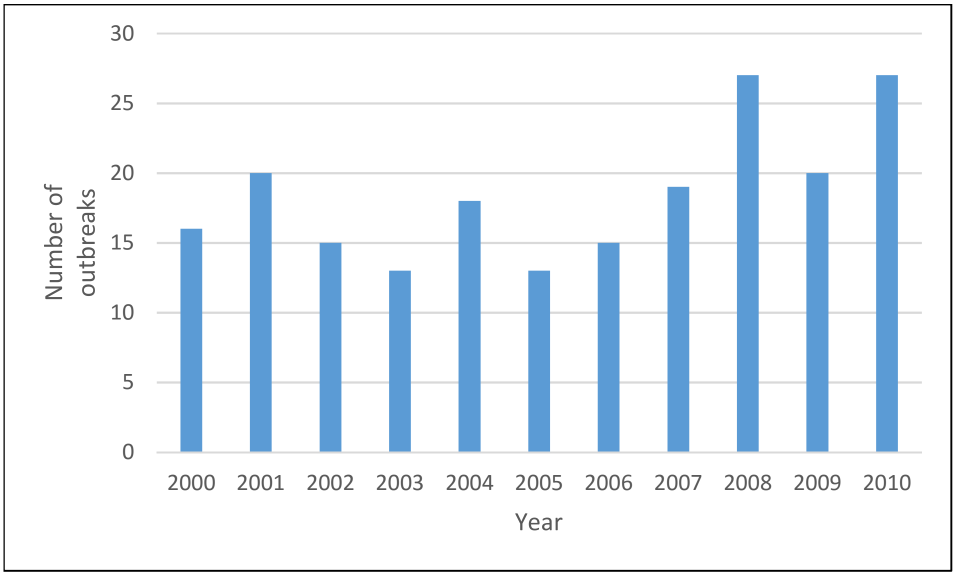

Figure 4.2. Yearly enteric disease outbreaks in Minnesota from 2000 to 2010.

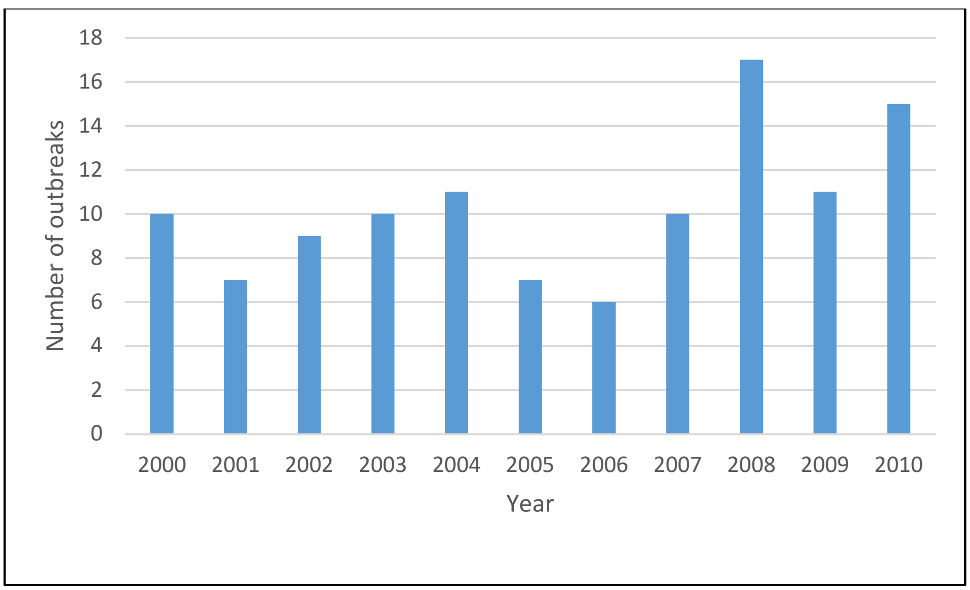

Figure 4.3. Yearly ZED outbreaks in Minnesota from 2000 to 2010.

Figures 4.4 and 4.5 plot graphs for the calculated center moving average (CMA) for total bacterial enteric as well as ZED outbreaks for the period 2000 to 2010. CMA is a technique to obtain an overall idea of the trends in a data set. It is extremely useful for forecasting long term trends**.** Center moving average of three-year time was calculated using Microsoft Excel. An increasing trend in the outbreaks was observed in both. As observed from Figure 4.5, there is a slight drop in the number of ZED towards the year 2005 and 2006, but then it took a sharp rise in the following years till 2010. The CMA graph for ZED suggests a significant rise of outbreaks in near future.

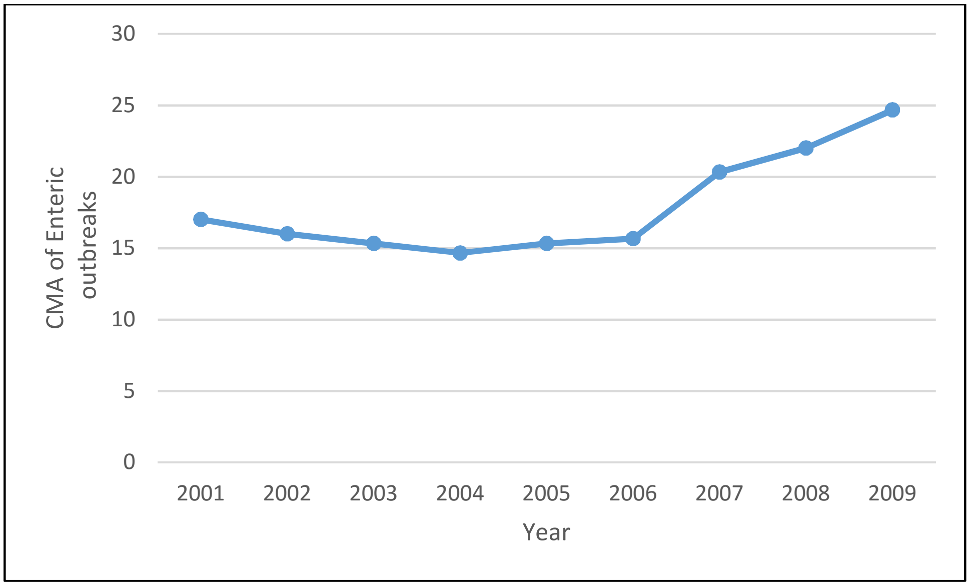

Figure 4.4. CMA of enteric outbreaks in Minnesota from 2000 to 2010.

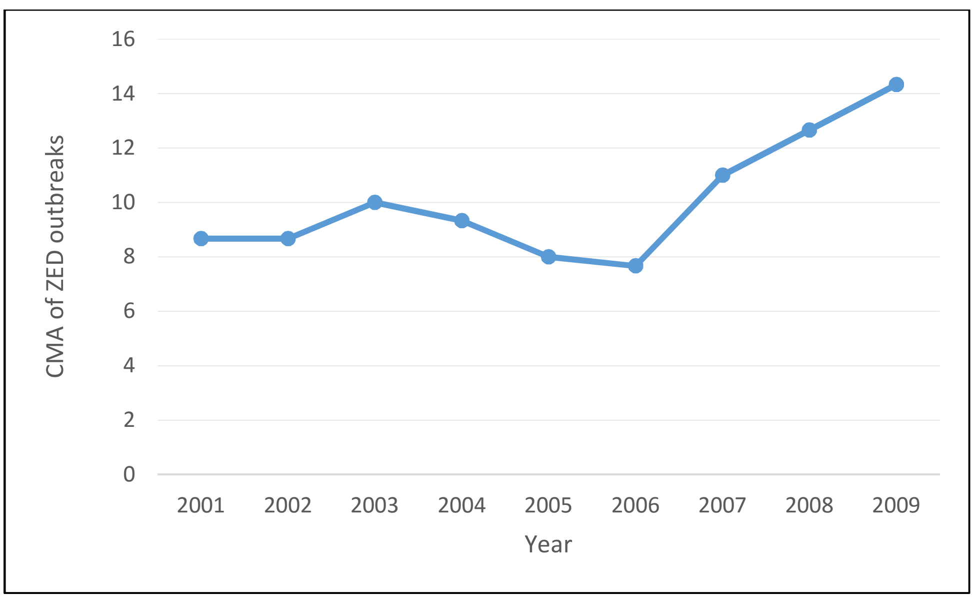

Figure 4.5. CMA of ZED outbreaks in Minnesota from 2000 to 2010.

Research question 2 part 2: Is there a spatio temporal pattern for ZED outbreaks?

Hot spot analysis was conducted to locate the statistically significant hot spots of ZED outbreaks in the State of Minnesota over the study period. A map was first prepared based on standard deviation of the frequency of ZED outbreaks in different counties of Minnesota. Standard deviation was particularly useful as it highlighted the areas significantly different from the average. Figure 4.6 determined the hot spot areas with a higher standard deviation of frequency of ZED outbreaks during year 2000 to 2010. The frequency standard deviation was classified into five classes based on Jenks optimization method (Jenks, 1967). This method of classification decreases variance within the classes while maximizing variance between classes. Figure 4.6 showed Hennepin County, Dakota County, and Olmsted County as hot spots with a value of 2.5 standard deviations above the mean frequency of outbreaks. It was followed by Anoka County and Ramsey County belonging to the second highest category of Jenk's classification.

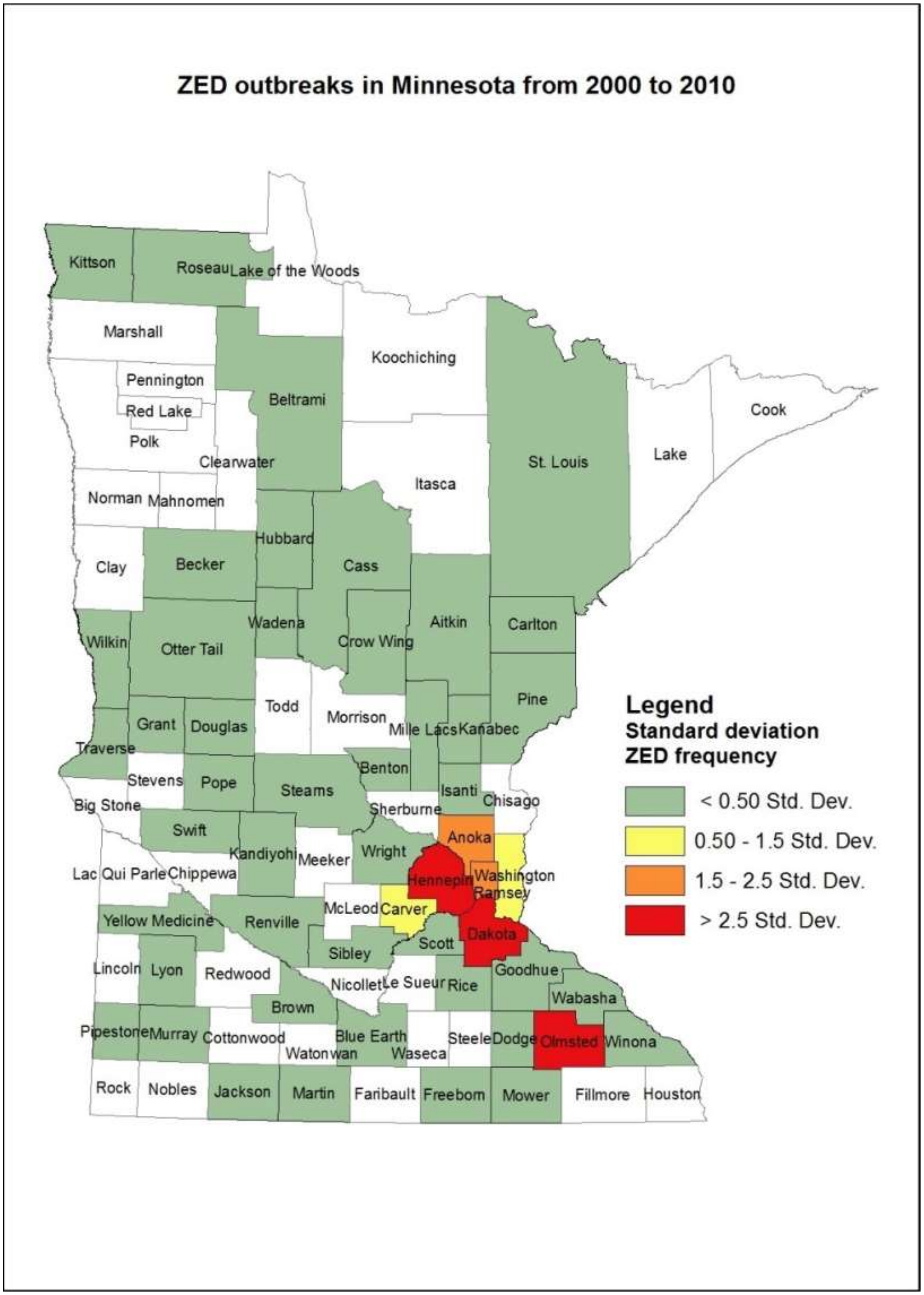

Figure 4.6. Map showing hot spots according to frequency of ZED outbreaks.

Hot spot analysis result was used to create a map in Figure 4.7. The larger the Z-score, the more intense the clustering of high values, thereby revealing the hot spots for ZED outbreaks. Thus, significant positive spatial correlation implies that the distribution of ZED outbreaks shows more spatial aggregation than a random process. Three confidence interval (CI) levels (90%, 95%, and 99%) were used with higher confidence levels indicating more aggregation of hot spots or cold spots. The map in Figure 4.7 revealed that Hennepin County, Dakota County, and Olmsted County cluster spatially, with a high Z-score of $> +2.58$. It is worth to note that while Dakota County is adjacent to Hennepin County in the south east, Olmsted County was found to be an isolated hot spot county with statistically significant Z-score. Anoka and Ramsey counties showed a spatial clustering of Z-score $> + 1.96$. Figure 4.7 did not identify any statistically significant cold spots for ZED outbreaks in Minnesota.

A county map for the State of Minnesota based on average population during the study period was plotted in Figure 4.8. Average population during the period 2000 to 2010 was calculated by adding the census population for respective counties for year 2000 and 2010 divided by 2. A comparison of Figure 4.7 and 4.8 indicates that highly populated counties tend to cluster spatially when considering significant chances of ZED outbreaks in Minnesota.

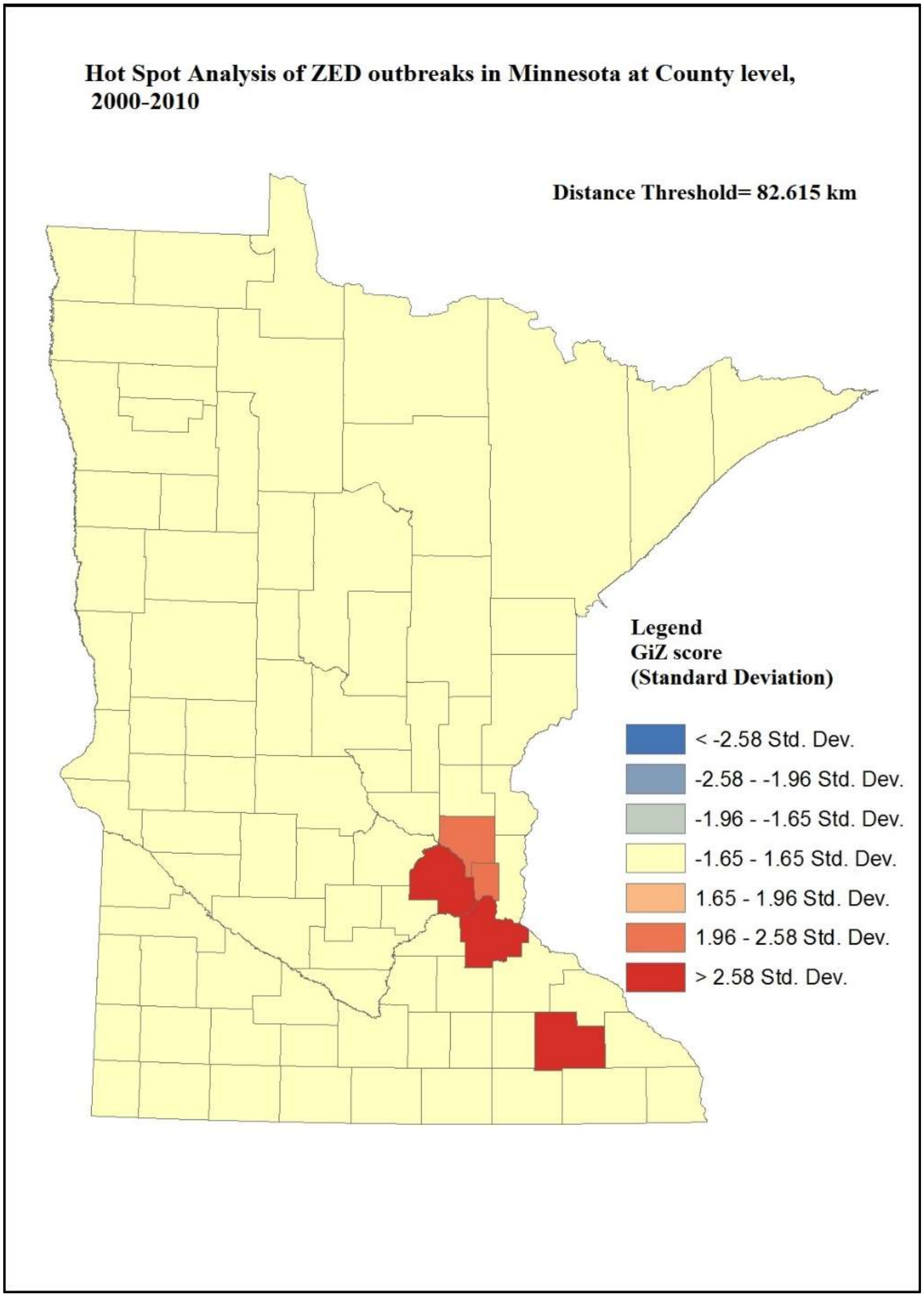

Figure 4.7. Maps showing hot spot counties favorable for ZED outbreaks.

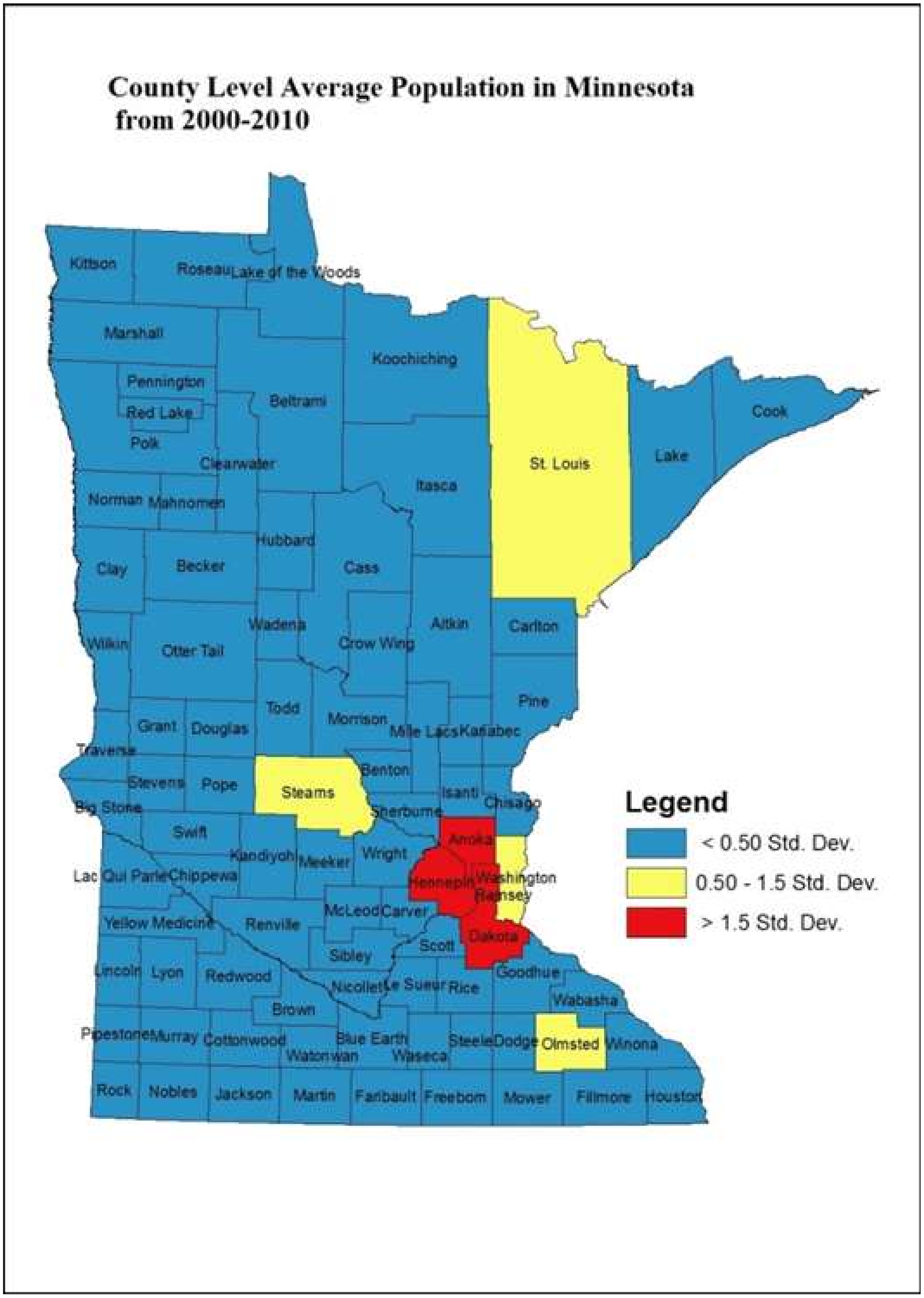

Figure 4.8 Mapping Z-score according of average population of counties in Minnesota.

However, an exception to the above conclusion was observed in Olmsted County. Although, Olmsted County is not very populated (Figure 4.8), it is still a hot spot for ZED outbreaks. Previous research has indicated that population density is a major concern for any kind of zoonotic infectious disease (Lal et al., 2012). Therefore, the findings are partially consistent with these patterns with Olmsted County as the only exception to these findings.

Another map was plotted in Figure 4.9, considering frequency of outbreaks per 10,000 population. This map identified the hot spot zones for the ZED incidence rate. Incidence rate is described as the measure of the frequency with which a disease occurs in a population over a period of time (CDC, 2012). The map reveals a complete different set of counties as the hot spot for ZED incidence rates as compared to ZED outbreaks. The hot spots in this map are Traverse County, Kittson County, and Pope County. Taking into account the sparse population of these counties the frequency of ZED outbreaks in these places was significant.

The temporal association of the ZED outbreaks is illustrated through Figure 4.10. The graph shows the frequency of outbreak over ten years period from 2000 to 2010 aggregated in different months of the year. The graph indicates peak outbreaks during the summer months. Seasonal influence on the ZED outbreaks is clear from the Figure 4.10 with outbreak incidence going down during colder months of the year. This suggests a seasonality correlation to the ZED incidences. A summer peak was noted for the zoonotic enteric pathogens from June to September. Lowest number of cases were recorded in winter months like December, January, and February. As compared to other winter months, November showed marked rise in outbreaks of ZED.

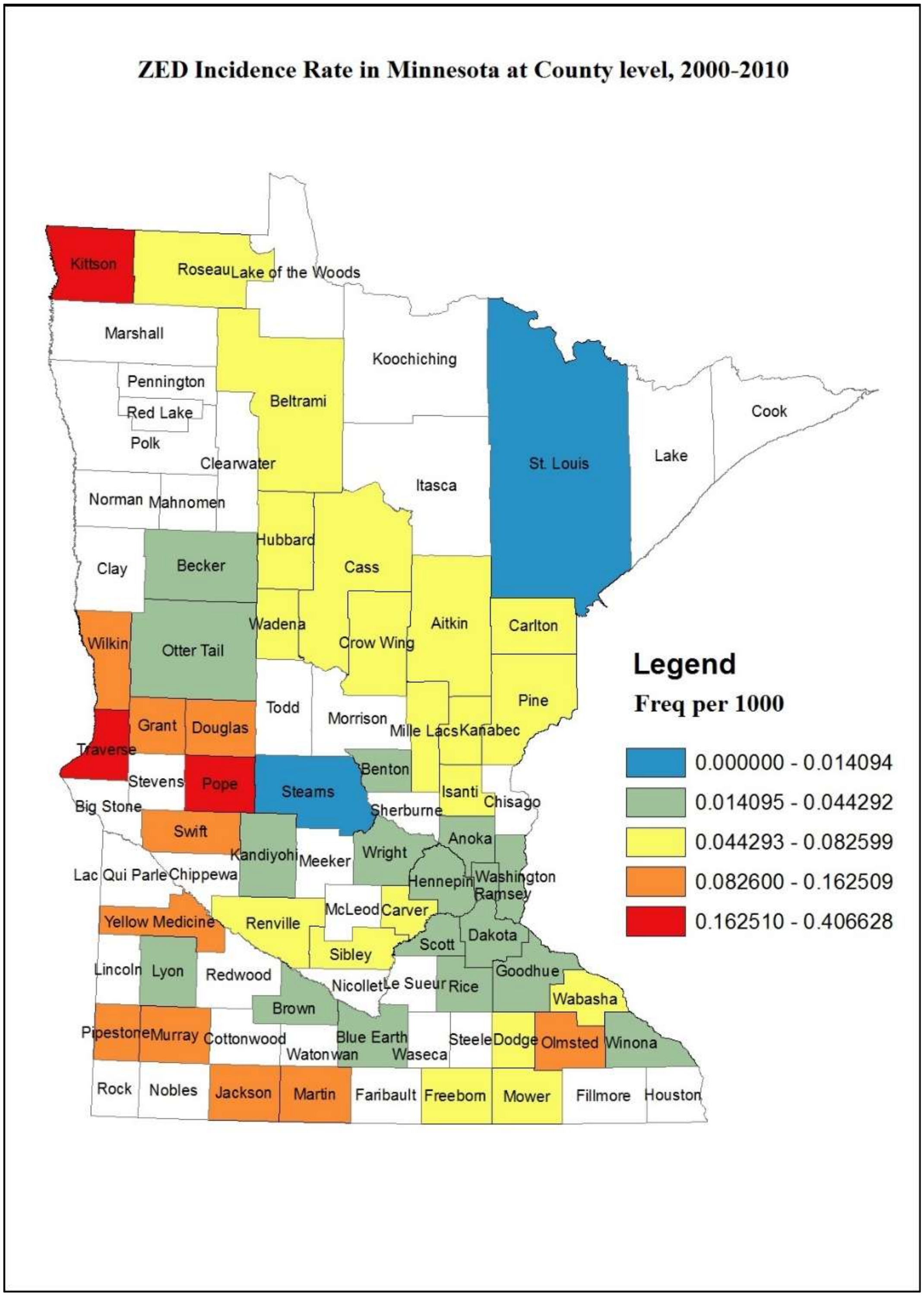

Figure 4.9. Map showing hot spot counties for high incidence proportion of ZED in Minnesota.

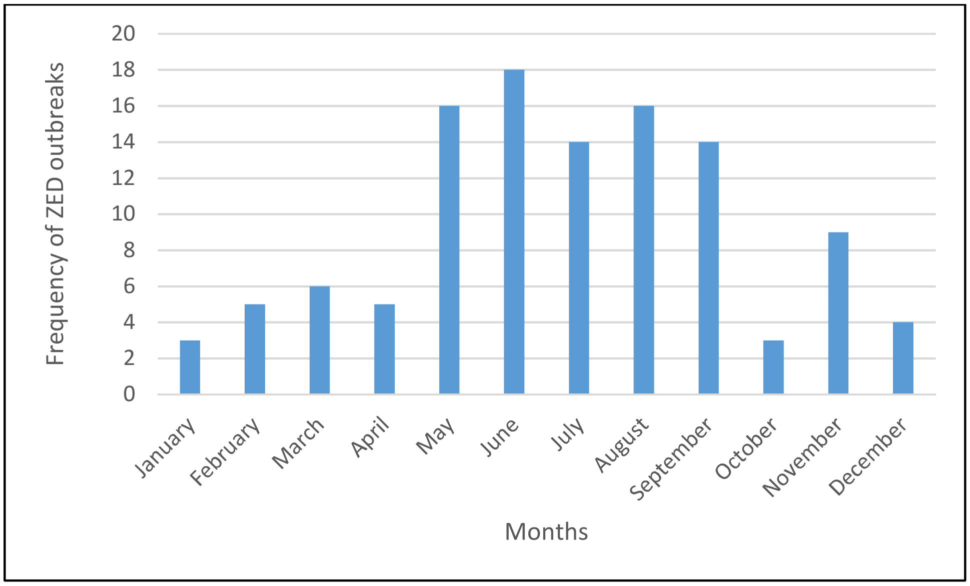

Figure 4.10. Monthly ZED outbreaks aggregated from 2000 to 2010.

Research question 3: How to raise awareness and knowledge about zoonotic enteric diseases and promote prevention to reduce the risks of zoonotic transmission through generating a causal theory?

As noted in the Appendix, a significant portion of ZED outbreaks (22%) occurred at public settings with animal contacts. Therefore, such settings are vulnerable environment for ZED outbreaks. Figure 4.11 illustrates the percentage of ZED outbreaks at venues where there is public contact with animals as compared to other settings. Out of the total reported ZED in the study period, one fifth of the outbreaks occurred in public settings with animal contacts. This necessitates designing of a health program plan to address the problem of ZED risks due to animal contacts at public places. In the process of developing a health program plan, it is imperative to build a causal model for the health issue.

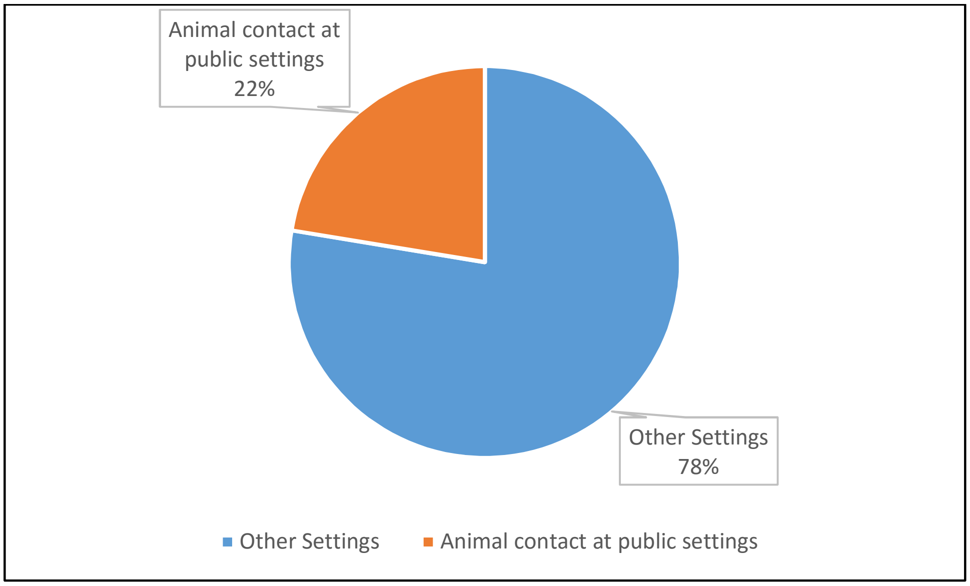

Figure 4.11. ZED outbreaks due to animal contact at public settings against other settings.

A Causal Model for Zoonotic Enteric Disease (ZED) Outbreaks

As illustrated in Appendix and Figure 4.11, public settings with animal contacts is a potential environment with ZED health risks. Therefore, a causal model tailored to context, target population, setting, and health outcomes was developed in this chapter in the form of a flowchart. Figure 4.12 explains the interconnectedness of various factors amplifying the health hazard of ZED outbreaks. The causal diagram has been generated based on theory and evidence of the data represented in Table 4.1. The diagram uses pathways to show cumulative effect of various category of factors on the severity of the health impact and outcome. The illustrated model categorizes several factors contributing to ZED health outcome at public settings into four major groups. The first group of factors in Figure 4.12 are the antecedent factors described as elements that must be present to give birth to a ZED health problem. The designed causal model reveals increased exposure to animals for education and entertainment purpose as contributing antecedents to the problem. Antecedent factors leads to the key/causal factors. These elements decide whether ZED will manifest itself as a significant problem in the presence of antecedent factors. As described in the model, inadequate hand hygiene was found to be a critical component of the key/causal factor. According to CDC, hand hygiene is a method to remove microorganisms from hand through proper cleaning (CDC, 2015b). Physical contact with animals and animal products followed by improper washing of hands increases the risk of hand to mouth contamination. Therefore, these set of factors are the determinants for ZED health issue. The next category is the moderating factors that have the ability to aggravate or alleviate the consequences of ZED. In the proposed model, the moderating factors act towards diminishing the strength of key/causal factors. They can be summarized as the existing professional knowledge and awareness on zoonotic diseases. The last set of factors are called mediating factors that lead the way for key/causal factors to result in ZED health outcome. As observed from the Figure 4.12, mediating factors for the ZED problem are the gaps in policies, recommended guidelines, and their compliance.

In Figure 4.12, the four categories of factors have been outlined after a thorough content analysis of the reported ZED outbreaks at public settings, from the data source. For example, an outbreak due to *E. coli* O157:H7 infections associated with a petting zoo in Scott County was reviewed (MDH, 2009). Lack of recommended guidelines, inadequate hand washing stations, absence of barrier between animals, and non-animal areas were reported as the contributing factors of the outbreak. This framework organizes the statistical analysis of the available data to illustrate the health impact and health outcome of ZED due to animal contacts at public settings. A causal theory model serves as an explanation of what causes ZED in public settings with animal contacts. This model serves as a guideline for the health program planners to design interventions at various levels to improve the health outcome.

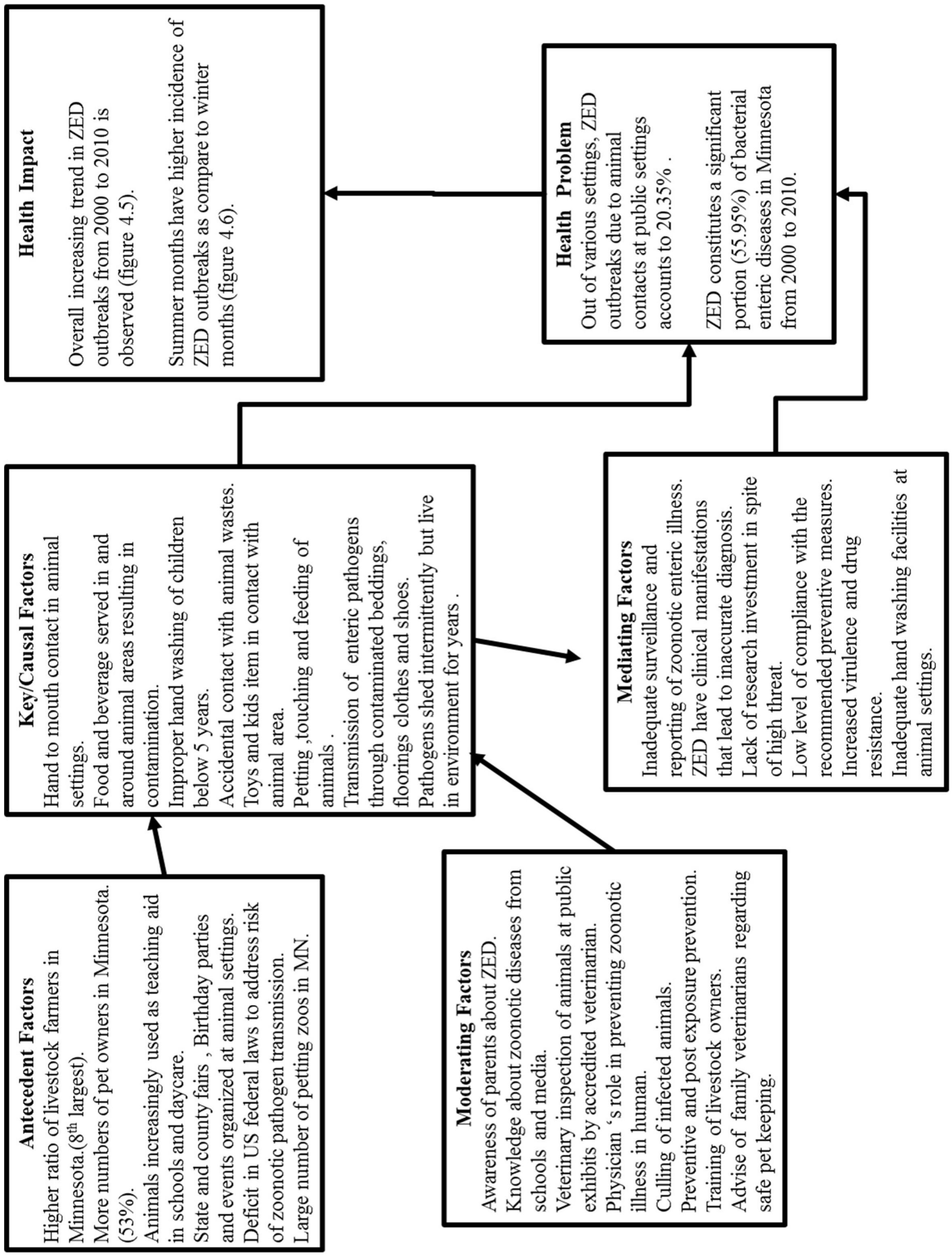

Figure 4.12. Causal theory model for ZED outbreaks due to animal contacts at public settings.

Chapter 5 - Summary and Future Recommendations

Summary

With recent increase in frequency of enteric outbreaks due to animal contacts at public settings, zoonotic enteric disease (ZED) is a rising public health concern. While cognitive capacities of animals leads to their increased use in entertainment and education, it is accompanied with risks of exposure to zoonotic pathogens. The potential areas of ZED threat comes from a variety of sources ranging from nontraditional pets like reptiles and rodents to animal exhibits at public places. To add to the disease burden, foodborne zoonoses contributes significantly to the hospitalization and death due to enteric infections each year. According to CDC (2011b), the top five pathogens causing hospitalization due to foodborne illnesses are *Norovirus*, *Salmonella*, *Campylobacter*, *E. coli* O157:H7, and *Toxoplasma gondii*. Out of these pathogens, *Salmonella*, *Campylobacter*, and *E. coli* O157:H7 are the bacterial enteric pathogens of zoonotic nature. While most of the cases are self-limiting, it can take the shape of deadly complications in many, depending on the severity of the infection. Fecal-oral route is the primary mode of transmission in enteric pathogens. ZED illnesses are associated with contamination through direct and indirect contact with animals and animal products. Poor hand hygiene practices and hand to mouth activities in vulnerable settings enhances risks of disease transmission. In addition, contamination with zoonotic pathogens during farm to fork also contributes to ZED health impact. Although anyone with zoonotic exposure might be at risk, young children less than five years of age, older adults, immunocompromised, and pregnant woman are at higher risk. Enteric disease hospitalizations among infants account for substantial health care expenditures and hospital time in the United States.

The purpose of this study was to identify the prevalent bacterial zoonotic enteric pathogens in the State of Minnesota and examine the trend in ZED outbreaks caused by them. Additionally, it explored the spatial and temporal correlations among those outbreaks. Furthermore, as a part of a health program plan, this study developed a causal theory model to understand the role of various factors causing ZED at public settings. The results of this study indicated the recent pattern of bacterial zoonotic enteric illnesses in the State of Minnesota from 2000 to 2010. The research found an upward trend in the number of ZED outbreaks during this time period. Out of total number of gastroenteritis caused due to the bacterial pathogen considered in the study from 2000 to 2010, 55.94 % were of zoonotic origin. Considering a limited study period of ten years, these numbers are staggering. Enteritis caused due to zoonotic origin was a vital part of the total number of outbreaks during this time period. It can be anticipated that these figures will rise in future with the increased use of animals for purposes of education and entertainment. Globalization and industrialization of animal products for several reasons also adds to the zoonotic threat, and overall incidences of ZED outbreaks (Marano, Arguin, & Pappaioanou, 2007). As discussed in chapter two, besides constant shedding of pathogens by sick animals, healthy animals harboring large number of zoonotic pathogens also increases the threat of ZED. To compound the risks, antimicrobial resistance in zoonotic enteric bacterial pathogens is a public health concern that needs serious interventions. Such resistant pathogens enter into human chain through direct or indirect animal contact, and food chain (Verraes et al., 2013).

Out of the bacterial enteric pathogens chosen for this thesis, major pathogens causing most ZED outbreaks in Minnesota were a) *Salmonella*, b) *E. coli* O157:H7 c) *Campylobacter*, and d) *Clostridium*. *Salmonella* prevalence was highest among all ZED outbreaks. The prevalence of *E.coli* O157:H7 and *Clostridium* were almost same followed by *Campylobacter.* However, it is worth noting that there were no outbreaks caused by *Clostridium* at public places due to animal contacts. This proves that all reported *Clostridium* infections of animal origin were foodborne zoonoses. They entered into human chain through fecal oral route due to consumption of contaminated animal products on their way from farm to fork. This supports the argument made earlier in the literature review that zoonotic origin of *Clostridium* needs further clarification. A higher rate of zoonotic Salmonellosis can be attributed to its already established ability to survive in the environment for a longer period without showing symptoms. Several other factors including its multi resistant properties, as discussed in chapter two, could have contributed to its increased prevalence (Wright et al., 2005). In addition, increased exposure to non-traditional pets like rodents, amphibians, and reptiles, play a critical role in zoonotic outbreaks of human Salmonellosis.

There were no enteric outbreaks attributed to *Campylobacter* in the year 2003, 2004, 2005, and 2006. Before 2003, Campylobacteriosis emerged as a disease with public health importance. The continuous presence of *Campylobacter* isolates resistant to fluoroquinolone antibiotics like ciprofloxacin needed immediate attention. Since the year

1995, fluoroquinolones were used rampantly in poultry industry for treatment as well as profit purposes. Hence, poultry was the primary source of resistant *Campylobacter* strains for humans. Realizing the significance of the problem, the United States Food and Drug Administration (FDA) in September 2005 withdrew the approval of enrofloxacin, a veterinary fluoroquinolone used in poultry industry (MDH, 2013). This may have contributed to the remarkable decline in the Campylobacteriosis outbreaks in these years.

Hot spot analysis conducted in the study reveals Hennepin County, Dakota County, and Olmsted County as the potential areas of ZED outbreaks. These hot spot clusters were consistent with the already suggested pattern of population dynamics (Keusch et al., 2009). According to Keusch and colleagues (2009), zoonotic disease outbreaks are correlated to population movement and population expansion. However, Olmsted County stood as an exception to this pattern by being a hot spot zone despite its low population. This might be attributed to an approximate of 30,000 persons commute to Rochester (the largest city of Olmsted County) daily for several reasons be it work, convention, or conferences. These factors increases food service opportunities and risks of zoonotic foodborne outbreaks in the complex food production and distribution network. Apart from the local petting zoo in this County, the trend of traveling petting zoo has created additional problems. For example, the Zerebko Zoo Tran traveling exhibit in Olmsted County in 2014 caused an *E. coli* O157:H7 outbreak making several people sick (MDH, 2014).

It is worth mentioning that the results of hot spot analysis presents a different pattern for incidence risks of ZED. As discussed earlier, incidence risks can be explained as the frequency of outbreaks in a population (CDC, 2012). Traverse County, Kittson County, and Pope County form the hot spots when incidence rate of ZED is considered. The thin population of these counties makes it unusual for them to be categorized as hot spots. Oftentimes, an apparent health problem needs to be investigated irrespective of an epidemic has occurred or not, and not restricted to the number of cases (CDC, 2012). Such hot spot zones might require a community survey to investigate on the antecedence of the ZED outbreaks.

It was concluded from the thesis that ZED has been reported to be present throughout the year but some months showed higher incidences than others. A seasonal pattern of outbreaks with a mostly predominant peak is seen during the summer months namely June, July, August, and September. Increased contact between animals and human population during recreational and entertainment activities in summer could enhance the risk factors. The onset of fair seasons, farm visits during camps, and reopening of petting zoos facilitates human animal interactions during summer. Although, it is difficult to infer causality, existence of a seasonal pattern may also be due to higher contamination of meat and eggs during summer months. These outbreaks are unavoidable consequences of human animal relationship. However, much can be attained by educating public about causal factors of zoonotic enteric risks along with control and prevention. At public places with animal exhibits, information about mitigating risks of disease transmission should be visually displayed. A healthy and safe visit to fairs and petting zoos necessitates better compliance to recommended guidelines outlined by National Association of State Public Health Veterinarian (NASPHV, 2011).

Previous research has found the importance of an effective public health program plan for diseases to attain maximum and cost effective public health outcome (CDC, 2012). In this study, a causal theory model addressing the ZED outbreaks at public places was generated. It identified several causal factors that must be changed to improve the process of ZED control and prevention at vulnerable settings. The thesis brought together all possible causation of the outbreaks in a form, easy to educate public and assist program planners. The described causal theory can serve as the first step in the process of constructing a health program plan to minimize ZED health risk. During the process of designing the model, the study explored the behaviors and factors that might have caused the zoonotic outbreaks in the reported cases. It then assembled them to fit the causal theory template as suggested by Issel (2004, p. 198). The practical implications of the model includes the need of understanding the gaps that requires attention to improve ZED outcomes in potential public places.

Recommendation for Health Educators

The peak incidence of ZED during summer months necessitates extensive health education and awareness regarding ZED prevention before onset of summer. Health educators must plan for an extensive list of summer opportunities with potential ZED threat and design interventions to educate visitors. Keeping in view the considerable health risk to young children from traditional and nontraditional pets, it is imperative to include zoonotic disease education in schools and daycare centers. However, the role of a family veterinarian cannot be undermined in this regard. Health educators must also stress upon veterinarians to improve client education on zoonotic risks at their settings.

This can be done by frequently arranging for workshops and presentations to discuss the role of veterinarians in promoting public health (CDC, 2016a).

Given the constant interaction between animal, human, and environment, reducing health threat from animals is not easy. Further, the vast range of direct and indirect exposure to animals and animal products enhances the complexity of interaction. Having said that, WHO has recognized health literacy as an important contributor to improve health outcomes (WHO, 2012). A causal knowledge aids in an in-depth understanding of a disease, enabling planners to design intervention to break the link between causal factors and disease. The causal theory model generated in this thesis organizes possible behavioral and associated factors for ZED at public places, in an easy to understand visual model. The purpose is to emphasize health educators to consider various behavioral changes as a means to improve ZED health outcome. Health educators must reinforce behavior change efforts like:

1. Emphasizing on restricted hand to mouth activities by employing more hand washing ambassadors as demonstrated during the Northwest Washington Fair in Lynden, Washington (Beecher, 2015).
2. Ensure strict supervision of proper hand hygiene among children by specially trained team. While training alone is not enough, health educators need to be role model supporting work environment. For example, they should promote adequate installation of hand sinks in and around ZED vulnerable zones.
3. Limited or no food exposure in animal area, and

4. Overall better compliance to recommended guidelines during visit to public places with animal settings with potential ZED risk. National Association of State Public Health Veterinarians (NASPHV) lays down the recommended guidelines for venues with potential zoonotic risks (NASPHV, 2011). For example, this could be done by distributing leaflets on "ZED risks and preventions" to the visitors at their entrance. These handouts has already been designed by MDH and available titled as "Have fun on the farm and stay healthy" (MDH, 2015). They can be used at different public venues with possible animal contact within the State of Minnesota. Also, advertising on social and digital media would be an effective method of raising awareness among public.

In addition, the causal theory model aims to empower the community and families to take responsibility in protecting their own health by increasing ZED awareness. High-risk counties were identified in the study, thereby enabling health educators to design for intervention at right time and right place. Hot spot analysis identifying the vulnerable zones shall help in understanding the potential contributions to ZED outbreaks. Investigation of the hot spots and non-hot spots will provide additional information to the nature and cause of ZED. Emphasis must be given on the counties identified as hot spots to reduce ZED disease burden.

Recommendation for Future Research

This study explored the bacterial enteric outbreaks due to zoonotic origin for a period of ten years ranging from 2000 to 2010. There was a significant rise in the ZED outbreaks, particularly from 2006 to 2010. This necessitates further research to examine the trend in ZED outbreaks till date. Forecasting trends will not only help to take rigid precautions but can also be useful to assess compliance to recommended guidelines. As this research examined the outbreaks attributed to only the bacterial enteric pathogens, it is imperative to study the burden of viral as well as parasitic zoonotic enteric pathogens. The zoonotic nature of *Clostridium* was still a controversy with no outbreaks reported due to the pathogen at public settings with animal contacts. A further research on the gastroenteritis outbreak data from 2010 till date might be helpful in validating the zoonotic nature of *Clostridium*.

Results of this research indicated a need to look deep into the ZED outbreaks in Minnesota for the year 2006. There was no ZED reported due to animal contacts at public settings in the year 2006. The literature review points to the release of "*Compendium of Measures to Prevent Disease Associated with Animals in Public Settings, 2006*" on behalf of NASPHV (NASPHV, 2006). Therefore, it is important to examine the effect of this compendium on the ZED outbreaks and follow up with its compliance in subsequent years.

Finally, expanding the geographical location of the ZED outbreaks beyond the State of Minnesota could provide a more comprehensive understanding of the spatio temporal patterns, and trends associated with it. Due to time and budget constraints, the causal model designed in the research could not be evaluated. Future research may want to consider the utility of the model in developing a health program plan. A logic model including interventions tailored to various categories of factors as displayed in the causal model may be designed to improve ZED health outcomes.

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APPENDIX

Frequency of Bacterial ZED Outbreaks due to Each Pathogen from 2000 to 2010

Year	Pathogen	Bacterial Enteric Pathogen Frequency	Bacterial ZED Frequency	ZED Outbreaks at Public Settings
2000	Campylobacter	2	2	1
2000	Clostridium	0	0	0
2000	E.coli	6	4	1
2000	Salmonella	8	4	2
2000	Total	16	10	4
2001	Campylobacter	2	1	1
2001	Clostridium	3	2	0
2001	E.coli	6	1	1
2001	Salmonella	9	3	1
2001	Total	20	7	3
2002	Campylobacter	4	4	2
2002	Clostridium	3	2	1
2002	E.coli	2	1	0
2002	Salmonella	5	2	0
2002	Total	14	9	3
2003	Campylobacter	0	0	0

Continued

Year	Pathogen	Bacterial enteric pathogen Frequency	Bacterial ZED frequency	ZED outbreaks at public settings
2003	Clostridium	4	4	0
2003	E.coli	4	2	1
2003	Salmonella	5	4	0
2003	Total	13	10	1
2004	Campylobacter	0	0	0
2004	Clostridium	4	1	0
2004	E.coli	5	2	0
2004	Salmonella	9	8	3
2004	Total	18	11	3
2005	Campylobacter	0	0	0
2005	Clostridium	3	2	0
2005	E.coli	5	0	0
2005	Salmonella	5	5	1
2005	Total	13	7	1
2006	Campylobacter	0	0	0
2006	Clostridium	2	0	0
2006	E.coli	3	2	0
2006	Listeria	1	0	0

Continued

Year	Pathogen	Bacterial enteric pathogen Frequency	Bacterial ZED frequency	ZED outbreaks at public settings
2006	Salmonella	9	4	0
2006	Total	15	6	0
2007	Campylobacter	1	1	1
2007	Clostridium	2	2	0
2007	E.coli	6	4	1
2007	Salmonella	10	3	2
2007	Total	19	10	4
2008	Campylobacter	2	2	0
2008	Clostridium	6	5	0
2008	E.coli	6	3	1
2008	Salmonella	13	7	2
2008	Total	27	17	3
2009	Campylobacter	1	1	0
2009	Clostridium	1	1	0
2009	E.coli	10	5	1
2009	Salmonella	8	4	1
2009	Total	20	11	2
2010	Campylobacter	3	2	1

Continued

Year	Pathogen	Bacterial enteric pathogen Frequency	Bacterial ZED frequency	ZED outbreaks at public settings
2010	Clostridium	4	4	0
2010	E.coli	6	3	1
2010	Salmonella	14	6	0
2010	Total	27	15	2
Grand Total		202	113	26