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Comparing geospatial approaches to delineating children's interactions with their physical environments: A case study of children in rural Northwestern Ontario

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Graduate Program in Geography
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Abstract

Researchers from a variety of disciplines have produced a large body of evidence indicating that the environment a child lives in can profoundly impact their overall health in a multitude of ways. Among this growing body of literature, there is a wide diversity of methodologies and general inconsistency in how the physical environment is conceptualized and delineated. The primary purpose of this study is to gain a better understanding of how the physical (natural and built) environment is conceptualized in children's health studies and to quantify how children engage with their environment. Using a multi-tool protocol, 128 children in grades 4 through 8 from four elementary schools in rural Northwestern Ontario participated in two 7-day data collection periods. GPS data within GIS were used to determine various delineations of their physical environment and quantify the extent to which children interact with different land uses and levels of greenness. The results suggest that how we conceptualize a child's physical environment has a significant impact on estimates of environmental accessibility, exposures, and engagements, which in turn can influence the researcher's interpretation of the relationship between environment and health. This research helps to fill gaps in knowledge on what environments can influence rural children's overall health. The findings from this study can help knowledge users to develop effective policies, programs, and services which are appropriate for children living in rural environments.

Keywords

Children; physical environment; activity space; GPS; GIS; rural

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List of Abbreviations

BE: Built environment

CCG: Context-based Crystal Growth

GPS: Global Positioning System

GIS: Global Information System

HDOP: Horizontal Dilution of Precision

HEAL: Human Environments Analysis Laboratory

MVPA: Moderate-to-vigorous physical activity

MAUP: Modifiable Areal Unit Problem

PA: Physical activity

STEAM: Spatial Temporal Environment and Activity Monitoring

UGCoP: Uncertain Geographic Context Problem

Chapter 1

1 Introduction

1.1 Research Context

In recent years, researchers from a wide variety of disciplines have generated ample evidence confirming that the environment a child lives in can profoundly impact their overall health (Ball, Timperio, & Crawford, 2006; Berrigan & McKinnon, 2008; Chaix, Mé Line, et al., 2013; Gordon-Larsen, Nelson, Page, & Popkin, 2006; R. J. Jackson, 2003; P. James et al., 2014; Troped, Wilson, Matthews, Cromley, & Melly, 2010; Tucker et al., 2009). Within Canada specifically, previous research has identified an association between the physical environment and numerous child health behaviours and health outcomes, such as physical activity (Mitchell, Clark, & Gilliland, 2016), active travel (Larsen, Gilliland, & Hess, 2012; Wilson, Clark, & Gilliland, 2018; Wilson, Coen, Piaskoski, & Gilliland, 2018), healthy eating (Gilliland et al., 2015; Sadler, Clark, Wilk, O'Connor, & Gilliland, 2016), obesity (Gilliland et al., 2012; Gilliland, 2010), and mental health (Tillmann, Clark, & Gilliland, 2018; Tillmann, Tobin, Avison, & Gilliland, 2018). Research on the influence of the physical environment on health is extremely diverse and dispersed, and therefore tends to be difficult to interpret. Previous researchers have recognized the problems associated with the lack of consistency among the common methods used across studies for conceptualizing children's environments (i.e., in terms of degree of interaction), delineating environments (i.e., identifying boundaries or spatial extent), and characterizing environments (i.e., quantifying features within) (Chambers et al., 2017; Diez Roux, 2001; Hasanzadeh, Broberg, & Kyttä, 2017; P. James et al., 2014; Perchoux, Chaix, Brondeel, & Kestens, 2016). Despite recognition of the problem, there remains an overwhelming need to critically evaluate the contemporary methods and measures that are being used for delineating and characterizing the physical environment. The purpose of this thesis is to examine how children's environments are conceptualized, delineated, and characterized in environment and health studies. The practical purpose is to use more consistent approaches and methodologies to allow for more generalizable findings within health geography research.

The physical environment is made up of multiple components, each broadly attributed to either the natural environment or the built environment (Handy, Boarnet, Ewing, & Killingsworth, 2002). The natural environment includes elements such as the topography, climate, pollution, water, and vegetation in an area. The built environment includes human-made structures such as buildings and transportation systems, as well as land use designations and the categorization of the unique activities across space such as urban design systems (Handy et al., 2002). A diversity of qualitative and quantitative methods such as surveys, participatory mapping, Global Positioning Systems (GPS) and Geographic Information Systems (GIS) have been used for the description and quantification of the physical environment (Gauthier & Gilliland, 2006; Gilliland & Gauthier, 2006); such methods have been used to generate a multitude of environmental variables to examine in relation to various health-related behaviours and/or outcomes among children and youth (Christian et al., 2015; Tillmann, Tobin, et al., 2018).

There has been considerable variation among the ways that researchers conceptualize, delineate, and characterize children's interactions with their environments. Despite the heterogeneity, we were able to identify three broad categories of studies in the environment and health literature which we hereafter refer to as 'accessibility', 'exposure', and 'engagement'. In the field of geography, accessibility essentially refers to the ease of reaching destinations; therefore, greater accessibility increases the likelihood a child will encounter or interact with a feature in the environment, but it does not necessarily mean that there will be a direct encounter or interaction. Accessibility measures are based on opportunities within a certain distance; they are typically calculated in GIS using a circular (ring) buffer or street network buffer of a certain distance from a point location such as the home (or school) and expressed in terms of distance/proximity to one or more elements of the physical environment, or count/density/coverage of one or more elements within an area (Larsen et al., 2012; Mitchell et al., 2016; Tillmann, Clark, et al., 2018).

In comparison, exposure can be defined as having contact with or being subjected to some effect or influence of the physical environment. Rather than mere opportunity, exposure implies some form of direct encounter with an environment. Nevertheless, in

most child health studies exposure is a measure of incidental contact with an environmental feature. This is operationalized in terms of spatial coincidence; that is, being located in an environment, or in close proximity to an environmental feature, at some point in time. Such studies have assessed exposure using subjective methods (e.g., focus groups and participatory mapping) (Wilson, Coen, et al., 2018) as well as objective methods (e.g., GIS shortest network path, GPS tracking) (Larsen et al., 2012).

Engagement refers to direct participation and sustained immersion in the physical environment. This differs from the other two conceptualizations in that it implies a direct, intentional, and sustained interaction with the physical environment. Engagement can be operationalized in terms of the proportion of “time spent in/near” a specific location. For example, engagement can be described as the sustained time a child spends skating on a frozen pond directly related to the physical environment. Engagement studies typically use GPS tracking to objectively measure time spent in different environments; however, qualitative studies often use interviews and focus groups to have participants recall large periods of time they spent in a location (Clark, Marmol, Cooley, & Gathercoal, 2004; Ritchie, Wabano, Russell, Enosse, & Young, 2014). In this thesis I argue that the way a researcher chooses to delineate and characterize a child’s physical environment – whether categorized as accessibility, exposure, or engagement – has serious implications for study outcomes and how study findings can be interpreted. It is important for researchers to properly define the environment, as assuming each term is interchangeable removes the individual agency of the child all together and may not truly represent the effects of the physical environment on health behaviours and outcomes (Bell, Phoenix, Lovell, & Wheeler, 2014). Within health geography, there has been a marked shift in preference from using arbitrary buffers and self-report data to a rapid growth in studies using personal sensor-based devices, like GPS trackers and accelerometers (Chaix, 2018). GPS trackers add a space-time component to help identify the behaviours and interactions in the immediate physical environment that may have an effect on children’s health outcomes (Chaix, 2018; Chaix et al., 2016).

Most studies in children’s health geography have focused on urban populations and phenomena in urban environments, with little investigation into rural populations and

environments (Ding, Sallis, Kerr, Lee, & Rosenberg, 2011a; Gordon-Larsen et al., 2006; R. J. Jackson, 2003). The area studied in this thesis is defined as rural as the population and geography can be classified by (1) rural small-town, which include settlements with a population between 1,000 and 10,000; and a (2) rural area, which has a low population density and is mostly characterized by agricultural land and natural areas (Ministry of Municipal Affairs, 2015). Previous research on the built environment and health in rural settings have tended to apply methods and measures based on studies of urban environments, therefore limiting the relevancy of findings for policy and practice in rural environments (Berrigan & McKinnon, 2008). The delineation of a rural environment often captures a larger areal extent than urban studies and potentially incorrectly characterizes the physical environment to which a child truly interacts with (Chaix, Méline, et al., 2013; Kestens, Thierry, & Chaix, 2016; Sadler & Gilliland, 2015; Zhao, Kwan, & Zhou, 2018). Similarly, the common elements present in the physical environment (e.g. land use, transportation networks) differ by urbancity and present different benefits and barriers to children (e.g. distance to school, available amenities and facilities) (Jilcott Pitts et al., 2015; Probst, Barker, Enders, & Gardiner, 2018; Seguin, Connor, Nelson, LaCroix, & Eldridge, 2014; Shearer et al., 2012). With consideration for these factors, researchers may provide useful insight into relationships between the physical environment and children's health behaviours, but should limit generalizing their findings across the urban-rural continuum. Therefore, the conceptualization and delineation of the physical environment should be specific to the population under study to ensure an accurate characterization of the natural and built environments (Arcury, Preisser, Gesler, & Powers, 2005; Joens-Matre et al., 2008; Parks, Housemann, & Brownson, 2003; Shearer et al., 2012).

In simplest terms, the physical environment is understood to affect behaviour, which in turn influences a health outcome (see Figure 1.1). The way the physical environment is conceptualized (e.g., accessibility, exposure, engagement) and delineated (e.g., buffers, GPS-derived spaces) can have an impact on how a child's environment is characterized (i.e., amount of features present or extent of coverage of specific land uses). In order for research to make accurate conclusions about children's behaviours and health outcomes, the approaches to conceptualizing, delineating and characterizing the physical

environment must be improved and defined more clearly and accurately. To understand health related behaviours and their outcomes, the focus must be shifted to understanding how differences in approaches and methods can influence the validity of findings. This thesis examines and interrogates the predominant methods used by researchers who examine the relationship between the physical environment and children's health.

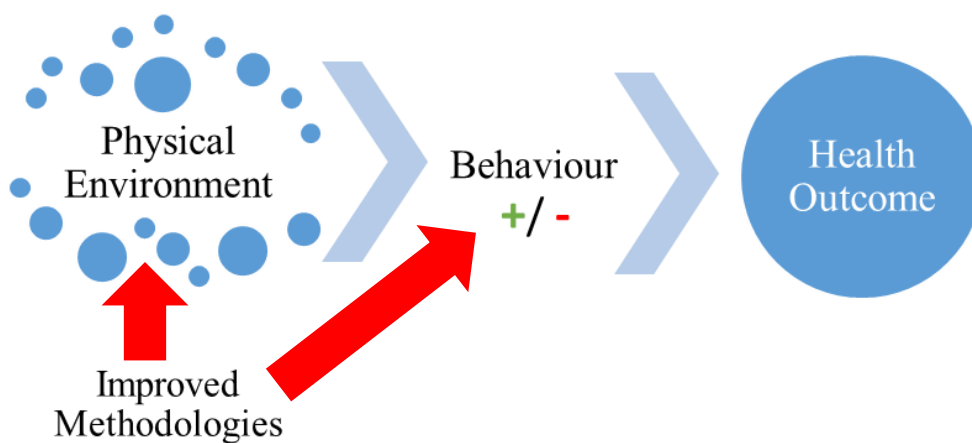


Figure 1.1 Relationship between the physical environment with children's health behaviours and outcomes

1.2 Research Objectives and Questions

The overarching purpose of this thesis is to determine how the method implemented to measure an interaction with the physical environment impacts the interpretation of findings. In addition to helping to fill gaps in the literature and advance research methodologies, this thesis will attempt to answer two important research questions.

Research question #1 is: ***How do different approaches to conceptualizing and delineating children's interactions with their physical environments effect the quantitative characterizations of built and natural features within their environments?***

Simply put, how do different approaches and measures produce different results?

Additionally, are any differences statistically significant? This question aims to fill a methodological gap in the literature using data for a sample of children aged 8-14 years from rural communities in Northwestern Ontario.

Building upon the first question, research question #2 is: ***What are the built and natural characteristics of the environments that girls and boys in rural Northwestern Ontario directly engage with on weekdays and weekends?*** Simply put, in which environments do these children spend their time? Additionally, are there any statistically significant differences by gender or day type? By answering question #2, I hope to fill an empirical gap in the literature, as very few studies have objectively measured the environmental exposures or engagements of rural children, especially in rural Canadian regions.

To answer research question #1, I propose to meet the following four specific objectives:

- 1) *To develop and execute methods of delineating children's accessibility, exposure, and engagement in their physical environments using buffers and GPS-derived activity spaces within GIS;*
- 2) *To determine how different delineations of children's accessibility, exposure, and engagement differ in terms of key geometric properties (i.e., area, length);*
- 3) *To determine how different delineations of children's accessibility, exposure, and engagement result in different characterizations of the primary land uses within their environments;*

4) To determine how different delineations of children's accessibility, exposure, and engagement result in different characterizations of the level of greenness within their environments;

In addition, to answer research question #2, I propose to meet these additional three specific objectives:

5) To determine how the activity spaces that rural children from Northwestern Ontario engage in differ in terms of primary land use characteristics, using GPS-derived activity spaces and land use data within GIS;

6) To determine how the activity spaces that rural children from Northwestern Ontario engage in differ in terms of level of greenness, using GPS-derived activity spaces and NDVI data within GIS;

7) To determine how the land use and greenness characteristics of children's engagement activity spaces differ according to gender (i.e., boy vs. girl) and day type (i.e., weekday vs. weekend).

It is hypothesized that investigation of the physical environment using a more objective measures of space and time to conceptualize and delineate a child's interaction will help to support the argument for researchers to adopt more explicit, consistent, and direct methods in their explorations of environment and health relationships.

1.3 Conceptual Framework

In contemporary research there is general agreement that children's views and habits must be experienced firsthand in order to support the individual agency of children themselves (Holloway, 2014; James, 2010). One of the major strengths of the protocol used in the Spatial Temporal Environment and Activity Monitoring (STEAM) project conducted by researchers in the Human Environment Analysis Laboratory (HEAL) in the Department of Geography at Western University is that involvement of children as researchers' provides opportunities to build relationships with the university researchers and engages participants to be a part of the research process. This supports the practice of research with children, not on children.

The STEAM project and this thesis was informed by a social-ecological model of health, which theorizes the relationships between multiple levels of factors effecting a given outcome to better understand health-related behaviours. These levels include intrapersonal (i.e. gender and age), interpersonal (e.g. household factors and peer relationships), environmental (e.g. natural and built environments), and policy (e.g. governmental or school board policies) (Cerin et al., 2017; Sallis et al., 2006; Sallis, Owen, & Fisher, 2008; Sallis & Glanz, 2006). Most experts agree that targeted interventions are necessary for specific subpopulations within the socio-ecological model. This model recognizes that the interactive characteristics of individuals with their environments underlie health outcomes that can help to shape and guide public health policy and practice. Additionally, from a top-down approach, the socio-ecological model recognizes individuals as embedded within a larger social system and recognizes each level-specific influence on health outcomes (Golden & Earp, 2012). To ensure a proper and successful intervention, each level must be assessed individually, but also understood as part of an interconnected interaction. Therefore, the notion that the implementation of urban interventions within rural communities, is impractical.

To better understand the current state of children's health, there must be a better understanding of the multiple levels of influence but also that these levels are interactive and reinforcing. Stokols (1992, 1996) and Sallis et al. (2008) recommend a multi-level focus to understand health outcomes and argue that the various levels are interactive as

well as have a cumulative effect on health. To assume that interventions need to be individually focused, neglects the environment underpinnings (Stokols, 1996). Notably, the environment to which we live in is multilayered, since the schools we attend and our defined neighbourhoods are rooted in larger social and economic structures, and that the geographic context (i.e. where you live and spend time) may influence each individual's health differently (Golden & Earp, 2012; Stokols, 1996). Previous studies of the physical environment and health are commonly grounded in an abstract view focused on the individual connected to the neighbourhood without any time-use information available. The integration of novel time-space studies using a socio-ecological framework can account for the dynamic interaction and feedback of multiple levels of influence (Chaix, 2018). As with any multifaceted problem, research should aim to provide interventions that are feasible and obtainable. Each level of the socio-ecological model is more than just a setting for intervention, but an opportunity to explore the needs of unique populations and recommend specific multi-level community-based changes (Golden & Earp, 2012). The socio-ecological model can help frame sustainable health improvements and is most effective when all levels are targeted simultaneously.

The relationship children have with the physical environment and its resulting impact on their health, development, and overall well-being is well conceptualized using the socio-ecological model of health. The socio-ecological model allows for the diverse and complex relationships between children and their environmental interactions to be better understood. This thesis focuses on two tiers of ecological model of health: intrapersonal and the environment (see Figure 1.2).

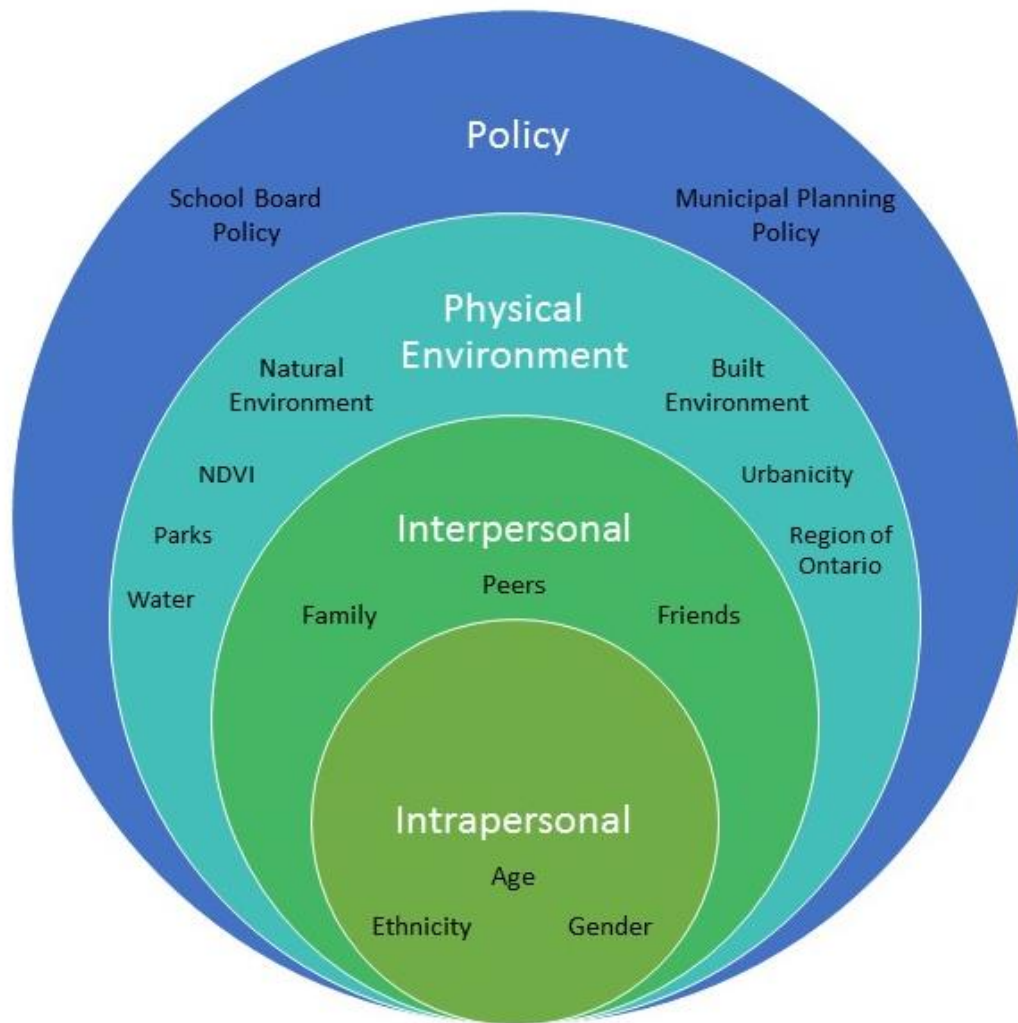


Figure 1.2 The Socio-ecological Model related to this thesis

Each individual's accessibility, exposure, and engagement to the physical environment can potentially be incorrectly related to complex health outcomes if improperly defined. In part, these methodologies to conceptualize the physical environment are all due to the various levels within the socio-ecological model including policy, environment, and intrapersonal level variables.

1.4 The Spatial Temporal Environment and Activity Monitoring Project

This thesis uses data drawn from the Spatial Temporal Environment and Activity Monitoring (STEAM) project, a multi-year study conducted across Ontario, Canada that has examined the effects of the environment on health-related behaviours on children aged 8 to 14 years (theheal.ca/projects/spatial-temporal-environment-and-activity-monitoring/).

The objective of the STEAM project was to assess how the physical environment, both natural and built, impacts health behaviours among elementary-school children. It focused on mapping all the environmental features that are believed to be barriers or enablers to a healthy lifestyle for children. Explicit details and the protocol of the STEAM Project can be found in Chapter 3: Methodology.

The STEAM project spanned multiple years with three phases involving over 1,000 children from across Ontario. A number of graduate theses within the HEAL have been submitted for degree requirements utilizing various combinations of the data collected from the various phases of this project. Each thesis answers questions about children's health-related behaviours or outcomes, including diet (Rangel, 2013), sleep (McIntosh, 2014), active transportation (Hill, 2012, Fitzpatrick, 2013; Richard, 2014; Rivet, 2016; Wilson, 2018), neighbourhood mobility and activities (Loebach, 2013), physical activity (Richard, 2014; Mitchell, 2016; Taylor, 2018), and mental health (Tillmann, 2018). This thesis is meant to compliment other studies completed within the HEAL, but makes unique methodological and empirical contributions to our understanding of children's interactions with their physical environments, particularly in the context of rural Northwestern Ontario.

Hill (2012) utilized data from the first phase of STEAM (2010-2011) to examine the influence of parent's and children's perceptions of their built and social environments on children's use of active transportation between home and school. In 2013, Fitzpatrick conducted a case study focused on how perception and use of school neighbourhoods varies according to the built environment. Similarly, to both Hill and Fitzpatrick, Wilson

(2018) incorporated STEAM survey data along with survey data from another ongoing project to examine the relationship between parent and child perceptions of the barriers and enablers of the built and social environment on active travel (2010-2016). Each of these theses have furthered our understanding of the influence of children's perceptions about their environment and the impacts on active travel. Multiple studies have utilized objective measures to analyze activity monitoring through the use of GPS tracking (to identify locations where children went) and/or accelerometry (to measure physical activity) in order to gain further insight on children's behaviours. Loebach (2013) examined children's environmental perceptions, activities, and mobility within their neighbourhoods using mixed methods, including child-led tours, focus groups, qualitative GIS, and GPS-tracking. Rangel (2013) characterized children's food environments by comparing different methods, including network and Euclidean buffers. McIntosh (2014) examined the relationship between children's sleep duration and greenspace. Within ArcGIS, neighbourhood-level greenspace and GPS-tracking was used to identify the amount of time spent exposed to greenspace while controlling for the home neighbourhood built environment. Richard (2014) used GPS tracking to identify children's routes to school (i.e., their commute), accelerometry to measure physical activity, and ArcGIS to characterize the home built environment to investigate how the commute to school impacts children's physical activity and bodyweight status. Mitchell (2016) examined how the built environment influences children's physical activity. Lastly, in a novel application of GIS, Rivet (2016) used a tessellated hexagonal grid across the STEAM study area to extract built environment measures to examine environmental determinants of active travel from both parent and children perceptions. Most recently, Tillmann (2018) combined quantitative and qualitative methods to investigate the relationship between children and nature by examining their health-related quality of life (HRQOL) in relation to accessibility to natural environments around home; and through focus groups which sought to understand how children define and experience nature as well as perceive its health benefits.

As a whole, each of these theses has built an extensive knowledge base to allow for this thesis to implement an advanced methodology to examine the accessibility, exposure and engagement of the physical environment to children living in a rural community. This

thesis uses a unique combination of survey data, GPS-tracking, and various methodologies in ArcGIS to characterize children's physical environments.

1.5 Thesis Format

The format of this thesis is presented in monograph style. Each of the following thesis chapters will proceed as described below.

Chapter 2 reviews existing literature on three themes: (1) the physical environment and children's health; (2) gaps in the research between urban and rural environments; and (3) delves into the problem of the inconsistent methods and conceptual models used to study the physical environment. This scoping review aims to identify the gaps in literature, with a specific focus on methodologies, to justify the need for the research presented in this thesis.

Chapter 3 provides an overview of the methodology of the STEAM study, including the protocol used for data collection and the data processing involved in this thesis. The definitions of the three methods to delineate children's environment will be described in greater detail. Lastly, the data analysis used to examine the statistical significance of the methodologies to conceptualize a child's interaction with the physical environment are presented.

Chapter 4 presents descriptive statistics of the study sample and the results of the statistical analysis comparing how different conceptualizations (i.e., accessibility, exposure, and engagement) impact the delineation of children's environments in terms of geometric properties and their characterization in terms of land uses and greenness. This chapter will meet the two key objectives of the study by (1) examining the different approaches to conceptualizing and delineating children's interactions with their physical environments and the effect on the quantitative characterizations of built and natural features within their environments; and (2) to determine the built and natural characteristics of the environments that girls and boys in rural Northwestern Ontario directly engage with on weekdays and weekends.

Chapter 5 concludes this thesis by presenting the key findings and the methodological contributions while connecting the findings to relevant literature, and discussing potential policy implications, research limitations, and opportunities for future research.

Chapter 2

2 Literature Review

This chapter provides an overview of the peer-reviewed academic literature relating to children's relationship with the physical environment, with an emphasis on the methods used to conceptualize and delineate the physical environment. This chapter builds on the foundation laid in the introduction and highlights the importance of this thesis. Section 2.1 will briefly describe the relationship between children's health and their physical environment. Section 2.2 and 2.3 presents the previous literature focused on understanding and conceptualizing the physical environment. Section 2.4 identifies the gaps in research between urban and rural environments, and Section 2.5 delves into the problem of the inconsistent methods and conceptual models which have been used to study the physical environment. Finally, Section 2.6 concludes with a discussion highlighting how this thesis aims to fill the gaps outlined in the literature and support future research.

2.1 Children's Health and the Environment

Within the fields of geography, planning, and public health, there is a long history of research focusing on the relationship between the physical environment and the overall well-being of children (Booth, Pinkston, Carlos Poston, & Poston, 2005; Ding et al., 2011a; Handy et al., 2002; Sallis & Glanz, 2006; Sallis et al., 2008). More recently, research focusing on children's health and the physical environment has grown to include contributions from various disciplines, including epidemiology and urban planning (Chaix et al., 2016; Chaix, 2018; Hand et al., 2018; Holliday, Howard, Emch, Rodríguez, & Evenson, 2017; Jia, Cheng, Xue, & Wang, 2017; Matisziw et al., 2016; Mitchell et al., 2016; Zhao et al., 2018). Exemplary studies have explored the physical environment in relation to several child health outcomes, such as levels of physical activity (Almanza et al., 2011; Colley et al., 2017; Coombes, Van Sluijs, & Jones, 2013; Krenn et al., 2011), obesity (Booth et al., 2005; P. James et al., 2016) and mental health (Tillmann, Tobin, et al., 2018; Triguero-Mas et al., 2015). Research findings indicate that health-related behaviours and outcomes can be influenced by one's "spatial context" or activity spaces

geographic location(s), which in turn influences how one interacts with certain health-damaging or health-promoting features of their surrounding physical environment (including the natural environment and built environment). Incorporation of the spatial context of the physical environment as an important component in these studies. It has resulted in the increased recognition that daily routines and the experiences of children in their everyday environments play an important role in their health and well-being.

There has recently been a surge in the number of studies using geospatial tools such as Geographic Information Systems (GIS) and Global Positioning Systems (GPS) to objectively measure where children interact and spend time in their neighbourhood spaces (Hand et al., 2018; Kyttä, Hirvonen, Rudner, Pirjola, & Laatikainen, 2015). Within this literature, spaces that children travel and interact with have been recognized to influence their developmental years (Christian et al., 2015). These developmental years are the period of time in a child's life where there is potentially more independence, awareness of their environment, and the generation of cognitive maps occurs (Golledge & Stimson, 1997; Herman, Blomquist, & Klein, 1987; Loebach & Gilliland, 2013). Within this developmental stage, children have varying degrees of set limitations and restrictions on their independent exploration of their surrounding physical environment, which can influence the extent of a child's cognitive map (Hand et al., 2018; Kyttä, 2004; Shaw et al., 2015). Often, parents set limits on their child's movements and the distance they may travel from home within their neighbourhood (Jones, Coombes, Griffin, & Mf Van Sluijs, 2009; Malone, 2007; Stewart et al., 2015). However, we know that the freedom and opportunity to explore the physical environment can have lasting health and developmental benefits for a child, fostering traits like independence, individuality and competence (Loebach & Gilliland, 2016; Shaw et al., 2015). A child's independent mobility and the associated experiences with the physical environment are important components of their developmental and physical health (Malone, 2007). Therefore, more restrictions on neighbourhood mobility limits the opportunities for a child to experience and benefit from the potential health benefits of accessing spaces outside the home. Research therefore needs to continue to explore how the physical environment and specific spaces that children spend their time can influence their overall health and development.

2.2 Understanding the Physical Environment

This section is focused on how literature has studied, defined and conceptualized the physical environment within the field of health geography. The body of research exploring the link between the physical environment and its potential influence on an individual's health has continued to grow in recent years, investigating outcomes such as a child's physical, social, and mental health (Ding et al., 2011a; Sallis & Glanz, 2006; Sandercock, Angus, & Barton, 2010). (Cleland et al., 2008; Gordon-Larsen et al., 2006; Sandercock et al., 2010; Wheeler, Cooper, Page, & Jago, 2010). Defining and conceptualizing the physical environment is complex due to the vast scale of the various natural, built, and social components within it (Booth et al., 2005; Handy et al., 2002). This scale is often operationalized based on a specific research question, which can define and contextualize the areal unit of the physical environment using different methods and may influence analytical results (Zhao et al., 2018). The components that make up the natural environment include vegetation, water bodies, climate, and topography (e.g., the shape and features of the Earth's surface). The built environment is defined by human-made structures and systems, including land use designations, buildings and transportation, and communications infrastructure (Handy et al., 2002). The social environment encompasses the complex relationships of humans, including labour markets, wealth, government, religious institutions and practices, the arts, and the historical and power relations embedded over time (National Institutes of Health, 2001). Many studies have defined physical environment variables subjectively, for example, through reports of child-or-parent perceptions (Lin & Moudon, 2010) or questionnaires (Tucker et al., 2009); meanwhile, geographers often apply objective measures that are operationalized using GIS, such as land use classification (Larsen, Gilliland, & Hess, 2012; Kerr, Duncan, & Schipperjin, 2011) or normalized difference vegetation index (Almanza et al., 2011; Groenewegen, van den Berg, de Vries, & Verheij, 2006). Neither subjective or objective measures have been proven to be more valid than the other, but when combined can provide valuable insights into the relationship between the physical environment and children's health (Lin & Moudon, 2010).

2.3 Contextualizing the Neighbourhood Environments

To understand the relationship with children's health, the physical environment is often contextualized within a specific areal unit, defined as a neighbourhood (Mitchell et al., 2016; Timperio, Crawford, Ball, & Salmon, 2017; Yin et al., 2013). It is important to consider the practical issues associated with defining a relevant neighbourhood, such as the scale and geographic context that can influence the degree to which a hypothesized effect is assumed significant. In her influential study on neighbourhood and area level effects on health, Diez Roux (2001) examines some of the issues associated with using local administrative units such as census tracts to define neighbourhood boundaries. This method has been recognized by social geographers and sociologists with the understanding that each neighbourhood has structural or natural conditions shaping individual lives and opportunities; however, administrative boundaries such as census tracts, dissemination areas, or postal zones can be somewhat arbitrary or imperfect representations of the areal extent of what one perceives to be their neighbourhood (Diez Roux, 2001; Vallée, Le Roux, Chaix, Kestens, & Chauvin, 2015). In urban areas in Canada, the smallest administrative areal units (e.g., postal code zones, dissemination areas, and census tracts) are used frequently in geographical research and can be used effectively to display spatial differences across neighbourhoods. However, defining neighbourhoods exclusively by local administrative units confines human interactions to pre-defined 'containers'. These containers omit potential health-promoting or health-damaging features beyond these arbitrarily defined zones and therefore misrepresents actual exposures and ignores individual agency (Bell et al., 2014; Chaix, Mé Line, et al., 2013; Ding, Sallis, Kerr, Lee, & Rosenberg, 2011b; Hasanzadeh et al., 2017).

The definition of an individual's neighbourhood becomes increasingly difficult when studied in rural and remote areas. Rural areas are often characterized and defined at these crude geographic scales (e.g. postal code, dissemination area) which are inaccurate representations of a neighbourhood (Hart, Larson, & Lishner, 2005; Sadler, Gilliland, & Arku, 2011; Shearer et al., 2012). Additionally, defining a rural child's neighbourhood based on large administrative units and/or distribution of built elements overlooks the fact that much of these vast areas are not equally permeable by children due to sheer distance

and lack of appropriate public transportation networks, or coverage in dense vegetation or private agricultural land (Malone, 2007; Shaw et al., 2015). Therefore, in rural areas because administrative units are typically vast and do not necessarily accurately represent areas that are accessible to the entire population within them, they should not be used in contextualizing a neighbourhood space (Sadler et al., 2011). Overall, incorrectly defining the neighbourhood space in which a child lives can impact or alter the amount and variation of physical environment variables present. The demographics of a neighbourhood can vary greatly across a small distance, therefore in a crudely defined rural area, research has the potential to misrepresent or misclassify the relationship between the physical environment and health outcomes (R. J. Jackson, 2003; Probst et al., 2018). This issue of misclassification serves as a potential barrier to the successful targeting and implementation of public policy and programs focused on improving rural children's overall health (Sadler et al., 2011).

Another approach to defining children's environments is called the "buffer approach". This method uses an "ego-centric buffer" around the home location (and sometimes school/work location) to define one's neighbourhood. With this approach, there are three key issues to consider: 1) how to locate home or school (i.e., more precise location using GPS or street address, or a proxy for home address such as a postal code centroid); 2) which buffer type to use (i.e., circular buffers of a pre-defined Euclidean distance from the home point location, or network buffers as delineated by distance calculated along a road or circulation network); and 3) which buffer size (e.g., 500m, 800m, 1000m, 1600m) is appropriate given the phenomena of interest (e.g., walking to school). Of the various existing definitions of using a "buffer approach", the most frequently utilized has been the application of interval based circular or road network-based buffers (Leslie, Sugiyama, Ierodionou, & Kremer, 2010; Triguero-Mas et al., 2015; Villanueva et al., 2012). Studies utilizing the various types of buffers to define individual neighbourhoods, typically are generated with a postal code to assume each individual's generalized home location as the centre point with varying circular distances from around that point (Loebach & Gilliland, 2016; Schönfelder & Axhausen, 2003). This method has associated limitations including the crude definition of an area. Because of the limitations of circular buffers, a road network buffer has been implemented to define areas within

which an individual can walk as a base for measuring the physical environment (Oliver, Schuurman, & Hall, 2007). Methodologically, the set buffer distance is commonly defined by the walkability threshold from a home location, such as 400m (Jago, Baranowski, Zakeri, & Harris, 2005), 500m (Kytä, Broberg, Haybatollahi, & Schmidt-Thomé, 2016; Markevych et al., 2017) to as large as ~8km (Gordon-Larsen et al., 2006). Similar to using local administrative units, defining an individual's interaction with the physical environment with pre-defined buffers around the home makes assumptions about an individual's neighbourhood to be operationalized as circular or network-based. More specifically for children, this can imprecisely assume their range of interactions, therefore, incorrectly defining the true area and the physical environment within (Perchoux et al., 2016). Therefore, the physical environment that an individual is truly exposed to may vary considerably depending on how the neighbourhood is defined, particularly with these inaccurate methods involving buffers (Villanueva et al., 2012).

2.3.1 Methods for Identifying Children's Activity Spaces

An activity space describes how an individuals' routine mobility interacts with their environment (Sherman, Spencer, Preisser, Gesler, & Arcury, 2005). Activity spaces are defined by Gesler and Albert (2000) as "the local areas within which people move or travel in the course of their daily activities (p. 200)". As such, activity spaces can extend well beyond the commonly defined neighbourhood scale to capture a complete daily routine of interactions with the physical environment. Other terms such as, 'action space', 'home range', 'activity range', 'territorial range' and 'daily contact space' have been used interchangeably with activity space in the small literature base examining activity spaces (Dijst, 1999; Herman et al., 1987; Karsten, 2005; Spilsbury, 2005). Although limited research focuses on activity spaces, children's mobility in the physical environment is not a new subject, as Hillman and colleagues first reported findings as early as 1990 (Hillman, Adams, & Whitelegg, 1990). Hillman and colleagues (1990) discussed trends of children's decreasing independent mobility within their environments as a result of modern society, urban design and what is now known as the "bubble-wrapped childhood" (Malone, 2007). Hillman's research was among the first to present the changes in how children interact with the physical environment and the relationship with children's

health. Despite this early work, there is still limited agreement on how to define children's daily spatial activities and interactions with environmental correlates associated with the physical environment (Dijst, 1999; Sherman et al., 2005; Spilsbury, 2005). Therefore, previous research has conceptualized activity spaces with both quantitative and qualitative methods.

Quantitative methods often focus on studying the physical environment and its characteristics with the use of technologies including GPS and GIS (Ding et al., 2011a). Qualitative methods such as open response surveys and focus groups are frequently used to examine children's activity spaces and environmental characteristics of children's neighbourhoods (Loebach & Gilliland, 2010). Recent advances in qualitative GIS have allowed for an integration of qualitative data, such as focus groups, photographs, drawings, and audio recorded "walk-about" to be incorporated and analyzed within GIS (Mennis, Mason, & Cao, 2013). Qualitative studies can provide useful insight into how children perceive, navigate, and use different built, natural and social environments in their everyday lives (Loebach & Gilliland, 2013; Wilson, Coen, et al., 2018). These types of qualitative data can add accuracy in our ability to understand how individuals interact with, are influenced by, and have emotional attachments to, their physical environment. But limitations still exist despite these advances in data application as there are few examples of how this potentially subjective data may be effectively studied and analyzed (Mennis et al., 2013). Often qualitative data is subject to recall bias of the participants, and the contextual variability across participants can limit the generalizability of findings (Loebach & Gilliland, 2016). For example, two studies found that using direct methods of observation, including the use of objective tools such as GPS monitoring, provides a more accurate spatial representation of children's activity spaces when compared to both participant and parent self-report estimations (Burdette, Whitaker, & Daniels, 2004; Elgethun, Yost, Fitzpatrick, Nyerges, & Fenske, 2007). Similarly, two well-cited reviews of literature examining the influence of the physical environment on health purposely exclude qualitative studies because of the lack of consistent themes, as well as the difficulty in comparing the qualitative results from one study against another (Davison & Lawson, 2006; Ding et al., 2011a). Further strengthening of these qualitative methods of

data capture, visualization, interpretation, and integration with quantitative activity space methods has the potential to enrich our future understanding of health-place associations.

Modern advances in quantitative methods such as GPS & GIS technology has allowed for improved accuracy in the spatial delineations of children's activity spaces and more rigorous analyses of the spatial patterns of their movements and activities (Chaix et al., 2016). These modern methodologies have allowed for a quantitative approach to overcome many of the limitations of using either local administrative boundaries or the "buffer approach". This method in environmental exposure studies defines the neighbourhood as individual-based activity spaces. Activity spaces are a promising methodology to assess real-life environmental exposures and a more precise representation of daily routines because GPS data delivers an improved accuracy of an individual's location over time (Loebach & Gilliland, 2016; Sadler & Gilliland, 2015; Veitch, Salmon, Ball, Crawford, & Timperio, 2013; Villanueva et al., 2012). Using GPS data helps to overcome the main concerns stated in a review by Leal and Chaix (2011) and a study by Inagami et al (2007), that the use of administrative boundaries do not truly represent the physical environment in which an individual enters, moves through, and interacts with. Through this method the neighbourhood can be correctly represented by an activity space which will not overestimate or underestimate the interaction an individual has with the physical environment (Inagami, Cohen, & Finch, 2007; Leal & Chaix, 2011). This method provides a more accurate delineation of one's neighbourhood, as well as a proper representation of the real-time interaction in the physical environment.

2.3.2 Understanding Interactions with the Physical Environment

These quantitative and qualitative methodological advances continue to deepen our understanding of the relationship between the physical environment and health. However, to allow for cross-comparison amongst researchers, common definitions, tools, and measures to assess the physical environment are necessary. A review on children's health and the natural environment states that there is still considerable heterogeneity among methodologies (Tillmann, Tobin, et al., 2018). Based on this review by Tillmann and colleagues (2018), studies were grouped into three categories according to the type of interaction between the individual and their environment: 'accessibility', 'exposure', or

‘engagement’. Accessibility refers to a child’s potential to encounter or interact with a particular element or space in the environment. This term typically contextualizes a child’s neighbourhood within the physical environment at the level of administrative units such as census tracts (Diez Roux, 2001), or by using variously sized ring or network buffers (Gordon-Larsen et al., 2006; Timperio et al., 2017; Villanueva et al., 2012). Many studies have focused on the study of the physical environment through accessibility, which can often disregard the need for individual agency to define and understand the true interaction with the physical environment.

On the other hand, ‘exposure’ implies having contact with or being directly subjected to some effect or influence of the physical environment. This measure, therefore, goes beyond having the potential or opportunity to access an environment. Studies have typically measured exposure using individual-based activity spaces. Some previous studies have used qualitative research, such as map-based focus groups and interviews to identify activity spaces (Wilson, 2018); however, GPS tracking methods are also becoming more popular in studies of activity spaces (Sadler & Gilliland, 2015). Additionally, a few studies have combined GPS tracking methods with map-based focus groups to elicit further understanding of the activity spaces identified through GPS tracking (Loebach and Gilliland, 2016).

Engagement implies direct, intentional and sustained interaction with the physical environment and therefore has a temporal component, in addition to the spatial measurement. As with the measurement of exposure, objective measures of ‘engagement’ with different environments typically involve using individual GPS tracking data to determine environments visited, but also the time spent in different environments (Sadler et al., 2016). Nevertheless, engagement can also be measured more subjectively, such as self-reported time spent in a garden, park, or recreation centre. For example, a study by Harper and colleagues in 2007 reported that children aged 13-18 years who participated in a 21-day wilderness therapy program experienced a significant improvement on suicidal thoughts/ideation. In this example, the measurement of time spent in an environment involved direct observation but was more subjective and less spatially precise than if GPS tracking was included.

Each category of interactions with the physical environment provides useful insight into exploring impacts on children's health. Each of these levels of interaction will be further explored throughout this thesis to help understand how children interact with their physical environments.

2.4 Rural Versus Urban Environments

In previous literature, many studies concentrate on children in urban and suburban settings, with very little research exploring the physical environment's relationship with children's health in rural settings (Ergler, Kearns, & Witten, 2017). (Gordon-Larsen et al., 2006; Gruebner et al., 2017; Lopez & Hynes, 2006; Statistics Canada, 2017). Many of the studies focusing on urban/suburban populations have found that accessibility to public parks and recreation facilities, density of sidewalks, greater mix of land uses, exposure to greenspace, accessibility to fast food restaurants, and connectivity of the neighbourhood street network are all significantly correlated with dimensions of improved physical and mental health (Christian et al., 2015; Humpel, Owen, & Leslie, 2002; McCormack & Shiell, 2011; Mitchell et al., 2016). However, the environmental characteristics that have proven to have a positive impact on the health of urban dwellers cannot be assumed to even be present or applicable in rural neighbourhoods (e.g., sidewalks, mixed land uses, recreation facilities). Therefore, researchers must give consideration to how many of these natural and built environment variables can be similarly constructed and measured in a way that works for rural environments. As such, there are gaps in understanding whether environmental variables, present or not, possess the ability to influence various health outcomes of rural children (Christian et al., 2015; Jackson, Tester, & Henderson, 2008).

Children's perceptions of the barriers and enablers to health-promoting and health-damaging features of their local environments can vary between urban and rural areas (Joens-Matre et al., 2008; Taylor, 2018). The largest challenges within rural regions are often caused by low population densities and geographical isolation (Joens-Matre et al., 2008; Probst et al., 2018; Shearer et al., 2012). These limited opportunities to access recreation and healthcare services, reduced healthy food options, expensive grocers, inadequate public transportation, and extreme travel distances are often common barriers

to supporting a healthy lifestyle when living in a rural community (Arcury et al., 2005; Joens-Matre et al., 2008; Probst et al., 2018). Additionally, children are often not in control of lifestyle choices and are at a greater disadvantage as a result of their reliance on an adult for transportation (Kyttä, 2004; Kyttä et al., 2015; Shaw et al., 2015). Within Canada, many rural regions have a lower average household income compared to urban regions (Beckstead, Brown, Guo, & Newbold, 2010) This translates to devoting the majority of the household income to necessities such as shelter, food, and clothing (Statistics Canada, 2018). Families that are considered low income often have less disposable income to allocate to funding their child's extra-curricular activities and programs which have been proven to contribute to improved physical and mental wellbeing, as well as instilling lifelong healthy habits and improved academic outcomes (Eccles, Barber, Stone, & Hunt, 2003; Feldman & Matjasko, 2005).

Although focused on adults, a review by Frost and colleagues (2010) is insightful for understanding environmental influences on physical activity in rural settings. The findings revealed that positive associations were found among pleasant aesthetics, trails, safety/crime, parks and walkable destinations. This differs from the body of research on urban and suburban settings, where safe neighbourhoods, multiple destinations within walking distance, sidewalks, light traffic, and greater accessibility to physical activity resources contribute to increased physical activity engagement of urban adults (Jilcott Pitts et al., 2015; Parks et al., 2003). These differences between rural and urban settings help reiterate the importance of community specific studies to help implement suitable policy and practice (Sallis, Bauman, & Pratt, 1998). Although more rural-urban comparison studies would be useful, they are difficult due to inconsistency in the availability and quality of data sources (Frost et al., 2010; McCrorie, Fenton, & Ellaway, 2014; Thornton, Pearce, & Kavanagh, 2011). Although urban children still face various disadvantages as a result of the physical environment in which they live, there is an understanding that findings from urban studies cannot be hypothesized to be similar in rural areas. This echoes that more specific and refined assessment tools to accurately measure and compare all urbancities is warranted (Frost et al., 2010).

2.5 Gaps in Methodology

It has been established that defining a child's neighbourhood as an activity space based on their individual GPS data allows for a more precise representation of their interactions with the physical environment (Chambers et al., 2017; Kestens et al., 2016; Thierry, Chaix, & Kestens, 2013). For previous studies that have assessed children's environmental interactions in their activity spaces using self-report data, we have to be cautious about conclusions due to potential recall bias and contextual variability across individuals (Loebach & Gilliland, 2016; Mitchell, Clark, & Gilliland, 2016; Sadler & Gilliland, 2015). Nevertheless, subjective measures of data collection can provide useful perspectives on the physical environment that can be coupled with an objective measure to improve the validity (de Vet, de Ridder, & de Wit, 2011). Data collected from GPS coupled with GIS has allowed for an accurate examination of children's interaction with the physical environment (Chaix et al., 2016; Ding et al., 2011a; Rundle et al., 2016). With consideration for these research contributions, limitations in the methodologies still remain present and research must make a conscious effort to mitigate their impacts.

2.5.1 Global Positioning Systems

Many recent health geography studies have emphasized the use of GPS to provide an objective measure of spatial location (Chaix, 2018; Hand et al., 2018; Hasanzadeh et al., 2017; Jia et al., 2017; Li & Kim, 2018). GPS allows for the identification of a precise location on the Earth's surface through the use of satellite-based global navigation systems (Hofmann-Wellenhof, Lichtenegger, & Collins, 2008). GPS has been used to help further the understanding and assessment of the spatial context of health outcomes such as physical activity and junk food purchasing (Krenn et al., 2011; Sadler et al., 2016). Despite the utility of GPS for health research, the tool and related methods have limitations. These include, but are not limited to, ensuring sufficient length of GPS recording and wear-time, the overall quality of the data, the device positional accuracy, and the degree of data post-processing that is undertaken (Chaix et al., 2016; Chaix, Mé Line, et al., 2013; Krenn et al., 2011). Many of these limitations can be overcome through the use of modern technologies and improved study design, including sufficient wear-time (Zenk, Matthews, Kraft, & Jones, 2018), as well as the addition of GIS to

illustrate spatial patterns and depict relationships to better understand the physical environment and a health outcome (Graham, Carlton, Gaede, & Jamison, 2011).

2.5.2 Overcoming Methodological Limitations

A large body of research focuses on defining and understanding neighbourhood environments. However, findings from these studies can face bias if the methodologies chosen by a researcher are unsuitable for the outcomes being assessed (Chaix et al., 2013, 2016; Chambers et al., 2017; Loebach & Gilliland, 2016; Sadler & Gilliland, 2015; Sadler et al., 2011; Thierry et al., 2013; Timperio et al., 2017). To move beyond these methodological limitations of GPS and GIS, the opportunities for error must first be identified then remedied.

When GPS data, or individual point-based data are studied, there is potential for the resulting statistical output to be skewed based on both the shape and scale to which the geographic context is studied, this is referred to as the *modifiable areal unit problem* (MAUP). Openshaw (1983, p. 3) states that “the areal units (zonal objects) used in many geographical studies are arbitrary, modifiable, and subject to the whims and fancies of whoever is doing, or did, the aggregating”. The use of a container metric, or a uniform polygon shape that contains physical environment variables can reduce the effects of the MAUP (Kwan, 2012b). Many research studies implement the use of activity spaces to conceptualize a true geographic context for each individual (Li & Kim, 2018; Loebach & Gilliland, 2016; Villanueva et al., 2012; Zenk et al., 2018; Zhao et al., 2018). Therefore, the use of GPS derived activity spaces may allow for a true causally relevant geographic context of an area-based group to be meaningfully conceptualized or explained. The use of activity spaces acknowledges that contextual influences are experienced differently by each individual and often, individuals are exposed to more than just their home neighbourhood (e.g., postal code, dissemination area) (Kwan, 2012b).

Likewise, Kwan (2012) developed the term, the *uncertain geographic context problem* (UGCoP) to caution health geographers examining neighbourhood effects, due to the spatial uncertainty of the contextual influences under study. Kwan (2012, p. 958) states that the problem “arises because of the spatial uncertainty in the actual areas that exert

contextual influences on the individuals being studied and the temporal uncertainty in the timing and duration in which individuals experienced these contextual influences”.

Addressing UGCoP is more than identifying the best container metric to compare the effects of different zoning, as it necessitates a “true causally relevant” geographic context (Kwan, 2012a, p.959). Often a grid formation, either square or hexagonal, is applied to the study area containing unique physical environment variables in each cell, which helps to avoid a crude definition resulting in an inaccurate and homogenous representation of the physical environment (Chaix et al., 2016). Compared to a square grid, a hexagon grid has a lower perimeter-to-area ratio that helps to reduce sampling bias and is useful if GPS data analysis includes aspects of spatial-temporal movement (Birch, Oom, & Beecham, 2007). Particularly in rural regions, where basic remote sensing methods use a repetitive fashion to classify types of land across large areas, a hexagon grid provides a smaller unit of measure and a more precise land classification (Birch et al., 2007; Government of Canada, 2015). Comparatively, in urban areas the land form is often more visually heterogeneous and remote sensing methods implement a coarser resolution allowing more unique land use classifications to appear. Therefore, the often more homogeneous land types of rural areas (e.g., dense forest, agricultural land) can often be misclassified across a broad area (Birch et al., 2007). Thus, in health geography studies, the limitations of the UGCoP are preventable and can be overcome through the reduction of scale of the measurable container metric to that which the variance of the physical environment is assessed through the use of hexagonal grids (Kwan, 2012b; Openshaw, 1983).

The collection of detailed space-time data through GPS devices to generate activity spaces that allow for neighbourhood effects to be geographically contextualized have proven accurate in capturing people’s daily interactions in various locations (Kwan, 2012a; Zhao et al., 2018). But, this method assumes that space is completely permeable and often ignores temporal patterns. Context-based Crystal-Growth (CCG) Activity Space not only considers the daily space-time patterns based on GPS data but also takes into account the facilitators and barriers of the environmental context of people’s daily activity (Wang, Kwan, & Chai, 2018). The fundamental question in understanding the relationship between individual activity spaces and the contact with their social and physical environment is affected by the UGCoP (Kwan, 2012b; Wang et al., 2018; Zhao

et al., 2018). On the contrary, CCG activity spaces include only the prominent parts of the points since they are more focused on the characteristics of the movement patterns instead of every single GPS point. Particularly for studies that incorporate an environmental context like transportation networks (i.e., highways, public transit, bike paths), that have barriers to movement, the CCG activity space method is particularly useful (Wang et al., 2018). To mitigate temporal uncertainty the CCG activity space method considers the accumulation of time that an individual has spent at a particular location. Therefore, the original definition of exposure to the physical environment can now have the added temporal aspect and can be measured as the level of engagement an individual has in a particular physical environment (Tillmann, Clark, et al., 2018). This new methodological advance can potentially provide future researchers with the ability to mitigate the error associated with both the MAUP and UGCoP.

2.5.3 Correlation Not Causation: Selective Mobility Bias

The growing body of literature focusing on the physical environment and its influence on people's overall health can often overlook the probable result of inferential error. Statistical tests rendering a significant outcome do not allow for researchers to assume causation between the independent and dependent variable. GPS and GIS studies have been criticized due to the relative biases related to selective daily mobility and can potentially disqualify the assessment of physical environment exposure and engagement and the casual effects (Chaix, Mé Line, et al., 2013). To overcome this challenge, it is argued by Chaix and colleagues (2013) that researchers must objectively assess the variables of study and the desired outcome and should exclude the places that are specifically visited to perform activities related to the outcome under study (Chaix, Mé Line, et al., 2013). For example, many studies that explore the relationship between physical activity (PA) and the physical environment, cannot assume that a particular space causes PA but that PA has to occur at a specific space (i.e., greenspace, recreation facility). Similarly to the STEAM protocol, the suggested method to neutralize selective mobility bias is a mixed-methods approach, with the integration of GPS, GIS, accelerometers, questionnaires and daily activity diaries (Loebach & Gilliland, 2016). In

future research, improvements to the measures of interaction to the physical environment by accounting for daily mobility patterns is critical.

2.6 Conclusions and Review of Gaps in Literature

In current literature, the major gap lies in addressing the differences between rural and urban physical environment opportunities (i.e., where children spend their time and how those vary between rural and urban). These physical environment opportunities are associated with different barriers and facilitators between children from either rural or urban settings (Gordon-Larsen et al., 2006; Humpel et al., 2002). Additionally, methodologically there is a lack of agreeance on how to define and describe the physical environment. Consideration for various limitations associated with the use of GPS and GIS is necessary to ensure the most accurate representation of the physical environment.

This thesis research will use different methods to study children's interactions with physical environments in a rural setting to help close some of the gaps identified in this review. It will also recommend improvements to how rural areas are studied to allow for the more effective implementation of policies and programs to improve children's overall health. The physical environment will be spatially contextualized using a multi-tool approach. Specifically, through measurement of a child's physical environment through their accessibility, daily exposures, and engagement with (using GPS monitoring and GIS), the physical environment (using GIS) within a rural area.

Chapter 3

3 Methods

The data used in this thesis is drawn from the larger Spatial Temporal Environment and Activity Monitoring (STEAM) project undertaken by the Human Environments Analysis Laboratory (HEALab). The STEAM project was conducted in Southwestern Ontario between 2010 and 2013, and in Northwestern Ontario in 2016. This thesis is focused on children in Northwestern Ontario and therefore only uses data from the 2016 phase of the STEAM project. Further details of the Southwestern Ontario study can be found elsewhere (steamproject.ca; Mitchell, Clark, & Gilliland, 2016). The remainder of this chapter will include a detailed description of the procedures for data collection (including the study area, recruitment, tools, and data collection process), data processing, and data analysis (including measures and statistics).

3.1 The STEAM Project: A Mixed-Methods Approach to Understand Children's Environments and Health

The STEAM project examines the daily spatial and temporal routines of children aged 9 to 14 years. This age group was chosen as it is considered a critical life stage, where children gain independent mobility and start to develop a sense of their own environment (Kytta, 2004). The STEAM methodology incorporates both quantitative and qualitative methods of data collection in its study design, including passive Global Position System (GPS) tracking, accelerometers, a daily activity diary, parent surveys, youth surveys, and focus groups. This mixed-methods research design, guided by the socio-ecological framework, allows for the observation of how children interact with their physical environment to understand their behaviours and habits. Data was collected for seven days over two different seasons (fall 2016 and winter 2016) to allow comparisons of behaviour across different seasons. The STEAM protocol has been approved by the Non-Medical Research Ethics board of Western University (NM-REB#:108029) and all local school boards (see Appendix A).

3.1.1 Study Area

The third phase of the STEAM Project, referred to as ‘STEAM North’, was conducted between September and December 2016 in rural Northwestern Ontario (Figure 3.1). The area of study is within the catchment of two local school boards (i.e., Superior Greenstone District School Board and Superior North Catholic School Board) and was conducted in four elementary schools that are located at the Southeastern edge of the Thunder Bay Unorganized dissemination area (DA) (population: 146,048) covering an area of approximately 385 km².

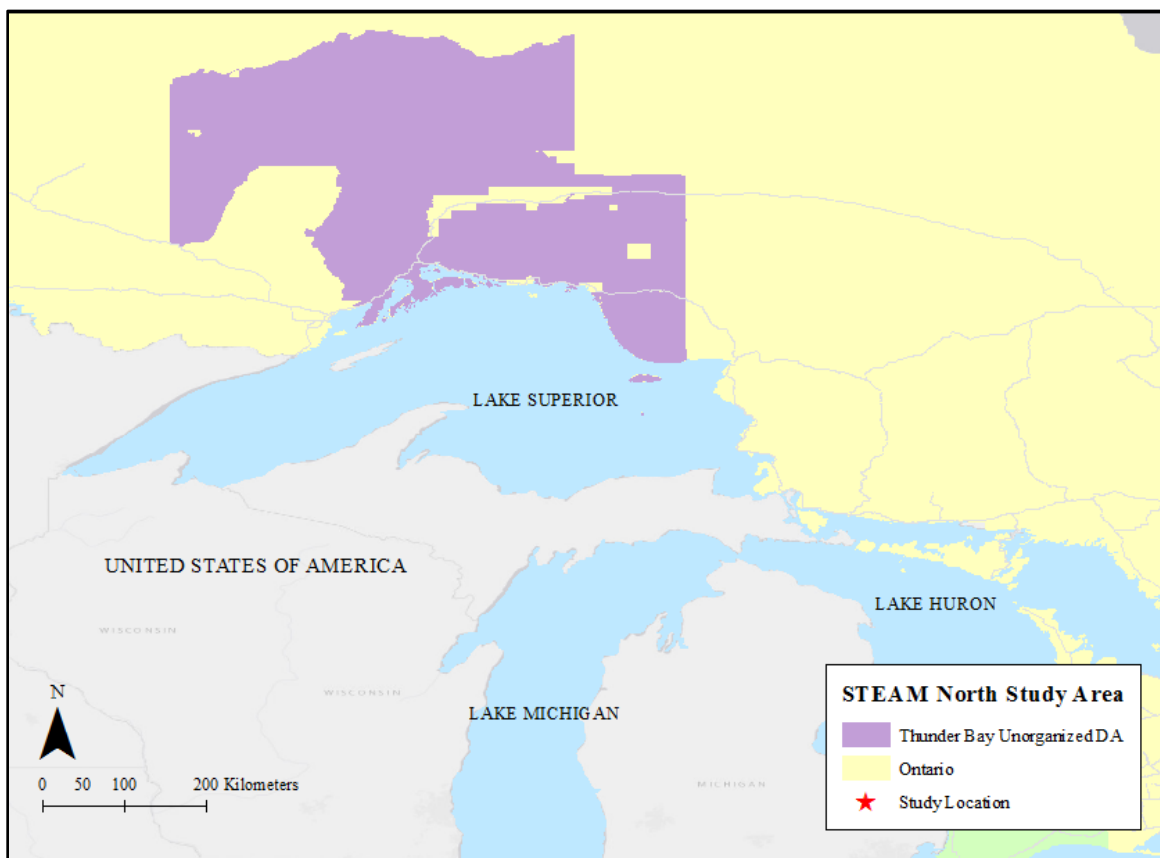


Figure 3.1 STEAM North study area

This study area captures three small rural communities including the Town of Nipigon, and the Townships of Red Rock and Dorion with the rest of the region classified as the Thunder Bay Unorganized DA or part of a First Nations Reserve (Figure 3.2). The average census family size of this study area is 2.7 people, with the majority of residents

living in a single-detached home. The languages spoken at home are predominantly English, followed by French, and Aboriginal/Algonquian languages (Statistics Canada, 2016).

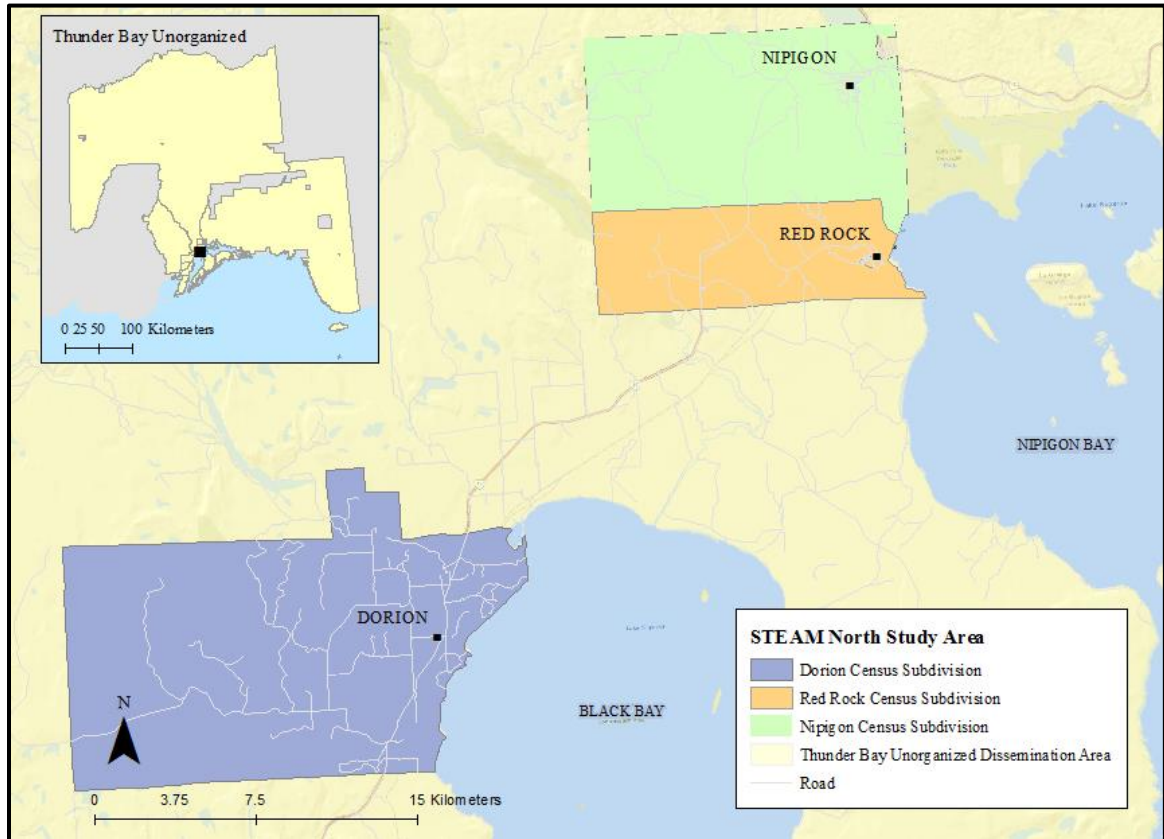


Figure 3.2 STEAM North study area

3.1.1.1 The Built and Natural Environment of the Study Area

The study area is located close to multiple fresh bodies of water including Nipigon Bay and Black Bay that feed into Lake Superior. The region is surrounded by dense boreal forest including species such as black and white spruce, jackpine, cedar, and white birch. Children can easily access a variety of natural environments including rivers, small and large lakes, forests, parks, wilderness, and a variety of terrains and mountains with a maximum elevation of ~ 530 metres. The schoolyards that participants play in, range in size and features. All four schools have playground structures with open grassy areas but some yards back onto forest and cliffs, while others are within the small towns and surrounded by houses. Two schools have a baseball diamond and a few trees scattered in

the yard. The other two have no trees where children play on school property and are simply grass with a small paved area for basketball and other games. Hunting, and to a lesser extent fishing, are very much a part of the local culture, where boys and girls participate regularly on weekends with their families. The town of Nipigon has a community centre in which a public pool, hockey rink, gym facility, two baseball diamonds, and a skate park are situated within. Similarly, the township of Red Rock has a recreation centre containing an arena, gymnasium, bowling alley, and an exercise facility. The largest city centre to the study area is Thunder Bay located ~ 115 km away.

3.1.2 Study Population and Recruitment

Recruitment for this study involved receiving approval from school board research officers, school principals, signed consent from parents, and signed assent from children. Prior to starting this research, we contacted the research officers at the two school boards within our study area to request permission to conduct research in their schools. Once receiving permission from both school boards, permission was requested from each school's principal to work with grades 4 to 8 students at their school. Once consent was received from the principals at all four schools, information about the project was posted on each school website and/or Facebook page to alert parents that the research team would be coming to the school to make a presentation to students. This gave parents the opportunity to learn about the project before their children. With permissions in place, the research team made presentations to all grade 4 to 8 classes to explain the STEAM project. A letter of information about the STEAM project and parental consent forms were sent home to the parents/guardians of all children (see Appendix B and C). The letters of information contained a parental/guardian survey asking parents to provide information about their household demographics and socio-economic status, as well as the child's neighbourhood activities, behaviours and perceptions. Children with signed parental consent were then fully informed about the project and asked to provide their own assent if they wished to participate (see Appendix D).

3.1.3 Data Collection

There were two seven-day data collection periods in this study, from September to October 2016 and November to December 2016, to allow for a seasonal comparison (i.e., fall versus winter) in behaviours. This thesis only uses the data collected during the first period (i.e., fall), because of the higher participant rate and higher quality of data. The full data collection process is illustrated in Figure 3.3. Each participant who received parental consent and provided their own assent were asked to (1) complete a youth survey. Then, for seven days, participants were asked to (2) carry a portable, passive-GPS tracker on a breakaway lanyard around their neck, (3) wear a tiny accelerometer attached to a waistband on their hip, and (4) fill out a paper copy of a daily activity diary. Additionally, some students volunteered to (5) participate in focus groups after completing the week-long protocol (1-4). To maximize data quality, our team visited each school every day during the data collection to ensure accelerometers and GPS-trackers were being worn properly, to download the GPS data from their tracker, and verify the activity diaries were fully completed.



Figure 3.3 STEAM full data collection process

Note: Only data from 1 & 2 used for this thesis

This thesis will only use data from (1) the child survey and (2) passive-GPS tracking. The passive-GPS tracking was conducted with all eligible participants during both the fall and winter collection periods. Each participant was assigned a passive-GPS tracking device (i.e., Columbus V-990 GPS Data Logger) attached to a breakaway lanyard that collected daily locational data measured at 60-second epochs. ‘Passive’ tracking means there is no ability to observe locations in ‘real time’ (i.e., as the event is actually taking place). Passive-GPS trackers store all information within the devices internal memory and require the research team to remove and store the data on an external drive daily, for processing, viewing, and analysis at a later date. Of the 136 participants from the fall 2016 collection period, 128 participants had valid GPS data to be used for the environmental analysis in this thesis (Mavoa, Lamb, O’Sullivan, Witten, & Smith, 2018). The spatial and temporal components of the GPS data provide the necessary information needed for further data analysis on day type (i.e., weekday or weekend). The child survey provided participant gender, as self-identified by the child, with all of our participants self-identifying in the binary categorization of girl or boy.

3.2 GPS Data Processing

Often when analyzing the contextual location and various interactions in environmental health studies, the exploration of space-time segments are overlooked (Chaix et al., 2016). The continuous monitoring of participants with passive-GPS tracking allows for the collection of individuals’ space-time segments rather than assessing individual non-continuous location data. The processing of a participant’s GPS data is essential to improving the validity of the locational dataset and to allow for meaningful statistical analysis. This section will review the process of generating the final data set to be used for answering the two primary research questions and objectives outlined in Chapter 1.

3.2.1 Preprocessing

The primary purpose of the GPS data is to identify where children are spatially located at any given time during the study period (i.e., ‘across space and time’), but raw GPS data requires a considerable amount of processing to be useful for analysis. Each individual’s GPS data was given a six-digit code, known as a student identification number (SID)

generated based on a two-digit school identification code (ZZ_ _ _ _), two-digit grade code (_ _04_ _) and number of students participating per grade (_ _ _ _ 25). This anonymizes the participants while still allowing the GPS data to be linked to other relevant sources of data (i.e., youth survey, parent survey, and accelerometer). GPS data was entered into one file geodatabase and set to the proper projection and coordinate system for the study area (North American Datum 1983, UTM Zone: 16 North). In addition to spatial location, the GPS tracker collects horizontal dilution of precision (HDOP), vertical dilution of precision (VDOP) based on the signal strength and assumed precision and accuracy of each point. Low HDOP and VDOP values represent better positional precision due to the wider angular separation between the satellites used to calculate the GPS device's position on earth (Langley, 1999). The HDOP and VDOP values were then combined to assign a level of confidence for each GPS point to allow inaccurate GPS data to be filtered out during processing. Other variables are attached to the GPS data to allow for us to combine them with the rest of our dataset, including day type and season.

3.2.2 Stops and Routes

Each participant's GPS data is classified as either a place visited or movement route, allowing for a stronger investigation of real-time associations rather than lumping and analyzing all points together (Chaix et al., 2013; Kestens et al., 2012). A methodology by Kestens and colleagues (2013), was used to transform the GPS data into meaningful space time segments, referred to as 'stops' and 'routes'. This methodology uses an algorithm to calculate a kernel density surface which takes all of the GPS points and generates peaks known as stops, or route segments (Thierry et al., 2013). This novel kernel-based algorithm allows for the exploration of the relationship between a child's daily mobility and the various interactions (including exposures and engagements) with the physical environment. This algorithm allows for the mass amounts of data collected from GPS trackers to be transformed into something more comprehensible, and therefore a meaningful, data set.

All processing was completed within ArcGIS 10.5 and guided by the methodology by Kestens and colleagues (2013) which was modified by our team to be run with the newest

Arc software. The kernel size used for this GPS data set was 75m. The kernel is the individual unit within the raster, in which the number of GPS points that fall within are counted to generate the weighted peaks indicating a stop. Multiple kernel sizes were tested and 75m kernel proved to generate the most accurate stop location (note: stop locations could be verified through high resolution satellite imagery and/or activity diaries). When a kernel is improperly sized, the differences between each stop can become unclear resulting in a more homogenous data set. The confidence value generated from VDOP and HDOP is necessary for the generation of these stops. If the confidence value indicates an error greater than four, the GPS points were not used to generate stops or routes.

Routes were created using a similar algorithm by Kestens and colleagues (2013) in ArcMap 10.5, known as the Polynomial Approximation with Exponential Kernel (PAEK). Once the points had generated weighted peaks in the raster surface and were indicated as true stops, the remaining points between each stop are smoothed into a continuous line feature in GIS. Routes are identified by the decreasing weight of each point along the distance of the line between generated stops.

3.2.3 Identify Home Locations

Each child's exact home location was identified from a participant's GPS data. In ArcMap 10.5, using an open source land use data file showing the study area from an aerial view and the participant's stops and routes data allowed for the exact home location to be identified as a unique point. Based on deduction, if the first and last stop locations of a participant's GPS data are the same and correspond to a residential area, then the participant's home location can be assumed. The generation of each participant's exact home location is necessary for further data analysis discussed in Section 3.4. It is important to note here that no maps printed within this thesis (or elsewhere) show the exact home location of any participants; home locations are either clipped from the map extent or spatially anonymized by moving the location.

3.2.4 Time Imputation

GPS trackers can have both hardware and software errors during the data collection periods which cause a loss of data. A tracker may lose signal, have a dead battery, or fail to collect locational information and result in time gaps of missing GPS data. To mitigate this data loss, a Python script (Python 3.7.0) was written and executed by our team based on the methodology from the Personal Activity Location Measurement System (PALMS) study (Jankowska, Schipperijn, & Kerr, 2015). The script identifies any portions of missing GPS data and calculates a centre mean from the first twenty points that occurred prior to the loss and fills the missing time with the mean centre latitude and longitude (Carlson et al., 2015). The results of our data analysis would be negatively impacted if these time gaps were not filled, therefore time imputation allows for the generation of the most complete dataset.

3.2.5 Post Processing

For additional accuracy of a participant's stops and routes data, each set of GPS tracks were manually checked. Using ArcMap 10.5, all points classified with the same unique stop or route were selected and scanned to ensure that the duration of a stop was static or that route movement truly occurred. During this manual check, each true stop was ensured to have the same latitude and longitude value for the duration of the stop. When selecting routes, each point within a unique route was ensured to have a fluctuating latitude and longitude value to account for spatio-temporal movement. Although the accuracy of the algorithm run to identify stops and routes is reliable, the manual check adds additional rigor and accuracy to this study.

3.3 GIS Data Processing

GIS software provides the tools to display, manage, manipulate and analyze the GPS data, allowing us to further understand a child's interaction with the physical environment. Integrating the GPS data with layers of environmental data (i.e. the natural and built environment) in GIS allows us to contextualize and better understand the locations visited and routes taken by children. To allow for further analysis, the development of land use variables, level of greenness and areal units to aggregate data

must be generated. This section will present the processes involved in developing the necessary data of the physical environment to answer the research questions and meet the specific objectives outlined in Chapter 1.

3.3.1 Environmental Data Sources

A combination of open source datasets and local digitized maps were used to identify all land use variables within the study area in accordance with the Ministry of Municipal Affairs Ontario Government standards (Ministry of Municipal Affairs, 2015) using GIS on ArcMap 10.5 (Environmental Systems Research Institute, 2011). Heads-up digitizing was completed based on the land-use maps provided by the local municipalities in the region to allow computation of the physical environment variables. The digitization resulted in the creation of six distinct land use classifications: commercial, industrial, institutional, residential, rural (combination of open and rural land use) and water. The description of each land use variable can be found in Table 3.1.

Table 3.1 Description of the physical environment variables of this study

Physical Environment Variable	Description
Commercial (km ² per unit)	Land used primarily for a full range of business establishments, including shopping facilities, personal and service commercial facilities, offices and mixed land use developments.
Industrial (km ² per unit)	Lands used primarily for manufacturing, assembly, processing, warehousing, or storage, with associated commercial uses.
Institutional (km ² per unit)	Lands used predominantly for the community, educational, health care, governmental or religious purposes.
Residential (km ² per unit)	Land used primarily for housing, with limited allocations for uses that are complementary to or serve basic residential uses. Single detached houses on large lots with a private water supply and private sewage disposal system were also added as residential.
Rural (km ² per unit)	Land set aside for conservation, such as significant wetlands, habitats, woodlands as well as active and passive recreation, farming or woodlot management are included in this category.
Water (km ² per unit)	Lands containing any water bodies.

Note: all land use definitions are in accordance with the Ministry of Municipal Affairs Ontario Government standards (2015)

In addition to classifying the study area by land use, we also classified it by level of greenness, using the Normalized Difference Vegetation Index (NDVI). NDVI is defined as a standardized index allowing the digitization and classification of an image displaying greenness (relative biomass) using satellite imagery (Environmental Systems Research Institute, 2016). For this study, images were extracted according to the September 2016 study time period using Landsat 8 images (United States Geological Survey, 2016). The final NDVI categories are used in this thesis are classified as (1) grass and shrubbery (NDVI values of 0.2-0.6) and (2) dense forest (NDVI values of ≥ 0.6) (United States

Geological Survey, 2016). NDVI variables were calculated from 30m resolution images all extracted during the summer months to maximize greenness in the study area (Tillmann, Clark, et al., 2018).

3.3.2 Hexagon Surface

To overcome some of the problems that arise due to the spatial imprecision inherent in GPS locations and when point data is aggregated to arbitrary and/or irregular areal units (as discussed in Chapter 2), the entire study area was covered with a tessellated hexagonal grid with 20m diameter grid cells (hereafter referred to as a hex grid). This hex grid was used to aggregate or 'bin' our GPS data for analysis (see Figure 3.4). When determining spatial movements and the different environments that a participant interacts with, a hex grid can overcome the ambiguity of a rectangular grid (Birch et al., 2007). The orthogonal nature of the hex grid allows for a better capture of diagonal movement (Birch et al., 2007; Hasanzadeh et al., 2017). Similarly, a hex grid reduces the inferential challenges associated with the Uncertain Geographic Context Problem (UGCoP). The UGCoP is a result of improperly defined geographic units affecting the findings about the effects of area-based attributes (i.e. land use and level of greenness) on individual outcomes (Kwan, 2012b). The 20m diameter of each hex cell/unit allows for a uniform spatial resolution that precisely captures the physical environment without overreaching the actual spatial extent of an interaction. This stable unit of measure allows for patterns to be identified and compared against one another, and therefore avoids the common issue associated with using irregular and variable areal units of measure in GIS analysis.



Figure 3.4 A hexagon grid overlaid on the study area (land use imagery source: ESRI, OpenStreetMap)

3.4 Delineating Children’s Environments

As identified in the Introduction (Chapter 1) and elaborated on in Literature Review (Chapter 2), this thesis compares three common methods found in the literature to delineate a child’s environment: accessibility, exposure, and engagement. Each method characterizes a child’s environment based on different approaches to delineating and quantifying the space. All three methods combine data on individual-level point locations (e.g., home address point, school address point, or GPS tracking points) with environmental data (e.g., on land uses or greenness) within GIS to characterize the (potential) interactions that children (may) have with their physical environment.

3.4.1 Accessibility

Accessibility is defined as the physical environment that a child has the potential to interact with through their daily movements. In this thesis a child's accessibility to their environment is quantified as a ring buffer measured from around the exact home location (Figure 3.5). In ArcMap 10.5, multiple ring buffers at distances of 500m, 800m, 1000m and 1600m were generated starting from each participant's exact home location (as identified using GPS). A spatial join was completed in ArcMap 10.5 between each participant's various ring buffers and the hexagon grid containing all the physical environment variables. To quantify a child's accessibility to components of their physical environment, each of the variables was calculated as a percent of the total areal coverage within each buffer ring.

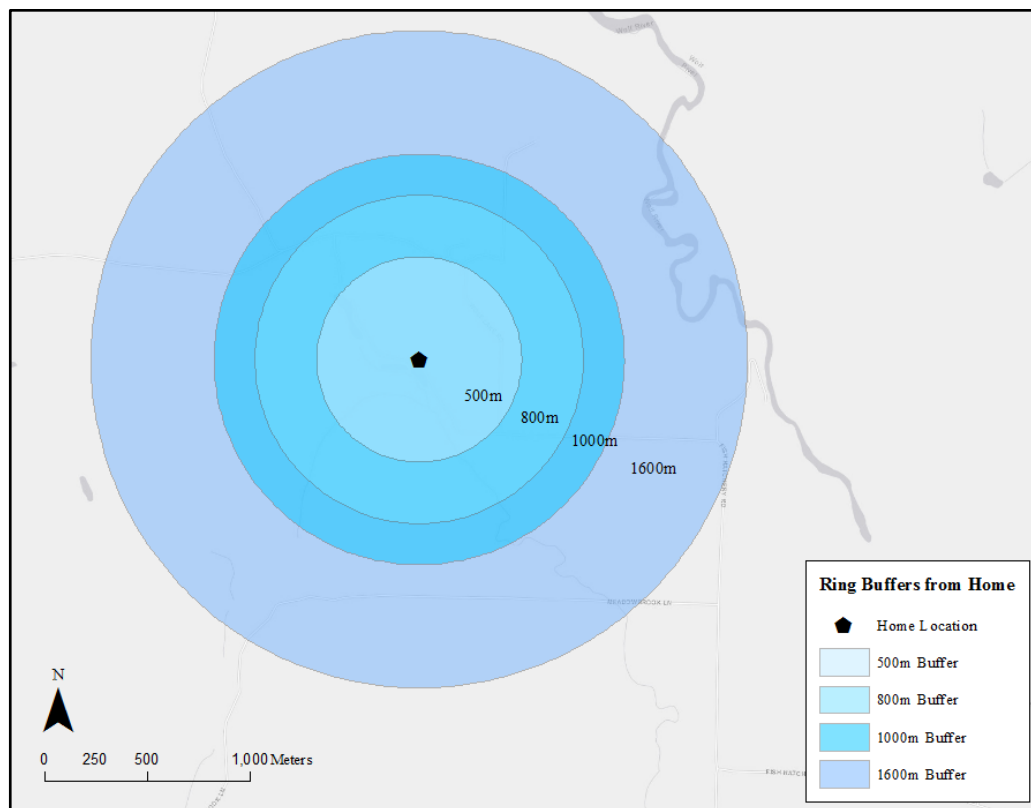


Figure 3.5 Accessibility as defined by multiple ring buffers around the home

3.4.2 Exposure

Exposure identifies and measures which environments a child comes in direct contact with, or comes into their view, based on their movements and locations visited; as such, it is a more direct measure of environmental interaction than accessibility. The method of combining the participant's stops and routes GPS data with the hexagonal grid was used to generate what we refer to as an *exposure activity space*. An activity space is defined by the environments within which people have contact with throughout their daily movements allowing for a measure of individual spatial behaviour (Arcury et al., 2005). The resulting exposure activity space accounts for the stops and routes taken outside of a buffer ring around the home and thereby capture the experienced environments. In ArcMap 10.5, a spatial join between the hexagon grid and each participant's GPS data was completed (see Figure 3.6). The spatial join generates an irregular shaped polygon based on the cells of the hex grid to which at least one GPS point is contained (see Figure 3.7). Each participant had three exposure activity spaces generated based on day type (i.e., all days, weekdays only, and weekend days only). Each participant's resulting exposure activity space contains the various physical environment variables that the participant directly interacts with or incidentally experiences within their immediate view. These exposure activity spaces allow for each physical environment variable to be calculated as a percent coverage of the entire space.



Figure 3.6 GPS tracks with the hexagon grid overlaid (land use imagery source (ESRI, OpenStreetMap))

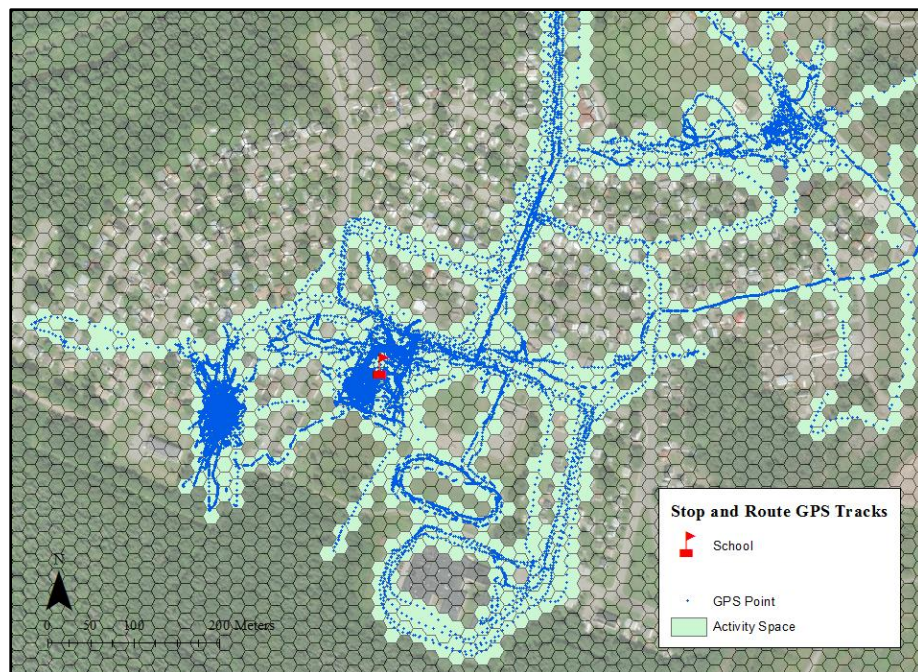


Figure 3.7 The resulting participant exposure activity space based on any hex with GPS data (land use imagery source: ESRI, OpenStreetMap)

3.4.3 Engagement

Engagement refers to the direct involvement with or immersion in the physical environment. The delineation of a child's engagement expands on the exposure activity space measure with the addition of weighting each hex unit by time. This step allows us to capture a more purposeful and sustained engagement with an environment. In ArcMap 10.5, each participant's GPS data was spatially joined to the hexagon grid to create an activity space. During the spatial join, an additional field was calculated to count the number of GPS points within each hex cell (point per second) to create a temporal weighting referred to as 'time spent' (see Figure 3.8). Therefore, the number of seconds spent in each hex cell provides a summary measure for each child, examining the percentage of time spent in each land use type or level of greenness of each participant. Each participant had three engagement activity spaces generated based on day type (i.e., all days, weekdays only, and weekend days only).

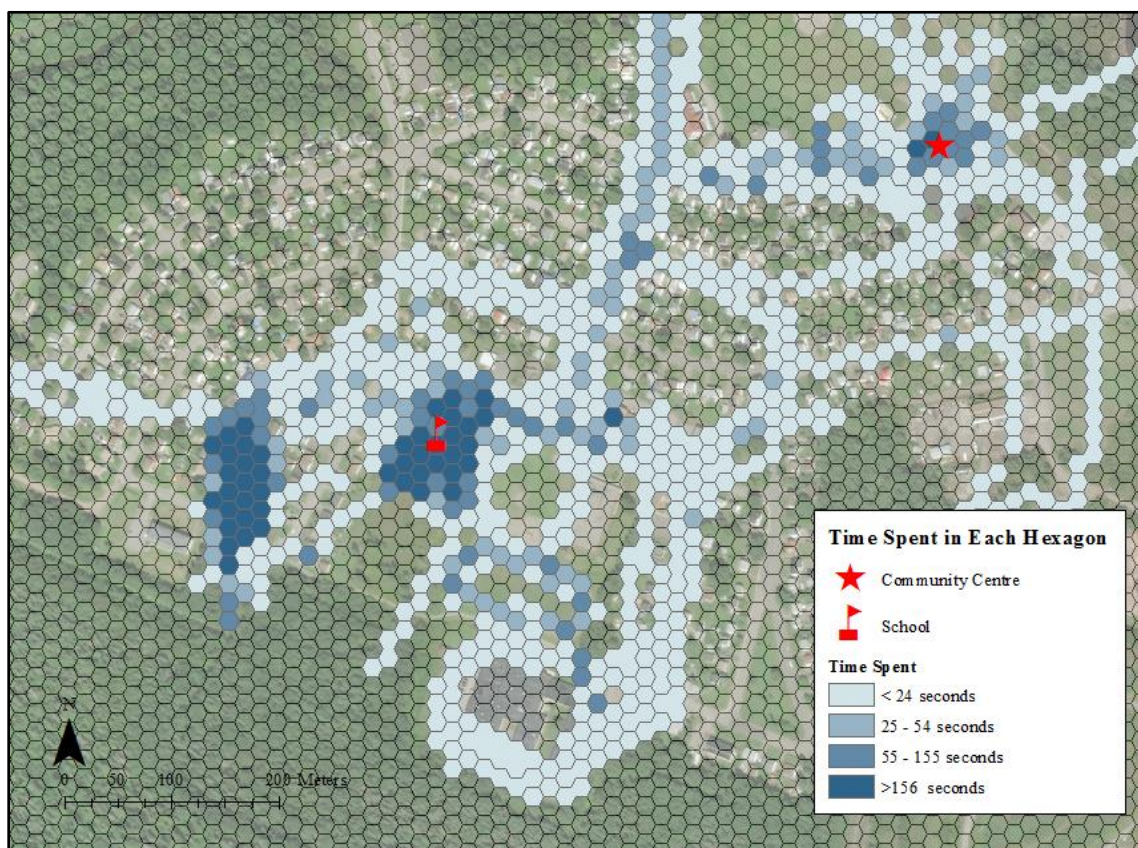


Figure 3.8 Engagement activity space based on a participant's time spent in a hex cell (land use imagery source: ESRI, OpenStreetMap)

3.4.4 Comparing Accessibility, Exposure and Engagement

Each of these three methods were used to conceptualize and measure a child's environment differently. Figure 3.9 visualizes the relationship and differences between the delineations of a child's environment as defined by accessibility, exposure, and engagement. Further data analysis allowed for a better understanding of the implications of conceptualizing the environment with one method versus another.

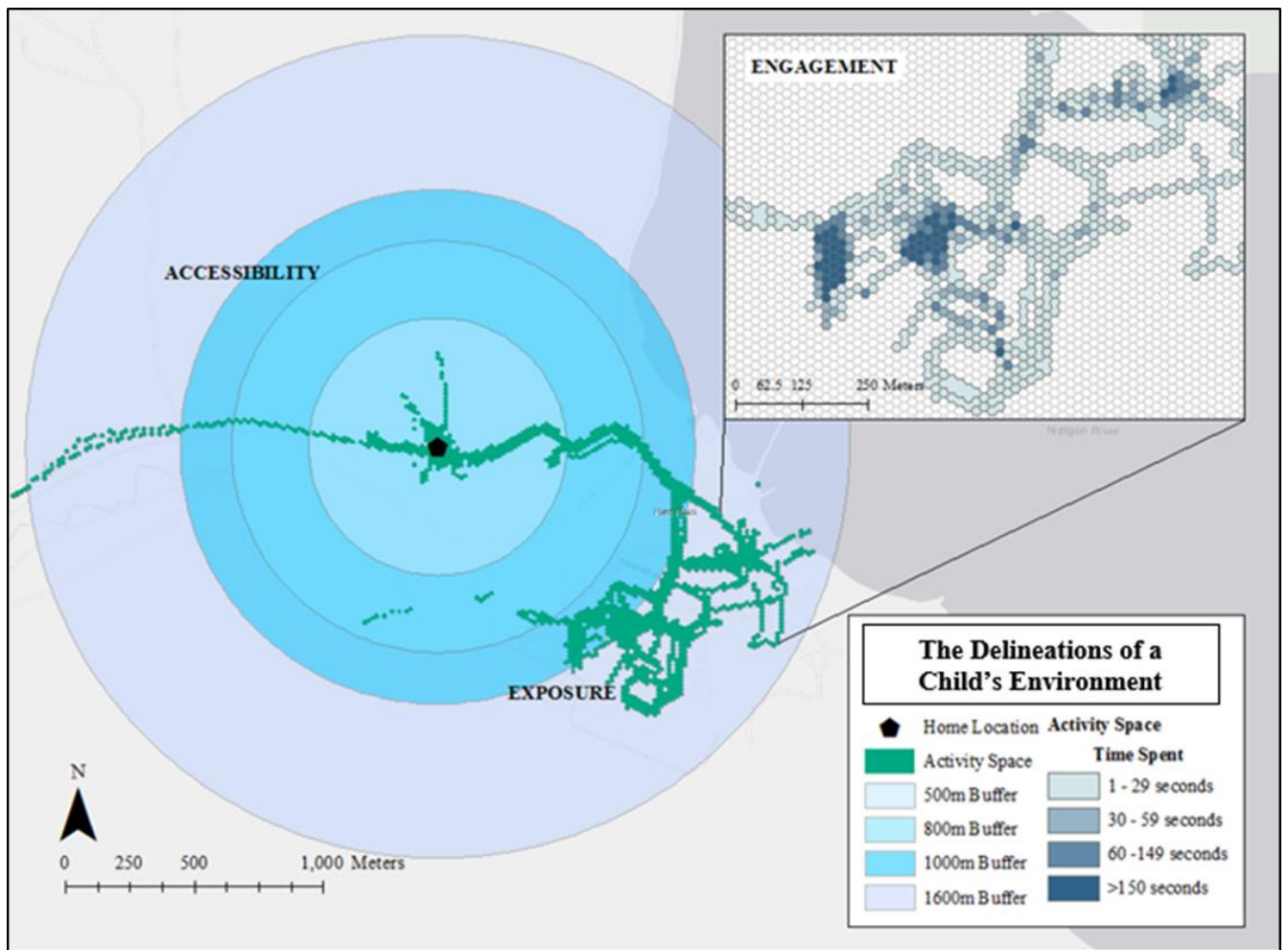


Figure 3.9 The three delineations used to define a child's environment

3.5 Data Analysis

The data analysis aimed to answer the two important research questions of this thesis. First, children's interactions with their physical environment were conceptualized and delineated using three different methods to determine the effect on the quantitative characterizations of built and natural features within those environments. And secondly, determined the built and natural characteristics of the environments that girls and boys in rural Northwestern Ontario directly engaged with on weekdays and weekends. A combination of youth surveys, GPS data within GIS, and statistical analysis was conducted to answer both research questions and the specific objectives presented in Chapter 1.

3.5.1 Descriptive Statistics

Descriptive statistics were used to compare the mean coverage of the physical environment variables across the three methods used (i.e., accessibility, exposure, engagement) to conceptualize a child's environment. The mean and standard deviation of each physical environment coverage in square kilometres (km^2) is calculated at each of the three delineations. These descriptive statistics provided a basic understanding of the similarities and differences between methods to capture a child's environment. ArcMap 10.5 was used to calculate the geometric properties of the buffers and activity spaces, including the total area (km^2) and the maximum length (km) of the activity space (measured as a straight line between the furthest two points from each other within the activity space). Additionally, the distance travelled to school (km) per participant was calculated using the home and school locations. A stacked bar graph was generated to allow for a visualization of the variation in the composition of the physical environment between accessibility, exposure and engagement.

3.5.2 Statistical Analysis Comparing Accessibility, Exposure and Engagement

A paired samples t-test was conducted to compare the percent coverage of each physical environment variable across the three methods used (i.e., accessibility, exposure, engagement). A paired t-test was completed in IBM SPSS Statistics v. 24 by physical environment variable across each of the environment delineations, including accessibility buffers (500m, 800m, 1000m, and 1600m), exposure activity spaces, and engagement (i.e., time-weighted) activity spaces to determine if there were any significant differences. The t-statistics and p-values were examined to determine statistical significance as to the differences between, or within, the delineations of mean coverage of the physical environment variables. Statistical significance was determined at $p < 0.05$.

3.5.3 Examining a Child's Engagement by Day Type and Gender

A statistical analysis was also conducted to compare the difference of means of a child's engagement in the physical environment between various sub-populations. This analysis solely focused on the data of physical environment coverage of a participant's engagement activity space (i.e., time-weighted). The GPS data provides the day type and the youth survey provides the Gender variable to generate the various subpopulations. An independent group t-test was completed using IBM SPSS Statistics v24 to examine engagement in the physical environment between the various subpopulations of (1) boys vs girls; (2) boys weekday vs boys weekend; (3) girls weekday vs girls weekend; (4) boys weekday vs girls weekday; and (5) boys weekend vs girls weekend. Statistical significance was determined at $p < 0.05$.

Chapter 4

4 Results

This chapter presents the results of the multiple spatial and statistical analyses used to delineate and characterize the physical environments of children who participated in our study in Northwestern Ontario. Section 4.1 presents the descriptive characteristics of the study participants. Section 4.2 presents the descriptive statistics of the children's physical environments as measured using three standard methods described as accessibility, exposure, and engagement. Section 4.3 presents results of the paired t-tests comparing the differences in outputs generated among the three methods used to define children's physical environment. To compare the three methods, physical environments are characterized in terms of coverage of different land use variables and levels of greenness. The mean coverage of each land use and level of greenness variable is presented as a stacked bar graph to allow a visual comparison of how a child's physical environment differs when conceptualized as accessibility, exposure, and engagement. Lastly, sections 4.4 provides further examination of the engagement method by presenting the findings of the independent t-tests comparing by day type and gender.

4.1 Sample Characteristics

A total of 128 participants out of the 136 total participants had the necessary valid and complete GPS data to be included for further analyses presented here. A valid GPS track includes 4 full days of data. Descriptive statistics of the study sample can be found in Table 4.1. Most participants are between the ages of 10 to 12 (62%). Of the 128 participants, 56.6% are girls and 42.6% are boys. 51.7% of participants identify as White/Caucasian, 27.9% as Indigenous (i.e., North American Indian, Metis or Inuit), and 6.15% identify as another ethnicity. As well, 96.9% of participants live in a detached family home, with 76.0% of participant's living in a two-parent household. The average median family income (in CAD) at the census subdivision level is \$66,599 (Statistics Canada, 2017) and the average median household income (in CAD) at the dissemination area level within a 500m buffer around the participants' homes is \$59,020 (Statistics Canada, 2017).

Table 4.1 Descriptive statistics of the study sample (n = 128)

Variable	n	%	
Age	Boy	55	42.6
	Girl	73	56.6
Age	8	10	7.4
	9	23	17.8
	10	19	14.7
	11	33	25.6
	12	28	21.7
	13	13	10.1
	14	2	1.6
Ethnicity	White/ Caucasian	67	54.5
	North American Indian, Metis or Inuit	36	29.3
	Other	20	16.3
Interpersonal			
Family Structure			
	Single parent home	28	21.7
	Two parent home	98	76
Type of Housing			
	Detached house	125	96.9
	Semi-detached house	3	2.3
Median family income in CAD (in thousands), Census level		-	\$66,599
Median family income in CAD (in thousands), DA level		-	\$59,020

Note: some variables may not add to full sample size (n=128) due to missing values

4.2 Descriptive Statistics of Accessibility, Exposure, and Engagement

Table 4.2 presents the geometric properties (i.e., area and distance) of the environments of the study sample population as measured using buffers and activity spaces (i.e., accessibility, exposure, and engagement). Table 4.3 presents the findings for all participants comparing the interaction a child has with their physical environment. The mean coverage of each physical environment variable are calculated at each buffer (500m, 800m, 1000m and 1600m), exposure activity space, and engagement activity space per participant.

4.2.1 Comparing Geometric Properties

As exhibited in Table 4.3, the use of the buffer approach means that the geometric properties of every participant's physical environment are fixed; the only variation occurs when the researcher uses more than one buffer radius for analysis. For example, using a circle buffer with a radius of 1000m for every participant means that the area of every participant's physical environment is naturally 3.14km^2 ; likewise, the area of a buffer with a radius of 1600m is 8.01km^2 (with no standard deviation, because all participants have the same value). On the other hand, the average area of an activity space across all participants is 5.64km^2 with a standard deviation of 5.40km^2 , suggesting there is great variation in activity spaces among participants.

Additionally, the maximum length of an activity space, averaged across all participants, is 82.55km, which is drastically greater than the maximum length for 1600m buffer, which is only 3.2km (i.e., the diameter of the circle). Furthermore, the large standard deviation (76.63km) reconfirms that there is great variation among the activity spaces of the participants, which cannot be captured with a simple fixed buffer size. Table 4.2 also reveals how the average participant travels 3.57km from their home to school, which is more than twice the distance represented by the 1600m buffer from home.

A closer look at the geometric properties of activity spaces show considerable differences in area and length of participants activity spaces based on gender (boy and girl) and day

type (weekday and weekend). Girls appear to have larger activity spaces and travel greater distances than boys, and this holds true during both weekdays and weekends.

Table 4.2 Geometric properties of buffer and activity spaces

	Geometric Properties		
	<i>Area (km²) Mean (SD)</i>	<i>Length (km) Mean (SD)</i>	<i>Distance to School (km) Mean (SD)</i>
Buffers			
500m	0.785	1	-
800m	2.01	1.6	-
1000m	3.14	2	-
1600m	8.04	3.2	-
Activity Spaces			
All	5.64 (5.40)	82.55 (76.63)	3.57 (7.36)
Boys	5.09 (5.20)	75.79 (75.54)	3.38 (6.62)
Boys Weekday	3.36 (3.60)	48.03 (50.94)	-
Boys Weekend	2.40 (4.00)	37.89 (60.56)	-
Girls	6.06 (5.54)	88.80 (78.01)	3.72 (7.94)
Girls Weekday	4.64 (4.78)	69.31 (70.54)	-
Girls Weekend	2.87 (4.29)	43.56 (63.31)	-

Notes: By design, the geometric properties of all buffers are the same across all participants regardless of gender or day type. The geometric properties of exposure activity spaces and engagement activity spaces are identical, and therefore not duplicated in the table.

4.2.2 Description of Accessibility

This section will present the findings of the natural and built environments characterized by accessibility. Table 4.3 indicates the coverage of land dedicated to each land use category within each buffer (500m, 800m, 1000m, 1600m); there is little variation in the distribution in the land uses variables across each buffer size. However, it is clear that as the buffers increase in radius from 500m to 1600m it appears that there is a decrease in the mean coverage of the land use variables related to the built environment (i.e., residential, commercial, industrial, and institutional) and an increase in the coverage of natural environment variables (i.e., rural land, water, and dense forest). An exception to the pattern is that the coverage of grass and vegetation goes down as the buffer size increases, in a similar fashion to the built environment, as grass is usually associated with

developed areas whereas rural, water, and dense forest are associated with less developed areas. It is noteworthy that the majority of each buffer is covered by land classified as dense forest (52%-63%), which is representative of most of the territory in this rural, northern region.

4.2.3 Description of Exposure

This section will present the findings of the natural and built environments characterized by exposure. Table 4.3 also presents the coverage of land dedicated to each land use category of children's physical environments as delineated by exposure activity spaces. Nearly half (47%) of the average participant's exposure activity space is dedicated to rural land, and nearly one-quarter (25%) is dedicated to residential land. All other variables combined cover less than 21% of the space. Grass and shrubbery is the dominant NDVI category, on average covering nearly three-fifths (59%) of a participant's exposure activity space; whereas, another 30% is covered by dense forest.

4.2.4 Description of Engagement

This section will present the findings of the natural and built environments characterized by engagement. The coverage of land dedicated to each land use category of children's physical environments as delineated by engagement activity spaces are presented in Table 4.3. More than half of a participant's engagement activity space is classified as residential (62%). Institutional land covers 17% of the average activity space, followed by rural at 10% coverage. There is little coverage of both industrial (1%) and water (<1%). Grass and shrubbery is the dominant NDVI category with 76% coverage.

Table 4.3 Physical environment coverage of each variable at accessibility, exposure, and engagement

		Land Use								NDVI							
		Commercial		Industrial		Institutional		Residential		Rural		Water		Grass & Shrubbery		Dense Forest	
		<i>Coverage (%)</i> <i>(SD)</i>	<i>Range</i>	<i>Coverage (%)</i> <i>(SD)</i>	<i>Range</i>	<i>Coverage (%)</i> <i>(SD)</i>	<i>Range</i>	<i>Coverage (%)</i> <i>(SD)</i>	<i>Range</i>	<i>Coverage (%)</i> <i>(SD)</i>	<i>Range</i>	<i>Coverage (%)</i> <i>(SD)</i>	<i>Range</i>	<i>Coverage (%)</i> <i>(SD)</i>	<i>Range</i>	<i>Coverage (%)</i> <i>(SD)</i>	<i>Range</i>
Accessibility	500-metres	5 (7)	(0, 32)	10 (12)	(0, 48)	5 (5)	(0, 37)	34 (20)	(1, 67)	38 (29)	(6, 99)	1 (5)	(0, 40)	41 (16)	(12, 69)	52 (20)	(18, 86)
	800-metres	5 (5)	(0, 25)	13 (10)	(0, 39)	3 (3)	(0, 23)	26 (15)	(1, 57)	38 (27)	(6, 99)	5 (9)	(0, 44)	34 (12)	(2, 56)	56 (18)	(19, 87)
	1,000-metres	5 (4)	(0, 20)	13 (9)	(0, 30)	2 (2)	(0, 15)	24 (13)	(1, 53)	38 (25)	(8, 99)	7 (10)	(0, 50)	31 (10)	(7, 46)	58 (15)	(33, 90)
	1,600-metres	3 (3)	(0, 9)	10 (7)	(0, 19)	1 (1)	(0, 6)	17 (10)	(1, 32)	43 (22)	(19, 99)	12 (9)	(0, 53)	15 (5)	(6, 31)	63 (11)	(42, 89)
Exposure		10 (5)	(0, 25)	7 (6)	(0, 24)	3 (4)	(0, 31)	25 (17)	(3, 67)	47 (28)	(1, 88)	1 (2)	(0, 14)	59 (8)	(40, 79)	30 (9)	(11, 53)
Engagement		6 (11)	(0, 79)	1 (1)	(0, 6)	17 (13)	(<1, 62)	62 (20)	(2, 94)	10 (12)	(0, 64)	<1 (<1)	(0, 1)	76 (25)	(<1, 99)	10 (11)	(<1, 61)

4.3 Comparing Accessibility, Exposure, and Engagement

This section will present the findings comparing the different approaches to conceptualizing and delineating children's interactions with their physical environments. Figures 4.1 and 4.2 uses a stacked bar graphs to visualize the differences in coverages by land use category and level of greenness (i.e. NDVI categorization), when using buffers, exposure activity spaces, and engagement activity spaces. Tables 4.4 to 4.11 present the statistical analyses by physical environment variable compared across accessibility, exposure, and engagement. Each paired t-test was conducted to determine statistical significance in the quantification of the physical environment variables. Statistical significance is determined at $p < 0.05$.

It is clear from Figure 4.1 that residential land is captured across all delineations with an increase in coverage in engagement activity spaces. The land use with the greatest coverage across all buffers is rural land. Similarly, exposure activity spaces have a large percent of rural coverage. However, the coverage of rural drastically decreases in engagement activity spaces. Institutional land has little coverage across all delineations except engagement activity spaces. Across all delineations, commercial coverage remains fairly static.

Meanwhile, Figure 4.2 also helps to visualize key differences in the coverage of different NDVI categories (dense forest, grass and shrubbery, built-up land) according to how the physical environment is delineated by buffers, exposure activity spaces and engagement activity spaces. It is clear that buffers have a greater coverage of dense forest compared to engagement activity spaces. Comparatively, grass and shrubbery coverage become the dominant NDVI category in exposure and engagement activity spaces. It is evident that the amount of dense forest that a child is exposed to or engages with is less than what is accessible to them from around their home.

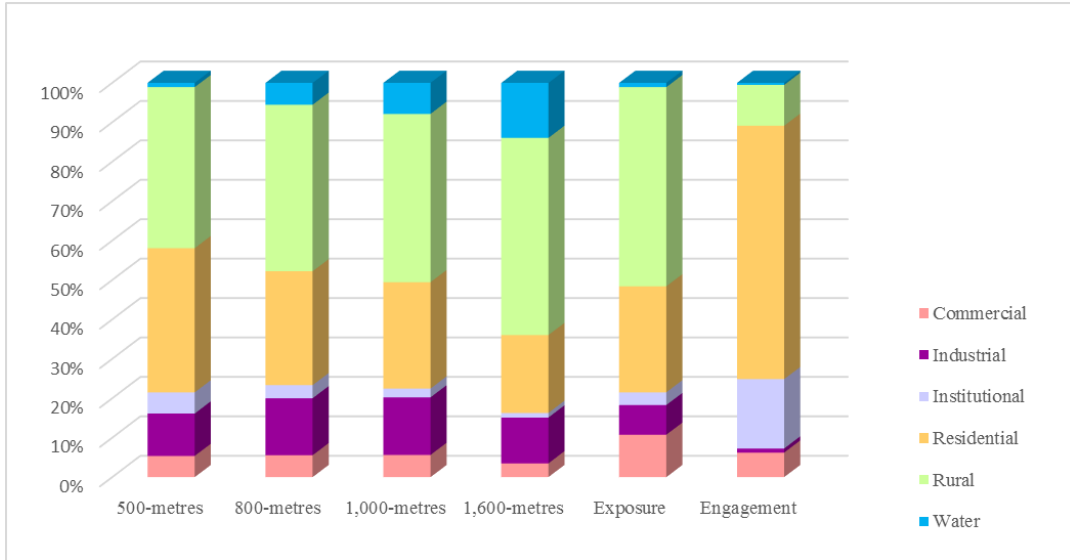


Figure 4.1 Stacked bar graph of land use by variable coverage by accessibility, exposure, and engagement

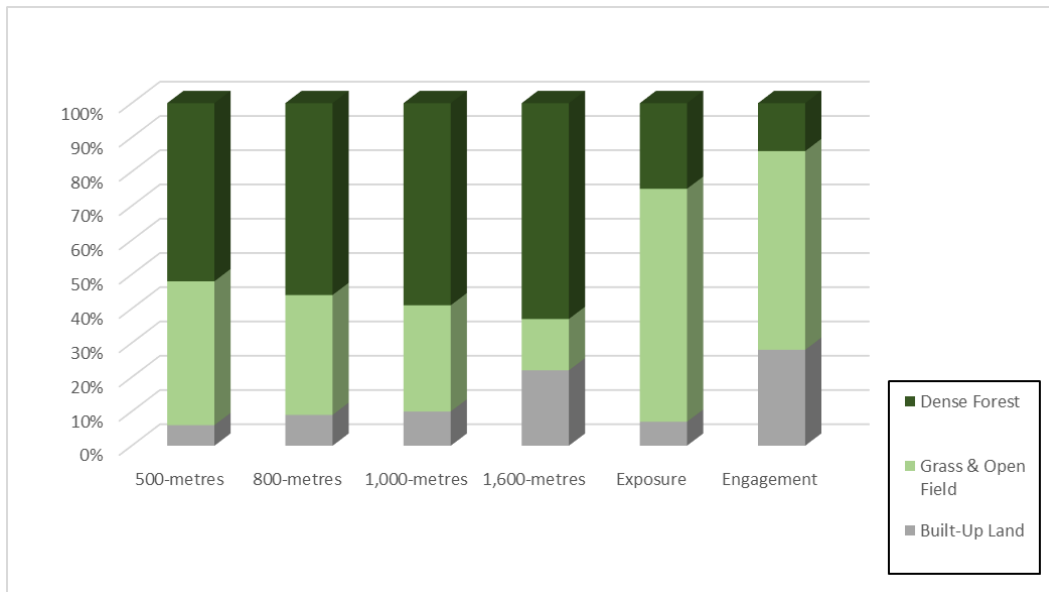


Figure 4.2 Stacked bar graph of NDVI variable coverage by accessibility, exposure, and engagement

The following section will present the results of the paired t-tests (Tables 4.4 to 4.11) determining the statistical significance in the quantification of the physical environment variables across the delineations (Table 4.3).

As indicated in Table 4.3, there is little difference in the commercial coverage between accessibility, exposure and engagement. Each of the buffers capture a similar coverage of commercial land ranging from 3% to 5%. In Table 4.4, the results of the paired t-test assessing commercial coverage by buffer conditions reveals a statistically significant difference between a 1600m buffer and all other buffers. Similarly, there is a statistically significant difference in commercial coverage between an 800m and 1000m buffer ($p = 0.001$). There is a slight increase in commercial land coverage to 10% within a participant's exposure activity space representing a statistically significant difference from all buffer conditions. With the addition of time, commercial coverage decreases to 6% of a participant's engagement activity space. Only the 1600m buffer had a statistically significant difference with engagement commercial coverage ($p = 0.017$).

The areal coverage of industrial land decreases between the delineations of a child's environment. Across all delineations, buffers have the greatest industrial land coverage of 10% to 13%. A participant's exposure activity space is covered by 7% industrial land. With consideration for time spent in these spaces through engagement measures, industrial land decreases to 1% coverage (Table 4.3). As seen in Table 4.5, all t-tests conducted to compare the difference in delineation of the environment and industrial coverage are statistically significant, except for two. There is a non-significant difference in the industrial coverage for 800m and 1000m buffer. Similarly, the 500m and 1600m buffer had a non-significant difference of industrial coverage.

Institutional land represents the smallest mean coverage at each of the buffers. Aside from water (1% coverage), institutional land has the smallest coverage of all participants' exposure activity spaces with 3% coverage. Across all participant's exposure activity spaces institutional land ranges from as little as 0% to 31% coverage. With the addition of time, a participant's engagement activity space has an increase in institutional land coverage to 17% with a maximum of 62% coverage (Table 4.3). As seen in Table 4.6,

the results of the paired t-test comparing institutional coverage are all statistically significant, excluding the paired t-test conducted to compare the 800m buffer and exposure activity spaces.

Residential land across each buffer ranges between 17% to 34% coverage. Participant's exposure activity spaces have an average of 25% residential coverage. The residential cover across all participants' engagement activity spaces increases to more than half, with 62% coverage (Table 4.3). Table 4.7 reveals how the results comparing residential coverage between all delineations are statistically significant, excluding exposure activity spaces and both the 800m and 1600m buffers.

Aside from water, rural is the only land use variable that increases in coverage from the 500m to the 1600m buffer. Rural land has the largest coverage within each of the buffers, with all participant's having a minimum of 6% rural coverage around their home. The results of the paired t-test assessing rural coverage by buffer conditions found a statistically significant difference between a 1600m buffer and all other buffers. Rural land has the greatest mean coverage (47%) across all participants' exposure activity spaces (Table 4.3). As seen in Table 4.8, the results of the paired t-test are all significant with exposure activity spaces except the 1600m buffer. A participant's engagement activity space decreases in the coverage of rural land to 10%. There is a statistically significant difference between engagement activity spaces and all other delineations for rural coverage.

Water has the greatest range of coverage within participant's buffers from 1% to 12%. The coverage of water decreases when calculated for a participant's exposure and engagement activity spaces. Both the exposure and engagement activity spaces have as little as 1% coverage of water within (Table 4.3). Table 4.9 reveals that the results of the paired t-test of water coverage resulted in only one non-significant paired t-test between the 500m buffer and exposure activity spaces. All other paired t-tests between delineations found statistically significant differences in water coverage.

More than half of a participant's buffers are classified as dense forest. A participant's exposure activity space has an increase in coverage of grass and shrubbery at 59% and a

decrease in dense forest coverage to 30%. Similarly, all participant's engagement activity spaces have a greater coverage of grass and shrubbery at 76% than dense forest with 10% coverage (Table 4.3). As seen in Tables 4.10 and 4.11, the paired t-tests conducted for both NDVI categories, grass and shrubbery and dense forest, resulted in statistically significant findings. There is a statistically significant difference in both NDVI categories coverage between all delineations.

These findings confirm that the conceptualization of a child's environment result in statistically significant differences in the quantification of the interaction a child has with their environment. All variables found a significant difference in the coverage of a child's engagement activity space and all other delineations, except commercial land. The statistically significant differences in engagement activity space coverage support further investigation into the differences in engagement activity spaces by subpopulation (Section 4.4).

Table 4.4 Results of the paired t-test assessing commercial coverage by various delineation of the environment

		Commercial				
	500m	800m	1000m	1600m	Exposure	Engagement
	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>
500m		0.611 (0.542)	0.670 (0.504)	3.430 (0.001)	8.185 (0.000)	0.079 (0.498)
800m			3.323 (0.001)	6.947 (0.000)	10.073 (0.000)	0.429 (0.669)
1000m				6.372 (0.000)	12.002 (0.000)	0.913 (0.363)
1600m					17.017 (0.000)	2.416 (0.017)
Exposure						-4.601 (.000)
Engagement						

Table 4.5 Results of the paired t-test assessing industrial coverage by various delineation of the environment

		Industrial				
	500m	800m	1000m	1600m	Exposure	Engagement
	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>
500m		-4.451 (0.000)	-3.422 (0.001)	0.236 (0.814)	-2.695 (0.000)	-8.939 (0.000)
800m			-0.317 (0.752)	-13.654 (0.000)	-6.216 (0.000)	-13.595 (0.000)
1000m				7.510 (0.000)	-6.684 (0.000)	-14.621 (0.000)
1600m					-3.959 (0.000)	-15.265 (0.000)
Exposure						-12.672 (0.000)
Engagement						

Table 4.6 Results of the paired t-test assessing institutional coverage by various delineation of the environment

		Institutional					
		500m	800m	1000m	1600m	Exposure	Engagement
		<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>
500m			6.480 (0.000)	7.737 (0.000)	8.687 (0.000)	-2.567 (0.011)	10.456 (0.000)
800m				8.558 (0.000)	9.156 (0.000)	0.694 (0.489)	12.353 (0.000)
1000m					9.166 (0.000)	2.881 (0.005)	13.241 (0.000)
1600m						5.902 (0.000)	14.306 (0.000)
Exposure							11.350 (0.000)
Engagement							

Table 4.7 Results of the paired t-test assessing residential coverage by various delineation of the environment

		Residential					
		500m	800m	1000m	1600m	Exposure	Engagement
		<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>
500m			9.826 (0.000)	9.781 (0.000)	12.236 (0.000)	-4.465 (0.000)	12.219 (0.000)
800m				6.782 (0.000)	11.690 (0.000)	-0.721 (0.472)	16.643 (0.000)
1000m					13.487 (0.000)	1.099 (0.274)	18.313 (0.000)
1600m						5.752 (0.000)	21.978 (0.000)
Exposure							4.368 (0.000)
Engagement							

Table 4.8 Results of the paired t-test assessing rural coverage by various delineation of the environment

Rural						
	500m	800m	1000m	1600m	Exposure	Engagement
	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>
500m		0.975 (0.331)	0.641 (0.522)	-3.663 (0.000)	3.049 (0.003)	-10.773 (0.000)
800m			-0.326 (0.745)	-6.477 (0.000)	3.471 (0.001)	-11.294 (0.000)
1000m				-9.011 (0.000)	3.526 (0.001)	-11.908 (0.000)
1600m					1.593 (0.114)	-16.257 (0.000)
Exposure						-15.383 (0.000)
Engagement						

Table 4.9 Results of the paired t-test assessing water coverage by various delineation of the environment

Water						
	500m	800m	1000m	1600m	Exposure	Engagement
	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>
500m		-5.597 (0.000)	-7.381 (0.000)	-12.963 (0.000)	-0.053 (0.958)	-3.302 (0.001)
800m			-8.171 (0.000)	-10.771 (0.000)	-4.320 (0.000)	-6.160 (0.000)
1000m				-10.361 (0.000)	-5.946 (0.000)	-7.634 (0.000)
1600m					-12.051 (0.000)	-13.386 (0.000)
Exposure						-6.493 (0.000)
Engagement						

Table 4.10 Results of the paired t-test assessing NDVI: grass and shrubbery coverage by various delineation of the environment

NDVI: Grass & Shrubbery						
	500m	800m	1000m	1600m	Exposure	Engagement
	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>
500m		10.927 (0.000)	13.068 (0.000)	16.901 (0.000)	12.741 (0.000)	15.559 (0.000)
800m			13.667 (0.000)	18.584 (0.000)	23.135 (0.000)	19.504 (0.000)
1000m				18.695 (0.000)	31.132 (0.000)	21.896 (0.000)
1600m					54.461 (0.000)	25.387 (0.000)
Exposure						7.465 (0.000)
Engagement						

Table 4.11 Results of the paired t-test assessing NDVI: dense forest coverage by various delineation of the environment

NDVI: Dense Forest						
	500m	800m	1000m	1600m	Exposure	Engagement
	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>	<i>t (p-value)</i>
500m		-6.742 (0.000)	-9.169 (0.000)	-10.600 (0.000)	-13.784 (0.000)	-20.053 (0.000)
800m			-8.798 (0.000)	-9.248 (0.000)	-18.621 (0.000)	-23.468 (0.000)
1000m				-8.513 (0.000)	-22.107 (0.000)	-26.068 (0.000)
1600m					-30.376 (0.000)	-31.931 (0.000)
Exposure						-16.416 (0.000)
Engagement						

4.4 Examining Engagement by Gender and Day Type

This section presents the results of an examination of engagement activity spaces by gender and day type. An independent-samples t-test was conducted to compare how children's engagement with their physical environment differs between (1) boys and girls; (2) boys weekday and girls weekday; (3) boys weekend and girls weekend; (4) boys weekday and boys weekend and (5) girls weekday and girls weekend. The results of each independent samples t-test are presented in Tables 4.12 to 4.16, where statistical significance is determined at $p < 0.05$.

An independent-samples t-test (Table 4.12) was conducted to compare how boys and girls engage in different types of physical environments. The results show that girls spend significantly more time on average in rural areas compared to boys ($t = 2.240, p = 0.017$). Girls are also significantly more likely to spend time in water compared to boys ($t = 2.198, p = 0.030$). Tables 4.13 and 4.14 examines the differences boys and girls have in their engagement to different land uses during the weekend and weekday (i.e., boy and girl weekday engagement, boy and girl weekend engagement), with no significant difference found in their engagement in any of physical environment. A comparison between weekday and weekend engagement was also conducted for boys (Table 4.15) and girls (Table 4.16) using an independent t-test with more significant differences found. Boys have significantly higher engagement in institutional space on the weekday compared to the weekend ($t = 10.105, p < 0.001$). Boys also engage in significantly more residential land on weekends compared to weekdays ($t = -4.129, p < 0.001$). The results for girls reveal similar differences in institutional ($t = 8.344, p < 0.001$) and residential ($t = -2.044, p = 0.046$) engagement by day type. Additionally, there is a significant difference in the industrial engagement between girl's weekday and weekend, where girls are engaging in more industrial land on the weekend ($t = -2.318, p = 0.024$). Finally, rural land engagement is significantly higher on a girl's weekend compared to weekday ($t = -3.378, p = 0.001$). Boys and girls share similarities in levels of engagement with the physical environment, but there are significant differences by the type of physical environments that children engage with when comparing by day type within both boys and girl

Table 4.12 Results of the independent t-test of boy's and girl's engagement activity space

PE Variable			Boy	Girl	Independent t-test	
			% Coverage (SD)	% Coverage (SD)	<i>t</i>	<i>p-value</i>
PE Variable	Land Use	Commercial	6.57 (13.39)	5.48 (9.70)	-0.526	0.600
		Industrial	1.19 (1.52)	1.15 (1.16)	-0.149	0.882
		Institutional	17.53 (11.32)	16.91 (13.55)	-0.272	0.786
		Residential	62.50 (18.98)	60.55 (20.33)	-0.545	0.586
		Rural	7.06 (8.62)	12.14 (13.35)	2.240	0.017
		Water	0.03 (0.07)	0.10 (0.22)	2.198	0.030
	NDVI	Grass & Shrubbery	76.23 (24.11)	75.91 (25.61)	-0.071	0.944
		Dense Forest	9.64 (13.09)	9.69 (10.24)	0.025	0.980

Table 4.13 Results of the independent t-test of boy's and girl's weekday engagement activity space

PE Variable			Boy Weekday	Girl Weekday	Independent t-test	
			% Coverage (SD)	% Coverage (SD)	<i>t</i>	<i>p-value</i>
PE Variable	Land Use	Commercial	5.49 (10.66)	5.68 (12.15)	0.088	0.930
		Industrial	1.07 (1.44)	0.99 (1.22)	-0.346	0.730
		Institutional	23.73 (15.32)	22.26 (15.63)	-0.525	0.600
		Residential	58.63 (20.45)	58.06 (19.89)	-0.156	0.876
		Rural	6.04 (7.17)	9.40 (12.64)	1.759	0.081
		Water	0.05 (0.17)	0.09 (0.26)	1.174	0.242
	NDVI	Grass & Shrubbery	75.57 (23.46)	73.24 (28.00)	-0.497	0.620
		Dense Forest	9.28 (11.01)	10.71 (10.95)	0.725	0.470

Table 4.14 Results of the independent t-test of boy's and girl's weekend engagement activity space

		Boy Weekend	Girl Weekend	Independent t-test		
		% Coverage (SD)	% Coverage (SD)	<i>t</i>	<i>p-value</i>	
PE Variable	Land Use	Commercial	9.09 (19.32)	6.10 (13.79)	-0.889	0.376
		Industrial	1.55 (2.7)	1.82 (2.61)	0.492	0.624
		Institutional	0.24 (0.58)	2.49 (12.14)	1.153	0.252
		Residential	73.00 (8.61)	64.97 (13.35)	-1.370	0.174
		Rural	11.45 (18.36)	19.95 (24.50)	1.843	0.068
		Water	0.04 (0.12)	0.13 (0.31)	1.613	0.110
	NDVI	Grass & Shrubbery	76.22 (31.44)	80.23 (27.70)	0.662	0.510
		Dense Forest	11.16 (21.81)	8.99 (15.71)	-0.572	0.569

Table 4.15 Results of the independent t-test of boy's weekday and weekend engagement activity space

		Boy Weekday	Boy Weekend	Independent t-test		
		% Coverage (SD)	% Coverage (SD)	<i>t</i>	<i>p-value</i>	
PE Variable	Land Use	Commercial	5.49 (10.66)	9.09 (19.32)	-1.324	0.193
		Industrial	1.07 (1.44)	1.55 (2.7)	-1.705	0.096
		Institutional	23.73 (15.32)	0.24 (0.58)	10.105	0.000
		Residential	58.63 (20.45)	73.00 (8.61)	-4.129	0.000
		Rural	6.04 (7.17)	11.45 (18.36)	-1.695	0.098
		Water	0.05 (0.17)	0.04 (0.12)	0.244	0.809
	NDVI	Grass & Shrubbery	75.57 (23.46)	76.22 (31.44)	-1.312	0.197
		Dense Forest	9.28 (11.01)	11.16 (21.81)	-0.245	0.808

Table 4.16 Results of the independent t-test of girl's weekday and weekend activity space

		Girl Weekday	Girl Weekend	Independent t-test		
		<i>% Coverage (SD)</i>	<i>% Coverage (SD)</i>	<i>t</i>	<i>p-value</i>	
PE Variable	Land Use	Commercial	5.68 (12.15)	6.10 (13.79)	0.081	0.936
		Industrial	0.99 (1.22)	1.82 (2.61)	-2.318	0.024
		Institutional	22.26 (15.63)	2.49 (12.14)	8.344	0.000
		Residential	58.06 (19.89)	64.97 (13.35)	-2.044	0.046
		Rural	9.40 (12.64)	19.95 (24.50)	-3.378	0.001
		Water	0.09 (0.26)	0.13 (0.31)	-0.579	0.565
	NDVI	Grass & Shrubbery	73.24 (28.00)	80.23 (27.70)	0.779	0.439
		Dense Forest	10.71 (10.95)	8.99 (15.71)	-1.985	0.052

Chapter 5

5 Discussion and Conclusion

This thesis aimed to answer two related research questions. The first question asked: *How do different approaches to conceptualizing and delineating children's interactions with their physical environments affect the quantitative characterizations of built and natural features within their environments?* The second question asked: *What are the built and natural characteristics of the environments that girls and boys in rural Northwestern Ontario directly engage with on weekdays and weekends?* This concluding chapter will discuss the key findings of this thesis which help answer these two research questions. The chapter also includes a discussion of the broader methodological contributions of this thesis and the specific contributions to literature on the relationship between the physical environment and children's health. In addition, this chapter will conclude with the limitations of this study, the implications of this research for policy and practice, and the recommendations for future research.

5.1 Summary of Study

To answer question #1, multiple methods were developed and executed to delineate children's accessibility, exposure, and engagement in their physical environments using a series of buffers and GPS-derived activity spaces within GIS, and then compared how the different delineations resulted in different characterizations of children's physical environments in terms of geometric properties, primary land uses, and level of greenness.

The analysis revealed that the average activity space has a much greater areal coverage and length than a buffer. A simple explanation for this finding is that rural dwellers must travel much greater distances to access amenities and facilities than captured within a typical buffer with a radius of 500m, 800m, 1000m, or 1600m (Bourke, Humphreys, Wakerman, & Taylor, 2012). For example, the average distance that our rural study participants travel between home and school on a daily basis was 3.57km, which is much larger than would be captured by a 1600m buffer. In fact, the maximum length travelled among the students was 82.55km, suggesting that these rural children were highly

dependent on automobiles for reaching destinations. The variability in the areal extent of a child's activity space by day type is associated with the different habitual routines a child has throughout the week, such as their commute to school, extra-curricular activities, or spending time in the larger city nearby. Buffer-based measures are useful for helping to characterize a participant's environment immediately surrounding their home; however, the findings of this thesis provide evidence that buffers are insufficient for assessing a rural child's actual spatial interactions with different features in their environments.

The analysis also found statistically significant differences in coverage by land use variable and level of greenness between the types of delineations. However, there was little change in the coverage of natural and built environment between buffers of different sizes. This is largely a reflection of the fairly homogenous topographic landscape of the study area in rural Northwestern Ontario (e.g., dense forest, rural land and water), rather than an indication of the actual spaces children interact with on a daily basis (i.e., home and school). These findings provide additional supporting evidence that buffers misrepresent children's environments as they ignore the fact that not all environments are permeable by children (e.g., rural land, industrial land). This thesis provides evidence that buffers are insufficient and inappropriate for assessing a rural child's actual interaction with different features in their habitual, everyday environments.

A child's exposure to the physical environment is best conceptualized in terms of an individual activity space, which is best measured using personal GPS tracking. In this study, each participant's GPS data was used to delineate an activity space, and then combined with environmental data in GIS to generate an individual characterization of the physical environmental features to which a child is exposed. Activity space approaches have been praised in previous literature for their more accurate representation of actual environmental interactions (Kestens, Thierry, Shareck, Steinmetz-Wood, & Chaix, 2018). An examination of the characterization of physical environments by what we called 'exposure activity spaces' revealed several statistically significant differences compared to characterizations by buffers. In particular, this study found that exposure activity spaces had a greater proportion of area in residential land uses compared to the

buffer-based characterizations. This finding aligns with previous literature which indicates that children spend the greatest proportion of their time at home (in residential spaces) compared to playing outside (ParticipACTION, 2018). It also provides evidence to support the assertion that conceptualizations of children's physical environments using activity space approaches are more direct and precise than buffer-based approaches which merely focus on opportunity for exposure, rather than actual exposure (Bürigi & de Bruin, 2016; Hand et al., 2018; Holliday, Howard, Emch, Rodríguez, Rosamond, et al., 2017; Perchoux et al., 2016).

There were also key statistically significant differences in the characterization of the physical environment using engagement activity spaces compared to exposure activity spaces. Engagement conceptualizes the interaction a participant has with the physical environment as an activity space, but also takes into consideration *time spent* in a space (i.e., they are time-weighted activity spaces). Methodologically, activity spaces precisely capture the physical environment that a child is exposed to as a whole, but the additional temporal component (i.e., time weighting) of the engagement measure allows for the identification of spaces of sustained interaction (Chaix et al., 2016; Chambers et al., 2017; Kestens et al., 2016). Analysis revealed that the physical environments that participants engaged in were similar to those identified in the literature about spaces children are known to spend time in, such as institutional land (i.e., school time), residential land (i.e., neighbourhoods, home time), and grass and shrubbery (e.g., parks and greenspaces) (Bürigi & de Bruin, 2016; Holliday, Howard, Emch, Rodríguez, Rosamond, et al., 2017; Matisziw et al., 2016). It is noteworthy that characterizations based on the delineations by multiple buffers and exposure activity spaces indicated that children's physical environments had very limited level of coverage of institutional land; this finding was inconsistent with the literature regarding the known interaction a child has with school (i.e., up to one third of their 24 hour day and most of their awake hours on weekdays). On the other hand, the coverage of children's environments in institutional land, as measured using the engagement activity space approach, was significantly higher compared to the values generated by the accessibility and exposure measures; the engagement activity measure effectively reflects both the *known* and *true* interaction of a child. There was a similar statistically significant difference in a child's

engagement in areas classified as grass and shrubbery and residential land compared to buffers and exposure. These findings may be because of the topography of the study area of Northwestern Ontario. Children living in a rural area such as Northwestern Ontario are typically surrounded by more rural land uses and dense forests, which results in the greater coverage of these features being represented in buffers and exposure activity spaces. These findings highlight the main problem in delineating a child's environment using a buffer or a simple exposure activity space which is atemporal. Buffers are a representation of potential, not necessarily actual, interaction, and exposure may be a reflection of incidental or momentary interaction but without consideration for the duration of the interaction. Additionally, engagement properly quantifies the spaces that children have limited interaction with due to the parental restrictions on crossing busy roads or barriers to entry, including designated private land, agricultural and farm fields, or industrial workspaces (Hand et al., 2018; Islam, Moore, & Cosco, 2016; Kytta, 2004).

Collectively, these key findings clearly indicate how different approaches to conceptualizing and delineating children's interactions with their physical environments impact the quantitative characterizations of built and natural features within their environments. It is concluded that greater adoption of the engagement activity space approach could provide the necessary method to help identify and quantify the type, dose, and duration of a given environmental feature that is understood to affect a number of health outcomes. This approach would allow for future researchers to draw stronger conclusions linking the physical environment with behaviours and health outcomes.

Elaborating on the methodological insights gained from the findings generated through answering the first research question, research question #2 was aimed at determining the built and natural characteristics of the environments that girls and boys in rural Northwestern Ontario directly engage with on weekdays and weekends. This study found very few statistical differences in the statistical comparisons of engagement activity spaces of boys vs girls. In simple terms, rural boys and rural girls engage in many of the same spaces on weekdays and weekends. This may be because of the somewhat

isolated rural location of the study area and the fact that there is a very limited range of spaces for children to spend time in within close proximity of home. Similarly, a child's weekday routine and many of the associated spaces where a participant would spend their time are independent of gender (e.g., school time). The lack of gendered differences may also be a result of the age of our sample. As many participants are nearing adolescence and may not yet have a concept of gender stereotyped spaces of play, resulting in the similarities between boys and girls (Änggård, 2011; Barbu, Cabanes, & Le Maner-Idrissi, 2011; Garcia Bengoechea, Spence, & McGannon, 2005)

This study did however find statistically significant differences among the physical environments engaged in by rural children on weekdays vs weekends. These differences between a child's weekday and weekend physical environment may be a reflection of the constraints of a highly structured school day, potential extracurricular activities, and family or home lifestyle (Bürgi & de Bruin, 2016; Maddison et al., 2010). These findings may be explained by the potential increased freedom children have on weekends to choose the spaces they want to spend time (Bürgi & de Bruin, 2016). Meanwhile, the spaces a child engages in during the week are more predictable because much of a child's time is designated for school and home. This study found that girls had greater differences in the spaces they interact with between weekday and weekend than boys. This finding indicates that girls may choose to spend their time in a variety of different spaces between weekday and weekends, while a boy's time is more concentrated to spaces like home and school. Both boys and girls spend more time during the weekend in spaces classified as grass and shrubbery; however, boys tend to spend more time in dense forest on weekends than during the week. This may be because boys in our sample choose to engage in certain activities during the fall season, such as hunting and hiking, that are associated with spaces classified as dense forest. Both boys and girls show a similar decrease in time spent in institutional land between weekday and weekends. Many participants travel almost 4 km to reach school and during the weekend may have less opportunity to engage in a school space as it may be inaccessible through pedestrian modes of travel.

This thesis hypothesized that the investigation of the physical environment utilizing both space and time would allow for a better delineation and characterization of the interaction a child has with their physical environment. Engagement recognizes a children's individual agency as it acknowledges that each child moves differently and accounts for the time spent in their habitual environment (Bell et al., 2014; Tillmann, Clark, et al., 2018). Results from this study provide empirical evidence of the natural and built environments in which rural children spend time. Specifically, the environments that children spend their time in differ by gender and across day type, underscoring the complexity of the relationship a child has with the physical environment. These findings contribute to the evidence base seeking to understand the underpinnings of gender and day type specific to environments and the associated health-related behaviours and outcomes.

5.2 Methodological Contributions

This thesis makes multiple important methodological contributions to the literature. First, the novel methodology designed to process and clean GPS data in this thesis provides useful instructions for overcoming many of the hardware and software challenges associated with GPS devices and integrating GPS data within GIS. The time imputation script used in this thesis can improve the data quality as a consequence of a failed satellite signal or a poor connection and resulting data scatter. Additionally, the process designed to manually examine the stop and route GPS data improves the accuracy of the dataset by ensuring the algorithm and resulting aggregated dataset of stops and routes is an accurate representation of a participant's movement patterns.

The methods used in this thesis to delineate exposure and engagement offers an alternative for GPS studies to mitigate the effects of the Modifiable Areal Unit Problem (MAUP) and the Uncertain Geographic Context Problem (UGCoP). The MAUP is a persistent issue in studies exploring environmental effects on people's experiences, behaviours or outcomes and arises when the areal unit used to measure the environment is inappropriately scaled or shaped in relation to the behaviour or outcome of interest (Kwan, 2012a). The UGCoP is related to the complications of geographically delineating space to solve a research problem, but instead of faults in scale or shape of an

aggregation, the problem is contextual, resulting from uncertainty in the actual specific attribute of an area that exerts influence on an individual's behaviour or experience (Kwan, 2012a, 2012b). This thesis overcomes the MAUP and UGCoP by using individual GPS-derived activity spaces which offer more accurate areal units of measurement to capture the actual spaces an individual is exposed to and directly engages with. The use of an isotropic hexagonal grid with uniform spatial units to aggregate GPS points and spatially delineate the natural and built environments within a child's activity space helps to overcome the UGCoP (Zhao et al., 2018). The physical environment variables are measured using a single 20m hex unit allowing to precisely aggregate and examine the actual context of an individual's exposure and engagement activity spaces. Aggregation of GPS points by coincident 20m hex cell also helps to overcome spatial inaccuracies inherent in most GPS units.

Lastly, through the combination of individual GPS data within GIS, this thesis found differences in the interaction a child has with the physical environment between accessibility, exposure and engagement. The results suggest that the conceptualization a child's physical environment has a significant impact on estimates of an interaction. This in turn can influence the validity of findings and a researcher's interpretation of a potential relationship between the environment and health. Although, accessibility is a useful methodology to study the physical environment from a specific point location (e.g. the home), the findings are only hypothetical and the ability to apply the individual agency of children is lost (Bell et al., 2014; Tillmann, Clark, et al., 2018). Similarly, exposure answers the question of *what* children interact with in their physical environment but ignores the temporal influence of *how* time is spent in the natural and built environments. This thesis provides a methodological contribution in that delineating a child's interaction with their physical environment as engagement provides the most explicit, consistent, and direct method for future explorations of environment and health relationships.

5.3 Contributions to Literature on Physical Environment and Children's Health

This thesis focuses on children living in a rural community, a population that is commonly overlooked or underrepresented in the literature. Previous literature on children's environments and health is dominated by studies of urban or suburban populations and the results of these studies are not generalizable to those living in a rural environment (Almanza et al., 2011; Jilcott Pitts et al., 2015; Sandercock et al., 2010). In many of these urban studies, a neighbourhood is defined by mere opportunity, or what we refer to in the current study as accessibility (i.e., administrative units or buffers) (Holliday, Howard, Emch, Rodríguez, & Evenson, 2017; P. James et al., 2014; Mitchell et al., 2016; Oliver et al., 2007). Using administrative units or buffers to define a child's neighbourhood in a rural environment incorrectly captures the truly vast areal extent of a rural child's habitual environment. The use of accessibility measures may accurately capture an urban child's environment, but this thesis confirms that this methodology is not suitable for the study of a rural children's environments due to the greater distances between destinations as a result of the lower population densities and dispersed settlement patterns. The delineation of neighbourhoods based on individual spatial and temporal interactions captured with an activity space allows for a shift away from the inaccuracies and misrepresentations associated with the MAUP. The incorporation of time into activity spaces builds on this valid methodology and allows for studies on urban environments to be more easily compared with rural environments. Using GPS-derived activity spaces and land use data within GIS, this study found that rural children engage in different natural and built environments between gender (i.e., boy vs girl) and day type (i.e., weekday vs weekend) contributing to the limited empirical evidence on the population group.

Previous literature has stated that the rural physical environment presents different barriers and challenges to achieving the same healthy lifestyle as to those living in an urban area (Boehmer, Lovegreen, Haire-Joshu, & Brownson, 2006; Douthit, Kiv, Dwolatzky, & Biswas, 2015; Joens-Matre et al., 2008; Wilcox, Castro, King, Housemann, & Brownson, 2000). Urban areas have increased opportunities and more

options of specific amenities and facilities that provide healthy lifestyle choices than in a rural area (e.g. Recreation facilities, neighbourhood sidewalks, supermarket chains and health services) (Shearer et al., 2012). These same amenities in a rural area are found in this study to be spread across a greater distance making them less accessible both geographically and economically (Boehmer et al., 2006; Thornton et al., 2011). The findings of engagement support that lifestyle interventions or community programs should be located and implemented within the residential neighbourhoods or institutional spaces of rural communities. These are the two predominant spaces that children spend the majority of their time, therefore providing the greatest opportunity to influence healthy behaviours. Overall, the finding of this thesis help to move health geography forward to provide a stronger and more explicit methodology to conceptualize and delineate the physical environment. Through the use of both space and time, the dose, type, and duration of a particular natural or built environment can be better understood. For example, there is significant research that attempts to find a positive link between nature and children's health (Hand et al., 2018; Tillmann, Clark, et al., 2018; Tillmann, Tobin, et al., 2018; Villanueva et al., 2016). One of the largest limitations of previous research is due to the inconsistent and diverse methodologies used to measure space (i.e. accessibility and exposure). There is little understanding of the type of nature that can have the greatest impact, how much of it is needed to create an impact, and for how long we need to spend in nature to see that impact (Tillmann, Tobin, et al., 2018) This study for that the use of engagement activity spaces can help to alleviate this limitation by providing the type and duration. Moving forward, research should whenever possible, incorporate both space and time into their measurements of a child's interaction with the physical environment.

5.4 Study Limitations

Although this thesis fills several gaps in our understanding of how the physical environment is studied by researchers and used by children, it is not without limitations. First, the specific empirical evidence on children's environmental engagements presented here is limited to children aged 8-14 years living in rural Northwestern Ontario, and therefore is not generalizable to other age groups of children, or children living in other

geographical contexts. Nevertheless, the methodological contributions of this research are of much broader value to the field of environment and health as they are applicable to all populations and geographic contexts.

Another limitation is related to the timing of the data collection. Although this thesis takes into consideration differences according to weekday vs weekend, as with most environment and behaviour studies of this kind, it does not take into consideration aspects of weather and seasonality.

Although an enormous amount of spatial data was collected through the GPS tracking and went through time intensive processing, there is always the potential for any GPS tracker to lose signal during the data collection period resulting in missing positional data and/or some degree of locational error. This locational error can result in land use or level of greenness misclassification. Nevertheless, to minimize these limitations inherent in GPS analyses, stops and routes based on individual GPS data were generated followed by a manual inspection of the entire data set to ensure spatial locations were accurate and that there were no temporal gaps. To reduce the degree of misclassification, the use of a hexagon grid allowed for a smaller container metric representing a more precise definition of the physical environment variables.

5.5 Implications for Policy and Practice

Public health has been moving towards establishing more preventative initiatives in reaction to the financial burden that current health issues exert on our healthcare system. These preventative forms of care target health issues at the population level. Often these initiatives, whether interventions or policy changes, ignore *how* the physical environment impacts their effectiveness. Developing and promoting effective interventions requires an explicit understanding of how individuals interact with the physical environment, and more specifically what features characterize the physical environment. Researchers must build up a comprehensive knowledge base of individual behaviour in the physical environment to provide the necessary information for policy makers and practitioners to make informed decisions. However, to successfully do so, the environment must be conceptualized and studied using proper methodology. Throughout the health geography

literature there are many examples of the impacts the physical environment on various health behaviours and outcomes. The success of future environmental interventions for health promotion depends on ensuring a community-specific approach that directly builds on the strengths and weaknesses of an area. This thesis emphasizes that how we measure and assess the physical environment can dramatically influence findings, and therefore has the potential to have a large impact on the development of health interventions.

There is currently an increased societal focus on understanding and explaining the influencers of children's overall health (ParticipACTION, 2018). However, as this field continues to grow, there is still limited evidence existing to guide rural planning and public health policies and interventions to improve the health and quality of life for children living in these areas. This thesis can contribute to the empirical evidence base supporting the need for improvements to regularly accessed facilities and the availability of amenities and community specific programs that support a healthy lifestyle. The specific focus on a rural environment is relevant to many policy makers and practitioners in making community-based decisions as literature states that inequality based on level of urbanicity exists in relation to accessing health promoting infrastructure, programs, and services (Boehmer et al., 2006; Smith, Humphreys, & Wilson, 2008; White, 2013). The relationship found regarding children's time spent in institutional and residential areas can support the development and investment in these specific elements of infrastructure in rural environments. Investments in specific elements include the addition of sidewalks or paths, street lights and improved school yards, and recreational facilities. School boards, public health officials and planners can make it part of their mandate to develop strategies that integrate the spaces children use and the promotion of positive health outcomes. Features that are unique to a rural environment, such as the abundance of greenspace and forested areas, should be incorporated into the development and implementation of health promoting infrastructure, programs and services. For example, this study found that participants spend the majority of their time in abundant spaces classified as grass and shrubbery. This evidence can be used to help plan and promote green spaces for the healthy growth and development of children. Previous research supports that many health related behaviours are developed in childhood and persist into adulthood (Loebach & Gilliland, 2016). Planning and investing in supportive, healthy

environments for children is a preventative rather than reactionary form of care (Islam et al., 2016; Telama et al., 2005).

Policy makers and practitioners also need to take a step back to consider how the ways in which we conceptualize and delineate a physical environment for children can influence how we interpret its impact on health, and therefore the type of action required for health promotion. The changes made to policies, regulations, and programs should consider the physical environment of concern, as well as the relationship between an individual and their surrounding physical environment as the potential contributions they have to their overall health.

5.6 Recommendations for Future Research

In the future, the lessons learned from this thesis will be used by researchers in the HEAL (and hopefully elsewhere) to explore a number of different health outcomes in relationship to the physical environment through accessibility, exposure, and engagement.

The STEAM methodology provides a rich data set assessing the behaviours of children in relation to where they live and a variety of associated health outcomes. Further research will explore the use of engagement measures to better understand the relationship between the physical environment and specific health outcomes. This novel methodology along with the combination of additional components of the STEAM project, such as accelerometer data, survey data, and activity diary data, can provide additional details to the context and relationship of *how* children spend their time in the physical environment, not just *where*. Future research will use accelerometer data to investigate the relationship between the physical environment and children's level of physical activity across time and space. Survey data will supplement this objectively measured data to provide intra- and interpersonal details of participants, allowing for various individual level factors to be controlled for and to help explain physical activity patterns. Activity diaries also provide information which allows researchers to determine *what* children are actually doing in different spaces at different times. The written descriptions of what, where, and

with who from the activity diaries will allow us to build the relationship between knowing a child is active and what they are actually doing to be active.

The STEAM methodology also allows for an exploration of how behaviour and attitudes may change over time, as data were collected for each subject in two different one-week periods. Next steps of this research program might include exploring where children spend their time and where they are specifically performing health-related behaviours such as physical activity in different seasons and weather conditions.

Linking data from the various STEAM project phases will allow us to investigate the differences between how children in urban, suburban, and rural environments spend their time in different environments. As indicated in the socio-ecological model, it is important to examine the various levels of the socio-ecological model in areas with different levels of urbanicity and municipal contexts. The variability across urbanities in the natural and built environments, as well as the by-laws and regulations require that the community specific interventions are tailored to the needs of a particular area. Therefore, the methodological contributions of this thesis focused on the environmental level of the model may provide the necessary additional information needed for the continued success of community specific interventions.

Beyond assessing the impact of engagement in different physical environments for physical activity, the same methods can be used to explore environmental impacts on other health-related behaviours and outcomes, including health-related quality of life, sleep, active transportation, and food purchasing behaviours. Future research will continue to measure interactions with the physical environment using accessibility and exposure, not just engagement, as it will be important to discover whether or not the same relationships between all three delineations hold true for all health outcomes studied.

5.7 Conclusions

In conclusion, the results show that the approach to conceptualize and delineate children's interactions with their physical environments affect the quantitative characterizations of built and natural features within their environments. One of the largest issues that previous researchers have faced in their attempts to understand how children interact with the physical environment has been how to accurately conceptualize, delineate, and characterize the complex spatial and temporal dynamics of a child's routine and lifestyle. The use of GPS within GIS technology to generate an engagement activity space allows for individual agency in the precise location of children's movements and activities in their environments. Through an objective assessment of engagement, this research discovered statistically significant differences in the built and natural characteristics of the environments in which girls and boys in rural Northwestern Ontario directly interact with on weekdays and weekends. This thesis took a step back to understand how differences in approaches and methods can influence the validity of findings. Collectively, these findings provide empirical evidence to support the use of an explicit spatial methodology in future research examining children's environments and behaviours.

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Appendices

Appendix A Research Ethics approval Form for use of Human Participants STEAM North (redacted)

Research Ethics



**Western University Non-Medical Research Ethics Board
NMREB Annual Continuing Ethics Approval Notice**

Date: July 26, 2017
Principal Investigator: Dr. Jason Gilliland
Department & Institution: Social Science/Geography, Western University

NMREB File Number: 108029
Study Title: Spatial Temporal Environment and Activity Monitoring Project: Understanding the environmental influences of health in rural and remote communities

NMREB Renewal Due Date & NMREB Expiry Date:
 Renewal Due -2018/07/31
 Expiry Date -2018/08/16

The Western University Non-Medical Research Ethics Board (NMREB) has reviewed the Continuing Ethics Review (CER) form and is re-issuing approval for the above noted study.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), Part 4 of the Natural Health Product Regulations, the Ontario Freedom of Information and Protection of Privacy Act (FIPPA, 1990), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario.

Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB.

The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941

EO: Erika Basile ___ Grace Kelly ___ Katelyn Harris ___ Nicola Morphet ___ Karen Gopaul ___ Patricia Sargeant

Appendix B Parent Letter of Information



Examining the Influence of the Neighbourhood Environment on Children's Health and Well-Being

Principal Investigator: Dr. Jason Gilliland, Dept. of Geography, University of Western Ontario

Dear parent or guardian,

We would like to invite you and your child to participate in a study aimed at understanding how the neighbourhood environment around your child's school affects his or her health. The study is being conducted with grade 4 to 8 classes at various elementary schools across North Western Ontario.

What is being studied?

Our research team is conducting a project which will study the various places or facilities in your neighbourhood that your child uses (or intentionally don't use) on a regular basis for recreational or physical activity, including how they typically travel to these places – for example, how they travel to and from school each day. We are also interested in examining their dietary patterns, in particular, the locations in the neighbourhood at which they typically eat or purchase food. In addition, we'd like to learn more about how children perceive and feel about their local environments, and how this may influence their neighbourhood activities or travel.

What will happen in this study?

If you and your child agree to participate, **your child will be asked to:**

1. Complete the *Healthy Neighbourhoods Survey for Youth* (typically takes 30 minutes to write) about their perception and use of their neighbourhood environment and its facilities for activities and/or food consumption. Surveys will be filled out by all participating students in their classroom at a time made available by their teacher. Members of the research team will be on hand to help children fill out their surveys and to answer questions. All children will be given as much time as needed to complete the survey.
2. Wear two small pieces of equipment - a lightweight GPS logger and a loonie-sized accelerometer – each day during their waking hours for two 7 day periods – once in the Fall (September or October) of this and again in the winter (November or December) of the same year. The GPS logger, worn on an armband or collapsible neck lanyard, only maps the general places the child visited in the neighbourhood and the routes taken to get there - it has no display or orienteering capabilities and the data cannot be seen in 'real time'. The tiny accelerometer, worn on an unobtrusive elastic belt around his or her waist (can be worn underneath clothes), is similar to a pedometer but instead measures intensity of activity (e.g. running is registered as a more intense activity than walking or sitting). These tools will help us to understand children's travel and activity patterns within their neighbourhoods. By having children participate for 2 periods approximately 2 months apart we can also better understand how children's behaviours and activities change with the weather. Researchers will be coming into the schools on a daily basis during school hours to make sure the equipment is functioning and study procedures are being followed.

3. Complete a short activity diary for each day they wear the 2 pieces of equipment, briefly outlining their activities that day.
4. Participating children will also be given the opportunity to meet with the researchers in a focus group to discuss their feelings about their neighbourhood and to help clarify how the built environment of the neighbourhood helps or hinders their ability to engage in various recreational activities, to eat healthy foods, or to travel easily to the places they would like, such as parks. The focus group will typically involve 4-6 youth, will take place either at lunch recess or outside of school time, last about 30-60 minutes, and will be held at the school or another community facility. Participation in the focus group is completely voluntary; a child can decide not to participate in a focus group and still be allowed to participate in the rest of the study. All focus groups are audio-recorded and transcribed verbatim, as it is not possible to audio-record some participants and not others. Therefore, if you do not wish your child to be audio-recorded they will not be able to participate in the focus groups. We as researchers cannot guarantee what is said in the focus group won't be shared by classmates, but we always remind all students not to share what they have heard.
5. Children are welcome to participate in any of the 4 stages of the study. We only ask that if they did not participate in the survey AND the GPS/accelerometer/activity diary portions they do not participate in the focus groups, as we would like to link the findings.

As the child's parent/guardian, **you will be asked to:**

1. Complete the *Healthy Neighbourhoods Survey for Parents* (takes 20-25 minutes to write) about household demographics as well as parent/guardian perceptions about your neighbourhood. The survey will be used to understand the various types of households participating within each school neighbourhood, as well as local parents' perceptions of the neighbourhood and their child's use of this environment. The Parent Survey is completely voluntary and doesn't disqualify your child from participating in the study themselves, but provides us with valuable information from parents' perspectives. We would greatly appreciate your participation.
2. Parents of participating children will also be given the opportunity to participate in a parents' focus group with the same aims as those with the children. The focus group will take place outside of school time, last approximately 45-60 minutes, and will be held at the school or another nearby community facility. Participation in the focus group is completely voluntary; a parent can decide not to participate in a focus group and their child will still be eligible to participate in the study as outlined above. All focus groups are audio-recorded and transcribed verbatim, as it is not possible to audio-record some participants and not others. Therefore, if you do not wish to be audio-recorded you will not be able to participate in the focus groups. We as researchers cannot guarantee what is said in the focus group won't be shared by other parents but we always remind all participants not to share what they have heard.

Do we have to participate in this study?

Your participation in this study is completely voluntary. You and your child are under no obligation to participate, you can refuse to answer any questions, and can choose to withdraw from the study at any time. Your decision will not affect your child's academic standing in any way.

What are the benefits and risks if my child participates?

Recent research has shown that our health is not only related to our personal lifestyle, such as the food we eat or physical activity we undertake, but also to the characteristics of the neighbourhood(s) within which we conduct our daily activities. Reviewing the information collected from this study will help us to better understand the links between our neighbourhood environments, our activities, and our health. The study results may be useful for local municipal and school board planners and decision makers who require input on how best to plan design healthy communities.

There are no costs to you or your child for participating in this study. However, each participant will earn \$2/day for each day they are enrolled in the study and \$3 for returning the equipment in each season. If children do not wear the GPS or return the diary for any given day, the \$2 will be withheld until the following day when they are able produce their GPS and diary.

The equipment in this study is easy to use, and the research team will spend time with your child to make sure he or she understands how to use and care for the equipment. However, if any pieces of equipment break or become lost during the time they are in their possession, we will immediately provide them with a replacement unit without any cost or consequence to you or your child.

There may be risks to your child if he/she participates in this study; fatigue or disinterest on the part of the child in continuing with the study for the full 7 days are considered the largest risks. However, each piece of equipment weighs less than 60g (0.12 pounds). The height and weight of each participating child will also need to be collected, strictly to properly set up the accelerometer. Measurements will be taken in a private area at the child's school in the presence of a trusted adult (e.g. school nurse or teacher); no other children or persons outside of the research team will be present. The equipment used to measure a child's weight has no visible display; measurements are sent wirelessly to a nearby laptop and therefore will not be visible to anyone except research team members.

There is no risk that you or your child will be identified or identifiable in any study materials or publications. All of the information collected in this study will remain strictly confidential. Anonymity will be assured by assigning you and your child a unique identification code so that names or personal information will not appear on any survey or data file. Also, completed surveys, focus group transcripts (audio and written), and any detailed maps created from the GPS data, will only be viewed by members of the research team and will be stored in a locked filing cabinet or on a password protected computer in a secure room at the University of Western Ontario. Teachers and other students do not have access to ANY of this information and it is only made available to the participant themselves and the research team. Focus group members are asked to keep everything they hear confidential and not to discuss it outside of the meeting. However, we cannot guarantee that confidentiality will be maintained by group members. Participating children will be able to review maps of their individual travel patterns on request for authentication purposes and to modify any information that they feel does not accurately reflect their experience. However, to ensure participation while protecting the privacy of each child, data or maps made from GPS units will not be made available to parents or guardians. We will inform the participants that the GPS unit is equipped with an "on/off" button and they can turn off the unit if ever there is an occasion where they wish not to be recorded. While we do our best to protect your information there is no guarantee that we will be able to do so. If data is collected during the project which may be required to report by law we have a duty to report.

If you or your child chooses to withdraw from the study at any time, up to 30 days after the completion of the project, any of your/their personal data collected to date will be immediately destroyed and excluded from the study analysis.

You do not waive any legal rights by signing this consent form

Who do I contact if I have any other questions?

Should you have any questions or concerns about participating in this project, you can contact the lead researcher Dr. Jason Gilliland, University of Western Ontario. [REDACTED]

Representatives of The University of Western Ontario's Non-Medical Research Ethics Board may require access to your study-related records to monitor the conduct of the research. If you have any further questions regarding your rights as a study participant, please contact the Office of Research Ethics at [REDACTED]

Research Team

Dr. Jason Gilliland, Department of Geography, University of Western Ontario
Dr. Piotr Wilk, Department of Epidemiology, University of Western Ontario
Brenton Button, Department of Geography, University of Western Ontario

**This letter is for you to keep. Please return the attached Parent/Guardian consent form.
You will also be given a copy of the consent form once it has been signed.**



Appendix C Parental Consent Form



[REDACTED]

Examining the Influence of the Neighbourhood Environment on Children's Health and Well-Being Parent / Guardian Consent Form

Principal Investigator: Dr. Jason Gilliland, Dept. of Geography, University of Western Ontario
[REDACTED]

Regardless of whether you are consenting to let your child to participate in this study, we would ask that you return this form to school with your child, sealed in the envelope provided. Envelopes will be collected by your child's teacher. Thank you!

A. Parent Involvement

Consent: I, _____ (*name of parent/guardian- please print*), have read this letter and have been given the opportunity to ask questions. Any questions have been answered to my satisfaction.

- I agree to participate by completing the *Healthy Neighbourhoods Survey for Parents (optional; if yes, please seal the survey in the envelope provided and return with signed consent form)*
- I am interested in being contacted about participating in a parent focus group (*optional*). Please provide either phone or email contact information _____

B. Child Involvement:

- I agree to let my child _____ (*child participant's name – please print*) participate in the full 14 days (two 7-day periods within the next 2-3 months) of monitoring as outlined above.

OR

- I agree to let my child _____ (*child participant's name – please print*) participate **ONLY** by way of completing the *Healthy Neighbourhoods Survey for Youth* (to be administered at child's school) rather than the full study.

C. If you are providing consent for your child to participate in this study, please answer the following questions:

- I agree to allow my child to participate in an optional focus group at the end of the study.
- I am aware that unidentified direct quotes from the focus groups could be used in future publications.
- Please check if your child has *health issues* which restrict their ability to walk/exercise or otherwise participate in this study.

Parent/Guardian Print Name

Parent / Guardian's signature

Date

Appendix D Child Letter of Information and Assent



How healthy is the Environment in Your Neighbourhood? Letter of Assent- Student

Principal Investigator:

Dr. Jason Gilliland, Department of Geography, University of Western Ontario

Hello! We are researchers from the University of Western Ontario and we are doing a study in your neighbourhood! We need students in Grades 4-8, like you, to help us with this project!

What are we going to study?

We all know that getting lots of exercise and eating the right foods can help keep us healthy. We'd like to know if the places or facilities that you have and use in your neighbourhood also help to keep you healthy. You will not be tested! We want to collect this information so we can share our results with you and others who can help make your environments healthier.

What would you have to do?

If you agree to be in the study there are 4 things we would like you to do:

1. Wear 2 small pieces of equipment every day for a week this Fall, and again in the Winter. A small GPS unit will help us to make a map of all the places you visit every day. You would also wear a 'loonie'-sized piece of equipment called an accelerometer on an elastic band around your waist that will tell us when you are doing physical activity, like running or playing sports. Both pieces of equipment are very light and easy to use. We will also come to your school every day in case you need help.
2. Fill out a short 1-page diary everyday about the activities you did that day during both sessions.
3. Fill out a short survey on what you think about your neighbourhood. You will fill this out one day at school with your classmates both during the Fall and Winter sessions. It takes about 30-45 minutes.
4. Then you would wear the equipment and fill out the diary again for a week later this Winter.

To work some of the equipment we'll need to measure your height and weight. We'll do this in a private area at your school. Your teacher can be in the room. We won't share the information with anyone else.

After both weeks are done, you could also join in a group discussion with some of your classmates to talk to us about where you like to go in your neighbourhood and the activities you like to do. You do not have to join in this group activity. This will take place at your school. We would like to audio record our talk. All focus groups are audio-recorded and transcribed word for word, as it is not possible to audio-record some participants and not others.

Therefore, if you do not wish to be audio-recorded you will not be able to participate in the focus groups. We as researchers cannot guarantee what is said in the focus group won't be shared by your classmates, but we always remind all students not to share what they have heard.

Do you have to join this project?

No – you will only join if you would like to. You can also decide at any time that you would like to stop. We will never share your information with anyone else, even your parents, but you can ask to see it at any time. You can ALWAYS talk to your teacher or the researchers if you have any questions or worries. We only ask that if you did not participate in the survey AND the GPS/accelerometer/activity diary portions of the study that you do not participate in the focus groups.

This letter is yours to keep for future reference.

I want to participate in this study!

If you would like to join this study in some way, choose one of the following two options:

I want to participate in the full 2 week study OR I only want to complete the in-class survey

AND please choose whether or not you would like to participate in a focus group:

Yes, I would like to participate in the audio-recorded focus groups OR
 No I do not want to participate in the audio-recorded focus groups

If you answered YES to participating in the focus groups:

Please check this box if you are aware that anonymous direct quotes from the focus groups could be used in future books or published papers.

Print First and Last Name

Signature

Age

Date

Signature of Person Obtaining Assent

Date

Curriculum Vitae

Name: Katherine Leslie Schieman

Post-secondary Education and Degrees: University of Waterloo
Waterloo, Ontario, Canada
2010-2014 B.E.S (Honours) Geography and Environmental Management, Minor Psychology

The University of Western Ontario
London, Ontario, Canada
2016-2018 (Expected) M.Sc. Geography

Related Work Experience: Teaching Assistant
The University of Western Ontario
2016-2018

Research Associate
Human Environments Analysis Laboratory
2015-Current

Conference Presentations: Oral Presentation
Schieman, K. & Gilliland, J. *Examining Environmental Influences on Physical Activity Levels on Children in Rural Northwestern Ontario*
American Association of Geographers
New Orleans, Louisiana, April 2018