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PRAMNET: Pediatric Risk Assessment Mapping Net(work):

Mapping the Health Gaps for Children with Complex Medical Needs, Children with Disabilities, and Infectious Pediatric Illnesses

By:

Kenneth Patrick Goughnour

Master of Public Health

Department of Global Health

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Kenneth G. Castro, MD, FIDSA

Committee Chair/Thesis Advisor

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Paul M.A. Baker, Ph.D.

Thesis Advisor

An abstract of a thesis submitted to the Faculty of the

Rollins School of Public Health of Emory University

in partial fulfillment of the requirements for the degree of

Master of Public Health

in Global Health

2018

**Abstract**

PRAMNET: Pediatric Risk Assessment Mapping Net(work):

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**Background:** Georgia's pediatric mortality rate is one of the highest in the nation (Gentili, Harati, Serban, O'Connor, & Swann, 2017). There are also significant differences in pediatric health across Georgia when measured in terms of geography and race (CDC, 2015). While there is a good deal of available pediatric health data, much of this body of data is complicated by not only: a) a great deal of variation in granularity in its collections (some as fine as on a sub-census tract basis, some more grossly aggregated); and b) the presentation in traditional modes (e.g. tables), while sufficient, could be enhanced by the application of spatial analysis systems that allow for the visual presentation of geographic factors. This thesis argues that particularly within the field of pediatric health, Geographic Information System (GIS) software is an underutilized set of tools which can improve the development of public health outcomes and interventions.

**Purpose:** The aim of this thesis is to present a practitioner's exploration of a conceptual model for aggregating and displaying different kinds of geographically-based data (geo-coded data, demographic, behavioral, biometric, etc.) with the proposed used of wearable devices to more demonstrate efficacious, data driven outcomes for pediatric populations in Georgia. Two unrelated digital technologies, when combined, show significant promise for enhancing the pediatric health field. GISs are being employed in the field of pediatric health care and health information systems in new and innovative ways, and wearable technologies including sensors and displays, are be used both to collect a wide variety of health related data, while providing feedback to the user.

**Methods:** A review of pertinent literature was used to identify key population demographic characteristics for pediatric health conditions (e.g. mother's age, child's diabetic status) in metro/urban Atlanta. A GIS software application, ArcGIS, was used to generate proof of concept maps that visually capture "hot spots" of negative pediatric outcomes.

**Results:** GIS mapping methodologies provide a powerful approach to visually reveal negative pediatric outcomes that might not be readily apparent in traditional tabular and textual presentations. As such, previously obscured population conditions can become visible. The resultant geo-coded longitudinal data can inform health practitioners and policy-makers of unique socioeconomic contexts, differential pediatric exposures, differential health outcomes and differential vulnerabilities. This, in turn, can improve access to appropriate and necessary pediatric care, particularly among pediatric urban/metropolitan populations.

**Discussion:** This thesis presents a conceptual model that explores the use of GIS spatial analysis using key pediatric health indicators as a way of testing the hypothesis that the visual enhancement and presentation of data can better serve public health professionals and policy makers.

**Acknowledgements**

First and foremost, I'd like to thank Dr. Paul Baker, my thesis and work advisor, for his encouragement, support, and advice throughout this process. I'm extremely grateful to you for the caring guidance you provided throughout my graduate studies, and continue to provide now as I embark on my professional career. To adapt a famous saying attributed to Mark Twain, I was astonished by how much my father learned while I was working on my Master's degree. Thank you for being the best dad a son could ask for.

I would like to express my gratitude to my thesis committee chair, Dr. Kenneth Castro, for his guidance on this project. I thank him for always making time for my many questions despite his busy schedule -- he has been a great source of advice and support.

Thanks are also extended to Dr. Michael Kramer for his valuable feedback on this project and for lending his expertise in geographic information systems. There are several other people I'd like to thank for their support and encouragement in this project and throughout my time at Emory and Georgia Tech as well.

Last but not least, I'd like to thank my friends and my loving family for their patience, encouragement, and support during this process and beyond.

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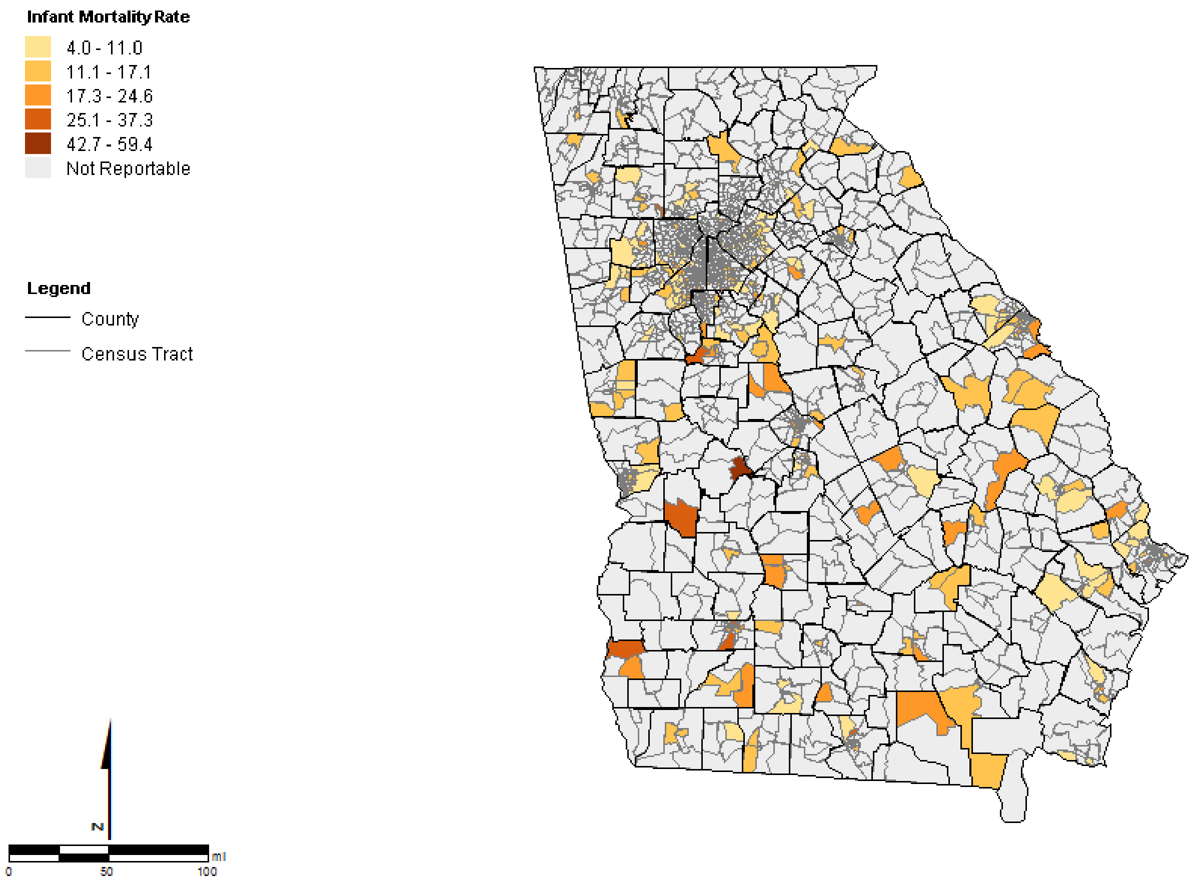
## Chapter 1
## Introduction and Significance

### 1.1.0: Pediatric Health and Outcome Disparities in Georgia

Georgia is a diverse state with both urban settings and large geographic rural areas leading to significant differences in availability and levels of pediatric health care. The state has 159 counties, and 18 health districts. According to the Georgia Department of Public Health (GDPH), twenty-nine counties account for 71% of the state's births and 70% of infant deaths (GDPH, 2013b). Rural counties have approximately half as many physicians and dramatic shortages of nurses, therapists, and nutritionists (per capita) as the metro counties (GDPH, 2008b). When pediatric populations have disproportionately higher illness rates and higher uninsured rates, it can result in higher costs to the health system overall (GDPH, 2017), in addition to raising questions on health inequity and social injustice. Despite a decline in infant mortality of nearly 18% between 2003 and 2013, Georgia still ranked 40th in infant mortality and 50th in maternal mortality in 2015 (Zertuche, Spelke, Julian, Pinto, & Rochat, 2016). According to the Centers for Disease Control and Prevention (CDC), Georgia also ranks low nationally in pediatric health outcomes, which may be, at least in part, due to the multi-faceted problem of access to pediatric care (CDC, 2015). A report published in the *Maternal and Child Health Journal*, noted that over half of Georgia communities outside metropolitan Atlanta lack adequate access to obstetric services and pediatric care, and speculated how health disparities emerge with groups have differential access to care overtime and across generations (Zertuche et al., 2016).

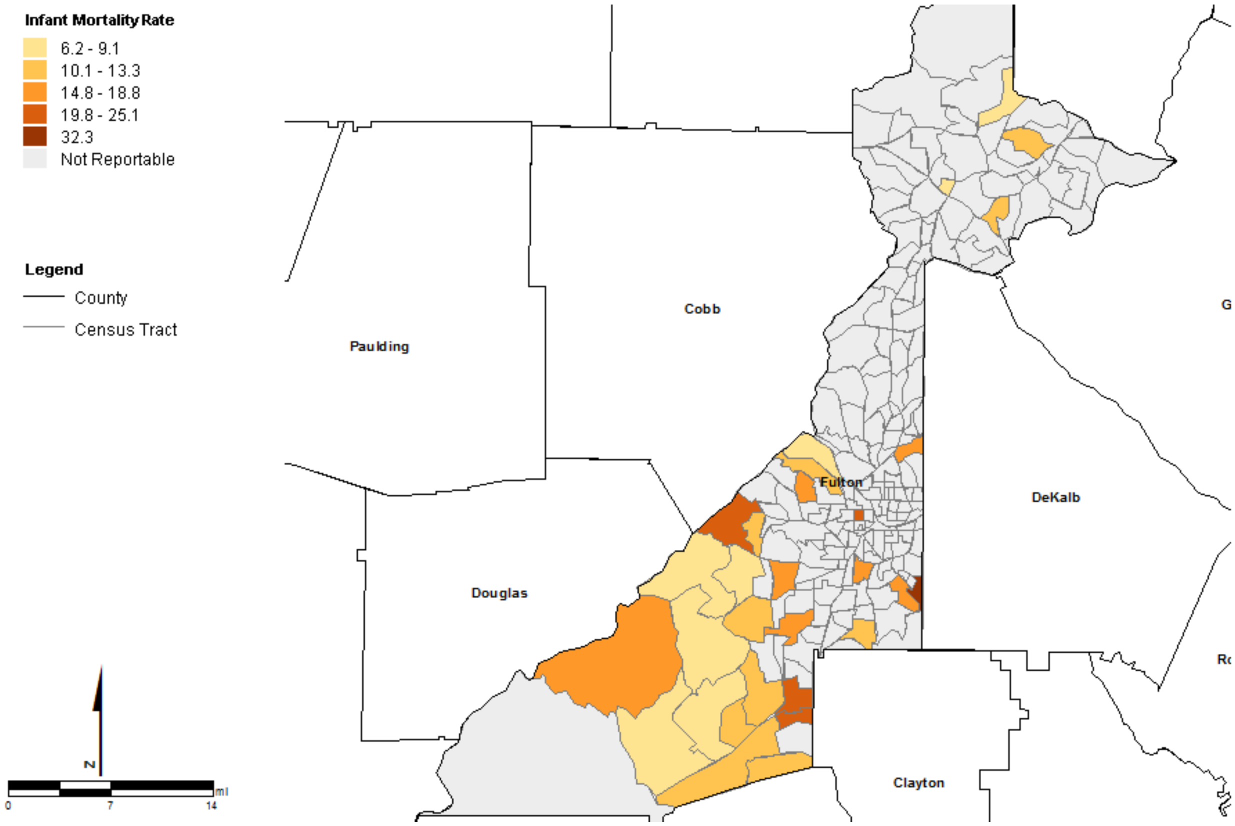
Further, according to a 2015 *March of Dimes Foundation* report, an average of 2,476 babies are born per week in Georgia. Of those, 17 will die before their first birthday (Dimes, 2015a, 2015b).

**Map 1: This map illustrates infant mortality rate by census tract of residence for the state of Georgia. Created in ArcGis utilizing the Georgia Department of Public Health's Public Health Information Portal (PHIP) (GDPH, 2018b) and the University of Wisconsin Population Health Institute (UWPHI, 2018).**

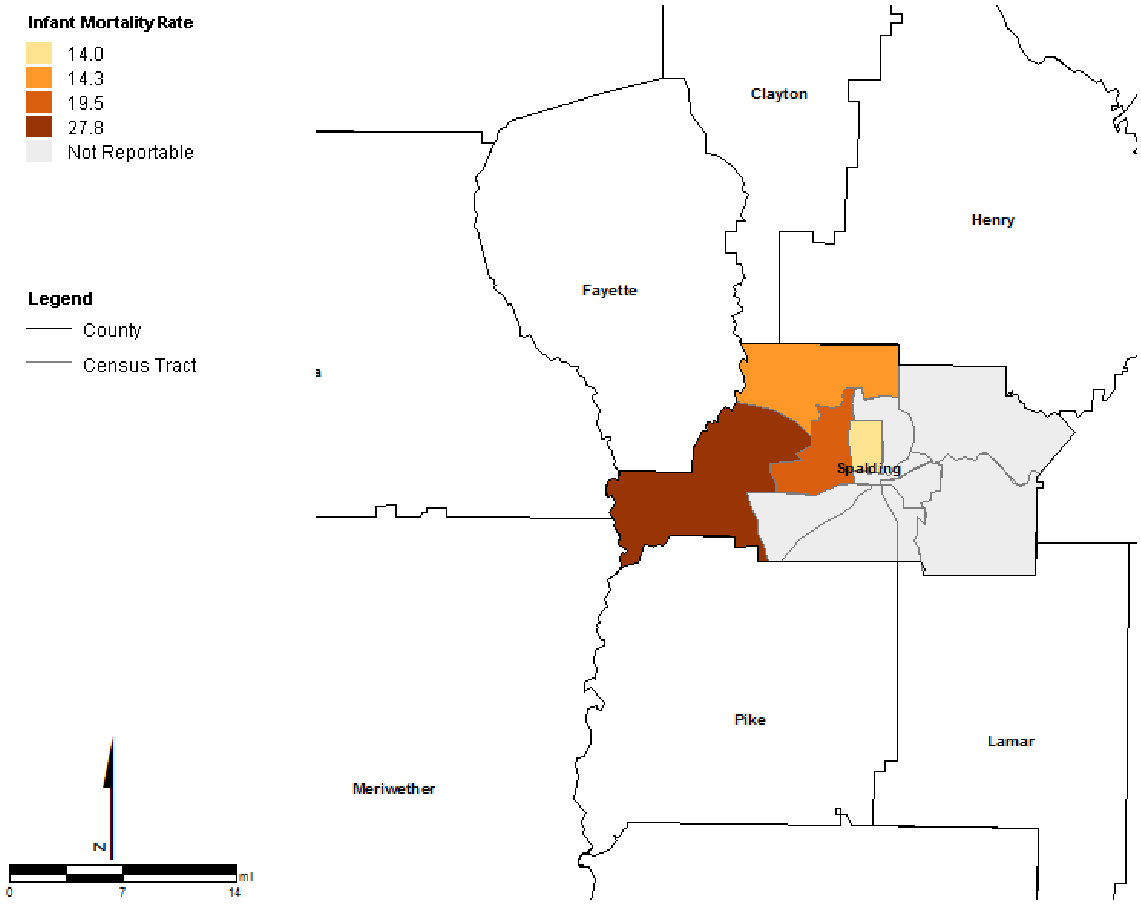



According to the World Health Organization (WHO), infant mortality is defined as the number of deaths occurring in the first year of life per 1000 births (Morisaki et al., 2014), and is an important indicator reflecting social, political, health care delivery and medical outcomes in a geographic area (Health, 2008a). According to the National Center for Health Statistics, the top five causes of infant deaths in Georgia per 100,000 live births in 2013 were: 1) birth defects (110.6), 2) premature/low birth weight (155.6), 3) SIDS (69.9), 4) respiratory distress syndrome (15.6), and 5) maternal pregnancy complications (50.8) (CDC, 2015). In a report by the University of Wisconsin Population Health Institute (UWPHI), Fulton Country ranked 24th of 159 counties for health outcomes and health factors (e.g. access to care, infant mortality), while Spalding was ranked 140$^{th}$ (UWPHI, 2018). Of note, there is insufficient or unavailable data for the counties ranked below Spalding to generate infant mortality geo-spatial maps.

**Map 2: This map illustrates infant mortality rate by census tract of residence for all races in Fulton County. Created in ArcGis utilizing the Georgia Department of Public Health's Public Health Information Portal (PHIP) (GDPH, Health, 2018b) and the University of Wisconsin Population Health Institute (UWPHI, 2018).**



**Map 3: This map illustrates infant mortality rate by census tract of residence for Spalding County in the state of Georgia. Created in ArcGis utilizing the Georgia Department of Public Health's Public Health Information Portal (PHIP) (GDPH, 2018b) and the University of Wisconsin Population Health Institute (UWPHI, 2018)**




Map 1 shows that infant mortality rates differ greatly across the state of Georgia, with the limitation that many counties have insufficient data to show their infant mortality rate. When comparing one of the highest ranking counties (Map 2, Fulton) with one of the lowest (Map 3, Spalding), it is worth noting that both have large census tract sections with insufficient data for visualizations, and both have differing rates of infant mortality by region. Between 2007- 2011, Georgia's Infant Mortality Rate was 7.3 deaths per 1000 live births, or 5,175 infant deaths (GDPH, 2013b). Preterm birth and low birth weight are the primary causes of infant mortality in Georgia. Not only are they the leading cause of infant death, they are also the major causes of childhood disabilities and contribute substantially to the rising cost of healthcare (GDPH, 2013a).

It is an unfortunate reality that Georgia's pediatric mortality rate is one of the highest in the nation. According to a recent report by the Robert Wood Johnson Foundation on Georgia's county health rankings, "the length and quality of life vary not only based on where we live, but also by our racial/ethnic background. In Georgia there are differences by race/ethnicity that are masked when we only look at differences by place (UWPHI, 2018)." More research is needed in order to achieve pediatric health equity, particularly among marginalized groups in Georgia. Data from a GIS/wearable system of sensors could provide health care practitioners and policy-makers with more comprehensive and up-to-date health status reports than currently available to help bridge these health gaps.

### 1.2.0: The Use of Geographical Information Systems and Spatial Analysis and Visualization in Public Health

Geographical information systems (GIS), in the broadest sense, have been deployed in public health practice for over 150 years (Higgs, 2009). The most famous example, according to Jain et al., "is the use of hand-drawn maps by Dr. John Snow in London in the mid-1850s to analyze the geographic location of deaths caused by cholera (Jain et al., 2017)." His maps, which superimposed the location of cholera deaths with those of public water supplies, pinpointed the Broad Street pump as the likely source of the cholera outbreak, resulting in the removal of the pump handle (Jain et al., 2017). This successful public health intervention subsequently led to a decline in the incidence of cholera. Since the 1850s, public health departments around the world have made frequent use of either hand-drawn maps or pin-maps to identify disease clusters and to focus their interventions (Talati, Stegmuller, Niiler, Xiang, & Atanda, 2016). GIS can be used in health care research to analyze need, measure access, and study variations in use and delivery of health care (Besse et al., 2015), in addition to performing spatial analysis aimed at examining access, demand, and use of pediatric care (Higgs, 2009). However, despite the expanding role of geography and mapping in health research and recent advances in related technologies (Cromley & McLafferty, 2011), GIS continues to be largely unused within the pediatric health domain (Talati et al., 2016).

By generating visual overlays of all pertinent data, use of a GIS allows one to discern the spatial distribution of affected populations and population characteristics simultaneously. This has allowed for more robust assessments of case location, resources spent on screening for lead levels, and potential risk factors (Clements, Judge, & Shaw, 2017). Once this information is seen graphically, public health officials or practitioners can gain a greater understanding of the efficacy of past performance of a lead screening program, for example, to evaluate the risks and develop a methodical and practical approach to screening (Alexander et al., 2013). The clustering of conditions of interest (e.g. asthma, lead poisoning) makes GIS technology an ideal mechanism for identifying new cases based on geographic risk (Clements et al., 2017). In addition to providing a clearer presentation of geographically related pediatric patterns, from analysis one can identify the location and clustering of pediatric conditions of interest (Alexander et al., 2013) and predict where negative child outcomes would most likely occur (Farazi et al., 2018). In this case, pediatric health data can be combined with census data to take into account socioeconomic factors, allowing targeted screening efforts and/or primary prevention interventions in neighborhoods with the highest concentration of the condition of interest, for example lead exposure or asthma.

With technological advancements such as the rapidly declining cost of computer technology and the development of complex computerized software for the mapping of public health data, public health departments have increasingly made use of computerized geographic information system to map and analyze their public health surveillance data (Craglia & Maheswaran, 2016). A more recent example of a study to utilize these technologies was a cross-sectional study of geographic information system-based screening for TB, HIV, and syphilis, where residences of incident TB, HIV, and syphilis cases in Wake County, North Carolina, between 1/1/05–12/31/07, were mapped. This mapping helped to identify the highest densities of all three diseases (Jain et al., 2017). The whole screening plan was based on this early mapping of data to implement targeted interventions. There are a few instances of large scale GIS utilization in Georgia, including the Georgia Soil and Water Conservation Commission (GSWCC), which gives its employees and the public the ability to use an interactive online system to show drainage basins, impaired streams, and political boundaries, among other relevant information (GSWCC,2018). In addition, centers such as Center for Spatial Planning Analytics and Visualization (CGIS) at Georgia Tech, the Georgia GIS Clearinghouse, and state actors such as the Bureau of Transportation Statistics, provide data sets and spatial analysis of boundaries, elevation and topography, population, traffic patterns, and climate, among others (CGIS, 2018). To date, however, there has been no coordinated effort in Georgia to utilize GIS to improve pediatric outcomes.

### 1.3.0: Enhancing Data Collection and Monitoring by Using Mobile Technology (Wearables) in Pediatric Health

For the purpose of this thesis, "wearables" will be defined as wearable electronic devices that provide quantifiable biometric information. This can include indicators such as heart rate and blood pressure. The definition is not hardware specific, as the wearable devices would vary depending on the unique needs of the user (e.g. glucose monitoring, heart rate monitoring). The concept, "connected health," refers to collecting and analyzing data across a population via electronic devices, so that healthcare systems can better provide targeted patient care. It is a term common in technological fields, that encompasses a variety of health care concepts such as tele-health, tele-medicine, and mobile health (mHealth) (Carroll, 2016). Connected health also refers to the use of health technology to deliver health care to patients remotely (Kvedar, Coye, & Everett, 2014). Typically, connected health involves the use of information/digital technology to aggregate information gathered through either wireless or wired connections to a communications network, or to a network of devices (e.g. Internet of Things) (Harte et al., 2017). Connected health devices can include sensors and wearable devices, and according to Harte et al. (2017), "these devices, systems, and services, when combined with an appropriate clinical-based information and communications technology infrastructure, can allow users to take control of their own health and wellness in their homes, while maintaining contact with health care professionals."

In urban and under-served primary care pediatric populations nationally, the vast majority (97%) of caregivers are regularly using, or are connected to, one form of digital technology, and nearly half are using at least four devices (DeMartini et al., 2013). However, as mentioned previously, the use of wearables in pediatric health is still a largely untapped market and understudied area. Still, uses of digital technology and "wearables" (ex. Apple Watch, FitBits, activity trackers, etc.) have steadily increased in recent years, even among underserved populations (Volsky et al., 2012). Although disparities in access remain, growing digital access and usage among families seeking care in urban, underserved pediatric areas, is helping to address a variety of suboptimal health conditions through interventions such as asthma management for children with a history of this health problem (Mackert et al., 2009).

**1.4.0: GIS Mapping of Suboptimal Pediatric Outcomes in Urban/Metro Atlanta**

By measuring and tracking pediatric health through wearables and sensors, Atlanta parents and practitioners will be able to collect more data related to key health indicators than ever before. Although some providers may not be totally comfortable with the use of consumer technology for self-diagnosis, by adapting existing wearable and sensor technologies a new model of collaboration between patient and physician can emerge, with strong framework health benefits for children. The proposed Pediatric Risk Assessment Mapping Net(work)(PRAMNET) envisions connectivity and data gathering at a scope and scale not currently seen in many U.S. cities –if any at all – but does present a number of operational challenges. The integration of large amounts of data from so many sources will pose myriad challenges, particularly around security and privacy. Specialized expertise will be required to implement a PRAMNET framework that protects the privacy of stakeholders and target populations, as it must securely handle their vital records. Perhaps the greatest challenge to this thesis is the present lack of a unified national regulatory framework governing the use of wearables and mobile health, and that a technological design process taking into account policy considerations, up front, could help address this condition (Gandy, Baker, & Zeagler, 2017).

Although the proposed PRAMNET currently exists only in conceptual form, additional research could help identity parameters to ensure that the system is responsive to the needs of Atlanta city government, nongovernmental, and community-based stakeholders if brought to clinical trials. While there is a growing body of literature on the use of GIS in health care and health information systems, there is an apparent gap in how these two fields of research can be integrated with existing pediatric health interventions (Nhavoto & Grönlund, 2014). Given the relative novelty of these combined applications, there is still a paucity of studies of how these two types of systems could be integrated into the information infrastructure of an organization (e.g. primary care provider or hospital) so as to provide a basis for data analysis and decision support (Nhavoto & Grönlund, 2014).

The spatial analysis made possible by application of GIS methodology can be used to establish and ascertain the feasibility and need for health interventions, and to facilitate comparison study sites at the Georgia census tract level. This modeling approach is preferable to catchment approaches, which can underestimate access in dense areas (Chen et al., 2017), and to simple ratios of providers and population by area (Gentili et al., 2017), which can inaccurately portray access, especially at lower geographic granularity.

Spatial analytical methods and geographic information systems have increasingly been used in public health, epidemiology, and nutrition research (Stopka et al., 2014). According to Arcaya & Figueroa, "health technologies such as telehealth or wearable devices that monitor physical activity, diet, sleep, and vital signs threaten to unevenly benefit patients with high socioeconomic status (Arcaya & Figueroa, 2017)." Half of U.S. children live in poverty or near poverty (Council on Community Pediatrics, 2016), which could mean that they "may be the first to fall behind as wearables and other health technologies come more sophisticated and actually lead to better health (Arcaya & Figueroa, 2017)." Indeed, according to Malanga et al., "the use of big data in these areas, however, has the potential to ignore a large portion of the population, because the sources of much of the data – social media, wearables, electronic health records, and insurance claims – are not utilized by that subset. These omitted populations, such as minorities and low-income individuals, are at a greater risk for health disparities and are the very populations that could most benefit from research and intervention (Malanga, Loe, Robertson, & Ramos, 2016)." In addition to looking broadly at health disparities in the urban/metro Atlanta area, a low cost wearable or sensor system that includes geographic data that feeds into PRAMNET could observe that racial and ethnic minorities experience distinctly different health care outcomes as compared to their white counterparts, even when socioeconomic and geographic conditions are held constant. Multiple factors influence health care disparities, including parental employment status and educational levels, which can impact income and other living conditions (GDPH, 2008b). PRAMNET's proposed reliance of context specific, low cost hardware solutions can help ensure that the nation's most vulnerable pediatric groups don't fall into health gaps due reasons of cost or access.

Collectively, these factors can influence access to preventive pediatric health care, healthy lifestyles, wellness resources, and experiences within the health care system (Antonelli, Stille, & Antonelli, 2008; Fiks, Mayne, Localio, Alessandrini, & Guevara, 2011). For example, anemia in one particular metropolitan area in Atlanta was more common in African American children (18.1%) than in Hispanic children (7.6%) (Cole et al., 2010). Another serious pediatric condition, asthma, also affects children disproportionately based on geography (Nicholas, 2017). PRAMNET could offer more robust pediatric health data that, when paired with GIS visualization of the data, could identify areas of concern and inform future interventions in Atlanta and beyond.

### 1.5.0: Ensuring Patient Privacy with Geographical Information Systems

PRAMNET would use census tract data to enhance "patchy" or non-existent pediatric health records. According to the CDC, census tracts are small, relatively permanent statistical subdivisions of a county or equivalent entity that are updated by local participants prior to each decennial census (CDC, 2017). A census tract usually covers a contiguous area, although the spatial size of census tracts varies widely depending on the density of population (Cromley & McLafferty, 2011). Census tract boundaries are delineated with the intention of being maintained over a long period of time so that statistical comparisons can be made from census to census

(United States Census Bureau, 2017), and is the typical level of granularity of data available for pediatric research.

The geocoded location of a patient address is considered protected health information and protecting pediatric patient anonymity is a foremost consideration in public reporting of spatially referenced patient data. One “workaround”, geo-masking, seeks to conceal patient or event locations through aggregation or the intentional introduction of ‘‘jitter’’ into the location’s coordinates (Clements et al., 2017). However, geo-masking leads to a trade-off between the accuracy of spatial information and protecting health information (Craglia & Maheswaran, 2016). As this thesis does not include maps of individual patient point locations, it does not utilize geo-masking. Reported tabulations are all presented in aggregate, with no potential way to identify individual patients (Soares et al., 2013). In healthcare, geo-masking has nonetheless proven to be an effective tool for maintaining patient confidentiality without compromising the data accessibility needs of the research communities (Jain et al., 2017).

### 1.6.0: Summary: Applications of GIS, and Spatial Data Visualization in Atlanta Pediatric Screening

This thesis was designed to address pediatric health gaps by (1) describing the kinds of GIS data and methods currently used in pediatric research; (2) examining primary application areas for GIS in pediatric research, and related key findings; and (3) identifying gaps and limitations in GIS applications in current related research that, if addressed, could inform future research. With increasing availability of spatial data and digital mapping technologies, this study could help researchers and other relevant stakeholders with limited GIS background understand the current and potential roles of GIS in pediatric research. PRAMNET is a potential tool, or approach, that can increase the amount of data available on the aggregate (census tract level) or on an individual level (via inexpensive sensors). It can be monitored by a health practitioner in conjunction with the underlying GIS system & wearable sensor monitoring system, which would be of great value. A personalized wearables/sensor network would allow for the collection of more robust health data, that when paired with GIS visualization of the data, would identify areas of concern and inform future interventions in Atlanta.

While much is known about how both intrinsic factors (such as gender, age, and weight) and extrinsic factors (for example, public transportation density) are related to physical activity levels (Althoff, Hicks, King, Delp, & Leskovec, 2017), evidence on how these factors interact (such as the influence of environmental factors on pediatric populations) is not readily available (Althoff et al., 2017; Bauman et al., 2012). A better understanding of these interactions is important for developing public policy (Chokshi & Farley, 2014), planning cities and health access (Sallis et al., 2016), and designing cost-effective, scalable solutions to pediatric challenges (Reis et al., 2016; Servick, 2015). A pediatric health/GIS system could monitor exposures to irritants and toxins at a significantly higher resolution than is currently available (Jia, Cheng, Xue, & Wang, 2017). Exposure to certain substances, air pollution for example, can be more likely to occur in one location and not in others. Children and mothers exposed to geographically-specific stressors may not be easily evident under current demographic and survey sampling methods. After years of being consolidated with other departments, the restoration of the (GDPH) as an independent agency in 2011 renewed government focus on improving health outcomes for Georgia mothers and infants (GDPH, 2013a).

A key policy problem in the pediatric health arena is that data are collected largely to a serviceable degree, but not presented, or readily available, in a way that is usable for practitioners and policy makers (Higgs, 2009). GIS-based mapping could allow for geographic analysis and presentation of data and patterns of pediatric health indicators, and also present data visually. These data-backed visualizations could, in turn, help inform policy makers and practitioners of "hot spots" of negative pediatric outcomes. From a health perspective, predictive models of pediatric health trajectories could be created from wearables, including geocoded and longitudinally-linked vital records that would more holistically reflect the real-world environment of the patient (Kramer, Dunlop, & Hogue, 2014). Innovative pediatric health solutions that capitalize on technology innovations have the potential to accelerate progress while leading to better health outcomes for women and newborns (Yan et al., 2014). Barriers to public health interventions are numerous, spanning awareness, motivation, ability (skills and knowledge), and environmental factors (Lee, 2011).

# Chapter 2:
# Review of Literature

## 2.1.0: Pediatric Health and Well-being in Georgia

Prior to this thesis, I had previously conducted a literature review of pertinent work in the areas of electronic health (EHealth), pediatric health, Internet of Things (IoT), health disparities by income and race in Georgia, and more broadly related topics within a Smart Cities context, to identify gaps and opportunities for technology solutions within the pediatric health area. Between August 2017 and January 2018, the following sources were accessed through content analysis of key terms: data base portals such as the Georgia Department of Public Health's Online Analytical Statistical Information System (OASIS); the CDC's WONDER database on pediatric mortality causes; the Agency for Toxic Substances & Disease Registry's Social Vulnerability Index mapping software; and the Atlanta Regional Commission's Research & Analytics Division database and mapping software; as well as key word searches for the above terms using Google Scholar.

This previous work explored the idea of a data-capture approach for small-area estimation of unfavorable pediatric indicators through a proposed network of wearable devices and sensors that would integrate data and health policy in a systematic way. In addition, the study illustrated the usefulness of this model for policy development and decision-making across target geographic regions, by enabling a systematic comparison of estimates at the census tract and county levels associated with the City of Atlanta.

## 2.2.0: Geographical Information Systems (GIS)

A growing body of research discusses the use of mobile technologies and GIS to enhance health care and health information systems, but there is little evidence of research covering how these two types of systems could be integrated into the information infrastructure of an organization, so as to provide a basis for data analysis and decision support (Nhavoto & Grönlund, 2014), particularly within the realm of pediatric health. For this literature review, I searched electronic databases (PubMed, BioMed Central, Wiley Online Library, Scopus, Science Direct, and Web of Science) to retrieve English language articles published in international academic journals after 2005. In addition, I utilized demographic health surveys such as the National Survey of Children's Health (2011/2012) and the National Survey of Children's with Special Healthcare Needs (2009, 2010). Only articles addressing the use of mobile or GIS technologies that met a pre-specified keyword strategy were selected for review. Of note, the term "pediatric" brings over 2,300,000 results on Google Scholar, compared to 12,100 results for the combined terms "pediatric" and "GIS." Worth note, many uses of the term "GIS" in this search referred to "gastrointestinal syndrome." When "geographical information systems" and "pediatric" are searched together, 3,250 results are presented. For further context, when the terms "pediatric" and "wearables" are searched together, 659 results are presented.

On the basis of relevant research findings, I conceptualized PRAMNET to analyze and illustrate how GIS-based data and methods could be integrated to construct GIS indicators to further serve pediatric health related research, including its main stages: (i) GIS data collection and preparation; (ii) GIS data processing; and (iii) GIS-based indicator generation. Increasingly, GIS studies that employ spatial data are being used to identify communities with poor health care outcomes (Clements et al., 2017; Zlotnick, 2007). Government datasets are usually free and open to the public, such as the Topologically Integrated Geographic Encoding and Referencing data regularly released by the US Census Bureau. The Topologically Integrated Geographic Encoding and Referencing data have been serving as a major source for much local and especially nationwide obesity-related research (United Census Bureau, 2017)(Jia et al., 2017). Still, if data are patchy and unreliable at the city or local level (as is sometimes the case), using these extant governmental databases can compound the problem of inconsistent data being used in public health research. Many local governments have their own GIS departments that produce more detailed data, which are often more suitable for local scale studies (Curtis et al., 2012). For example, the Office of Geographic Information of Massachusetts is offering local recreational open space and road network data, including detailed sidewalk information, which was originally used to investigate the association between walkable environments and children's body mass index (BMI) scores adjusted for age and gender (Talati et al., 2016). The unit of GIS measurement used in this thesis is the census tract, which according to the CDC, is a small, relatively permanent statistical subdivision of a county or equivalent entity that is updated by local participants prior to each decennial census (Krieger et al., 2001).

GIS is essentially a computerized automation of cartographic analysis that involves generation of graphical representation of spatial layers to identify areas where they align, or correlate, such as block-groups that have high values for low educational attainment, high single-parent households, and high numbers of families for whom English is not the first language. Substantial evidence suggests that "disadvantage" appears to be geographically concentrated; disadvantaged people tend to live with other disadvantaged people; and neighborhood disadvantage (or neighborhood deprivation) is associated with a number of factors (e.g., socioeconomic resources) that differentiate people who live in more or less affluent neighborhoods (Rosenbaum et al., 2009). This apparent correlation of social vulnerability characteristics suggests the need for further investigation. A possible next step would be to perform a spatial analytic technique to test these apparent relationships. Then, if this area is identified as a locus of multiple vulnerability characteristics, it could be prioritized for updated pediatric population counts, since children in these situations are likely more at risk for adverse health outcomes (Curtis et al., 2012).

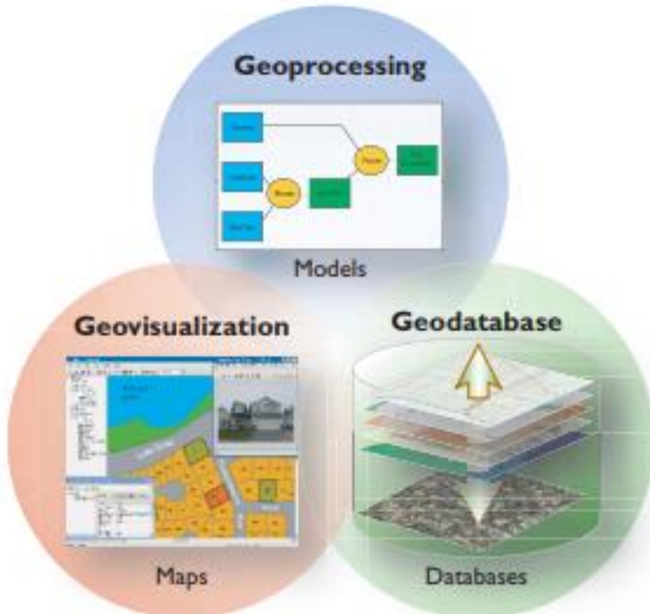
Hot Spot Analysis is a statistical-based method for assessing geographic clustering (ESRI, 2018). Specifically, Hot Spot Analysis is used to pinpoint locations of statistically significant high- and low-value clusters of a "phenomenon of interest," by evaluating each feature (e.g., census tract) within the context of neighboring features and against all features in the data set. The data are also aggregated into census tracts, community areas, and neighborhoods, to create profiles of high-risk neighborhoods. Still, the process of data aggregation at the neighborhood level for the purpose of evaluating health disparities is not new (Dunn & Cummins, 2007). Some census tracts have been designated by the U.S. Government as medically underserved areas (MUAs) that include for instance, residents with low incomes, inadequate use of health care services, high infant mortality rates. (Gaston, 1997; Rosenbaum et al., 2009).

### 2.3.0: Geographical Information Systems Analysis Platform (ArcGIS)

According to its maker the Environmental Systems Research Institute (ESRI), "ArcGIS is a suite of desktop software applications used for visualizing (mapping), managing, editing and analyzing data that are geospatially referenced. ArcMap is the primary application in the ArcGIS suite, the component used to generate individual geospatial layers and compile maps from that information. A map in GIS terms consists of multiple individual layers of geospatial information. These "layers" take the form of vector or raster data types. Vector data are the simple representation of spatial information using coordinate geometry; points (x,y coordinates), lines, and polygons (shapes, areas, boundaries)(ESRI, 2018a)." Vector data are data types that represent real world features in the form of points, lines or polygons with geographic coordinates. For example, a household or restaurant could be simplified as a point on a map; a street could be modeled as a line; a recreational park could be presented as a polygon; and a household or restaurant could also be represented by a polygon, if area matters as much as location. Each type of entity (point, line or polygon) could be stored as a separate vector layer that could be incorporated for advanced analysis. Raster data, "on the other hand, is slightly more complex and represents values for a particular phenomenon as a continuous grid-based surface (ESRI, 2018b)."

ArcGIS utilizes a geodatabase, which serves as a data "container" wherein the geographic information and spatial attributes of a data set are stored (ESRI, 2018b). Application examples could include utilizing ArcGIS to map Rotavirus or Salmonella outbreaks in rural communities by including geographic information such as the location of houses relative to water sources (Kistemann et al., 2000). Within ArcGIS, it is possible to view your data in one of three modes: geodatabase view (databases), geo-visualization view (maps), and geoprocessing view (models, tables). While there are some examples of GIS in pediatric health research, they have mostly been limited to asthma, obesity, child motor vehicle accidents, and access to care applications (Jia et al., 2017; Keddem et al., 2015; Talati et al., 2016). To my knowledge, this is the first work that suggests coupling GIS spatial analysis with wearable sensor information to improve pediatric health outcomes in Atlanta.

**The following graphic demonstrates the three modes of data visualization in ArcGIS (ESRI, 2018b)**




**2.4.0: Review of Wearable Technology Literature**

Between August 2017 and April 2018 key word searches for the terms "wearables," "pediatric wearables," and "mobile pediatric health" were conducted in Google Scholar and Google. This allowed for the identification of both business and industry reports on the development of wearables as a burgeoning field, but also within the context of pediatric health. The increase in popularity, versatility and quality of wearables and mobile health devices, and the falling cost of technology, can potentially address some of the barriers that currently prevent perinatal health problems from being adequately diagnosed, while increasing options for prevention or treatment (Torous et al., 2014).

The use of wearables and sensors for health monitoring, particularly in pediatric settings, has been growing steadily (Vu, 2016). The pace of adoption will undoubtedly accelerate, while self-monitoring and self-diagnosis are here to stay. With more users, the availability of big data in pediatrics, patient-generated data sources, and bio specimens aggregated from multiple institutions and thousands --if not millions-- of children will continue to grow. Wearables can be defined as wirelessly-connected devices that can be used for personal health or environmental monitoring (Misra et al., 2015). Recent technological advances on the development of wearable devices, medical sensors, and wireless communication systems support a new generation of unobtrusive, portable, and ubiquitous health monitoring systems for continuous patient assessment and more personalized pediatric health care (Banos et al., 2014).

### 2.5.0: Summary

According to Jacobs, “software based geospatial mapping tools allow rapid visualization of condition-specific patterns throughout a geographic region with comparison to relevant co-variable data (Jacobs, 2012)”, to which Talanti et al. add, “it [GIS] has not been extensively studied within the realm of pediatric health (Talati et al., 2016).” During my literature review and throughout the preparation of this thesis, I found limited use of GIS data analysis in current pediatric health research, particularly with the use of spatial statistics, such as finding and identifying spatio-temporal clustering of conditions of interest (e.g. asthma)(Talati et al., 2016). As healthcare providers continue to explore efficiency and family-centered approaches to service delivery, using methods like GIS mapping will be valuable to quantify, to some degree, pediatric patient- and family-related burden in accessing care. I propose that a conceptual pediatric health/GIS system, with biometric input from wearable sensors, could be used by various disciplines of healthcare and service delivery models, whether rural or urban, specialty or primary care, telehealth or brick-and-mortar settings, to improve pediatric health outcomes. In summary, if efficiently used, GIS can be a useful tool for assessing pediatric community needs, for planning appropriate initiatives and interventions, and for evaluating and refocusing community-based healthcare (Jain et al., 2017).

## Chapter 3:
## Research Approach

### 3.1.0: Methodology

Children and infants constitute a population of interest because of age-specific physiologic and developmental variances that may not be adequately addressed by adult-specific data tools (Simpson, 2009; Thune et al., 2013). This thesis focuses solely on the distinct needs and functionalities of pediatric health applications and infrastructures to ensure effective and safe pediatric health care delivery, rather than adult-oriented systems (DeMartini et al., 2013). Unfortunately, as the selected pediatric cases demonstrate (asthma, HIV, cystic fibrosis, osteomyelitis), there are currently insufficient data available to create visualizations with confidence. This thesis utilized ArcGIS to generate "proof of concept" visualization of infant mortality, used here as a surrogate measure for pediatric health (He et al., 2015). This thesis introduces the idea of a data-capture approach for small-area estimation of unfavorable pediatric indicators through a proposed wearables network, integrating data and health policy in a systematic way (i.e. PRAMNET). In addition, this study illustrates the usefulness of this model for policy development and decision-making across target geographic regions, by providing a systematic comparison of estimates at the census tract and county levels associated with the Atlanta Metropolitan Area. Census tract-level data containing geographic information for the state of Georgia was downloaded from the Census Bureau's website.

PRAMNET draws on previous literature suggesting that wearable devices and wirelessly-connected sensors are uniquely positioned to bridge gaps in health disparities and reach across demographics (Militello et al., 2012). Existing recommendations for tailored, interactive, and family-centered pediatric care can be strengthened by the addition of mobile technology and GIS spatial analysis to augment clinical interventions and health behavior change efforts in Georgia mothers and their children. More rigorous, theory-based intervention research using wearable technology and GIS is warranted in pediatric and adolescent populations. According to Talati et al., "this approach to population health is likely to uncover opportunities for healthcare improvement, disease prevention targets, and treatment strategies (Talati et al., 2016)."

### 3.2.0: Variables and Project Approach
**Key Variables:**

*Independent variables*: maternal age, ethnicity, income, education, marital status, and location.

*Dependent variables:* birth defects, premature/low birth weight, sudden infant death syndrome, respiratory distress syndrome, and maternal pregnancy complications, asthma, complex medical conditions, and children with disabilities.

These variables were selected after an extensive review of extant public health literature in order to: 1) determine the most common pediatric conditions for Georgia children with adverse health consequences, and 2) identify population demographic characteristics necessary to study the degree to which social and cultural variables are associated with health conditions. There are racial and social demographic disparities that exist in urban and metropolitan populations that occur at the hyper-local level, i.e., from individual households to single streets to neighborhoods. PRAMNET would allow for greater geospatial resolution to inform policy designed to improve pediatric outcomes.

For this thesis, I sought to explore key parameters necessary for the development of a conceptual pediatric health/GIS system for increasing surveillance and reducing negative pediatric outcomes using: (1) large health service data sets covering various biometric indicators (e.g. asthma, cystic fibrosis); (2) novel GIS methodologies; and (3) ongoing public stakeholder dialogue. According to English et al., "increases in mapping resolution seem to represent a substantial improvement in the information that has been available historically (English et al., 2006)," and if the proposed system were implemented, portions of the urban/metro Atlanta area may be newly identified as having a higher than previously supposed incidence of negative pediatric outcomes for certain conditions. GIS has demonstrated to be a useful tool for identifying clusters of cases, based on an isolated exposure source (e.g. lead exposure, pollution) (Roberts et al., 2016). According to Nicholas, "spatial analytics allows generation of a more nuanced picture of conditions, such as asthma, when incorporated with aspects of both the physical environment (e.g., traffic pollution) and the social environment (e.g., health care access)(Nicholas, 2017)," can provide a more holistic picture of pediatric health in Atlanta.

To this end, this thesis was guided by the following questions on how best a pediatric health/GIS system could use wearable sensor data to enhance the visual presentation of geographic and health factors for pediatric health in Atlanta.

***Q1 – Do current methods of capturing data on key pediatric variables provide sufficient data resolution (i.e. collected data is aggregated at census tract as opposed to individual or a defined group level) to be able to design meaningful health solutions?***

As noted throughout this paper, Georgia's pediatric mortality rate is one of the highest in the nation (GDPH, 2013a). Infant mortality is intimately tied to maternal demographics, and as such, access to high-quality pediatric care is by definition subject to socio-economic conditions. Unfortunately, there is insufficient data for many rural/metropolitan Atlanta mothers, and as such, it can be difficult to determine, prevent and treat negative pediatric outcomes. Certain exposures, air pollution for example, can be hyper concentrated in one location and not in others (Curtis et al., 2012). Moreover, children and mothers exposed to geographically-specific stressors may be invisible under current demographic sampling methods. To prevent Georgia mothers and their infants from falling through the cracks, a system capable of capturing more data on the hyper-local, individual level, would be valuable in guiding subsequent interventions.

***Q2 – Can wearable/GIS sensor-based data collection increase/improve understanding of pediatric population characteristics, location, geographic variation and health?***

Atlanta is well on its way to becoming a 'Smart City.' The "smart" aspects of its new infrastructure will include environmental sensors, data analytics, real-time situational awareness tools, data management and other citizen services. PRAMNET could be integrated seamlessly into Atlanta's growing infrastructure. Such a system would allow for vulnerable and traditionally hard to reach populations, such as migrant or low-income families, to benefit from better communications and care from health providers, while providing improved data to inform maternal, neonatal and child health interventions. In effect, the development and application of a wearable and/or sensor technology system could be an effective tool for improving pediatric health outcomes in Georgia.

This thesis proposes using GIS software (e.g. OASIS, ArcGis, Georgia Spatial Data Infrastructure) to identify areas in the City of Atlanta with negative pediatric outcomes that may not be evident using traditional tabular formats. According to Jia et al., "geospatial mapping tools will allow for rapid visualization of condition-specific patterns, such as children with low-birth weight, throughout targeted geographic regions with comparisons to relevant co-variable data (Jia et al., 2017)." Spatial information, such as numbers of pediatric patients in a hospital catchment area, would be displayed in graduated color maps (Curtis et al., 2012). As appropriate, variables would be presented using "overlay" data, stacking spatial information in a search for common intersections. For example, overlaying demographic information on a highway network might be used to show that higher levels of poverty spatially correlate with close proximity to highways, which, in turn, could be used to inform policy makers that impoverished pediatric cohorts suffer disproportionately from particulate matter exposure in these areas.

## Chapter 4:
## Pediatric Health: Selected Use-Cases

### 4.1.0: Wearable/Geographical Information Systems Technology and Children with Complex Medical Needs and Children with Disabilities

Children with disabilities and their families have multifaceted medical, developmental, educational, and habilitative needs that are best addressed through strong partnerships between parents, providers, and communities (Murphy & Christian2007). However, traditional health care systems are generally designed to address acute rather than chronic conditions. Historically, hospital-based or institutional care were the only options for most children with complex medical conditions, technology dependence, and significant behavioral and emotional needs (Murphy & Carbone, 2011). That said, digital technology usage has steadily increased in recent years, even among underserved pediatric populations (Khoo et al., Khoo, Bolt, Babl, Jury, & Goldman, 2008).

Although disparities in access remain, informal surveys have demonstrated significant increases in digital access and usage among families seeking care in urban, underserved pediatric primary centered care (PCC) facilities (Lim, 2016). As more caregivers become digitally connected and use those connections to obtain medical information, the opportunity to develop innovative strategies to deliver pertinent, reliable, and easily accessible health information increases (Wainstein et al., 2006)(Talati et al., 2016). Underserved pediatric populations can, however, be hard to reach because families frequently change addresses and phone numbers are often disconnected or temporarily out of service. Hyper connectivity makes digital technologies particularly effective tools for reaching targeted families (Kempe et al., 2001; Szilagyi et al., 2006).

Children and youth with special health care needs are defined as those who "have or are at increased risk of having a chronic physical, developmental, behavioral, or emotional conditions, and who also require health and related services of a type or amount beyond that generally required by children (McPherson et al., 1998)." According to Kogan et al., "more than 10 million children in the United States meet this definition (Kogan et al., 2009)." Many children and youth with special health care needs have intellectual disabilities, physical impairments, and sensory deficits that require specialized therapeutic and educational interventions (Perrin, 2002). As defined by Simon et al., a subset of children with special health care needs was recently termed "children with medical complexity," which included: "substantial health care needs, one or more chronic conditions, functional limitations often associated with technology assistance, and extensive health care needs (Simon et al., 2014)." For example, on average, children with special health care needs receive five times the number of medications than do typical children (Fiks et al., 2011). Feudtner et al., define technology dependency as: the use of medical devices without which—if they were to fail or be discontinued—adverse health consequences and hospitalization would likely follow (Feudtner et al., 2005)."

Some children and youth with special health care needs have chronic conditions associated with complete and irreversible dependence on technology. As a consequence, they may require lifelong private-duty nursing care, which according to the Georgia Department of Education (GADOE), "the provision of uninterrupted home care is threatened by national nursing shortages, limited availability of skilled pediatric nurses in rural areas, and lack of funding (GADOE,2017)." In addition, pediatric health equipment is not universally available (GADOE, 2017). Thus, home care services must be carefully monitored to ensure that the requirements of children and youth with special health care needs, and their families, are safely and effectively met without interruption (American Academy Committee on Child Health Finances, 2006).

According to Elias & Murphy, "the issues faced by children with multiple disabilities and special health care needs, and their families, are often complex, including significant feeding and respiratory problems associated with technology dependencies (Elias & Murphy, 2012)." Diagnoses of health problems common to children and youth with special health care needs are numerous, as "children with special needs include those with preterm birth, congenital genetic and metabolic disorders, neurologic disorders, sequelae of severe infections, and trauma and malignancies (Elias & Murphy, 2012)." Moreover, many children and youth with special health care needs have been diagnosed with intellectual disabilities, physical impairments, and sensory deficits that require specialized therapeutic and educational interventions (Perrin, 2002). According to Lipkin et al., "the multifaceted medical, developmental, and psychosocial needs of children with diverse diagnoses typically require the expertise of many pediatric subspecialists and related health care providers in a coordinated system of care (Lipkin et al., 2005)." Beurhaus stated that "the unique needs of children with complex, chronic conditions, and their families, who reside in urban areas with limited pediatric and community resources should be anticipated and addressed (Buerhaus, 2008)." The use of wearables and sensor devices can be of enormous help in this area.

Across the State of Georgia, and especially in rural areas, there is a serious shortage of pediatric specialists and subspecialists (GADOE, 2017). There is also a tremendous lack of access to providers that accept Medicaid, while low health insurance reimbursements prevent more specialists from taking Medicaid patients. This all adds up to gaps in service to the neediest children and continued delay in taking important corrective measures (GDPH, 2013b). Recent technological advances on the development of wearable devices, medical sensors, and wireless communication systems are supporting a new generation of unobtrusive, portable, and ubiquitous health monitoring systems for continuous patient assessment and more personalized pediatric health care (Banos et al., 2014). On average, children with special health care needs receive five-times the number of medications than do children without (Fiks et al., 2011). Looking towards a more promising future, a "wearable" or sensor device could more effectively monitor health behaviors and adherence to a child's prescribed drug intake, decreasing the need for hospital visits, and caregiver attention.

According to Elias and Murphy, "there are multiple etiologies of chronic pediatric conditions associated with special healthcare needs and disabilities. Sometimes, the underlying diagnosis is straightforward, and a child's needs are well understood (Elias & Murphy, 2012)." However, they argue that some children leave clinical and hospital settings without a clear diagnosis, and that "differentiating among time-limited acute conditions, chronic but stable conditions, and progressive and life-limiting conditions in children receiving home care ensures that the care rendered is appropriate to the needs of each individual child (Elias & Murphy, 2012)." Also, as Elias and Murphy posit, "children with chronic conditions and disabilities may be insured by Medicaid rather than by private insurance companies; the effect of this policy on individual practices needs to be considered (Elias & Murphy, 2012)." Families of children with disabilities rely on a variety of public and private programs such as private insurance, Title V programs, special education services, Supplemental Security Income (SSI), and Medicaid (Homer et al., 2008). Despite evidence that a sense of partnership between families and providers is associated with fewer unmet needs and better outcomes overall, of U.S. families with children with special health care needs, one million (14%) report a lack of such partnerships. Poverty, racial/ethnic minority status, lack of insurance, and greater severity of functional limitations are associated with a higher risk of underserved families lacking a sense of partnership (Denboba, McPherson, Kenney, Strickland, & Newacheck, 2006).

### 4.2.0: Wearable/Geographic Information Systems Technology and Infectious Pediatric Illnesses

Infections are the leading cause of disease in children, and especially common in infancy (Long, Prober, & Fischer, 2017). All children are susceptible to infectious diseases, and they are the leading cause for sick leaves under the age of eight in schools and day care facilities (Ross et al., 2014). Infectious diseases are caused by diverse pathogens, or micro-organisms that infiltrate the body causing different type of diseases. These pathogens might be bacteria, fungi or viruses (Leaper et al., 2010). The infecting micro-organism causes a child's immune system to respond, which may manifest itself as local inflammation in the mucous membranes (e.g. in the bronchus [bronchitis]), or as a change in the number of white blood cells in the bloodstream (Long et al., 2017). An infectious disease always causes an inflammatory response in the body, which can be particularly dangerous for newborns due to their undeveloped immune systems (Aronson & Shope, 2016).

Bacterial infections are caused by bacteria that enter the body and try to conquer living space by direct damage or by producing toxins (Hu, Gong, & Wang, 2015). Bacteria are single cell organisms that resemble the structure of a human cell, with certain differences, such as a hard outer shell, that make them more resilient to the environment (Hu et al., 2015). There are also millions of bacteria that are caught on the mucous membranes of the nasal cavities or respiratory tracts (Hannegan et al., 2017). This is the body's primary defense against invading micro-organisms. Viruses differ from bacteria by not having a cellular structure; instead, they are ball like spheres made up of proteins and DNA. One thousandth of a millimeter in size, viruses enter the body and once they find their target cell, for example, a cell in the nasal cavities, they take over the cell forcing it to produce parts of new viruses, which then kills the cell (Hannegan et al., 2017). This causes a cell to send a signal to the immune system, which then causes an immune response in the form of inflammation. Infection of the airways can be categorized into upper and lower respiratory tract infections (Noterman & Nurmio, 2016). The upper airway consists of the mouth, throat and nasal cavities, pharynx, larynx and the upper part of the trachea. The lower respiratory tract consists of the rest, lower trachea, bronchus and the lungs and alveoli

(Noterman & Nurmio, 2016). An infection is named for the area of the respiratory tract where the infection occurs, e.g. bronchitis means an infection of the bronchus (Hockenberry & Ward, 2013).

Despite great advances in technology in recent years, it remains a challenge for health care providers and parents to identify appropriate and timely interventions for pediatric illnesses (Morse et al, 2017). GIS applications can be categorized by four themes: disease surveillance, health support systems, health promotion and disease prevention, and communication to or between healthcare providers (Nhavoto & Grönlund, 2014). GIS may be an ideal mechanism to identify clustering of pediatric cases based on an isolated exposure source (Roberts et al., 2016), and to improve the management of chronic and long-term illnesses. The purpose of this section is to identify where GIS/wearable technology utilization from pediatric patients, their parents, and primary care providers can bring benefits to enhance health outcomes and disease management.

### 4.3.0: Condition of Interest 1: Cystic Fibrosis

**Statement of Need**

Cystic fibrosis (CF) is a disease of exocrine gland function that involves multiple organ systems, but chiefly results in chronic respiratory infections, pancreatic enzyme insufficiency, and associated complications in untreated pediatric patients (Quittner et al., 2016). Pulmonary involvement occurs in 90% of patients surviving the neonatal period (Hampton et al., 2014). End-stage lung disease is the principal cause of death. More than 10 million people in the U.S. are carriers of the cystic fibrosis gene. These people are not affected by the disease, and usually do not know that they are carriers. Studies have identified illness associated with CF early in life, but there is no comprehensive accounting of the prevalence and ages of disease manifestation and progression described in individual studies. Transcutaneous electrical nerve stimulation (TENS) is a non-invasive pain management tool often used in the treatment of CF (Emaminejad et al., 2017). As demonstrated by Emaninejad et al., new, more portable, forms of TENS can be used in measuring blood and sweat levels non-invasively, while providing the pain relief and therapeutic features of traditional TENS devices (Emaminejad et al., 2017).

The peer-reviewed literature is remarkably consistent: CF-associated growth impairment and airway abnormalities are reported at birth, and disease progression is reported in infancy and throughout childhood (Quittner et al., 2016). It has long been appreciated that newborns with CF can have serious pancreatic insufficiency and gastrointestinal complications related to their disease, as discussed in two recent reviews (Franzese, Mozzillo, Fattorusso, Raia, & Valerio, 2015; Hampton et al., 2014). In contrast, only fairly recently, reviews (Quittner et al., 2016) and critical analyses have begun to suggest that abnormalities of the respiratory system consistent with early disease progression can be observed early in life in children with CF. To date, a comprehensive review of the ages of earliest disease manifestation and progression across organ systems is lacking, which represents a knowledge gap (Quittner et al., 2016). Earlier access to routine CF management is associated with improved subsequent health status (Ramírez, Filbrun, Hasan, Kidwell, & Nasr, 2015).

## Signs and Symptoms

Many children today are diagnosed with CF before they have symptoms (Hampton et al., 2014). This is due to an increase in newborn screening programs. Before screening programs existed, most children with CF were diagnosed after one of the following: (1) respiratory symptoms (most commonly cough, wheezing, or breathing difficulty); (2) meconium ileus (a thick and sticky first bowel movement of a baby that can block the small intestine); or (3) failure to thrive (Smyth et al., 2014). Infants born with CF usually show symptoms within the first year (Quittner et al., 2016). Some children, though, may not shown symptoms until later in life. The following symptoms may indicate CF; infants having these signs should be tested for CF: Diarrhea that doesn't go away, foul-smelling stools, greasy stools, frequent episodes of wheezing, frequent episodes of pneumonia, persistent cough, skin that tastes like salt, poor growth and chronic sinus infection (Children's National, 2018).

## Diagnosis

Median age at diagnosis is 6-8 months. However, age at diagnosis varies widely (Smyth et al., 2014). Clinical manifestations vary with the patient's age at presentation. Requirements for a CF diagnosis include either positive genetic testing or positive sweat chloride test findings, and either evidence of chronic obstructive pulmonary disease (COPD) or documented exocrine pancreatic insufficiency (Stoltz, Meyerholz, & Welsh, 2015). CF can be diagnosed by measuring the amount of chloride in the sweat (Franzese et al., 2015). This test is done by placing a solution on the forearm (or the thigh, if the child is too small) and attaching electrodes. The skin is stimulated to sweat with a mild electric current, which does not cause pain or harm the child. The sweat is collected onto a gauze pad and analyzed. Higher than normal amounts of chloride may suggest CF (Stoltz et al., 2015). The sweat test is not painful and usually causes only minor discomfort.

The youngest age at which disease progression was reported was six months in both digestive (pancreatic sufficiency decline) and respiratory systems (lung function decline) (Franzese et al., 2015). Accumulation of lung damage was reported by one-year of age, and lung structure and function worsened significantly each year of life in young children, with potentially irreversible lung damage reported by the age of two-years (Franzese et al., 2015). Earlier access to routine CF management improved subsequent health status. Earlier diagnosis (by 4–14 months) and standard-of-care treatment initiation in infancy, compared with later diagnosis and subsequent treatment initiation, improved long-term outcomes including survival (Quittner et al., 2016).

## Prevention and Treatment

As CF is a genetic disorder, it cannot be prevented (Stoltz et al., 2015). There are, thankfully, many interventions available to provide children with an improved quality of life and survival outcomes (Quittner et al., 2016), some of which will be described below.

**Geographical Information Systems/Wearable Use Case**

Transcutaneous electrical nerve stimulation is widely used for treatment of chronic pain. Transcutaneous electrical nerve stimulation (TENS) is the delivery of electricity across the intact surface of the skin to activate sensory nerve fibers (Gozani, 2016). The technology was originally developed as a screening technique for predicting which chronic pain patients would respond to implantable stimulators. However, it became apparent that a significant percentage attained pain relief from TENS alone (Gozani, 2016). Since that time, the efficacy of TENS for the treatment of chronic pain has been studied extensively. When evaluated with proper attention to methodological and technical factors (Bennett, Hughes, & Johnson, 2011), TENS has generally been shown to be safe and effective in various forms of chronic pain Fixed-site High-frequency Transcutaneous Electrical Nerve Stimulation (FS-TENS) and in treating chronic low back and lower extremity pain (Bennett et al., 2011). As demonstrated by Emaminejad in recent clinical trials, smaller, more portable TENS devices can have the same efficacy as traditional models, while increasing the portability of the device and patient comfort with use (Emaminejad et al., 2017). An example of a wearable electrochemical sensor to treat CF was developed by Schazmann et al. Their Ion Sodium Sensor Belt (SSB) can accurately measure breathing rate and sweat secretion, and be worn on the body underneath the patient's clothing (Schazmann et al., 2010).

The most significant impact of the use of TENS was a decrease in the use of concomitant pain medications. In addition, trends toward reduced interference with walking ability and sleep, and greater pain relief were observed (Gozani, 2016). These results further motivate the use of FS-TENS in the development of wearable analgesic devices, though it should be noted that it has not yet been tried on pediatric patients. A Google Scholar search of the terms "cystic fibrosis" and "geographical information systems" brings up 225 results, of which less than ten use both terms in their title or abstract. The use of GIS mapping methodologies and cystic fibrosis remain under-studied, but adapting a TENS wearable device is not a matter of technical or medical impossibility, but rather, reflects a lack of understanding of the potential market and health benefits it could bring to children with CF and in chronic pain management.

**4.4.0: Condition of Interest 2: Osteomyelitis**
**Statement of Need**

Acute osteomyelitis and septic arthritis are two infections with increasing frequencies in pediatric patients (Castallazzi et al., 2016). They need to be carefully assessed, diagnosed, and treated to avoid devastating sequelae (Okubo et al., 2017). Traditionally, the treatment of acute osteoarticular infection in pediatrics has been based on prolonged intravenous anti-infective therapy (Martin et al., 2016). However, results from clinical trials have suggested that in uncomplicated cases, a short course of a few days of parenteral antibiotics, followed by oral therapy, is safe and effective (Castellazzi et al., 2016).

In recent years, the emergence of bacterial species resistant to commonly used antibiotics, that are particularly aggressive, highlights the necessity for further research to optimize treatment approaches and to develop new molecules able to fight the war against acute osteoarticular infection in pediatric patients (Castellazzi et al, 2016). Several gaps in the management of acute osteoarticular infections remain. There are relatively few studies of the diagnostic methods that should be performed for the identification of the different pathogens and the most appropriate parameters to be used in children to switch from parenteral to oral antibiotic therapy in relation to the etiology (Martin et al., 2016). Consequently, further research should focus on these issues to optimize the duration of intravenous and oral anti-infectives.

Acute osteomyelitis and septic arthritis represent two inflammatory diseases that affect bone and synovial joints and are both primarily caused by bacterial infection (Castellazzi et al., 2016). These two diseases can occur alone or in combination. Traditionally, their incidence is approximately eight cases per 100,000 children per year, with high prevalence in those five-years ole or younger (Moreira, 2016). However, in recent years, an increase in incidence has been observed. Moreover, there is higher incidence in males, most likely because they are more physically active, which predisposes them to repeated microtrauma (Martin et al., 2016). Hips, knees, and ankles are the most frequently involved joints (Martin et al., 2016). In most cases, the infection is cured with antibiotic medication. In severe cases of osteomyelitis, the infection can be very destructive to the bone, surrounding muscles, tendons, and blood vessels, resulting in long-term or chronic infection (Cristiano, 2015).

## Signs and Symptoms

Acute osteomyelitis develops rapidly over a period of seven to 10 days (Martin et al., 2016). The symptoms for acute and chronic osteomyelitis are very similar and include: fever, irritability, fatigue, nausea, tenderness, redness, and warmth in the area of the infection, swelling around the affected bone, etc. (Cristiano, 2015)

## Diagnosis

No single test can confirm acute osteomyelitis (Martin et al., 2016). A combination of careful history and examination, accompanied by a high index of clinical suspicion followed by laboratory and imaging studies, are key parts of the clinical investigation. It is worth noting that childhood malignancies (for example, leukaemia, lymphoma, and neuroblastoma) can present with non-specific musculoskeletal symptoms (Yeo & Ramachandran, 2014).

## Prevention and Treatment

Antibiotic therapy is the gold standard for treating acute osteomyelitis and septic arthritis (Martin et al., 2016). The antibiotic is initially chosen on an empirical basis to cover the most frequent pathogens responsible for these conditions based on the age of the child, and is then driven on the basis of the antibiograms obtained from the cultural investigations performed before starting antimicrobial therapy (such as blood culture or, when available, intra-articular liquid or bone fragment)(Moreira, 2016). However, there is an urgent need for treating all the infants and children who are admitted with these diseases due to their severe clinical conditions and risks of complications. Unfortunately, in several cases, the blood culture is negative and the other invasive procedures, different from what is done in adults, are not performed in the first years of life (Moreira, 2016). Therefore, it is important to know the epidemiology reported in the literature for different age groups to help choose an appropriate empirical treatment.

The identification of the pathogen responsible for the acute osteoarticular infection requires time due to the slow growth of some etiologic agents (Moreira, 2016). Moreover, invasive procedures that require the patient's sedation are limited in pediatric patients. According to various studies, it seems possible in anywhere from 30% to 70% of cases, and the severity of the clinical picture as well as the patient's age are key aspects for the selection of antibiotic therapy (Cristiano, 2015; Martin et al., 2016). In cases of acute uncomplicated osteomyelitis and septic arthritis, antibiotic treatment can be provided intravenously for a short period of a few days, and then orally until the end of the disease. The improvement in the clinical status and the inflammatory markers can be used by clinicians to decide on the timing of the switch to oral therapy (Castellazzi et al., 2016). The latter should only be administered if the patient is capable of taking it adequately, and only if it has the same spectrum of coverage as the antibiotic used parenterally.

## Geographical Information Systems/Wearable Use Case

It is currently accepted that initial treatment of acute osteomyelitis and septic arthritis involves empirical antibiotic therapy that addresses the pathogens potentially responsible for these infections based on age groups. However, there is no consensus on which molecule(s) should be used in various countries. This lack of consensus is mostly due to different antibiotic-resistant microorganisms in the different regions of the world. Consequently, the choice of antibiotic should be individualized to cover the microbial profiles of the different regions, while considering the patient's age and clinical status. Using GIS, it is possible to map the incidence of pediatric osteomyelitis over a target area, which could give researchers a better understanding of where new cases are concentrating, and what antibiotics might be required for that specific strain. Additionally, a GIS/wearable use device could be used to monitor adherence to long-term antibiotic therapy and response to treatment (e.g., by monitoring the presence/absence of fever and other vital signs).

There are limited data on the efficacy and safety of corticosteroids in patients with acute osteoarticular infection, and further studies on this issue would be useful. For this thesis, I was unable to find data on osteomyelitis for either the state of Georgia or the United States in a GIS-ready format. There is a tabular format for adult and pediatric cases of osteomyelitis, but I have been unable to find data with geographic and spatial information attributed to it. Devices such as the EU FP7 SWAN-iCARE (Texier et al., 2013) and the Sensoria Core (Raviglione et al., 2017) have demonstrated their efficacy in providing real-time feedback to patients and primary care providers in the treatment of osteomyelitis. Of note, a search of the terms "osteomyelitis" and "geographic information systems" brings up 85 results, of which none mention these two terms explicitly in their abstract. Future devices for the treatment and diagnosis of osteomyelitis could conceivably capture geographic data that would allow researchers to better understand the geographic spread of the condition and identify interesting trends when mapping incidence and geographic factors.

### 4.5.0: Condition of Interest 3: Asthma

**Statement of Need**

According to the CDC, in the United States there are 6.8 million children living with asthma (Stripelis et al., 2017). Asthma represents a worldwide health problem with strong morbidity and major impact on the health care system. Approximately 11% of Georgia's children have asthma, while many more may go undiagnosed (GDPH, 2018a). Despite the importance of the disease, the available prognostic tools are not sufficient for biomedical researchers to thoroughly investigate the potential risks of the disease at scale. In addition, according to Akinbami et al., "Children in minority ethnic groups, low socioeconomic groups, and with greater disease severity have been shown to have lower accuracy in asthma symptom perception compared with referent groups (Akinbami, Moorman, Simon, & Schoendorf, 2014)." Multiple efforts have been made to develop new strategies for the prevention and treatment of this disorder (Nicholas, 2017), though to my knowledge, few if any have attempted to merge GIS spatio-temporal analytics with asthma surveillance research (Keddem et al., 2015).

As noted by Roberts, "as with many diseases, the epidemic of asthma among children over the past few decades has been shaped by a social and environmental context that is becoming progressively more evident (Roberts et al., 2016)." Commonly used methods for asthma surveillance, however, are based on national rather than local data (such as the National Health Interview Survey, the National Health and Nutrition Examination Survey, the National Ambulatory Care Survey, and the Behavioral Risk Factor Surveillance System) (English et al., 2006). English et al. argue that for counties and organizations for which local data are important, however, "they must frequently rely on inference when applying these general findings to their communities (English et al., 2006)."

A recent study noted that ambient air pollution varies drastically across city districts, as mixtures from pollutants have combined effects exceeding single-pollutant areas (Winquist et al., 2014). The study also presented a further look into factors that affected the physical environment (i.e. traffic, pollution), and social environments (i.e. health care acces). According to English et al., "although this type of information is only now being introduced, preliminary discussions suggest that it responds to the evolving needs of local government, nongovernmental, and community-based stakeholders (English et al., 2006)."

## Signs and Symptoms

There are two types of asthma: allergic (caused by exposure to allergen), and nonallergic (caused by stress, exercise, illnesses, extreme weather, irritants in the air, and some medications) (Sindher, Stinson, & DaVeiga, 2015). Common childhood asthma signs and symptoms include:

- "Frequent, intermittent coughing
- A whistling or wheezing sound when exhaling
- Shortness of breath
- Chest congestion or tightness
- Chest pain, particularly in younger children (Clinic, 2018)"

Other signs and symptoms of childhood asthma include:

- "Trouble sleeping caused by shortness of breath, coughing or wheezing
- Bouts of coughing or wheezing that get worse with a respiratory infection, such as a cold or the flu
- Delayed recovery or bronchitis after a respiratory infection
- Trouble breathing that may limit play or exercise
- Fatigue, which can be caused by poor sleep (Mayo Clinic, 2018)"

The first signs of asthma in young children may be recurrent wheezing triggered by a respiratory virus (Gerald et al., 2007). As children grow older, asthma associated with respiratory allergies is more common. Asthma signs and symptoms vary from child to child and may get worse or better over time. Some children may have only one sign or symptom, such as a lingering cough or chest congestion.

## Diagnosis

There is no existing instrument that can reliably identify pre- symptomatic children with asthma. Therefore, existing surveys are case detection instruments (to identify symptomatic children). Population-based case detection, often referred to as screening, may increase disease recognition, improve treatment, and reduce symptoms and health care use. Population-based screening has been found to be appropriate in communities with high prevalence of undiagnosed asthma and where newly identified patients have functional access to consistent, high-quality asthma care (Gerald et al., 2007). The Asthma Control Test is one method of diagnosing the condition, which children 12-years or older can fill out themselves, or with their parent's help. Questions remain on topics such as allergies, breathing, frequency of coughing/wheezing, night disturbance, interference with school and day-to-day activities, and severity after exercise (Gerald et al., 2007).

## Prevention and Treatment

According to Lanari et al., "non-pharmacological interventions have been focused on identifying the genetic and environmental factors underlying the pathogenesis of this disease, including the individual genetic susceptibility, the early allergic sensitization, the role of the environmental microbiome and the exposure to infections and to pollutants (Lanari, Bottau, & Calamelli, 2017)." Likewise, "the optimization of the existing pharmacological strategies and the development of new treatment options have improved markedly the management of this disease, thereby reducing the health care costs and ameliorating the quality of life of patients (Lanari et al., 2017)." Reduction in risk can be achieved by preventing recurrent exacerbations of asthma and minimizing the need for emergency room visits and hospitalizations, preventing progressive loss of lung function. For children, preventing reduced lung growth and providing optimal pharmacotherapy with minimal or no adverse effects is important (Sindher et al., 2015). The goal of long-term therapy is to prevent acute exacerbations. The patient should avoid exposure to environmental allergens and irritants that are identified during the evaluation. Regular follow-up visits are essential to ensure control and appropriate therapeutic adjustments. In general, patients should be assessed every 1-6 months (Sindher et al., 2015). At every visit, adherence, environmental control, and comorbid conditions should be checked.

## Geographical Information Systems/Wearable Use-Case

Childhood asthma prevention and treatment still represents a worldwide challenge. Asthma is the most common serious chronic disease in infants and children, affecting an estimated 9.3 percent of the American pediatric population (Stripelis et al., 2017). The Federal Interagency Forum on Child and Family Statistics estimated that in 2010, 3 out of 5 asthmatic children had at least one asthma attack during a 12-month period (Stripelis et al., 2017). However, according to Lanari et al., "current tools are limited in the types of information they can gather, which constrains their predictive power. Future efforts should be aimed at identifying high risk target populations, minimizing the cost of interventions while increasing adherence to treatment strategies (Lanari et al., 2017)." According to English et al., "the use of high-resolution geospatial analysis of health care use data has contributed to a more detailed depiction of pediatric asthma disparities than was previously available to community members, public health professionals, and clinicians (English et al., 2006)." One study illustrated the use of spatio-temporal modeling of traffic density to pediatric asthma hospitalization, wherein they related traffic density to pediatric asthma hospitalizations in San Diego County, California (Zhu et al., 2000). They then compared two different measures of the traffic covariate (neither of which is aligned with the zip code-level asthma data), mapping the resulting fitted risk estimates in the Geographic Information System ARC/INFO. Results in both cases are consistent with those of several previous authors who have investigated the traffic–asthma link (Strickland et al., 2010).

Wearable examples of pediatric asthma management tools do exist and are currently on the market. One product is Adherium's Smartinhaler, which was "successful in promoting adherence to the recommended usage of a long-acting beta agonist and inhaled corticosteroid for a treatment group, at 81 percent, and improved the treatment group's asthma control compared to patients in a control group (The Pharmaceutical Journal, 2018)." Another device developed by the University of California Davis School of Medicine is a wearable sensor system that continuously monitors breathing and environmental chemicals to reduce pediatric asthma (Kenyon & Elizabeth, 2017). Another study from the University of Colorado Denver School of Medicine found that using machine learning algorithms to predict asthma severity resulted in 90% accuracy with respect to respiratory rates and pre-asthmatic behaviors (Nam, et al., 2017). The authors stated that this type of algorithm could be paired with a wearable device to ensure continuous monitoring.

To improve the state of pediatric asthma affairs, the National Institute of Biomedical Imaging and Bioengineering (NIBIB) established the Pediatric Research using Integrated Sensor Monitoring Systems (PRISMS) program to integrate environmental, physiological, and behavioral factors in epidemiological studies of asthma (Stripelis et al., 2017). Within this context, the Pediatric Research using Integrated Sensor Monitoring Systems (PRISMS) and Data and Software Coordination and Integration Center (DSCIC), known as PRISMS-DSCIC, is developing a general data integration and analysis system that enables biomedical researchers to investigate prediction algorithms for asthma attacks and eventually provide close-loop interventions (Stripelis et al., 2017). According to Juarez et al., "information generated using these techniques and wearables could facilitate discussion among stakeholders of the environmental and social contexts of asthma and health disparities in general (Juarez et al., 2014)." Although this information has only recently been introduced, preliminary discussions suggest that it responds to the needs of local government, nongovernmental, and community-based health sector stakeholders.

### 4.6.0: Condition of Interest 4: HIV/AIDS

#### Statement of Need

The vast majority of pediatric human immunodeficiency virus (HIV) Type 1 infections are the result of mother-to-child transmission (MTCT) of the virus through three possible routes: at some point during pregnancy, delivery, or via breast feeding (Luzuriaga & Mofenson, 2016). While it is possible for childhood cases of HIV to be contracted via sexual assault, several studies investigating sexually transmitted diseases (STD) contracted after sexual assault in children and adolescents note an extremely low (0% to <1%) prevalence of HIV in child sexual assault victims after their abuse (Bechtel, Ryan, & Gallagher, 2008; Girardet et al., 2009; Seña et al., 2015) (Seña et al., 2015; Girardet et al., 2009; Bechtel, Ryan, & Gallagher, 2008). So for the purpose of this thesis, I will be focusing on perinatal transmission of HIV.

As newer and more effective HIV medications are developed, rates of MTCT of HIV have fallen dramatically in wealthy countries such as the United States (Luzuriaga & Mofenson, 2016). A 2011 study of MTCT estimated the transmission rate in the US to be approximately 2.8% resulting in an estimated 138 newborns with HIV (Whitmore et al., 2011). However, when broken down between groups that received treatment during pregnancy and those that didn't receive treatment during pregnancy, transmission was higher -- 8.5% of newborns whose mothers didn't receive preventive MTCT care versus 1.6% of newborns with mothers who did receive care (Whitmore et al., 2011). This gap suggests there is a vulnerable population that is either unaware of its HIV status or that cannot afford medications to reduce the viral load. Barriers that can limit access to HIV treatment and prevention in HIV-infected, pregnant women include reduced access to healthcare, as well as complex psychosocial barriers such as drug usage and social marginalization (Taylor et al., 2011).

Missed opportunities to prevent HIV in women of reproductive age also factor into transmission of to newborn babies. These can include late HIV testing (at either birth or after delivery), no antiretroviral (ARV) medication during pregnancy, and the lack of breastfeeding information after delivery. About half of newborn HIV positive diagnoses resulted from at least one missed preventative opportunity (Aberg et al., 2013), the most common being a lack of ARV medications, even though ARV is the most effective preventive measure for MTCT of HIV (Whitmore et al., 2011b). Thus, there is a clear need to increase access of ARV medications and adherence to the corresponding treatment regimens.

Unfortunately, some communities are more at risk than others for having HIV-exposed births. Immigrants from lower and middle income countries share 21% of HIV-exposed deliveries in the US (Nesheim et al., 2013); while children of African American and Latina women share a disproportionate burden of newborn positive HIV diagnoses, accounting for 85.5% (Whitmore et al., 2011). As such, MTCT is not only a public health concern, but also a community concern. Still, this knowledge allows for more precise community targeting of information and access to care.

While transmission rates are at their lowest in years, a fairly recent study indicated a 150% increase in children born to HIV positive mothers since 1995 (Nesheim et al., 2013). This means that it's more important than ever to keep track of HIV-infected women of childbearing age or women at risk of contracting HIV during pregnancy to ensure that the recommended interventions are implemented to prevent MTCT of HIV. A major impediment to reducing MTCT of HIV is related to limitations of health departments in the US that don't have the resources to identify HIV-infected pregnant women and facilitate their access to the services necessary to reduce the risk of transmission (Luzuriaga & Mofenson, 2016). Therefore, a framework is needed that encompasses access and/or information about comprehensive family planning, preconception, and prenatal services; comprehensive testing of HIV; and real-time case-finding of HIV-infected pregnant women and their exposed fetuses (Nesheim et al., 2012). Having a network in place to provide vulnerable women with access to such care would be an extremely positive development.

## Signs and Symptoms

HIV-infected newborns are generally asymptomatic, meaning early diagnosis is dependent upon laboratory testing (Aberg et al., 2013). However, children who develop postnatal HIV via contact with body fluids of an HIV-infected individual (such as breast milk) and aren't monitored via lab tests, can develop clinical manifestations of HIV (Griner et al., 2011). These symptoms are generally grouped into three categories: mildly, moderately, and severely symptomatic. Mildly symptomatic pediatric patients can present with swollen and hardened lymph nodes (lymphadenopathy), recurrent or persistent upper respiratory tract or sinus infections, and/or enlarged liver and/or spleen (Selik et al., 2014). Moderately symptomatic patients can present with anemia, decreased neutrophil or thrombocyte concentration *in serum*, recurrent or chronic diarrhea, persistent fever lasting more than a month, and/or persistent (>2 months) oropharyngeal candidiasis infections, among other symptoms (Selik et al., 2014). Severely symptomatic patients can present with many of the symptoms of moderately symptomatic patients, in addition to multiple or recurrent severe bacterial infections (such as pneumonia, meningitis, septicemia, abscesses, or infections of the bones and joints), lymphoma, wasting syndrome in the absence of any other concurrent illness (Caldwell et al., 1994). Clinical manifestations of HIV can vary with each individual, and can sometimes be mistaken for other illnesses, especially if there's a failure to recognize recurrent infections as a symptom of HIV infection. As a result, it is important for new or expecting mothers to get tested for HIV so that preventive measures can be implemented.

## Diagnosis

There are generally no clinical manifestations of HIV infection in newborns, therefore diagnosis is dependent upon laboratory testing (Griner et al., 2011). However, clinical symptoms of HIV can help to identify cases in which laboratory testing might be needed. Diagnosis is dependent solely upon positive laboratory confirmation of the HIV virus in serum (Luzuriaga & Mofenson, 2016). Since maternal antibodies persist in the newborn for up to 18 months after birth, standard HIV antibody tests should not be used for a newborn child less than 18-months old (Selik et al., 2014). Instead, diagnosis should be conducted with assays to detect HIV DNA or RNA, HIV isolation in a viral culture, or genotyping for HIV nucleotide sequences (Selik et al., 2014). Testing should occur at three points after birth: within 14-21 days, at 1-2 months, and then at 4-6 months (Aberg et al., 2013). If at any of those points the virulogic tests read positive, the CDC recommends a follow-up test. A positive HIV diagnosis is confirmed if virologic test results come back positive for two separate specimens (Mofenson et al., 2009).

## Prevention and Treatment

Prevention is becoming much more feasible as more reliable treatment options are being developed. However, there are multiple steps involved in preventing MTCT of HIV. The first step begins with HIV prevention in women with the regular use of pre-exposure prophylactics and regular testing including her partner (Mofenson et al., 2009). If a woman does contract HIV, then adequate preconception care and family planning can help her decide the best time for pregnancy (such as when her viral load is undetectable). Unfortunately, 88% of sexually active HIV positive women in the US admit to at least one unplanned pregnancy. As such, affordable and accessible prenatal care is an important link in preventing MTCT of HIV (Mofenson et al., 2009).

As discussed above, pre-natal, natal, and post-natal usage of ARV drug combinations can significantly reduce the risk of MTCT. Additionally, it is important to identify mothers who may not know they are HIV positive, so the proper prenatal steps can be taken to reduce the risk of MTCT. For that reason, routine HIV tests are recommended during prenatal care. During birth, it is safest to deliver a baby via Cesarean delivery than a vaginal delivery, especially if maternal viral load is >1000 copies/ml (Nesheim et al., 2013). At least two separate postnatal HIV virology tests of the newborn should be administered between months 1-6 of age. Additionally, the infant should go on a regimen of ARV post-exposure prophylaxis (Aberg et al., 2013). The last link in the chain is educating the mother about not breastfeeding the child, as breast milk can contain the virus (Nesheim et al., 2013).

In terms of treatment, there are several different options available. There are six different classes of antiretroviral drugs to treat HIV: entry inhibitors, fusion inhibitors, reverse transcriptase inhibitors, integrase inhibitors, protease inhibitors, and multi-class combination drugs (Kredo et al., 2009). The most commonly prescribed drugs for HIV are tcombinations commonly called “Highly Active Antiretroviral Therapy (HAART),” which include three ARV drugs from at least two of the above classes, designed to help prevent drug resistance (Luzuriaga & Mofenson, 2016). The next most common drug therapy is a combination of three or more nucleotide reverse transcriptase inhibitors (NRTIs), while the most common drug cocktail in this therapy includes zidovudine, lamivudine, and abacavir (Luzuriaga & Mofenson, 2016). Although treatment is not limited to these two therapy options, 93% of expecting HIV-positive mothers took either one or the other (Griner et al., 2011). The type of treatment depends on strain of HIV and individual tolerance to the drugs. More recently, the ARC class of integrade inhibitors is added to the treatment regimen. With today’s treatment options, HIV is no longer a fatal condition; it is one you live with. With proper care, women with HIV/AIDS can also have children that are free of the virus.

**Geographical Information Systems/Wearable Use-Case**

This wearable use case differs from the previous four examples as it is specifically targeted for pregnant women, and is inserted into the body vaginally. Biomedical engineers at Northwestern University have tested an intravaginal ring that contains levonorgestrel, a synthetic progestin hormone, and tenofovir, an anti-retroviral drug (Ugaonkar et al., 2015). The innovative device, which allows for the prevention of unwanted pregnancy and HIV using a single method, has been in development for five years. It comes amidst what Ugaonkar calls a period of renewed interest in finding a better way to fight HIV before it's contracted. Still, innovation in the IVR has remained largely flat since it was invented in 1970 (Ugaonkar et al., 2015; Ward et al., 2017). Unlike traditional HIV-preventing methods such as pre-exposure prophylaxis (PrEP) which require consistent patient adherence with their drug intake, the dual-purpose ring removes patient error and ensures the correct dosage of both the hormone and the drug. The financial and health benefits of preventing women from becoming HIV, as well as the benefits of preventing HIV-infection in pediatric patients are well known (Aberg et al., 2013; Ticconi et al., 2003). HIV can be a source of discrimination for many (as is true for many health conditions), and as such, geocoded data that utilizes HIV patient information should be ideally masked to avoid sharing potentially sensitive health information.

Given the growing and near ubiquitous use of the Internet, smartphones, and other mobile devices, further efforts in the realm of mhealth (e.g., applications or "apps") and electronic health are needed to develop novel pediatric-focused HIV preventive interventions with GIS and wearable technologies. An important consideration is that HIV and other diseases mentioned before, can carry a significant amount of stigma, and as such, patients could balk at the idea of a wearable that can identify them on a publicly available dataset. Within ArcGIS there are tools to protect patient confidentiality such as "masking," wherein incidence points on a map can be shifted (by an amount known only to the researcher so that points on the map no longer correspond to specific individuals or populations. A wearable device that provides medication intake for HIV patients would be useful, or alternatively, it could be modified to remind non-HIV infected people at risk of intections to take their PREP medication. These devices are also of value in promoting adherence to recommended treatment regimens requiring long periods of time.

**4.7.0: Summary**

The following infectious pediatric illnesses -- Osteomyelitis, Cystic Fibrosis, and HIV/AIDS -- were selected after a review of the extant pediatric literature to: 1) identify their current pediatric health burden, and 2) determine how wearables/GIS technology could help to address this burden. In addition, this thesis examines asthma, as it affects a disproportionately large amount of children in Georgia versus the rest of the nation (O'lenick et al., 2016). If efficiently implemented, GIS can be a great tool for assessing pediatric community needs, for planning initiatives or intervention, and for evaluating and refocusing work in the community (Talati et al, 2016). PRAMNET's aggregation of biometric data collected from wearable sensors (e.g. sweat, heart rate, breathing pattern, gait pattern), which includes geographic data from the user, could be used to analyze and illustrate how GIS-based data and methods can be visually presented to better inform pediatric health interventions. PRAMNET's sensors could provide parents and healthcare providers with continuous out-of-clinic monitoring; educators with the data they need to serve children with special needs; and policymakers with the information they need to manage public resources.

The novel combination of mapping disease incidence and spatial analysis provides a detailed level or disease surveillance, allowing for identification of small geographic areas with elevated rates of specific conditions (Williams et al., 2003). Each condition is defined clinically and presented with possible technology solutions. One of the things that became apparent throughout the course of my literature review for the above four cases, is that many did not have data available in GIS-ready formats. All cases have considerable research which is displayed in tabular formats, but few combine geospatial attributes with visual mapping of the data. Further, there was little academic or consumer material available on the use of wearables to treat and diagnose these conditions. This presents two gaps within the existing literature: the use of GIS mapping methodologies for pediatric asthma, HIV, cystic fibrosis and osteomyelitis; and the use of wearable technologies for the same conditions.

As stated earlier, there are multiple factors that influence pediatric health status and the presence of health disparities. Root causes include parental employment status and educational levels that influence family income, poverty and other economic conditions. In turn, these factors influence safety and the adequacy of housing, environmental conditions (air and water quality), crime rates, mental health (including depression), diet, physical activity, and drug and alcohol use. As a result, these conditions impact access to preventive health care, healthy lifestyles, wellness resources and positive experiences within the health care system. A pediatric health/GIS system could provide regional information health networks, patients and providers with data such as condition incidence and geographic spread, while personalizing patient care with up to the minute biometric data.

Geographic information systems and wearables provide promising opportunities for studying many public health questions, including visually illustrating the spatio-temporal distribution and changes in health outcomes and studying the effects of environmental exposures (He et al., 2015). According to Buerhaus, "the unique needs of children with complex, chronic, conditions and their families, who reside in urban/rural areas with limited pediatric health access and community resources, should be more effectively anticipated and addressed (Buerhaus, 2008)." Frequent and consistent communication between primary care providers and early intervention providers is essential to optimize each child's medical, developmental, and functional outcomes (Duby, 2007). Wearables and GIS technologies are uniquely suited to address many of the barriers that currently impede pediatric health access for children with disabilities and complex medical needs.

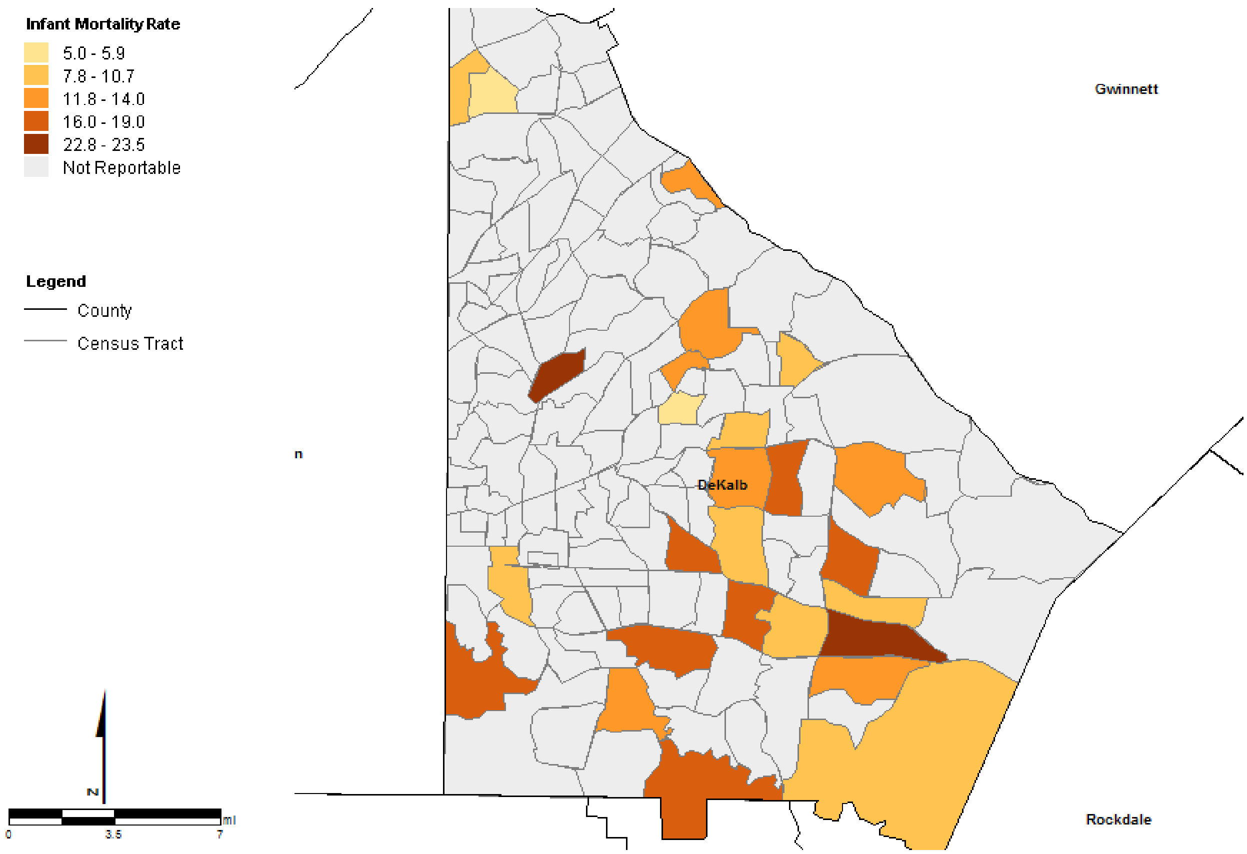
# Chapter 5:
# Results

Utilizing the methodology described above, the following maps present examples of how census tract data can be used to produce maps of Atlanta metropolitan statistical area (MSA) as compared to traditional tabular displays of the same data sets. Georgia's population is younger, lower-income, and more mobile than the population of most states (Dobson et al., 2013). According to the U.S. Census Bureau, Georgia has an overall population approaching 10 million, making it one of the most populous states in the nation. Most significant, 7.65% of Georgia's population is under the age of five, which is the fifth highest percentage among the 50 states. In Georgia, whether urban, suburban, or rural, the percentage of low income children is higher than the national average (GDPH, 2013a). Moreover, 28% of Georgia's low-income children have recently moved, as compared to the national average of 21% (Pew Research Center, 2017).

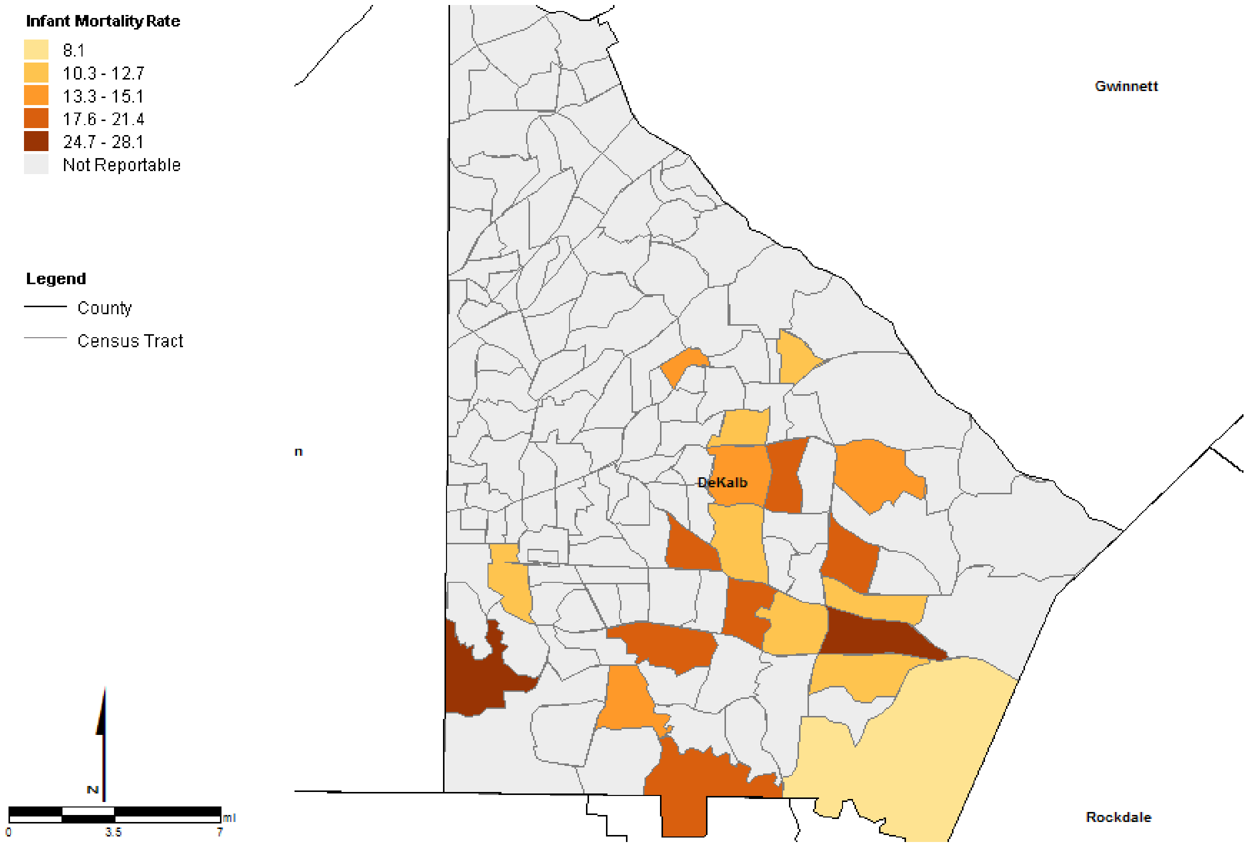
The challenges to a coordinated PRAMNET system that incorporates pediatric health/GIS data and wearable/sensor data may seem daunting. But when one considers the health implications and fiscal pressures faced by, state and federal government, it is abundantly clear that today's issues demand innovative approaches. Due to the high mobility of many of Georgia's urban children and the fact that more than half never participate in a recognized pre-school or daycare environment, there is great need for a coordinated, family-centered Pediatric Health/GIS system. Collaboration across all health agencies, with information accessible to medical care providers across diverse data collection points including Head Start and Pre-K, the Department of Public Health, and the Medical Home, will result in savings in time and fewer missed diagnoses, leading to fewer children falling through the cracks of the current system.

**5.1.0: Example Use of Geographical Information Systems to Map Pediatric Conditions in Atlanta**

**Map 4: This map illustrates the infant mortality rate by census tract of residence for all races in Dekalb County. Created in ArcGis utilizing the Georgia Department of Public Health's Public Health Information Portal (PHIP) (GDPH, 2018b) and the University of Wisconsin Population Health Institute (Foundation, 2018).**



**Map 5: This map illustrates the infant mortality rate by census tract of residence for Blacks and African Americans in Dekalb County. Created in ArcGis utilizing the Georgia Department of Public Health's Public Health Information Portal (PHIP) (Health, 2018b) and the University of Wisconsin Population Health Institute (UWPHI, 2018).**

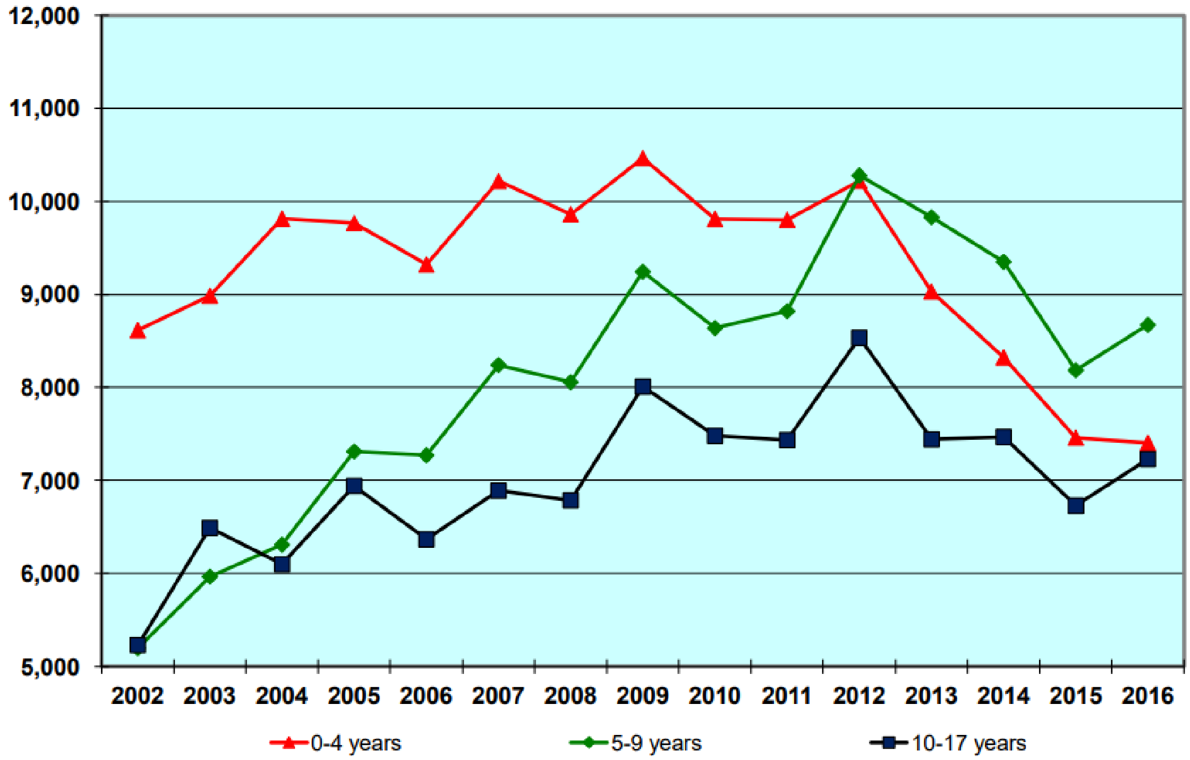



An analysis of the above maps (4 and 5) visually illustrates differences in infant mortality by census tracts and race in Dekalb County. For example, there are not only differences in the geographic spread of infant mortality rate across the county by race, but also by severity and race. Black and African Americans experience greater relative severity than whites and more geographic spread of negative outcomes. Both maps display large census tract areas with insufficient data to create a visualization, which is of concern when one considers that DeKalb county has some of the highest health outcomes in the state and the best health infrastructure (UWPHI, 2018).

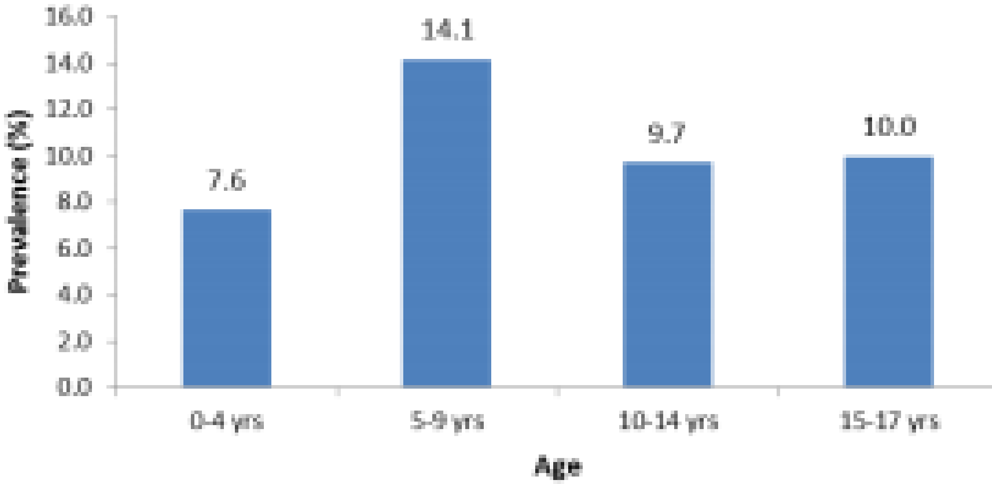
**5.2.0: Traditional/Tabular Presentations of Data Compared to GIS Visualizations of Data**

For comparison, the following charts and map demonstrate displaying the same set of data (asthma in Georgia) via traditional tabular displays, as well as GIS spatial analytics.

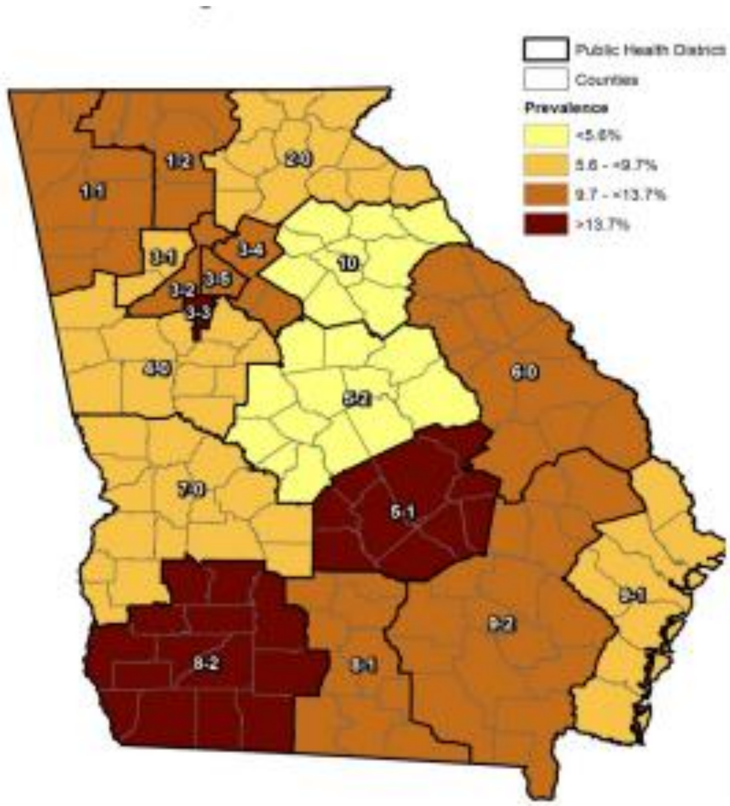
**Graph 1: This graph demonstrates the number of asthma emergency room visits in Georgia, by age group, 2002-2016. Created in ArcGis utilizing the Georgia Department of Public Health's Public Health Information Portal (PHIP) (GDPH, 2018b) and the University of Wisconsin Population Health Institute (UWPHI, 2018).**



**Graph 2: This graph illustrates the same data as above, the number of asthma emergency room visits in Georgia, by age group, 2002-2016. Created in ArcGis utilizing the Georgia Department of Public Health's Public Health Information Portal (PHIP) (GDPH, 2018b) and the University of Wisconsin Population Health Institute (UWPHI, 2018).**



**Map 6: This map illustrates asthma prevalence among children 0-17 years, by health district, Georgia 2013 in Georgia, by age group, 2002-2016. Created in ArcGis utilizing the Georgia Department of Public Health's Public Health Information Portal (PHIP) (GDPH, 2018b) and the University of Wisconsin Population Health Institute (UWPHI, 2018).**




The two graphs and map above were generated in ArcGis from the Population Health Institute of the University of Wisconsin data set. The third visualization, which takes into account geographic attributes, is the most "data rich" of the visualizations, as one can readily compare not only differences in asthma prevalence geographically at a glance, but also relative severity.

### 5.4.0: Results Summary: Traditional Presentation of Pediatric Health Outcomes versus GIS-Based Data Mapping to Pediatric Health Outcomes

As a way of enhancing both data collection options and display/informational modes, the integration of wearables and GIS analysis in community pediatric screening can be summarized as follows:

- Data acquisition and management
    - The value of a geographical information system for preparation and managing plans relies on the availability of precise and appropriate data

(Scotch et al., 2006). Data needs to be collected with the scope and objectives of the study in mind.

- Visualization of collected data—mapping/geo coding
  - Once the data are collected, the next step is to create a database file for use in the GIS software (Aronson et al., 2007). This is the most critical component of the screening since the intervention planning will be done based on the mapping and the data projection on the same.
  - Mapping can allow for precise, visual tracking of program efforts and program evaluation measures.
- Spatial analysis
  - In this stage, the objective of the analysis is to explore the statistical characteristics of the spatial patterns that were created in data visualization (Riner et al., 2004). It is first important to determine if disease patterns are real and not due to random spatial variation. What may appear to be meaningful spatial patterns on a map could be attributed to spurious spatial variation (Riner et al., 2004).
- Integration of wearable sensors
  - PRAMNET's integration of more robust pediatric health data collected from wearable sensor devices (e.g. Apple Watch to monitor heart rate, wristband to monitor pre-asthmatic symptoms)(Yonchuk et al., 2017), when paired with GIS visualization of the data, could identify areas of concern and inform future pediatric interventions in Atlanta. This would be accomplished by the data collected via PRAMNET informing researchers and policy-makers with a "higher resolution" than current methodologies allow.

Pediatric health outcomes in Georgia have seen significant, yet inconsistent, improvements over the past 15 years (GADOE, 2017). Still, a key policy problem in the public health arena is that demographic and individual data are often inadequate or too patchy to inform effective health sector policymaking. Standard public health statistics, for instance, can be outdated, or aggregated at too broad of a geographical basis in both rural and urban settings (Rydin et al., 2012). Further, research tools for data collection in low-resource settings are not well developed, and consequently, can lead to ineffective policy interventions for target populations. Innovative, technology-related pediatric approaches have the potential to facilitate better health outcomes for women and newborns, although specific barriers to adopting these public health system improvements are still not well understood. In summary, if efficiently used, GIS can be a great tool for assessing pediatric community needs, for planning initiatives and interventions, and for evaluating and refocusing related work in the community.

## Chapter 6:
## Discussion and Future Directions

### 6.1.0: Electronic Health Records and Geographical Information Systems

As mentioned previously, a major concern for many users, particularly pediatric users, is ensuring the safeguarding of confidential information contained in their medical records. According to Jacobs, Electronic Health Records (EHRs), “provide a rich source of electronically accessible discrete patient data related to demographics, race, age, patient address, vital signs, laboratory results, radiology results and healthcare provider clinical documentation (Jacobs, 2012).” As EHRs are available digitally, there “is an opportunity to aggregate, analyze and compare its geographic characteristics to related regional co-variables utilizing geospatial information systems (GIS) technology (Jacobs, 2012)”. EHRs have been used for over thirty years, but particularly due to their digital nature, many patients remain wary of sharing sensitive health information electronically (Simpson, 2009). Even with progress in digitizing U.S. hospitals and physicians’ offices, research into usability, implementation, patient safety, and cost and value of EHRs has demonstrated that much work remains to improve the quality, functionality, usability, and effectiveness of inpatient pediatric health systems (Gracy et al., 2012).

Having fitness and health data transferred from a wearable device directly to a patient’s health record would help physicians:

- Better monitor patients remotely
- Expand the reach of patient care to rural areas
- Improve the quality and amount of data physicians receive on metrics of interest related to their patients

One of the greatest benefits to using devices to send information to EHRs, however, is that it effectively supplements the efforts of telemedicine and remote patient monitoring. EHR data can also be used for geospatial analysis and visualization. To do so, according to Jacobs, “patient address data derived from EHRs must be de-identified and geocoded (latitude and longitude determined) to produce GIS point data representing the spatial location of individuals in the original dataset (Jacobs, 2012).” The EHR can be used to query, aggregate and analyze large samples of accurate, reliable health data for a population. A vital consideration when using EHRs is that a breach of the patient’s protected health information due to security vulnerabilities could be devastating. If used properly, however, EHRs offer an excellent method for tying biometric data from wearables and GIS technologies into a richer, more accessible data format.

### 6.2.0: Integrating a Pediatric Health/GIS Framework with Existing Pediatric Surveillance Methods

Children and infants are a particularly vulnerable population because of age-specific physiologic and developmental variances that may not be adequately addressed by adult-specific data tools (Simpson, 2009; Thune et al., 2013). The United States has witnessed a surge in the adoption of health information technology (HIT), largely due to incentives offered by the American Recovery and Reinvestment Act (ARRA) of 2009, and the Health Information Technology for Economic and Clinical Health (HITECH) Act (Miller et al., 2015). Also of note, HITECH has provided approximately $18 billion for practices and practitioners that meet criteria for "meaningful use" of certified EHR technology, with the goal of improving care and facilitating aggregated reporting of quality measures from electronic clinical data (Lehmann,2015).

Pediatric data collection systems are not novel, per se, as examples of existing pediatric surveillance programs are readily available. The CDC's Pediatric Nutrition Surveillance System (PedNSS) is a public health surveillance system that monitors the nutritional status of low-income children in federally-funded maternal and child health programs. Data on birth-weight, anemia, breastfeeding, short stature, underweight and overweight conditions, and obesity are collected for children who attend public health clinics for routine care, nutrition education, and supplemental food (Dalenius et al., 2011). In Georgia, PedNSS includes almost 50% of children eligible for federal-funded maternal and child health and nutrition programs, many of whom are preschool-age children living in low-income families (Pan et al., 2012).

In Atlanta, several families participate in Women, Infants and Children (WIC), the Supplemental Nutritional Assistance Program (SNAP), Temporary Assistance for Needy Families (TANF), and Medical Assistance Program (MAP) initiatives, which provide critical nutrition and health benefits to low-income families. Still, Gilbert et al. state that "while concurrent enrollment in these programs provides a powerful safety net, simultaneous participation is reported to be low (Gilbert et al., 2014)." Such programs can work synergistically and provide a powerful safety net for our nation's most vulnerable citizens (Jacknowitz & Tiehen, 2009). Unfortunately, enrollment in these programs is often uncoordinated, with differing and complicated administrative requirements leading to inconsistent services and reduced participation (Swann, 2007). Barriers to WIC participation, for example, include: perceived stigma, clinic-based barriers (e.g., long waits and difficulties associated with bringing one's child to an appointment), perceived eligibility restrictions, and other logistical considerations (e.g., lack of transportation, child care availability, and inconvenient office hours) (Christie et al., 2006).

### 6.3.0: Enhancing GIS Spatial Analytics for Pediatric Health

Within the field of pediatric health, GIS spatial analytics has not been implemented widely. This is perhaps due to a combination of its novelty within the field of public health, and, as demonstrated by the little published literature on the subject, relatively low awareness among pediatric health researchers and policy makers of this powerful public health tool. This is true also of the published literature on wearables and GIS applications, perhaps due to the relative newness of wearables, and also privacy concerns that come associated with an always on, individual-centric system. Despite the field's relative nascence, GIS is currently being used in select cases within the field of public health, mostly for research purposes.

In Georgia, GIS has been used by local public health agencies under the recommendation of the CDC for public health studies, including efforts to identify children who are at risk of lead exposure. The study compiled data on housing age, age of residents, and lead testing results within the Jefferson County area of Kentucky. From that data, GIS maps were produced indicating that many children, even in high risk areas, were not being tested for lead exposure (Schuch et al., 2017). In Atlanta, GIS has been used to identify metropolitan areas where air quality exacerbated asthma symptoms in pediatric patients, causing emergency room visits. This study compiled air monitoring data from 13 research stations in the metropolitan area, medical data from pediatric patients admitted to the ER with asthma symptoms, and residential locations of patients to create a map delineating areas of the city where pollutants (such as ozone) exacerbated asthma symptoms (Tolbert et al., 2000). These data should inform state and local officials about potential high-pollution areas, and could help create legislation to reduce pollution.

These are just a few examples of how GIS has helped inform public health officials about areas of need and the effectiveness of public health programs. Additionally, this kind of research could inform lawmakers about potential pediatric public health problems that should be addressed through legislation. With the increase in accuracy of global positioning systems (GPS) and wearable devices that use such systems, GIS has the potential to avail more data to researchers and public health officials than ever before. A study by Statter et al. used GPS-enabled devices to track pediatric physical activity levels and overlay the data with GIS information to determine the locations where the physical activity took place (Statter et al., 2011). As this study indicates, it is possible to merge GIS with GPS data from wearables to better understand human health behaviors, providing a greater wealth of information than was thought possible.

### 6.4.0: Limitations

This thesis explores the novel application of GIS to pediatric health and the use of new (sensor) technologies as a way of enhancing pediatric data gaps. Although GIS has been increasingly used in various aspects of obesity research, my review reveals several key research gaps, particularly in the area of pediatric health. More efforts are needed before GIS can be fully incorporated into the conceptual framework and implementation of traditional obesity research on related health problems (Jia et al., 2017). First, GIS data have limitations. According to English et al, "communities of concern are often smaller than ZIP codes or cross ZIP-code boundaries, and require higher geographic resolution for health surveillance and when traditional mapping techniques are used, gradations of health risk are often misrepresented as abrupt changes at ZIP-code boundaries (English et al., 2006)."

A future study could identify "hot spots" or clusters for a condition of interest in collaboration with community health practitioners such as nurses and disease intervention specialists from the clinics at county health departments. Community-based advertising and incentives could be used to ensure the successful facilitation of the program. Education is also an important factor. In a research study that utilized GIS to identify hot spots of child lead poisoning incidence, steps were taken to deliver to every household in the affected neighborhoods informational leaflets on the importance of child lead level screening (Jain et al., 2017). These efforts resulted in greater participation in the screening program (Jain et al., 2017).

Accurate geocoding has not been widely used in public health studies because of unavailable personal addresses in most studies; ergo, the straight-line and road-network buffers in most studies were established around an area unit (e.g. census unit or zip code) rather than an address point, which created difficulty in measuring the realistic exposures of residents to the surrounding obesogenic environment. Using the zip code system as a unit for such analysis is problematic, because zip codes were initially developed for delivery purposes, and demographic attributes are more likely to be heterogeneous within zip codes than, for instance, within census units (Craglia & Maheswaran, 2016).

As an example, thus far GIS applications in studying food environment and its impact on obesity have been limited in that they measure only the community food environment, e.g. the number, location, type and accessibility of food outlets in individuals' residential communities (Jia et al., 2017). There are other critical dimensions of the food environment: (i) consumer: the food environment that consumers actually have access to (e.g. the food outlets or markets in which the consumers buy food), including such factors as availability and quality of healthy food, pricing, promotion, placement of food and food information (e.g. nutrition labelling); (ii) organizational: the food environment not only in the community but also at home, school and the workplace as a whole; and (iii) information: the influences of government and industry policies on public attitudes and the appeal of certain foods and food sources that are created via media reporting and advertising (He et al., 2015). These spatial factors are more easily accountable when considered together visually.

In addition, within the pediatric health sector there has been limited use of advanced GIS data analysis methods in current research, especially spatial statistics, whose use remains at a descriptive stage, such as seeking spatio-temporal clustering patterns of obesity rates (Jia et al., 2017). Additionally, separately built environment indicators have been simultaneously included in a single analysis model in many existing studies, which may result in an over control issue (Jia et al., 2017).

**6.5.0: Conclusion and Recommendations**

This thesis presents a conceptual model that explores the use of GIS spatial analysis using key pediatric health indicators as a way of testing the hypothesis that the visual enhancement and presentation of data can better serve public health professionals and policy makers. By comparing the same sets of data in traditional tabular formats versus visual-spatial formats, “hot spots” of outcomes of interest are more readily apparent. This thesis explores infant mortality as a surrogate measure for negative pediatric outcomes to introduce the concept of GIS applications for spatial analysis for improving pediatric health care. Building on this foundation, it also presents the potential of wearable technologies for data collection and display in combination with GIS to generate solutions to obtain preferable pediatric health outcomes. PRAMNET’s sensors could provide parents and healthcare providers with continuous out-of-clinic monitoring; educators with the data they need to serve children with special needs; and policymakers with the information they need to manage public resources. Having accurate data from Georgia's early pediatric care stakeholders is a key element in providing solutions to care coordination issues, filling gaps in services, following up on children's health and developmental screenings, assessing quality in child care and early education programs, and in developing strategies to improve the quality of related services (GDPH, 2013b).

Future directions for GIS applications in public health research, and in particular, regarding pediatric health could include: First, changing the most basic reporting unit of personal residence from zip code to census unit. This would represent quite an advancement not only in accuracy, but also in the measurement of individual exposure to the obesogenic environment, which in turn would provide a better match with census data. Second, the collection of more accurate and timely GIS data. "Volunteered GIS" means citizens voluntarily use Internet-enabled mobile devices to share their real-time location information via mobile apps (e.g. Facebook and Twitter), which could be a potential solution for overcoming current data limitations (He et al., 2015). Third, enrich GIS data collection to measure multiple dimensions of the pediatric environment to assess their impacts on pediatric health outcomes. For example, besides neighborhood air quality as an indicator for asthma, aerial level socioeconomic data from the Census could be used to measure physician accessibility.

Future research could develop friendly data processing and analysis methods to enable more researchers to process, combine and analyze GIS and other types of data (He et al., 2015). This could include regression methods that take into account spatial patterns such as geographically weighted regression, spatial lag regression, spatial error regression and spatial multi-level regression, to investigate spatial inequalities of the associations between environmental factors and health outcomes. The exploration of a pediatric health/GIS system that longitudinally-links vital records as a viable approach for improving not only access to care, but continuity as well as quality of care for all Georgia mothers, warrants further research. It is an approach that is reasonably attainable at the level of the Georgia Public Health Department, providing descriptive and analytic insight into the hyper-local environmental factors and behaviors that affect pediatric outcomes in target populations. Dr. Martin Luther King, Jr. wrote, "Of all the inequalities, inequalities in health are the most inhumane of all (Physicians For a National Health Program, 2017)." The goal of this thesis is not to highlight the lack of health data in many vulnerable counties, but rather, to identify pockets of inequality in pediatric health care and outcomes and serve as a catalyst for action to achieve health equality for all Georgians.

### 6.6.0: Definition of Terms and Abbreviations

**Geocoding:** Geocoding is the systematic assignment of spatial coordinates to data based on address information; it is a key feature of geographic accessibility studies. An example within GIS would be converting street addresses into spatial data that can be displayed as features on a map, usually by referencing address information from a street segment data layer.

**Geographical Information Systems (GIS):** According to Craglia & Maheswaran, "GIS is a system designed to capture, store, manipulate, analyze, manage, and present spatial or geographic data (Craglia & Maheswaran, 2016)." GIS is used in healthcare to understand, investigate, and improve need assessments, health service availability, and healthcare utilization patterns using various geographic, visual, and spatial analytic techniques, where, according to Jacobs, "a map in GIS terms consists of multiple individual layers of geospatial information (Jacobs, 2012)."

**Mobile Health (mHealth):** Mobile health are technologies and wireless devices and sensors (including mobile phones) intended to be carried and accessed during normal daily activities for the purpose of monitoring health status, changes in health outcomes, or for wireless diagnoses and clinical decision support (Hollis et al., 2017). Potential advantages of mHealth include improved patient communication, education and monitoring for adherence with recommended interventions (Kay et al., 2011), real-time data collection, and the ability to deliver personalized, interactive, and adaptive interventions to participants in their residential environment (Kumar et al., 2013).

**Pediatric Health:** Pediatrics is a field of medicine that is concerned with the health of infants, children, and adolescents; their growth and development; and their opportunity to achieve full potential as adults (American Academy of Pediatrics, 1995). For the purpose of this thesis, pediatric health includes infants from birth until adolescence.

**Spatial Analysis:** According to Stopka et al., "spatial analysis is the study of the distribution and clustering of events and/or objects in space, in conjunction with their attribute characteristics (Stopka et al., 2014)." In recent years, spatial analysis has become increasingly important for health based and epidemiological investigations in the monitoring and evaluation of community based pediatric interventions (Jacobs, 2012), examining relationships between health outcomes and socio-economic disparities (Craglia & Maheswaran, 2016), investigating cause and effects relationships of environmental exposures (Haley et al., 2016), as well as identification of disease clusters (CSPAV, 2018).

# Chapter 7
# Bibliography

## 7.0.0. Bibliography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