The place of geographic information and analysis in global health: A case of maternal health in regions of southern Mozambique

by

Prestige Tatenda Makanga

M.Sc. Eng (Geomatics), University of Cape Town, 2010

B.Sc. (Surveying and Geomatics), Midlands State University, 2006

Thesis Submitted in Partial Fulfillment of the
Requirements for the Degree of
Doctor of Philosophy

in the
Department of Geography
Faculty of Environment

SIMON FRASER UNIVERSITY

Summer 2016

Approval

Name:	**Prestige Tatenda Makanga**
Degree:	**Doctor of Philosophy (Geography)**
Title:	***The place of geographic information and analysis in global health: Maternal health in regions of southern Mozambique***
Examining Committee:	**Chair:** Nicholas Blomley Professor

Nadine Schuurman
Senior Supervisor
Professor

Peter von Dadelszen
Supervisor
Professor

Valorie Crooks
Supervisor
Associate Professor

Martin Andresen
Internal Examiner
Professor
School of Criminology

Stephen Munjanja
External Examiner
Professor, Obstetrics and Gynecolocy
University of Zimbabwe

Date Defended/Approved: August 26, 2016

Ethics Statement

The author, whose name appears on the title page of this work, has obtained, for the research described in this work, either:

a. human research ethics approval from the Simon Fraser University Office of Research Ethics

or

b. advance approval of the animal care protocol from the University Animal Care Committee of Simon Fraser University

or has conducted the research

c. as a co-investigator, collaborator, or research assistant in a research project approved in advance.

A copy of the approval letter has been filed with the Theses Office of the University Library at the time of submission of this thesis or project.

The original application for approval and letter of approval are filed with the relevant offices. Inquiries may be directed to those authorities.

Simon Fraser University Library
Burnaby, British Columbia, Canada

Update Spring 2016

Abstract

Maternal ill-health is a major global health burden, responsible for approximately 350000 deaths every year. While this is a very high figure considering that most maternal deaths are avoidable, it represents close to a 45% reduction in maternal death rates from 1990, and is a largely the result of successful clinical strategies that were pioneered through the Millennium Development Goals. However, emerging strategies in global maternal health now acknowledge the broad nature of the socio-cultural and environmental determinants associated with maternal health, and call for multi-sectoral approaches to complement the dominant clinical perspectives. While there is mounting evidence on the importance of the social determinants of health, there are multiple challenges associated with identifying, measuring and taking action on the context specific determinants of health.

This dissertation posits that some of the techniques that have been developed in the discipline of health geography offer potential to address these challenges. The objectives of this dissertation were to implement geographic methods for identifying and measuring the context relevant determinants of maternal ill-health, and to elucidate the place specific characteristics of associations between these social determinants and maternal health outcomes. The thematic premise of this dissertation was partly determined through extensive exploration of literature on what is known concerning the use of geographical information systems in maternal health. The core empirical work supporting this dissertation was completed in the southern region of Mozambique and addressed the objectives through both qualitative and quantitative exploration, identifying community perceptions of these determinants and validating them using geostatistical methods. Key data challenges concerning the use of geographical analysis are also addressed. Chiefly, this dissertation contributes a suite of methods that demonstrate how to measure the social determinants of maternal health. While this research was conducted in Mozambique and addresses maternal health, the geographic approach highlighted in this work could be used to understand other health concerns and in different places.

Keywords: global health; maternal health, health geography; GIS; social determinants of health

Dedication

To Baba na Amai,

Thank you for all you have done…

Acknowledgements

First I would like to thank Nadine, my senior supervisor for inviting and trusting me to be part of this important project. Your insights and leadership have been of much benefit to me. Your model of running the lab up at SFU, is something I hope to replicate in the future. Thank you for teaching me how to write, I am still on that journey but you have surely set me up. To Peter and Laura, thank you for allowing me into your team. Attending the Thursday meetings at Women's and conversations in the offices and corridors have been very enlightening. Thank you for the opportunities that you have awarded me, to present my work at to your circle important global health players, including the USAID, Gates foundation, and the Ministry of health in Mozambique. To Valorie, thank you for your critical input into shaping my work from the start of my PhD, through my comps and proposal defence. Your methods class was also an eye opener. Thank you for the opportunities you gave me to interface with your group, in organizing the IMGS. Thank you Prof Stephen Munjanja my external, and Prof Martin Andresen for reading my dissertation and making yourselves available for my defense.

To Tabassum, you are one of a kind! Thanks for your clinical insights into our MOM work and for working overtime, reviewing papers and reports. To the CLIP teams in Manhica and Canada, thank you for accommodating my geographic perspectives. All of you have your fingerprints all over this work through the different roles that you have played; from processing my stipend, getting data to me in usable formats, sitting through mock presentations during the VIPER sessions, translations from Portuguese, field data collection etc. Thank you! To Blake, Mike, Jon, Britta, Ofer, Aateka and David, thanks for being great lab mates. I know our paths will continue to cross, and I look forward to working together more as we attempt to convince the rest of world that they are better off thinking geographically. Thank you to my Trinity Central family. Vancouver felt like home from the first day, thanks to you. Finally, Charlene. You have been amazing! You have done very well for me and the kids through these busy years of being away in Mozambique and Zim for extended periods. I hope to return the favor one day.

Table of Contents

List of Tables

List of Figures

Chapter 1. Introduction

1.1. Overview

Health is a function of more than just the presence or absence of disease. In addition, health is influenced by social determinants of health (SDH) that include local histories, globalization, culture, socio-economic status and other factors that characterize the everyday contexts of populations (de Andrade et al., 2015; Koplan et al., 2009; Labonté & Schrecker, 2007a). Priority setting in health has however, largely been disease-driven, with a focus on biomedical interventions and technical innovations for treatment of disease and reduction of mortality, with less emphasis on the broader contextual forces that contribute to generating the observable patterns in disease outcomes (Leroy, Habicht, Pelto, & Bertozzi, 2007; Östlin et al., 2011; Ranson & Bennett, 2009). This focus on disease and mortality is reflected in that 3 of the 8 Millennium Development Goals (MDGs) were health related. These goals focused on reducing under-five mortality and maternal mortality by two-thirds and 75% respectively between 1990 and 2015, and halting the spread of HIV/AIDS, malaria and other diseases (MDGs 4, 5 and 6) (Sachs & McArthur, 2005). Although none of these ambitious targets were met by their 2015 deadline, remarkable strides were made, with under five mortality rates declining by more than 50%, maternal mortality ratio by 45%, new HIV infections by 40%, while 6.2 million malaria deaths were averted (United Nations, 2015). A substantial portion of these improvements can be directly attributed to successful medical and clinical interventions, which include the implementation of vaccination programs, increase in hospital births assisted by a skilled birth attendants, and increased access to antiretroviral therapy (United Nations, 2015).

While the MDGs are evidence of the efficacy of clinical approaches in improving health, there is wide consensus that medical care alone is insufficient to fully and effectively address the disparities in health. The underlying social drivers that generate the global patterns in health also require attention (Braveman, Egerter, & Williams, 2011; Marmot, 2005). Much of the evidence in support for this paradigm was gathered after the conception of the MDGs through the work of the World Health Organization's (WHO) commission on the social determinants of health (Marmot, Friel, Bell, Houweling, Taylor, et al., 2008). This new paradigm on health is now somewhat reflected in the new Sustainable Development Goals (SDGs) (United Nations, 2015), with health only explicitly covered through one goal, though implicitly covered through many other goals that address known determinants of health (e.g. goal 1 on poverty, goal 2 on nutrition, goal 4 on education etc.). On the one hand, the SDGs may therefore be perceived to be de-prioritizing health to just 1 of 17 goals (compared to 3 of 8 MDGs) (Murray, 2015). On the other hand, they echo the trend in global health thinking that disease outcomes are a symptom of wider set of determinants, and that a focus on these distal factors will have a ripple effect on health through a preventative rather than curative emphasis (Buse & Hawkes, 2015).

This paradigm shift in the conceptualization of global health, has not been without challenges. One of these challenges has to do with the scale at which health problems are imagined and understood. While macro trends in disease burden (through national estimates of disease prevalence) have been a dominant driver for determining global health priorities (Murray & Lopez, 2013), there is an increasing awareness of the value of local (subnational) experiences in health (United Nations, 2015). However, it is also acknowledged that major global determinants still have an influence on these local experiences (Labonté & Schrecker, 2007b). The implication is that global health strategies have to be conceptualized in line with local circumstances, and therefore not necessarily generalizable to other contexts, unlike clinical interventions that by design are meant to be readily generalizable for global impact. Further to that, methods of measuring progress on improving health at the subnational level, and quantifying relationships between the local social determinants of health and health outcomes both locally and globally is a foreseen challenge (Murray, 2015). In fact, at the time of writing this dissertation there are no finalized guidelines and indicators for measuring progress for the new SDGs, making this dissertation a timely contribution to this discourse.

This dissertation adds to the ongoing discourse on improving health by addressing broader structural and social determinants of maternal health in a region of southern Mozambique. It is outside the purview of one PhD dissertation to analyse or explain all the complex linkages between determinants of health and health outcomes, hence my thematic focus is on maternal health, which I elaborate on later in this chapter. In particular, the dissertation used geographic methods to identify and elucidate the local determinants of maternal health in the study region. The two structural underpinnings to the core contributions of this dissertation are thus global health and health geography, which I introduce and review in the following section.

1.2. Global health

Global health is a paradigm of health that does not respect national borders (Kickbusch, Silberschmidt, & Buss, 2007), focusing instead on improving health and achieving equity in health for all people worldwide (Koplan et al., 2009). This new model broadly addresses health disparities across the globe through action on the SDH; the conditions or contexts that people are born, live and age in that influence their health (Kelly & Bonnefoy, 2007; Krieger, 2001; Marmot, Friel, Bell, Houweling, & Taylor, 2008). Global health is distinguished from its predecessor International health, a paradigm that originated in the early 1950s, and was driven largely by the need of wealthy countries to help poor countries improve their health (Banta, 2001; Brown, Cueto, & Fee, 2006). As global health transcends national boundaries, health issues in one place are more than just the responsibility of the populations directly affected (Kickbusch et al., 2007).

Despite the evidence supporting links between the SDH and health outcomes (Bhutta & Reddy, 2012; Labonté & Schrecker, 2007a; Marmot, Friel, Bell, Houweling, & Taylor, 2008), very little action has been taken to address determinants of health on a global scale. The impact of action on the SDH on health outcomes is also less directly quantifiable when compared to the impact of curative interventions on reducing disease burden. Therefore, these determinants have been of less interest to global health funders, who seem to be largely driven by the clear targets, quick results and impact that clinical interventions promise (Cueto, 2004; Irwin & Scali, 2007; Locker & Scambler, 2008; Potvin, 2009). It is, therefore, not surprising that vertical clinical interventions, targeted at reducing mortality induced through very specific and well understood disease pathways have been of greater interest – given the difficulty of changing fundamental economic relationships (Kirk, Tomm-Bonde, & Schreiber, 2014).

While the equity drive in global health calls for addressing the determinants that lead to bad health outcomes (Kelly & Bonnefoy, 2007), action on these determinants remains a challenge to operationalize in the way that clinical interventions can. Within maternal health, these determinants could be a function of geographic space; for example, women living in geographically isolated communities are generally at a higher risk of dying in the event of a pregnancy complications (Grzybowski, Stoll, & Kornelsen, 2011). SDH could also be a function of culture and other socio-economic factors. An example is how that cultural perceptions towards childbearing has an impact of fertility rates which have a direct impact on child and maternal mortality (Smith, 2004). SDH could also be a function of history. We know that communities that have a history of war or are emerging from war will likely have some critical infrastructure destroyed in a manner that has hampers access to pregnancy related emergency care (Jambai & MacCormack, 1996; O'Hare & Southall, 2007). These three facets of what could characterize people's contexts are in no way exhaustive, but give an indication of how the diverse nature of these contextual elements are, thereby making it challenging to tailor blanketing interventions that address the SDH.

This dissertation in anchored in these emerging perspectives in global health. It also posits that some of the techniques that have been developed in the discipline of health geography offer potential to address the above challenges.

1.3. Health Geography

Health geography is a sub-discipline of human geography, which offers a holistic view on health by linking health and disease outcomes to the socio-cultural and physical environment, and the places that generate them (Dummer, 2008).

Historically the terms 'medical geography' and 'geography of disease' were used interchangeably to describe the discipline (May 1950), which had much influence from biomedical models of health, and was driven largely by the disease ecology framework (Meade 2012). The work of medical geographers has therefore naturally been more empirical and quantitative in nature, and has been more popular with funders of health research for the same reasons that interventions of a biomedical nature attract more funding than action on SDH (Kearns and Moon 2002). The work of medical geographers thus features prominently in medical journals, which have greater impact factors than the geography journals, maintaining the medical geographers' visible presence and relevance, especially to a clinical and epidemiological audience (Mayer 2010), while remaining conspicuous through an absence from geography literature.

It has been just over two decades since the landmark call for a reformed medical geography was made by Kearns (1993). A major prompt for this call was a claim that medical geographers had a too simplistic interpretation of space as a container of health and illness and had neglected the role that context plays in generating good and bad health outcomes (Kearns and Joseph 1993). Space is defined as 'the dimension within which matter is located or a grid within which substantive items are contained' (Agnew 2011). In medical geography space has been the organizing principle for health data, mainly through using it as the basis for describing prevalence rates and patterns for disease within distinct spaces (Dorn 1994), an approach also commonly used in global disease burden studies. In other words, spatial (or space based) data is used to describe the composition of disease within distinct spaces (Macintyre, Ellaway et al. 2002). It has been argued that this use of space as a container for disease count results in aggregate measures of disease trends, and aggregate analysis is essentially 'incapable of distinguishing the contextual (the difference a place makes) from the compositional (what is in a place)' (Jones and Moon 1993).

Place is a more subjective and less intuitive term that speaks specifically to the contextual rather than compositional matters that make up spaces (Macintyre, Ellaway et al. 2002). It encompasses the social and cultural characteristics that influence health and health care delivery (Andrews, Evans et al. 2012). The need for mechanisms to traverse through a place and acquire knowledge about the interactions between health and the contextual forces that generate it was one of the things that prompted the need to define a new health geography research agenda. The new health geography which values mechanisms for exploring health through the lens of place goes beyond the geometric construction of space to understand the contextual forces behind good or bad health outcomes (Kearns and Joseph 1993; Brown 1995). With place being the central guiding rod for health geography research and space for medical geography, a different set of methods are preferred in each of the two sub-disciplines. Health geography mainly uses methods from human geography; for example narratives and storytelling (Kearns 1997) or focus group discussions (Vuksan, Williams et al. 2012). However studies that are aligned with medical geography mainly utilize methods rooted in the natural sciences and spatial epidemiology like Geostatistics (Shoff, Yang et al. 2012) and mathematics (Berke 2004). These differences in methods have made the chasm between the two disciplines more apparent.

Two decades on, it remains unclear whether or not there has been broad consensus on what should constitute a reformed geographies of health between the health and medical geographers. What is apparent though, is that both streams of work are still happening, and that both offer useful perspectives to the geographic inquiry of health. Both streams of thought also offer potential to address the challenges stated earlier concerning the determinants of health.

1.4. Maternal health

Maternal health is the thematic focus of this dissertation, though I think that the principles established through this work are crosscutting and apply broadly to other social determinants of health as the same determinants that are explored in this work could influence other disease outcomes. This section discusses the global maternal health burden, the known determinants of maternal health as well as how upcoming strategies within global health that could potentially interface with efforts to improve global maternal health.

1.4.1. The global burden of maternal ill-health

Maternal ill-health is a major global health burden, responsible for approximately 350,000 deaths every year (Hogan et al., 2010). Most of maternal deaths are avoidable, because they result from modifiable factors that could be addressed through targeted interventions (Collender, Gabrysch, & Campbell, 2012). A maternal death is defined as “the death of a woman while pregnant or within 42 days of terminating a pregnancy, irrespective of the duration and site of the pregnancy, from any cause related to or aggravated by the pregnancy or its management but not from accidental or incidental causes” (World Health Organization, 2004). Maternal deaths are, however, a small portion of the global maternal health burden as it is estimated that for each death, close to twenty more women suffer from life-long disabilities induced from severe maternal morbidities such as fistula which results from obstructed labour (Alvarez, Gil, Hernández, & Gil, 2009; Firoz, Chou, von Dadelszen, Agrawal, Vanderkruik, Tuncalp, et al., 2013). Maternal death rates have however fallen by approximately 45% from 546 000 annual deaths in 1990 when the MDGs were established (United Nations, 2015).

Seventy-five percent of all maternal deaths result from direct obstetric causes (Thaddeus & Maine, 1994; Wall, 1998). Postpartum hemorrhage (PPH) is the leading cause of maternal deaths followed by hypertensive disorders for pregnancy then sepsis/infections (Khan, Wojdyla, Say, Gülmezoglu, & Van Look, 2006). The risk of a woman dying as a result of pregnancy complications during her lifetime ranges from 1 in 6 (Afghanistan) in the poorest countries to about 1 in 30 000 in Northern Europe, with Africa having an average of 1 in 16 (Ronsmans & Graham, 2006). There is no other health burden with a reliable health indicator and data, that has a disparity greater than the maternal health of LMIC compared to High Income Countries (HIC) (Mahler, 1987; Wall, 1998).

1.4.2. Risk factors for adverse maternal outcomes

The known risk factors leading to adverse maternal outcomes (deaths and severe morbidity) are many and exist both at the level of the individual women and her environment. At the individual level, a Nigerian study showed maternal age to be an important factor as 43% of all maternal deaths in the study were women older than 35 (Olowonyo, Oshin, & Obasanjo-Bello, 2005). Reproductive health education for both men and women is also an important factor (Wall, 1998) as this directly empowers women to make decisions about having children and when. Contraceptive use was shown to have averted 44% of all maternal deaths in 172 countries worldwide (Ahmed, Li, Liu, & Tsui, 2012). Birth spacing is also important, with both long and short birth intervals being associated with risk for pre-eclampsia (Conde-Agudelo, Rosas-Bermúdez, & Kafury-Goeta, 2007). Longer birth spacing increases risk for third trimester bleeding and short intervals increase the risk for uterine rupture. Marital status, social standing, self-esteem, or psycho-social stress are also individual factors associated with risk for adverse maternal outcomes (Ronsmans & Graham, 2006).

Environmental and community level factors also have an impact on the risk for adverse maternal outcomes in pregnant women. For example, it is known that women living in areas that are just emerging from conflict are at higher odds of dying from pregnancy complications than women in areas that have had sustained peace and stability (Jambai & MacCormack, 1996; O’Hare & Southall, 2007). The same applies for natural disasters (Nour, 2011). Religion is also a well-documented socio-cultural determinant for maternal deaths as in some religions women will not be allowed to visit health facilities and some are suppressive to women’s basic rights (Evjen-Olsen et al., 2008; Jambai & MacCormack, 1996; O’Hare & Southall, 2007). Ethnicity, caste, or race are also factors, though largely by association (Ronsmans & Graham, 2006). According to (Cheng, Schuster-Wallace, Watt, Newbold, & Mente, 2012) 15% of all maternal deaths result from infections acquired in the 6 weeks after childbirth. This is largely a result of poor hygiene at home and poor infection control during labor and delivery. Half of these deaths can be averted by good hygiene and improved water and sanitation.

Health systems related factors also matter. From the onset of a pregnancy complication there are three major delays that elevate the risk of an adverse maternal outcome; delay in deciding to seek care, delay in reaching the facility and delay in receiving adequate care at the facility (Thaddeus & Maine, 1994). The factors that result in delaying to seek care are perceived long distance to the facility, high cost of services, perceived bad quality of care at a facility and lack of maternal education. Distance has a dual effect as long distances may demotivate women from going to the facility (first delay) and make it too long to get to a facility as well (Wall, 1998) (second delay). Other factors in the second delay include the spatial distribution of health facilities, which may result in inaccessibility due to distance or bad/missing road infrastructure (Olowonyo et al., 2005) and the unavailability of ready transport. The second delay is thus explicitly geographical, whereas the first delay is implicitly so. The third delay happens in the facility where a woman will be delayed getting treatment mainly because of poor staffing and equipment (Olowonyo et al., 2005; Wall, 1998). Delayed referrals are also a direct consequence of the third delay. Other factors related to the health system include prenatal care coverage, birth assisted by skilled birth attendants, literacy and school enrollment (Alvarez et al., 2009; Boerma, 1987; Evjen-Olsen et al., 2008).

1.4.3. Emerging global health strategies and the interface with maternal health

The Maternal Mortality Ratio (MMR) is a widely used population level indicator for measuring progress on improving maternal health. Most maternal deaths happen between the third trimester and a week after delivery, with a significant peak at day one and two after delivery (Ronsmans & Graham, 2006). Interventions aimed at reducing maternal deaths have thus targeted saving women's (and children) lives at birth. There is wide consensus that strengthening health systems in a manner that allows them to better deliver emergency obstetric and intrapartum care for pregnant women, and increase the number of births administered by skilled health workers will have the greatest impact on reducing maternal mortality (Adegoke, Utz, Msuya, & van den Broek, 2012; Lawn et al., 2011; Oestergaard et al., 2011; Scott & Ronsmans, 2009).

Emerging strategies for addressing the global maternal health burden, are increasingly being informed by the knowledge that the risk factors are broad, as illustrated in previous sections, and need to be addressed through multi-sectoral approaches. Specifically, a key strategy for the new SDGs is to "draw on contributions from indigenous peoples, civil society, the private sector and other stakeholders, in line with national circumstances, policies and priorities" (United Nations, 2015). This multi-sectoral pursuit for perspectives on how to address pressing global health issues acknowledges that the global patterns in health do indeed have a local expression and local drivers that need to be understood at that level.

Another aspect of the SDGs that is important to this dissertation is the call for greater disaggregation of subnational trends in health outcomes and associated risk factors (United Nations, 2015). This was not a priority for the MDGs and this new idea will help to create an understanding of more granular trends and better elucidate the place specific nature of associations with health outcomes. Mechanism and guidelines to measure these disaggregate trends have however not been made explicit in policy documents, and this is an opportunity for exploring spatial techniques.

There is an increasing awareness among health practitioners and researchers surrounding the value of applying geographic thinking and methods to health research in general (Richardson et al., 2013), and maternal and newborn health in particular (Ebener et al., 2015). This increase in attention on the value of geography to health is also an opportunity to explore its potential in operationalizing the mentioned global health strategies. The qualitative exploration of the geographies of health, equipped with methods like focus group discussions and interviews has been used for creating new knowledge on the place specific determinants of maternal health (Audet et al., 2015; Munguambe et al., 2016), and can further the exploration of community level intelligence on the important factors associated with maternal health outcomes. This approach speaks directly to the first SDG strategy mentioned in the previous section. The visual and analytical prowess of geographical information systems has been explored in epidemiological studies linking maternal outcomes and utilization of maternal health services with the social determinants of health (Shoff, Yang, & Matthews, 2012). This has enabled disaggregate analysis of maternal health trends and speaks to the second SDG strategy in the previous section. A fusion of these two perspectives is generally lacking, and this dissertation at its core, makes steps towards filling this gap by illustrating the value of both methodologies in understanding the SDH.

1.5. Objectives, study area and dissertation structure

1.5.1. Objectives

This dissertation contributes to both global health and health geography, and posits that geographic thought helps to address the mentioned challenges concerning the social determinants of health. Broadly, the dissertation explores the intersection between the geographic inquiry of health and global health, in elucidating the contextual forces that generate good or bad health outcomes. Specifically, the dissertation adds value to these ongoing ideas by using geographic methods to identify and measure the context specific social determinants of maternal ill-health in a region of southern Mozambique.

The larger objectives of this dissertation are:

1. To implement geographic methods for identifying and measuring the context relevant determinants of maternal ill-health
2. To elucidate the place specific characteristics of associations between these social determinants and maternal health outcomes.

The theoretical underpinning for this dissertation draws largely from the global health knowledge sphere, through the social determinants of health paradigm (Figure 1.1). The methods used in this research are primarily situated within the health geography sphere and include both quantitative and qualitative techniques. A common value for context and scale undergirds both knowledge spheres. While this research is an application specifically to maternal health, the methods and conceptual framework used in this research could be applied to other global health themes as well.

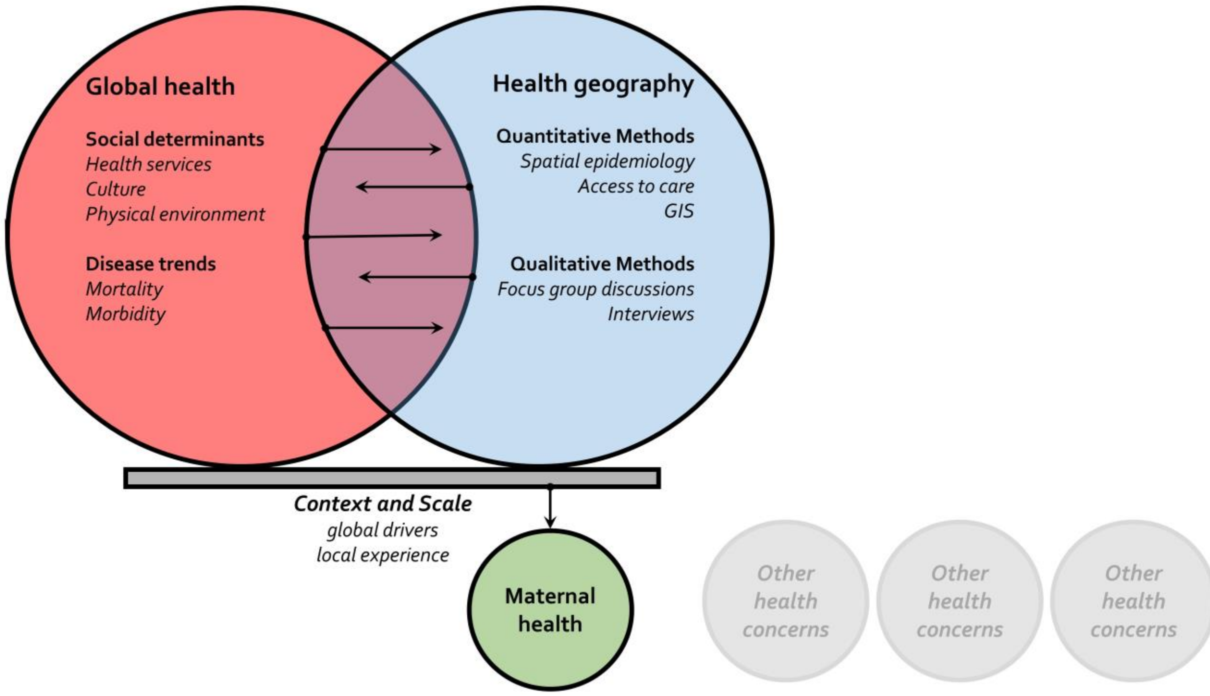


Figure 1.1: Conceptual framework for research

1.5.2. Study area

The core empirical work for this dissertation was conducted in an area of southern Mozambique that includes 36 administrative regions (localities) in Gaza and Maputo provinces. Mozambique has a maternal mortality ratio (MMR) of 480 per 100,000 live births, and is among the top 20 countries with the highest MMRs in the world (United Nations Commission on Information and Accountability., 2013). Previous studies in Mozambique have indicated that post partum haemorrhage (PPH), eclampsia and sepsis are the leading causes of maternal deaths (David et al., 2014; Pereira et al., 2007). Between 40 and 45% of all births in the country happen 'out of facility' in the absence of a skilled birth attendant, with most of these high risk births happening in the home (Instituto Nacional de Estatística & MeasureDHS, 2011; United Nations Commission on Information and Accountability., 2013).

The important role of the determinants of maternal ill-health that are not typically addressed by the health care system has been illustrated through previous studies in Mozambique. Examples of these determinants include, lack of emergency transport funds, long distances to health facilities, bad roads and flooding (David et al., 2014; Jamisse, Songane, Libombo, Bique, & Faúndes, 2004; Munguambe et al., 2016). The patriarchal nature of culture, as well as a lack of knowledge concerning pregnancy complications have been reported as factors that elevate the vulnerability of pregnant women and also hamper care seeking related to maternity (Audet et al., 2015; Boene et al., 2016). This vulnerability is even further intensified by poverty, inequality and the absence of male decision makers from matters related to pregnancies (Chapman, 2003, 2006).

Recent health policy priorities in Mozambique somewhat reflect a prioritization of aforementioned determinants, particularly through an emphasis on addressing issues like the geographic inequities in health and gender inequality through multi-sectoral cooperation (World Health Organization, 2014). It is however unclear whether or not strategies exist to turn these policies into programs that support measurement of these determinants and evaluating their impact on maternal outcomes.

1.5.3. Dissertation structure and overview of chapters

The rest of this dissertation is made up of four stand-alone papers that address the objectives described earlier, and a concluding chapter. The first paper (Chapter 2), a scoping review that was published in the International Journal for Gynecology and Obstetrics, serves as a broad exploration of the use of how geographic information systems have been used in maternal health. The second paper (chapter 3) is under review in the International Journal for Health Geographics and addresses the first objective of this research while the third (Chapter 4), which is ready for submission to a peer reviewed journal, addresses the second objective. The fourth paper (Chapter 5) serves as a resource for health researchers working in a typical data poor setting, and is based on my experience leading the work presented in chapter 3 and 4. This paper was published in The Canadian Geographer. Finally, chapter 6 is the conclusion, where I reflect on the objectives and discuss the implications of my core findings.

Chapter 2 of this dissertation describes what is known concerning the use of geographical information systems in maternal health research and practice. Using the scoping review method, this chapter serves partly as a broad and systematic exploration of published and grey literature on the subject central to this dissertation. It also sets the thematic premise for this dissertation by identifying key knowledge gaps in the application of GIS in maternal health. Some of these gaps are addressed in the subsequent chapters.

Chapter 3 presents a new approach to modeling geographical access to maternal health services, accounting for the impact that precipitation and flooding have on impeding access to maternal health services in the Mozambique study area. The study introduces a new approach for modeling travel that accommodates multiple transport modes, and respects the hierarchy of the health facility referral network. Data from both a census and from assessments of health facilities in the study area informed our understanding of the likely modes of transport that women would use to travel to different level health facilities. The purpose for this study was to address some of the knowledge gaps concerning access to maternal health services that were identified in the scoping review, highlighting the value of adopting context relevant measures for maternal health services provision.

Chapter 4 is a study of the place specific factors that are associated with rates of adverse maternal, fetal and newborn outcomes. The study was conducted as part of the feasibility study for the Community Level Interventions for Pre-Eclampsia (CLIP) cluster randomized control trial in the study area. As part of this study, findings from focus group discussions and semi-structured interviews conducted with local participants were used to determine key variables that were perceived to either elevate risk for adverse maternal outcomes, or promote resilience in the face of risk. This information was used to design a questionnaire that was used as part of the baseline census for CLIP, to collect household level data concerning these determinants. Geostatistical techniques were employed to identify the key variables that explained rates of adverse outcomes, and how these associations were different among the communities under study. This study's purpose was to demonstrate the utility of geographic methods in both identifying and measuring the context specific determinants of maternal health, and is a contribution to the broader discussion on how social determinants impact health outcomes, and how this impact can be quantified.

Chapter 5 addresses some of the challenges around accessing good quality framework GIS data for use in health research in low and middle income countries. In this chapter, I highlight some of the processes for overcoming them. I challenge common beliefs concerning the tedious nature of manual digitizing of framework data and propose that this approach is a necessary first step to conducting health related GIS work in low resource settings, highlighting how it is becoming faster and cheaper. This chapter complements the preceding two chapters by highlighting the efforts that go into data creation before any meaningful spatial analyses can be performed in a typical low resource setting. A set of guidelines for generating framework data are presented and serve as a contribution to the discussion on building geo-data infrastructures that will support health related GIS research in low and middle income countries.

Chapter 6 concludes this dissertation by highlighting and reflecting back on the objectives as discuss some limitations of this work and possible future research directions.

Chapter 2. A scoping review of geographic information systems in maternal health

This chapter has been published in the International Journal of Gynecology & Obstetrics

Citation details: **Makanga, P. T.,** Schuurman, N., von Dadelszen, P., & Firoz, T. (2016). A scoping review of geographic information systems in maternal health. *International Journal of Gynecology & Obstetrics, 134(1), 13–17*

2.1. Abstract

Geographic information systems (GIS) are increasingly recognized tools in maternal health. The objective of this scoping review was to evaluate the use of GIS in maternal health and to identify knowledge gaps and opportunities. Keywords broadly related to maternal health and GIS were used to search for academic articles and gray literature. Reviewed articles focused on maternal health, with GIS used as part of the methods. Peer reviewed articles (n = 40) and gray literature sources (n = 30) were reviewed. Two main themes emerged: modeling access to maternal services and identifying risks associated with maternal outcomes. Knowledge gaps included a need to rethink spatial access to maternal care in low- and middle-income settings, and a need for more explicit use of GIS to account for the geographical variation in the effect of risk factors on adverse maternal outcomes. Limited evidence existed to suggest that use of GIS had influenced maternal health policy. Instead, application of GIS to maternal health was largely influenced by policy priorities in global maternal health. Investigation of the role of GIS in contributing to future policy directions is warranted, particularly for elucidating determinants of global maternal health.

Keywords: Geographic information systems; Global health; Health policy; Health services; Maternal health; Spatial access; Spatial epidemiology

2.2. Introduction

Worldwide, at least one woman dies from the complications of pregnancy and delivery every two minutes (Maternity Worldwide, 2014). For every woman who dies in childbirth, at least 20 more experience long-term life-altering health problems (Hardee, Gay, & Blanc, 2012).

Furthermore, 99% of such deaths and complications occur in low- and middle-income countries (LMICs), particularly Sub-Saharan Africa and South Asia (Alvarez et al., 2009). Most of these deaths are avoidable because they result from modifiable factors—e.g. prompt recognition of illness, access to transport, and appropriate treatment—that could be addressed through targeted interventions. Maternal outcomes are also influenced by the broad contexts within which individual women live (the social determinants of health); consequently, it is becoming widely accepted that taking action on social factors is an important aspect to improving population health on a global scale (Marmot, Friel, Bell, Houweling, & Taylor, 2008).

Geographic information systems (GIS) are decision support systems that involve the integration of location-referenced data in a problem-solving environment (Cowen, 1988). The potential application of GIS to health is gaining recognition (Richardson et al., 2013). Their potential for elucidating risk factors for adverse maternal events, as well as the relationship between access to care and maternal outcomes, has become increasingly apparent. GIS has the ability to integrate data on health-related social and environmental risk factors and thus explain variations in maternal outcomes. This capacity to link the social and environmental risk factors to disease outcomes is consistent with the call to reduce global ill health, including adverse maternal outcomes, through action on social determinants (Marmot, Friel, Bell, Houweling, & Taylor, 2008).

The present scoping review aimed to investigate what is already known about the use of GIS in maternal health research and practice in both LMICs and high-income countries (HICs).

2.3. Methods

The scoping review method was selected for the present study because it facilitates identification of knowledge gaps and opportunities that exist regarding an emerging subject of interest (Arksey & O'Malley, 2005). A literature review on mapping technologies and methods used within the broad theme of maternal and neonatal health was published in 2015 (Ebener et al., 2015). Therefore, the focus of the present review was specifically on the use of GIS in maternal health.

The design of the present scoping review was guided by the York method developed by Arksey and O'Malley (Arksey & O'Malley, 2005). The design comprised a five-step process that involved: identification of the questions to be addressed; identification of the relevant literature sources; selection of literature sources to be included in the present review; recording key themes emerging from the literature; and collation, summary, and reporting of the results.

A search was undertaken to identify relevant peer-reviewed articles and gray literature published up to July 31, 2013. No language restrictions were imposed. LMICs were identified using the World Bank classification. The Medline, GeoBase, and Web of Science databases were searched to identify peer-reviewed articles using the terms shown in Table 2.1. A Google search was performed using the terms "GIS" and "maternal health" to identify relevant gray literature, which included unpublished conference papers and abstracts, descriptions of maternal health programs and initiatives, government websites, books, popular media, and videos. The websites of key organizations (mHealth Alliance, WHO, US Agency for International Development, and United Nations Population Fund) were also searched.

Table 2.1: Sample of search terms used to identify relevant peer-reviewed articles

GIS	Maternal Health	Low to middle income countries
Geography	health	Developing countries
Mapping	maternal death	subsaharan
Geographic Information systems	maternal mortality	South Asia
Geographic Information Science	adverse maternal outcomes	Africa
Geographic Analysis	antenatal	Asia
Location	perinatal	Angola
Place	Prenatal	Burundi
Spatial Analysis	epidemiology	Democratic Republic of the Congo
Spatial Epidemiology	referral systems	Rwanda
Health Geography	indicators	São Tomé and Príncniple
Medical Geography	Referral chain	Cameroon
Other Related Keywords…	Other Related Keywords…	Other LMICs…

The authors met on separate occasions to review the abstracts and full papers to determine the final set of papers that met the criteria for the review. Articles were included in the present review if they focused on maternal health (prepartum, peripartum, or postpartum) and used GIS in the analysis. Articles that focused on the effect of pregnancy related exposures on neonatal and perinatal outcomes were excluded. Data on the study setting and the key applications of GIS described in each article were recorded and organized into different themes in Microsoft Excel 2010 (Microsoft Corporation, Redmond, WA, USA). Information obtained included the place where the research was conducted (e.g. LMIC/HIC, rural/urban), the nature of the study (e.g. epidemiology, spatial epidemiology, health services), and the type of analysis techniques used (e.g. spatial analysis, statistical analysis).

2.4. Results

2.4.1. Search results

As shown in Figure 2.1, the literature searches and subsequent review identified 40 peer-reviewed articles and 30 gray literature sources that met the inclusion criteria. Two broad research themes were identified from the selected sources: assessing geographic access to maternal health services, and analyzing risk factors and their associations with maternal outcomes. Articles that covered both of these categories used maps to describe the geographic trends in maternal outcomes, including mortality.

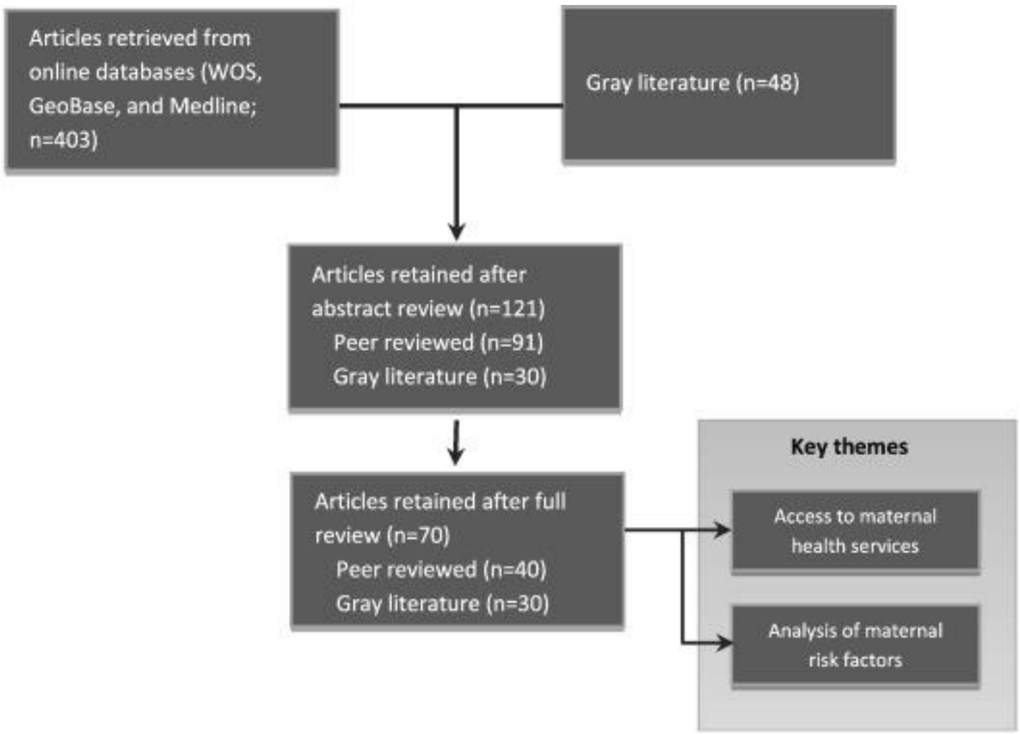


Figure 2.1: Search results and key themes that emerged from the review

2.4.2. Access to maternal health facilities

The bulk of the published literature regarding the use of GIS in maternal health focused on potential geographic access to care on the basis of the spatial distribution of health facilities (Gething et al., 2012; Gjesfjeld & Jung, 2011). Some articles focused on the use of GIS to describe uptake of maternal services depending on proximity to health facilities (Cullinan, Gillespie, Owens, & Dunne, 2012; Friedman et al., 2013). Most papers explored potential spatial access to primary levels of care, including prenatal visits (McLafferty & Grady, 2004). Few articles covered access to tertiary level care, including facilities with the capacity to deliver emergency obstetric care. In terms of scale, most studies described the spatial patterns for access to maternal care at the national or provincial level (Bailey et al., 2011; S. Brown, Richards, & Rayburn, 2012), with less emphasis placed on community-level trends (Tomintz, Clarke, Rigby, & Green, 2013).

Travel distance and time to the health facility based on the road network were the main means for quantifying potential spatial access to maternal care services, particularly among HICs where road network data were readily available (S. Brown et al., 2012; Joharifard et al., 2012). Nonetheless, a large number of studies conducted in HICs used Euclidean ("as the crow flies") distances to estimate potential spatial access to maternal care. Among LMICs, travel distances based on road network algorithms in GIS were also used to model potential access to maternal care, although in almost all the studies identified, the researchers had to create the road network data in GIS before conducting any analysis, making the research process both time-consuming and expensive (Bailey., P., et al., 2011; Gething et al., 2012).

Owing to the unavailability of comprehensive street data among LMICs, some studies used friction surfaces for modeling travel time (Masters et al., 2013). This approach is used to model the easiest—and therefore most likely—pathway between communities and health facilities, depending on the travel obstacles that an individual must contend with. Publicly available digital elevation models and data on other potential travel barriers (e.g. bodies of water or land use) were exploited to determine the easiest route to the heath facility and so estimate the travel time. Demographic data were used similarly in LMICs and HICs to align potential spatial access with modes of transport available to populations (Tomintz et al., 2013). For example, (Gething et al., 2012) used data from populations of reproductive-age women and the transport options available to them to identify subgroups of women expected to need to access maternal care and the time required for them to reach a health facility depending on the mode of transport.

Road classifications and speed limits were used to calibrate the models of potential spatial access to maternal health services. In some instances, clinical records with information on uptake of maternal health services were used to validate the predictive accuracy of spatial accessibility models (Gabrysch, Zanger, Seneviratne, Mbewe, & Campbell, 2011). Maternal mortality rates in different geographic regions within countries were used to assess the impact of poor access to maternal care on maternal outcomes (Simoes & Almeida, 2011). None of the reviewed studies in either LMICs or HICs calibrated spatial accessibility models on the basis of measured travel times. Compared with estimated travel times, this approach would have provided a more realistic picture of access to care and matched the realities of the travel experience. The use of GIS in modeling access to maternal care includes assessing the geographic distribution of health facilities as well as modeling the impact of modifying the geographic distribution of health facilities on extending the reach of maternal health services (Bailey., P., et al., 2011).

Some studies used GIS to map the availability of interventions that aimed to improve maternal outcomes. For example, identifying areas with an unmet obstetric need on the basis of standards of care delivery prespecified by WHO (Hunger, Kulker, Kitundu, Massawe, & Jahn, 2007; Sudhof et al., 2013). Demographic data were used to quantify the potential need for obstetric intervention among populations, which was then compared with the geographic distribution of health facilities and their capacity to deliver both non-urgent and urgent maternal care (Hunger et al., 2007; Sudhof et al., 2013)

2.4.3. Assessing risk factors for poor maternal outcomes

Spatial epidemiology is defined as the study of spatial variation in disease risk or incidence (Ostfeld, Glass, & Keesing, 2005). This concept is important for advancing the assessment of risk factors for maternal ill-health and utilization of maternal health services (Owoo & Lambon-Quayefio, 2013). Some risk factors described in the literature fell broadly within the spectrum of social determinants of health and formed the basis for exploring non-biomedical features that characterize the complex pathways leading to poor maternal outcomes. Examples from the literature included risk factors linked directly to characteristics of the physical environment where the pregnant woman lives, including pollution (I. Aguilera et al., 2008) and natural disasters (Curtis, 2008), and other risks related to the woman's sociocultural environment, including ethnic origin, education, and poverty (McLafferty, Widener, Chakrabarti, & Grady, 2012; Owoo & Lambon-Quayefio, 2013).

Spatial interpolation is the estimation of values in different locations (e.g. atmospheric concentrations of nitrogen dioxide) on the basis of the measured values at other locations. This technique has been used to model the spread of environmental risks posed by exposure to pollutants during pregnancy (I. Aguilera et al., 2008; Dedele, Grazuleviciene, & Aleksandras Stulginskis, 2011). Sociocultural risk factors have been quantified through the use of statistical indicators, such as deprivation, which are usually derived from census data and modeled for populations (Charreire & Combier, 2006).

The nature and spatial distribution of risk factors for maternal ill-health were generally modeled with either adverse maternal outcomes or a maternal services utilization indicator as dependent variables (Owoo & Lambon-Quayefio, 2013). The use of geographically explicit methods for modeling the effect of risk factors on maternal outcomes was minimal. Geographically explicit methods include geostatistical techniques and statistical modeling that assumes that statistical associations are affected by geography and therefore not necessarily constant across space. These methods extend beyond simply using GIS to calculate geographic variables, such as travel times and community deprivation scores. Most studies that introduced geographic variables as risk factors into analyses used non-spatial statistical approaches, including odds ratios, least-squares regression, and multilevel models, with the geographic data serving as one of many explanatory variables (Gabrysch, Cousens, Cox, & Campbell, 2011; Meng, Thompson, & Hall, 2013).

2.5. Discussion

The present scoping review found that evaluating access to maternal health services constituted the main use of GIS in maternal health. This finding was not surprising given that increased access to skilled birth attendants through a formal healthcare system is a global priority for improving maternal health (Bhutta & Black, 2013). Nonetheless, new approaches must be explored when modeling access to maternal services in LMICs. Most models for accessibility have been developed and tested in HICs; however, 99% of the adverse maternal outcomes occur among LMICs, particularly in rural areas (Alvarez et al., 2009; Bailey., P., et al., 2011). Many of the existing spatial accessibility models cannot be readily replicated in these highly burdened settings.

The present review identified several knowledge gaps and questions that must be addressed in future work. First, geographic datasets on road infrastructure were scarce among LMICs. Spatial accessibility modeling will therefore require creation of the requisite road network data as a first step (Bailey., P., et al., 2011), a process that often seems to be overlooked by researchers, particularly those from HICs who are conducting research or interventions in LMICs. New protocols are, therefore, required to guide the creation of road network data in resource-limited settings to support mapping of geographic access to maternal care. Second, maternal deaths among LMICs tend to rise during the wet season as a result of reduced access to maternal care owing to precipitation-induced damage to the poor road infrastructure that characterizes many rural areas (Blanford, Kumar, Luo, & MacEachren, 2012). The static measures for access to maternal services that currently dominate the literature are, therefore, an inadequate means for quantifying its seasonal variation. The lack of dynamic measures of access to care is a key knowledge gap, suggesting a need for new methods to quantify spatio–temporal access to maternal care that consider the seasonal impact of weather events. Third, community health workers are increasingly being recognized as agents of official healthcare delivery among rural communities in Africa and South Asia (Bhutta & Black, 2013). Consequently, models that assess spatial accessibility to maternal care by measuring distance from health facilities, without taking into account how community health workers extend the reach to geographically isolated areas, fail to provide an accurate picture of access to care. Finally, 90% of all armed conflicts since the Second World War have occurred in LMICs, with maternal deaths being disproportionately high in these conflict zones (O'Hare & Southall, 2007; Urdal & Che, 2013). An important area to address in spatial accessibility modeling is how best to evaluate the impact of conflict on access to maternal health care.

Although GIS are widely used to assess potential spatial access to maternal care, there is a lack of published data evaluating geographic patterns in the association between access to care and maternal outcomes. In most studies, spatial accessibility scores simply serve as input to statistical analyses, together with other variables that are usually non-spatial (Cullinan et al., 2012; Masters et al., 2013). Geography thus remains at the periphery of analysis in maternal health research (Friedman et al., 2013). The use of geographically explicit techniques that explore the spatial structure of associations has been minimal but is receiving more attention from researchers. For example, geographically weighted regression has been used to investigate geographic variation in the association between having medical insurance and access to prenatal health services in the USA (Shoff et al., 2012). Other examples of tools potentially useful for modeling maternal health risk include land-use regression (I. Aguilera et al., 2008), for modeling spread of pollutants and how these relate to adverse maternal health events. Spatial lag regression (Owoo & Lambon-Quayefio, 2013) also assumes that risk factors in one location are affected by other factors in nearby locations. These approaches might offer insight into the influence of socioeconomic determinants on maternal health. The use of GIS in this way introduces a new geographic dimension to statistical processes and better elucidates the spatial variation in associations with poor maternal outcomes than would conventional statistical techniques.

Although the use of such methods is still novel, the growing "value add" of introducing a geographical perspective to epidemiological research related to maternal health is twofold. First, these approaches might explain the association of risk factors with adverse maternal outcomes, and promote targeted interventions, by highlighting the place-specific patterns that substantially influence adverse maternal outcomes. Conventional statistical methods attempt to collapse patterns in a dataset into a single estimate that best describes the trend in the data (e.g. R^2 or β coefficient); however, the evidence from geographically enabled statistical techniques suggests that parameter values are not always constant across space (Shoff et al., 2012). Second, geographically enabled statistical techniques tend to improve model efficiency and predictive power (Shoff, Chen, & Yang, 2014), largely owing to their increased ability to organize data and fit models to the data on the basis of geography. However, this ability limits the generalization of spatial models beyond the populations where the data were collected, a key limitation given that generalization is an important marker for the utility of health findings. Consequently, although these value additions could increase assimilation of spatially explicit analysis techniques in maternal health research, it remains unknown whether the increased specificity of geographically enabled models is more important than the ability to generalize the results.

To date, the nature of how GIS have been applied to maternal health research and programs for intervention has largely been driven by trends in global health policy concerning maternal health in general. This situation is expected because health GIS comprise an applied discipline and trends in health would obviously determine how GIS are applied. The use of GIS in maternal health research is similar to how this technique is used to evaluate the impact of maternal health programs and mapping maternal outcomes. Reasonable levels of collaboration between academia and the health sector seem to have enabled transfer and refinement of GIS applications.

The GIS approach has the potential to aid evidence-informed policy formulation because it provides proof for the role of access to care in producing good or bad maternal health outcomes, as well as the means to measure population-based characteristics and how they relate geographically (Boulos, 2004). Nevertheless, the present review found no evidence to suggest that maternal health policy was being influenced by new knowledge emerging from the geographical sciences as they are applied to maternal health. Instead, the application of GIS to maternal health was influenced by policy priorities in global maternal health (Figure 2.2) (Colston & Burgert, 2014). Clearly, there is potential for GIS to generate further evidence for action to improve maternal health and deliver targeted interventions. Such data are essential, particularly in resource-constrained settings where the burden of adverse maternal outcomes is high and resource allocation must be prioritized.

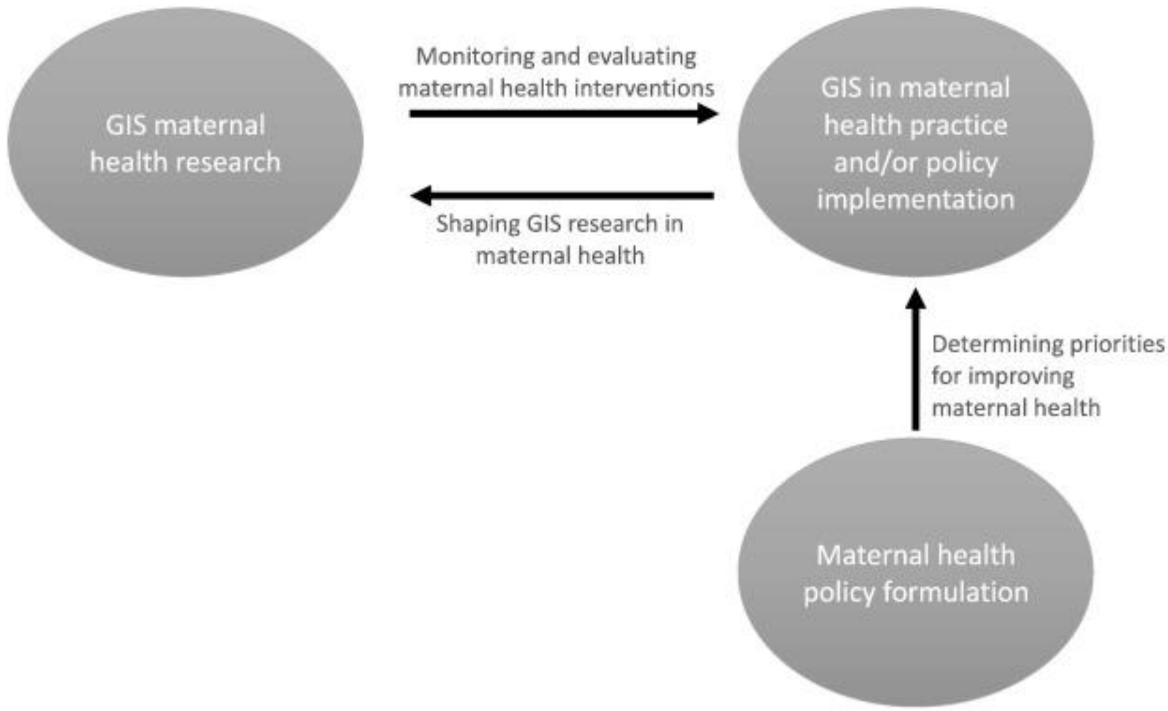


Figure 2.2: GIS in maternal health and the links to policy formulation and implementation

Efforts to reduce the global burden of maternal ill-health have been driven predominantly by clinical interventions; therefore, GIS have exerted minimal influence on the data. The reason why GIS have remained at the periphery of maternal health policy is that the technology is largely used to evaluate policy implementation, usually on the basis of predetermined indicators, such as access to maternal health services. Increased recognition of the need to promote health through action on social determinants (Marmot, Friel, Bell, Houweling, & Taylor, 2008) could potentially complement clinical interventions. Examples of social determinants that have been associated with adverse maternal outcomes include maternal education, socioeconomic status, literacy, marital status, and religion (Evjen-Olsen et al., 2008; O'Hare & Southall, 2007). The use of GIS might aid identification of the spatial patterns of these important determinants and explain how they relate to maternal health, potentially offering an integrated approach with appreciable links across sectors, socioeconomic background, and the environment.

2.6. Conclusion

In conclusion, the present review has revealed the emergence of GIS in maternal health research and constraints on their implementation. An increased level of sophistication has been observed among GIS methods applied to maternal health; however, their uptake and contribution to policy remains limited. The main focus in the use of GIS has been to develop and improve spatial techniques for evaluating maternal health interventions, particularly access to maternal care. Describing spatial patterns in the burden of maternal ill-health and how these patterns relate to risk factors are also key applications of GIS to maternal health. For example, GIS is used to assess exposure to pollutants among pregnant women during the prenatal period, although the effect of these exposures on neonatal health (rather than maternal health) is in the focus of most published studies.

A number of challenges hamper the use of GIS in LMICs, including the inadequacy of key GIS methods in these settings. The full potential of GIS is also not realized in LMICs owing to inadequacies of spatial data infrastructures to fully support GIS processes in their current form. Approaches developed to assess maternal health in HICs cannot be used in low-resource settings without adaptation to the local contexts. Currently, GIS are being used to evaluate the impact of policy in improving maternal health, with much less done to aid policy formulation related to improving maternal health. There is potential for the exploration of the role of GIS in contributing to new policy directions, particularly in elucidating the role of social determinants in global maternal health.

2.7. Acknowledgments

The present study was funded by the Grand Challenges Canada Stars in Global Health program and Canadian Institute of Health Research grant KPE-124730.

Chapter 3. Seasonal variation in geographical access to maternal health services in regions of Southern Mozambique

This paper was submitted for peer review to the International Journal for Health Geographics

Authors: *Makanga, P.T., Schuurman, N., Vilanculo, F., Sacoor, C., Munguambe, K., Boene, H., Vidler, M., Magee, L., von Dadelszen, P., Sevene, E., Firoz, T.*

3.1. Abstract

Background

Geographic proximity to health facilities is a known determinant of access to maternal care. Methods of quantifying geographical access to care have largely ignored the spatio-temporal uncertainties in access that are induced by severe weather events, particularly precipitation and flooding. Further, travel has largely been imagined as unimodal where one transport mode is used for entire journeys to seek care. This study proposes a new approach for modeling spatio-temporal access by evaluating the impact of precipitation and floods on access to maternal health services using multiple transport modes, in southern Mozambique.

Methods

A facility assessment of 56 health care centres in Gaza and Maputo provinces of Mozambique was used to categorize health centres into primary, secondary and tertiary levels. GPS coordinates of the health facilities were acquired from the Ministry of Health while roads were digitized and classified from high-resolution satellite images. Data related to geographic distribution of populations of women of reproductive age and pregnancies, as well as the transport options available to them were collected from a household survey conducted in the study area. Daily precipitation and flood data were used as basis for deciding on maximum speeds and potential disruptions on different road types for different modes. Travel times to the nearest health facility for all the communities in the study area were calculated using the closest facility tool in ArcGIS software, respecting the hierarchy of the clinical referral chain. These routes were dependant on the daily conditions of precipitation and flooding for a 17-month timeline.

Results

Most women either walk or use public transport to access maternal care at the primary level, while most primary facilities provide transport to higher level facilities. The number of pregnant women who lived within a one-hour walking time to the nearest basic primary care facility dropped by 9% at the peak of the wet season, while that of women within 2 hours of life-saving care dropped by 9% for secondary facilities and 18% for tertiary facilities. The results indicate that 13 of the 417 communities under study were completely isolated from maternal health services as a result of flooding at some time during the study timeline. Access to public transport increased the number of women within 1 hour of primary care facilities by 41% while women with 2hrs of life saving facilities increased by 33%.

Conclusions

Seasonal variation in access to care should not simply be imagined through a dichotomous, and static lens of wet and dry seasons, as access continually fluctuates in both. This new approach for modelling spatio-temporal access allows for the GIS output to be utilized not only for health services planning and assessment, but also aid near real time community level health delivery of maternal health services.

Keywords: Maternal health services, geographical access to care, global health, health geography

3.2. Background

Geographical proximity to health facilities is a known determinant of both access to maternal care (C. A. Brown, Sohani, Khan, Lilford, & Mukhwana, 2008; Gage & Guirlène Calixte, 2006; Johnson et al., 2015) and better maternal outcomes (Grzybowski et al., 2011; Shah et al., 2009). These improved outcomes have been attributed to improved access and utilization of both antenatal care, as well as delivery in health facilities with skilled birth attendants (Heaman et al., 2015; Olowonyo et al., 2005; Osorio, Tovar, & Rathmann, 2014).

Quantifying geographic access to care is the main application of Geographical Information Systems (GIS) to maternal health (Ebener et al., 2015; Makanga, Schuurman, von Dadelszen, & Firoz, 2016). The information so obtained can aid in the planning and design of health services by evaluating the geographic reach of the health system to serve its intended population (Kruk & Freedman, 2008), and showing how underserved regions can be reached (Grzybowski, Kornelsen, & Schuurman, 2009). GIS modelling of access to care requires information about the location of the sites that deliver the relevant health services, the geographic distribution of populations (Tatem et al., 2014), and how the population moves to access care.

There is a dearth of research on spatio-temporal modelling that incorporates the component of time to account for changes in access during seasons. This is particularly relevant to Sub-Saharan Africa where substantial rainfall and flooding in the wet seasons affects the accessibility of roads (Blanford et al., 2012; Munjanja, Magure, & Kandawasvika, 2012). Whether or not this may be associated with the seasonal nature of some severe maternal morbidities (such as eclampsia) in tropical climates is unclear; although women may become sicker in the wet season and attend care later (Okafor, Efetie, & Ekumankama, 2009; Subramaniam, 2007), it is clear that these women need emergency obstetric care when it is least likely to be accessible.

Many of the models for spatial access to maternal care have been developed in high-income settings and cannot be applied directly to low-income regions. For example, in high-income settings, the one-hour driving time threshold is used as a gold standard for identifying populations that are underserved by the health care system. While a one-hour travel time to care is clinically important in high- or low-income settings, many people in Sub-Saharan Africa do not drive cars to access maternal care services (Munjanja et al., 2012). These women usually walk to health centres and facilities, or use public transport which represents a mix of walking and driving modes (Mwaniki, Kabiru, & Mbugua, 2002; Porter, 2012). Further to that, most of the models for quantifying spatial access to maternal care have not accounted for the impact of seasonality; we are aware of one such study from Sub-Saharan Africa (Blanford et al., 2012). However, the mentioned study ironically presented results the form of static maps, making it difficult to ascertain how the results could be operationalized and incorporated into health promotion programs that reflect the daily experiences of women as they travel to seek care.

This study aimed to extend current models for access to maternal care services by accounting for the impact of adverse weather events, making them more relevant for a typical LMIC setting. As part of the feasibility work for the Community Level Interventions in Pre-Eclampsia Trial (CLIP, NCT01911494) conducted in Mozambique, we developed a spatio-temporal model to describe how women of reproductive age in study areas of Mozambique access all maternal health care services, by various modes of transport, and how that access may change during different seasons. CLIP is a community-based cluster randomized control trial, aimed at reducing all cause maternal mortality and morbidity in the study region.

3.3. Methods

3.3.1. Study area

This study was conducted in 36 administrative regions (localities) in Gaza and Maputo provinces of southern Mozambique. Both Gaza and Maputo provinces stretch from the Indian Ocean on the east, westward to the border with South Africa, Swaziland and Zimbabwe. Within the study area, is a confluence of the four major rivers in this region of Southern Africa; Limpopo, Save, Changane and the Rio dos Elefantes. This has resulted in severe flooding in some regions throughout the rainy season. The impact of severe weather on the poor road infrastructure in some regions of the study area have been described as a barrier for women to seek pregnancy related care (Munguambe et al., 2016). Flooding in the study area has also previously resulted in entire neighbourhoods being displaced or isolated from health care facilities, with pregnant women in some instances being cut off from emergency obstetric care for months (Jamisse, Songane, Libombo, Bique, & Faúndes, 2004).

3.3.2. Data

Precipitation and floods

To account for the impact of adverse weather events we sought to use empirical records of precipitation and floods. GIS data of daily precipitation within the study area from March 2013 to October 2014 were acquired from the Famine Early Warning Systems Network (FEWSNET, 2016). This timeline was chosen to coincide with the timeline of a baseline census of all women of reproductive age in the area. Daily flood data for the same period were acquired from the Global Flood Observatory (Global Flood Observatory, 2016). All the required precipitation and flood data were available except for 25 days of flood data and 4 days of precipitation data. These datasets were combined as a first step for creating an impedance surface used to estimate the effect of precipitation and floods on reducing access to health centres. Impedance surfaces are a grid based geographical representation of the ease of traversing through space, with high speed features such as highways, taking less time to traverse when compared to lower speed features such as footpaths/tracks for the same unit distance (Gething et al., 2012). We assumed that flooded areas were not navigable by any means of transport, while road segments that had precipitation above 1mm, based on the rainy day threshold (Zhang et al., 2011), would have had reduced maximum travel speeds as expressed in Table 2.1.

A new geographical dataset of average weekly rainfall was created from the daily precipitation data. This shift in temporal scale was to account for the impact of precipitation beyond the day it occurred. The 1mm rainy day threshold (calculated as a weekly average) was used to determine whether a week was to be classified as a rainy week.

Road network

An initial road network dataset was provided by CENACARTA, the national mapping agency in Mozambique. These data constituted mainly of highways and a few major paved roads and were therefore highly inadequate for the community-level analysis that was intended for this study. We also considered open street map data (Open Street Map, 2016) for the study areas but found it to be inadequate for modeling spatial access at the intended scale due to many missing roads at the community level. Data gaps were filled through a process of manual digitization of the missing roads from a high resolution Bing Maps satellite image service (Makanga et al., 2016). These roads were classified into highways, major paved roads, major unpaved roads, minor paved roads, minor unpaved roads and trails. A separate verification process was done by staff at CENACARTA and two other independent reviewers to identify and correct instances of misclassification, missing roads and other geometric errors (Makanga et al., 2016).

Each road segment was assigned a value for travel time based on the length of the road segment and the speed limit. The speed limit was dependant on the road type, whether or not there was precipitation above the 1mm weekly threshold, and if the road segment had been classified as being flooded at the particular time, with precipitation inducing a 20% and 30% reduction in the speed limit on paved roads and unpaved roads respectively. The estimates for the impact of precipitation on speed limits were derived from previous studies (ACIS, 2011; Alegana et al., 2012; Blanford et al., 2012; Hranac et al., 2006; Rakha et al., 2007) and are summarised in Table 3.1.

Table 3.1: Impact of precipitation on speed limits

		Speed Limits (KM/HR)		
Precipitation	**Road Type**	**Driving**	**Walking**	**Public Transport**
Dry Weather	Highway	120	5	120
	Paved Major Road	80	5	80
	Unpaved Major Road	60	5	60
	Paved Minor Road	40	4	4
	Unpaved Minor Road	20	4	4
	Trail	4	3	3
Wet Weather	Highway	96	4	96
	Paved Major Road	64	4	64
	Unpaved Major Road	42	4	42
	Paved Minor Road	32	3	3
	Unpaved Minor Road	14	3	3
	Trail	2.8	2	2
Flood	Impassable	(Travel time = 99999999)		

Heath Facilities

The GPS coordinates of all public health facilities in the country were acquired from the Ministry of Health in Mozambique and research partners at Manhica Research Centre in Mozambique. These facilities were classified into Primary Health Centres (PHCs), Secondary Health Facilities (SHF) and Tertiary Health Facilities (THF). Data from a 2014 assessment of public health facilities that was conducted as part of the feasibility study for the CLIP trial was used to alter that classification of some of the facilities acquired from the Ministry, because the CLIP facility assessment had more recent results. None of the facilities outside the study area were reclassified due to a lack of recent data. Data on transport options available at each facility was also acquired from the CLIP facility assessment and used as the basis for deciding the most likely mode of transport that women would use to navigate through the facility referral chain.

Women of reproductive age

GPS points representing the households where all women of reproductive age in the study area lived were captured from the CLIP baseline, and were used to determine their spatial population distribution. Instances where a household had a woman who had been pregnant within the 12 months prior to the baseline census were also recorded. Both sets of data were used to determine where populations that required access to maternal health services lived.

3.3.3. Modeling access to care

Transport options

Three modes of transports were considered for this project; walking, driving or using public transport. Both walking and driving were treated as single transport modes. However, for public transport, we modelled travel assuming that women would walk to the nearest major road to access transport, and then be in drive mode from that point on. Therefore, for the public transport option we used the same speed limits for travelling through minor roads and trails as we did for walking, but changed the speed limits to be the same as driving for major roads and highways (see Table 3.1).

The likely scenarios of travel from the home to the PHCs and subsequent levels of the health care system were determined from the CLIP facility assessment and baseline census. During the facility assessment, information was recorded pertaining to the transport arrangements that each facility in the study area had made for patients needing referral to higher level facilities. Data on the personal transport options, as well as transport plans in the event of pregnancy related emergencies were also recorded for every household included in the baseline census and used to decide on the most likely characteristics of the women's journeys to access maternal care.

Modeling spatio-temporal variation in access to care

Access to care was modelled from the central location of the populated regions within all the neighbourhoods, instead of the commonly used centre of the actual neighborhood boundaries, which would include uninhabited regions including forests and agricultural zones. The model was developed to estimate travel times from these population centres of 417 neighbourhoods to the nearest health facility accounting for multiple modes of transport, and how this changed overtime. We assumed that most of the population would navigate through the facility referral chain in a hierarchical sequence; i.e. from home to PHC to SHF then THF.

The closest facility tool in the ArcGIS software was used to calculate the quickest route between neighborhoods and facilities based on the predefined speed limits along the road network dataset (ESRI, 2016a) for each of the 87 weeks of the study. Speed limits depended on the impedance values imposed on the road by the road type, precipitation and floods as illustrated in Table 3.1. The service area tool (ESRI, 2016b) was used to create cartographically generalized visualizations illustrating the change in spatial access throughout the study at a macro scale.

Once the quickest travel times to the different level facilities for all travel scenarios were calculated for each week in the study timeline, the data was organized into 4 quartiles, for each week, indicating the travel times at the 25th, 50th, 75th and 100th percentiles for all neighborhoods. This explorative process was done to highlight the disparities that existed in travel times.

We also compared the travel times on the best day in the dry season and the worst day in the wet season to evaluate the extreme impact of precipitation and flooding on access to maternal care for women of reproductive age in general, and those that were likely to have been pregnant during these times. Given that it is impossible for women that were registered as having been pregnant during the study to have been pregnant for the entire timeline, we estimated the number of pregnancies at any given time assuming equal likelihood of being pregnant throughout the timeline. The 1-hour and 2-hour travel time thresholds were used for primary care facilities and all other higher level facilities (SHF and THF) respectively, to differentiate women's access to basic maternal and antenatal care from life-saving care delivered through basic and comprehensive emergency obstetric care at SHF and THF (Munjanja, Magure, & Kandawasvika, 2012).

Determining isolation of communities

Communities that would have been totally isolated from health care services as a result of flooding were also identified. Isolation was when the total travel time to the nearest facility was ≥ 99999999 min, which was the total time assigned for travelling through a flooded road segment that would have essentially been impassable using vehicular transport or on foot. As the network algorithm used in this study identified the optimum routes that had the quickest possible time for traversing from a community to a health facility, instances where travel times were ≥ 99999999 indicated that no alternate route existed except through a flooded road, meaning the road infrastructure could not be used to transit from communities to health facilities.

3.4. Results

3.4.1. Transport options

According to the baseline census, most women of reproductive age in the study area are likely to either walk or use public transport to travel to the nearest primary health facility (Table 3.2). This is based on the fact that 70% of all households indicated not having private transport, and almost 72% of household indicated that pregnant women would nonetheless have access to transport funds when needed.

According to the facility assessment, most women were likely be driven from primary care facilities to higher level facilities, either by ambulance from secondary to tertiary facilities, or private cars from primary health centres to secondary facilities that are available in through pre-arranged agreements with car owners in the community (Table 3.2).

Table 3.2: Transport options available to travel through different levels of the health care system, based on the CLIP baseline census and facility assessment

Facility Level	Transport Options	N	%	Most likely Mode of Transport
Neighborhood to PHC	Number of households that do not own private cars	35368	69.8%	Most women will either i) walk to PHC (based on 70% not having personal transport) ii) use public transport to PHC (based on 72% having access to transport funds)
	Number of households with a bicycle	10521	20.8%	
	Number of households with a motorbike	972	1.9%	
	Number of households with a boat	87	0.2%	
	Number of households with a car	2847	5.6%	
	Number of households with other forms of transport	784	1.5%	
	Number of households where pregnant women have access to money for transport to nearest facility	36648	72.4%	
	Number of households that would get transport help from neighbors or family	6787	13.4%	
PHC to SHF	PHCs with functional ambulance or other vehicle for emergency	2	4.0%	Most women are likely to be driven from primary to secondary facilities
	PHCs with transportation for patients referred to another facility	43	93.0%	
	PHCs with access to an ambulance or other vehicle from another facility	44	96.0%	
SHF to THF	SHFs with functional ambulance or other vehicle for emergency	7	100.0 %	Most women are likely to be driven from secondary to tertiary facilities

These findings led to a 6 scenario spatiotemporal model of access to care, that depicts the common modes of transport from the community to PHCs and through the facility referral network, including;

i. Walking to PHCs

ii. Public Transport to PHCs

iii. Walking to PHCs and driving to SHFs

iv. Public transport to PHCs and driving to SHFs

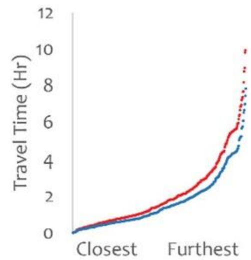
v. Walking to PHCs, driving to SHFs and driving to THFs

vi. Public transport to PHCs, driving to SHFs and driving to THFs

3.4.2. Seasonal variation in travel times to health facilities

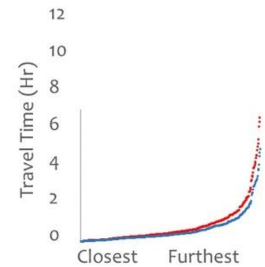
Spatial access to maternal health services generally decreases during wet season for all modes of transport and to all level facilities due to the increase in travel times that are imposed by precipitation and flooding. At the peak of the dry season, 49% (n = 38887) of women of reproductive age included in the census lived within a one-hour walking time to the nearest PHC (Figure 3.1). Of these, approximately 6311 women would have been pregnant at the time, with 46% (2932) also living within an hour walk from PHCs. The population of women of reproductive age within 1-hour walking time to PHC dropped by 9% to 31716 while that of pregnant women dropped by 11% to 2364 at anytime during the wet season. The furthest communities were up to 7.9 hours walking time to PHC during the dry season. However, this increased to 9.9 hours at the peak of the wet season.

WALKING TO PHC



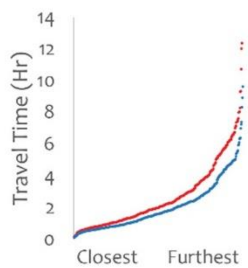
	BEST DAY				WORST DAY			
	WRA		PREGNANCIES		WRA		PREGNANCIES	
TIME	N	%	N	%	N	%	N	%
<1hr	38887	49	2932	46	31716	40	2364	37
>1hr	40338	51	3379	54	47509	60	3947	63

PUBLIC TRANSPORT TO PHC



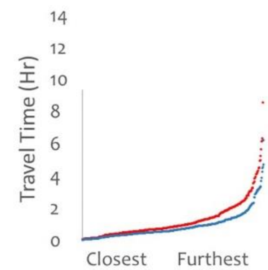
	BEST DAY				WORST DAY			
	WRA		PREGNANCIES		WRA		PREGNANCIES	
TIME	N	%	N	%	N	%	N	%
<1hr	69299	87	5478	87	65165	82	5110	81
>1hr	9926	13	833	13	14060	18	1201	19

WALKING TO PHC THEN DRIVING TO SHF



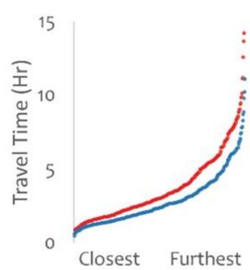
	BEST DAY				WORST DAY			
	WRA		PREGNANCIES		WRA		PREGNANCIES	
TIME	N	%	N	%	N	%	N	%
<2hrs	50352	64	3840	61	42211	53	3188	51
>2hrs	28873	36	2471	39	37014	47	3123	49

PUBLIC TRANSPORT TO PHC THEN DRIVING TO SHF



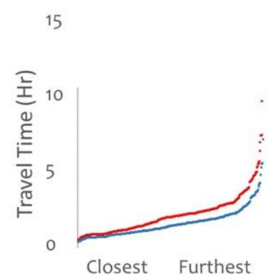
	BEST DAY				WORST DAY			
	WRA		PREGNANCIES		WRA		PREGNANCIES	
TIME	N	%	N	%	N	%	N	%
<2hrs	75281	95	5958	94	71208	90	5572	88
>2hrs	3944	5	353	6	8017	10	739	12

WALKING TO PHC THEN DRIVING TO SHF AND THF



	BEST DAY				WORST DAY			
	WRA		PREGNANCIES		WRA		PREGNANCIES	
TIME	N	%	N	%	N	%	N	%
<2hrs	36151	46	2722	43	21764	27	1584	25
>2hrs	43074	54	3589	57	57461	73	4727	75

PUBLIC TRANSPORT TO PHC THEN DRIVING TO SHF AND THF



	BEST DAY				WORST DAY			
	WRA		PREGNANCIES		WRA		PREGNANCIES	
TIME	N	%	N	%	N	%	N	%
<2hrs	59475	75	4618	73	40053	51	3004	48
>2hrs	19750	25	1693	27	39172	49	3308	52

Travel times to health facilities on the best day in the dry season

Travel times to health facilities on the worst day in the wet season

Figure 3.1: Travel times using different transport modes and percentage of women within 1 hour of basic care and 2hrs of life-saving care for the best day in the dry season and worst day in the wet season

A similar pattern of reduced access is observed for travel to other level facilities for women that began their journeys with walking to PHCs. At the peak of the dry season, 64% (n = 50,352) and 46% (n = 36,151) of women of reproductive age lived within 2 hours travel time to the nearest SHF and THF that respectively offer life-saving maternal care. Of these, approximately 61% (n = 3840) and 43% (2722) of pregnant women also lived within an a 2-hour travel time to SHF and THF respectively. Populations of women of reproductive age living within 2 hours from SHF and THF dropped to 53% (n=42,211) and 27% (n=21,764) respectively, while that of pregnant women dropped to 51% (n = 3188) and 25% (1584) respectively during the rainy season.

The models scenarios involving the use of public transportation markedly reduce the travel times to all level facilities. At the peak of the dry season, 87% (n = 69,299) of women of reproductive age lived within a one-hour travel time to the nearest PHC using public transport. Of these, 87% (n=5478) of pregnant women also lived within an hour travel to the nearest PHCs. The population of women of reproductive age within 1-hour travel time by public transport to PHC dropped by 5% to 65,165 while that of pregnant women dropped by 6% to 5110 at anytime during the wet season. The furthest communities were up to 4.9 hours of travel time to PHC using public transport during the dry season. However, this increased to 6.6 hours at the peak of the wet season.

The 2 hour catchments for SHF and THF are significantly larger and travel times much quicker for journeys that commence with public transport to PHC when compared to journeys that would have begun with walking to PHC. At the peak of the dry season, 95% (n = 75,281) and 75% (n = 59,475) of women of reproductive age lived within 2 hours travel time to the nearest SHF and THF respectively. Of these, approximately 94% (n = 5958) and 73% (4618) of pregnant women also lived within an a 2-hour travel time to SHF and THF respectively. These populations of women of reproductive age living within 2 hours from SHF and THF dropped to 90% (n=71,208) and 51% (n=40,053) respectively, while that of pregnant women dropped to 88% (n = 5572) and 48% (3004) respectively during the rainy season.

There is a near exponential increase in travel times between the communities that are closest to health facilities compared to the ones that are the furthest (Figure 3.1), indicating that huge disparities exist in access to maternal health service. For the furthest communities, there is a 2.1-hour increase in travel time to PHC, 2.7 hours to SHF and 3.1 to THF for journeys that commences with walking to PHCs in the wet season. This increase in time is equivalent to walking approximately 10 extra kilometers to the nearest primary facility. Similarly, travel time increases by 1.7, 2.5 and 2.8 hours to PHC, SHF and THF respectively are also observed for the furthest communities when journeys commence with public transport.

The results suggest that the longer the travel time to a health facility the more likely populations are to be affected by precipitation or flooding; in and out of season hence the greater degree of fluctuation in travel times, particularly for the furthest communities in the fourth quartile of travel times (Figure 3.2). While there are more stable travel times to health facilities during the dry season, there are minor fluctuations during this time resulting from the few instances of rainfall in the dry season. Figure 3.2 also illustrates the extent to which the furthest communities are disproportionately isolated (and potentially disproportionately more vulnerable) as the upper quartile of communities (red colour) has a much larger range when compared to the 1st, 2nd and 3rd quartiles for all modes of transport and facilities.

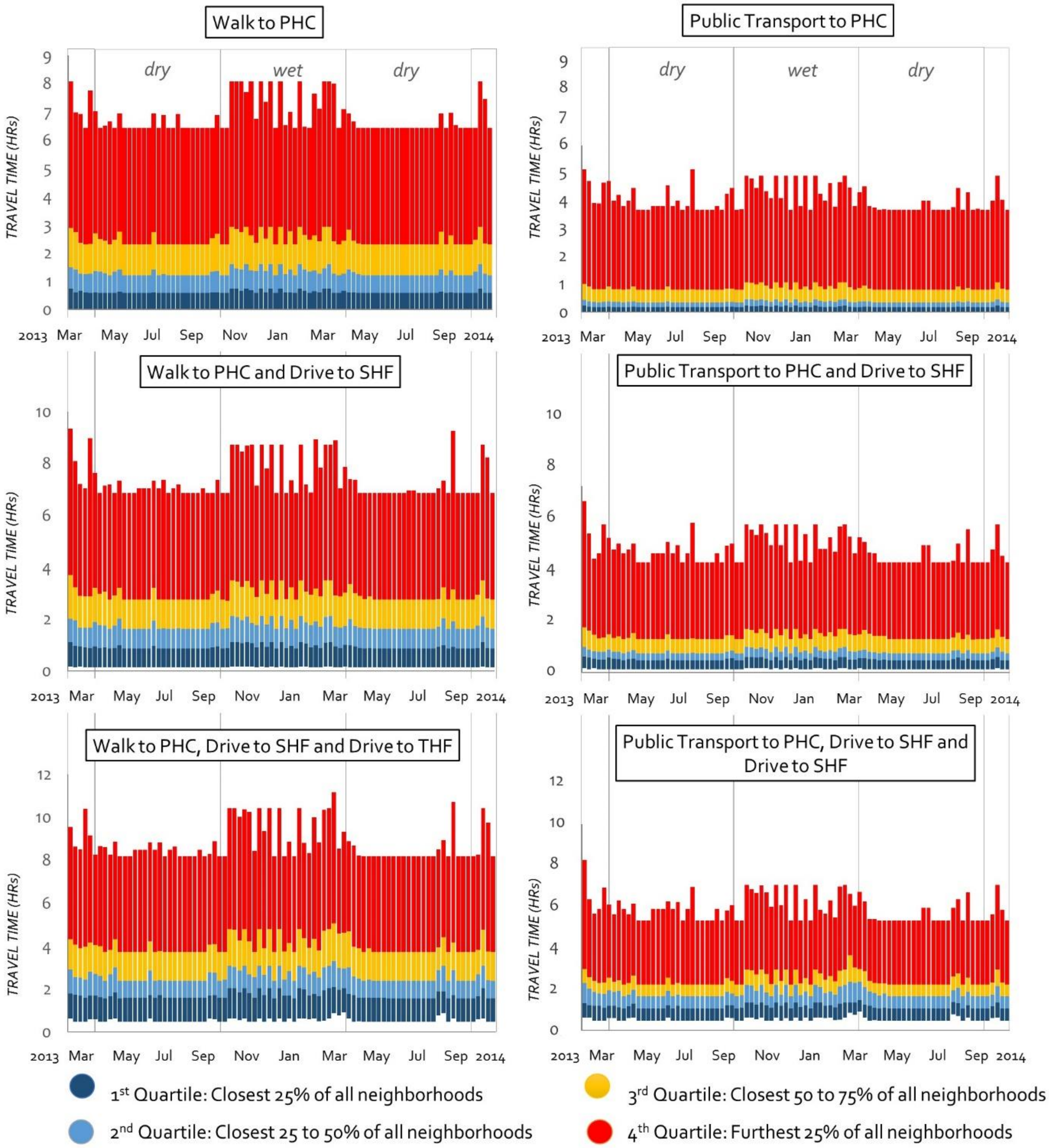


Figure 3.2: Seasonal variation in travel times for different modes for the entire 17- month timeline

In terms of the place specific impact on severe wet weather on access, it appears as though Magude district, Ihla Josina + Calanga and Chaimite regions within the study area are the areas that are affected the most by the wet weather (Figure 3.3), as they appear redder and yellower in B (wet weather) when compared to A (Dry weather) for walking to PHCs. The reason for this is the apparent low density of facilities as well as the poor road infrastructure in these regions. This means that populations in this regions will generally need to travel long distances on bad roads to access care. This is obviously aggravated by wet weather and flooding. The full set of maps indicating dry/wet weather differences in travel times have not been included due to space limitations. However, some of spatio-temporal animations can be accessed at https://pre-empt.cfri.ca/monitoring/mapping-outcomes-mothers-mom.

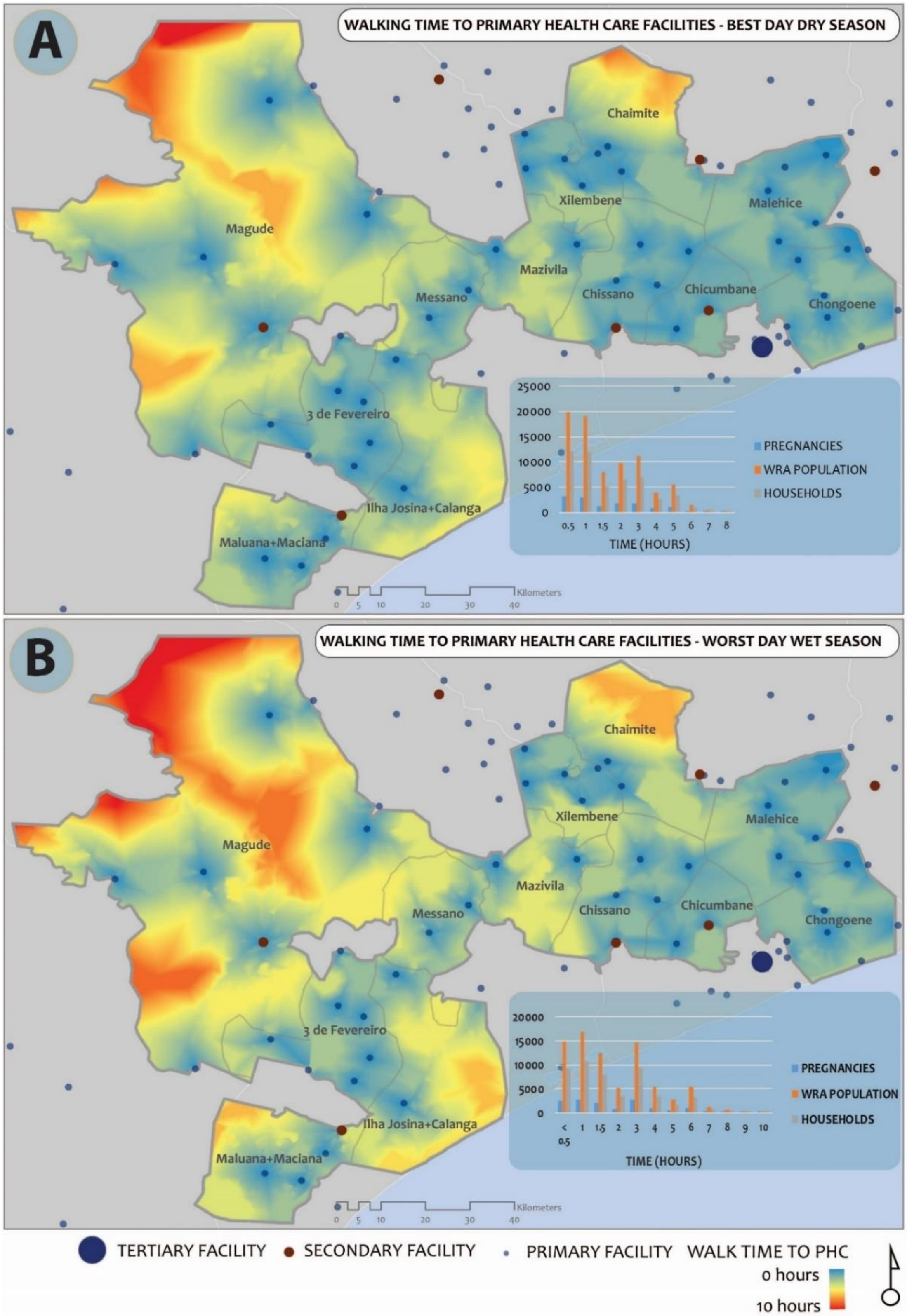


Figure 3.3: A comparison of two surfaces for walking times to the nearest PHC on the best day in the dry season (A) and worst day in the wet season (B)

13 of the 417 neighbourhoods were at some point completely isolated from health facilities (travel time ≥ 99999999) during the study; 12 for one week and 1 for 16 weeks (Figure 3.4). Most of these areas are unsurprisingly located in the regions show in Figure 3.3 to be most severely affected by the wet weather.

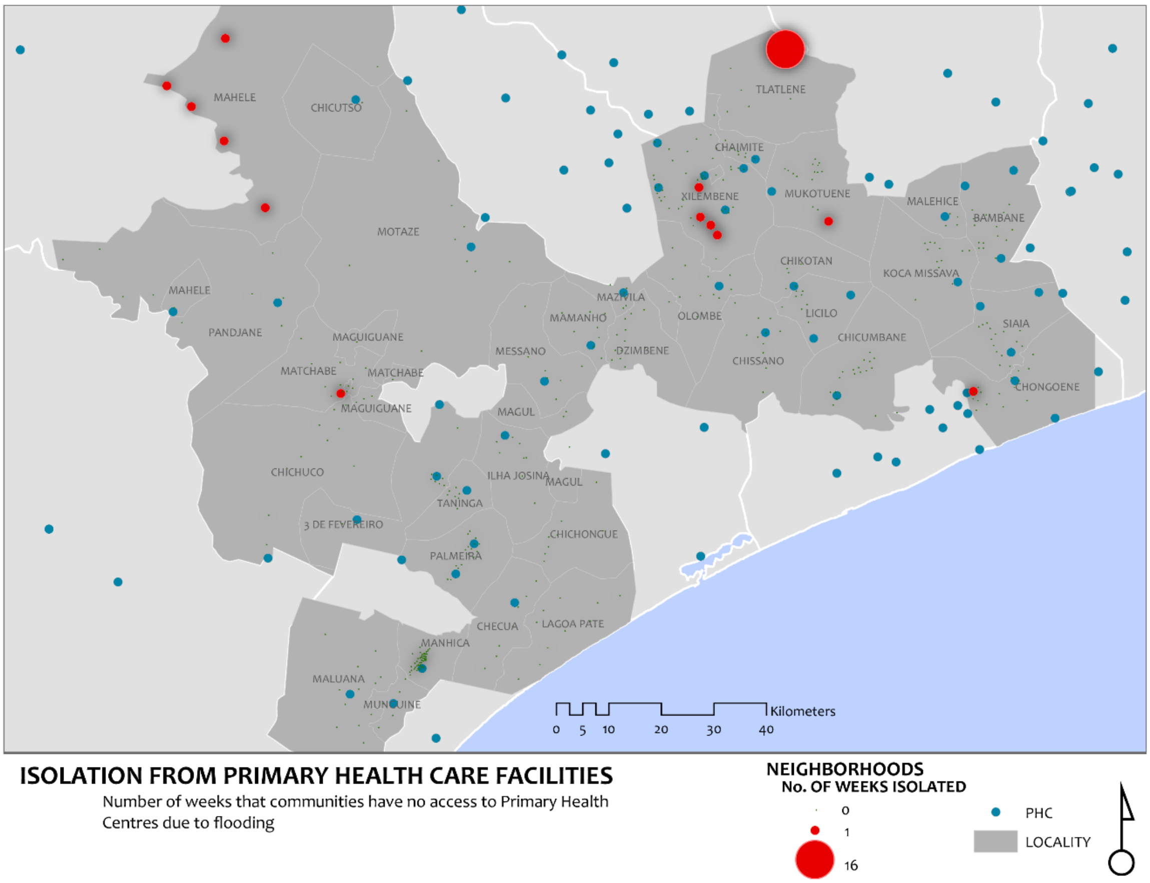


Figure 3.4: Communities isolated from care as a result of flooding

3.5. Discussion

This paper describes a new approach for measuring and visualizing spatio-temporal access to maternal health services in rural southern Mozambique. To our knowledge this is the first time that empirical records of precipitation and floods have been incorporated into modelling spatiotemporal variation in access to care. This work extends the current models of geographical access to maternal care by accounting for the multiple transport options that characterize women journeys, and how their transit from home to access maternal health services changes depending on season.

The daily transport realities highlighted in the facility assessment and baseline census warrant for spatial accessibility models that account for the mix of transport modes as this what a typical woman's journey from home to primary care facilities and through the rest of the health facility referral network looks like. While Gething et al. (2012) demonstrated a model of spatial accessibility that accounts for mechanized and non-mechanized modes of transport, simulations of access were done for each mode in isolation. Other studies have projected travel times through the health facility referral chain in a hierarchical fashion similar to this study (Bailey et al., 2011), but have overlooked the multiple transport options (walking, public transport, and use of ambulances) that characterize women's journeys. Our study explored travel times that result from the use of mixed transport modes through the various tiers of the health care system and advances spatial modeling of access to maternal care in a direction more suited for the daily realities of women in LMICs.

While a previous study (Blanford et al., 2012) examined the potential impact of the seasonality on access to maternal health services, our use empirical daily records of precipitation and floods has demonstrated that the seasonal variation in access cannot simply be imagined through a dichotomous, and static lens of wet and dry seasons, as access continually fluctuates in both. The elements do not only slow down travel to health facilities, but in some instances can isolate whole communities from accessing these services (Jamisse et al., 2004). The use of real weather records enhanced our understanding of how access to maternal care may be hampered in and out of season. Media sources from the study region confirm that the communities identified as having been isolated because of floods, were actually flooded, in some instance resulting in the community members being evacuated (Mozambique News Agency, 2014; United Nations Office of the Coordination of Humanitarian Affairs, 2013; World Health Organization, 2013).

While these results indicate a sizeable reduction in the number of women, who live within 1 hour of basic care (PHC) and 2 hours for life saving care (SHF and THF) as a result of precipitation and floods, the transport mode used has a much greater impact on increasing travel times to health facilities. For example, pregnant women living within an hour of primary care facilities are shown to increase by 41% when women access public transport from their community, compared to when they walk to PHCs to seek care (Figure 3.1). A similar pattern exists for SHFs with an increase of 33% for pregnant women who live within 2 hours of these facilities, resulting in 95% of all women living within 2 hours of life-saving maternal care. This illustrates the potential impact of community level transport related support for women needing to access maternal care, and further confirms the value of initiatives aimed at increasing access to transport as they will potentially greatly impact on increasing access to care both in the dry and wet seasons.

While the dominant view on geographical access to care assumes a need to measure distances or travel times from communities to health facilities, an emerging model of care in many low and middle-income countries (LMIC) includes care by community health workers (CHWs) (Lehmann & Sanders, 2007). CHWs are “lay members of communities who work either for pay or as volunteers in association with the local health care system in both urban and rural environments and usually share ethnicity, language, socioeconomic status and life experiences with the community members they serve” (Goodwin & Tobler, 2008). These minimally trained workers extend the reach of basic health services to communities that are not well covered by health centres’ (Tulenko et al., 2013). The impact of flooding on hindering community health workers from accessing pregnant women in need of services have been reported by (Teela et al., 2009). The blend of weather sensitive spatio-temporal models of access with the upcoming strategies for reaching the most isolated populations with health services through a mobile health force (Bhutta & Reddy, 2012; von Dadelszen et al., 2012) will potentially take to utility of spatio-temporal models of access beyond macro-planning of health services and make them operational on a daily basis at the community level. The increased recognition of community level health surveillance, including pregnancy surveillance and mobile health technologies (Braun, Catalani, Wimbush, & Israelski, 2013; von Dadelszen et al., 2012) will set the context where these daily pictures of access could inform decisions by community health workers as they link communities to formal health services.

While this study is set is an LMIC, the ideas and methods proposed in this paper can be translated to other health disciplines and settings where seasonal elements affect access to care. Similar problems of harsh weather impeding access to health care for geographically isolated regions exist in Aboriginal communities of Northern Canada for example (Sevean, Dampier, Spadoni, Strickland, & Pilatzke, 2009). Data shows that women living in these communities are disproportionately more vulnerable and more likely to experience adverse maternal outcomes when compared with the rest of the Canadian population (Grzybowski et al., 2011). The proposed approach could be used to imagine new models of access that cater to the geography of, and temporal patterns in precipitation affecting women in these remote regions.

A limitation to our approach to modelling spatio-temporal access is that it does not account for wait times at facilities, as these data were not available. Wait times would provide a more accurate picture of how long it takes to navigate through the health care systems, accounting for both geographical and health services related delays. Including waiting times in the modelling process would be a step closer to modelling all three delays of triage, transport and treatment (Thaddeus & Maine, 1994) and how they affect access to maternal care. Further to that, in modelling the use of public transport, we also did not account for the amount of time a woman may need to wait to get a vehicle once she gets to the main road. Waiting for transport is a known barrier to care seeking in the study area (Munguambe et al., 2016), thus making our travel time estimate very conservative.

Another limitation for this study has to do with the estimates for speed and travel time. While the ones used in this study have been adopted from previous studies on access to care, there is a lack of good evidence that these estimates are relevant for our study setting. Further, there is also a lack of empirical data on the real extent to which precipitation reduces travel speed on different road types under study. Future research is needed on developing methods of generating empirical data of how precipitation really affects travel.

3.6. Conclusions

Models for spatio-temporal access that account for the daily realities of women's transport options in their communities are increasingly necessary. Understanding populations' geographical access to maternal health services and how it varies by season will enable health services planners to better identify populations that are underserved by their spatial configuration, and therefore, increase access to health care facilities. This study highlights how to combine daily records on precipitations and floods to enhance the understanding of the variation on spatial access to care, in a way that has an impact, not only on long-term planning of maternal health services, but potentially on improving daily planning concerning access to care at the facility and extending the reach of care to the community. Initiatives for transport support at the community level will complement the understanding of these spatio-temporal dynamics to accessing maternal care and will help women get to health facilities quicker.

3.7. Acknowledgements

Funding: This work was part funded by Grand Challenges Canada- Stars in Global Health program (Grant 0197) and was conducted as part of the PRE-EMPT (Pre-eclampsia/Eclampsia, Monitoring, Prevention and Treatment) initiative supported by the Bill & Melinda Gates Foundation.

Chapter 4. The place-specific factors associated with maternal ill-health for regions in southern Mozambique

This Chapter will be submitted for review to Health and Place

Authors: *Makanga, P.T., Schuurman, N., Sacoor, C., Lee, T., Vilanculo, F., Munguambe, K., Boene, H., Ukah, U.V., Vidler, M., Magee, L., Firoz, T., Sevene, E., von Dadelszen, P*

4.1. Abstract

Background

Emerging global maternal health strategies acknowledge the broad nature of the associated determinants, and call for multi-sectoral approaches to complement health system enablers for improving maternal, fetal and child health along the continuum of care. This implies that in addition to addressing risk factors that are specific to women, community level factors also need to be addressed. The aim of this study was to identify and measure the specific determinants that are associated with maternal ill-health in the southern region of Mozambique.

Methods

Focus group discussions and semi-structured interviews were conducted in the study area to elicit community perceptions of the determinants of maternal health. Other standard variables from previous studies were also considered and used to design a census form for collecting household level data on these factors. A Delphi consensus was convened to prioritize variables. Ordinary least squares regression was performed to explore the associations between the determinants and combined rates of maternal, fetal and neonatal outcomes. Geographically weighted regression was used to explore the geographic variability in the effect of the variables on the combined outcome.

Results

A total of six variables were statistically significant ($p \leq 0.05$) in explaining the combined outcome. These include; geographic isolation, access to an improved latrine, private

transportation, age of reproductive age woman, family support and fertility rates. The performance of the OLS model was an adjusted R^2 = 0.65. There was significant geographic variability in the effect of each of the variables on the outcome except for isolation. The performance of the GWR increased to adjusted R^2 = 0.72.

Conclusion

The community exploration was successful in identifying the context specific determinants of maternal health. The results have implications for targeting interventions aimed at addressing the place specific social determinants of maternal health in the study area. The geographic process of identifying and measuring these determinants has implications for global health strategies.

Keywords: Maternal health, global health, health geography, geostatistics

4.2. Introduction and Background

Improving maternal health has been a global health priority for the past 3 to 4 decades. The main policy drive for improving maternal health during this time were the Millennium Development Goals (MDGs), which aimed to reduce maternal deaths by 75% by 2015. While this target was not met, significant strides were made and the global Maternal Mortality Ratio (MMR) is now 45% lower than in 1990 (United Nations, 2015). Maternal deaths are however a small portion of the global maternal health burden; it is estimated that for each death, nearly twenty more women suffer from life-long disabilities induced from severe maternal morbidities (Alvarez et al., 2009; Firoz, Chou, von Dadelszen, Agrawal, Vanderkruik, Tunçalp, et al., 2013). Further, a new drive for improving maternal health also emphasizes improvements along the continuum of care including further commitment to fetal, newborn and child survival (World Health Organization, 2015).

The known risk factors leading to adverse maternal outcomes (deaths and severe morbidity) exist both at the level of the individual women as well as in her community. Some of these factors, although experienced at the individual level, are somewhat a function of broader socio-cultural factors, thereby making it hard to separate the two. Individual level factors include maternal age (Olowonyo et al., 2005), level of education for both the women and their partners

(Wall, 1998), contraceptive use (Ahmed et al., 2012), birth spacing (Conde-Agudelo et al., 2007), marital status, social standing, self-esteem, and psycho-social stress (Ronsmans & Graham, 2006). Examples of environmental and community level factors that elevate the risk for adverse maternal outcomes include physical isolation from health facilities (Grzybowski et al., 2011), living in war zones (Jambai & MacCormack, 1996; O'Hare & Southall, 2007), natural disasters (Nour, 2011), religion (Evjen-Olsen et al., 2008; O'Hare & Southall, 2007), ethnicity, and race (Ronsmans & Graham, 2006). Mozambique has a Maternal Mortality Ratio (MMR) of approximately 250/100000 live births (Bailey., P., et al., 2015; David et al., 2014), and is among the top 20 countries with the highest MMRs globally. There has been close to a 50% reduction in MMR from 541/100000 live births since 1990, largely due to falling rates of maternal deaths resulting from direct obstetric causes (Bailey., P., et al., 2015). However, a relative increase in maternal deaths from indirect causes (HIV, malaria) was also observed for the same period, as obstetric interventions do not cater for these.

Previous studies that were conducted in Mozambique have documented some of the determinants of maternal health in the country. In southern Mozambique, women who suffered severe maternal morbidities reported that lack of money for transportation and poor road infrastructure caused delays in reaching health facilities, when they sought emergency pregnancy related care (David et al., 2014). Long distances, bad roads, and severe weather have also been cited as barriers to seeking pregnancy related care (Munguambe et al., 2016). Flooding is known to sometimes isolate communities from emergency obstetric care for months (Jamisse et al., 2004). A cultural acceptance of male's absence from matters concerning the woman's pregnancy has also been attributed to increasing the vulnerability of pregnant women (Audet et al., 2015). In a patriarchal culture, the absence of men from such decisions potentially leaves the woman vulnerable as she may not be empowered to make decisions concerning her pregnancy (Munguambe et al., 2016). Prevailing myths around the causes of pregnancy related illness (Boene et al., 2016) are also likely to influence women's choices to seek access to care when required.

Emerging global maternal health strategies acknowledge the broad nature of the associated determinants, and call for multi-sectoral approaches to complement health system enablers for improving maternal, fetal and child health along the continuum of care (Kuruvilla et al., 2016; United Nations, 2015). These strategies mirror the broader set of the Sustainable Development Goals (SDGs) that aim to "draw on contributions from indigenous peoples, civil society, the private sector and other stakeholders, in line with national circumstances, policies and priorities" (United Nations, 2015). Further to that, the SDGs call for greater measurement of disaggregate subnational trends in life-course health outcomes and associated determinants (United Nations, 2015). This drive to understand the granular population health trends and associated determinants will likely help to better elucidate the place-specific nature of these associations with maternal health outcomes.

The aim of this study was to identify and measure the community specific determinants that are associated with maternal ill-health in the southern region of Mozambique. In line with the recommendations from the SDGs, the study sought to gain a local understanding of these determinants and how their associations with adverse maternal outcomes varied geographically.

4.3. Design and methods

4.3.1. Study setting

The study was conducted as part of the feasibility study for the Community Level Interventions in Pre-Eclampsia Trial (CLIP, NCT01911494) in Mozambique. CLIP is a community-based cluster randomized control trial, aimed at reducing all cause maternal mortality and morbidity in the study region led by the University of British Columbia in partnership with the Centro de Investigação em Saúde de Manhiça (CISM) in Mozambique. The study was conducted in total of 12 clusters (Figure 4.1) made up of 36 localities. Ethics approval for the study was acquired from the Research and ethics boards at the Simon Fraser University, CISM and the University of British Columbia.

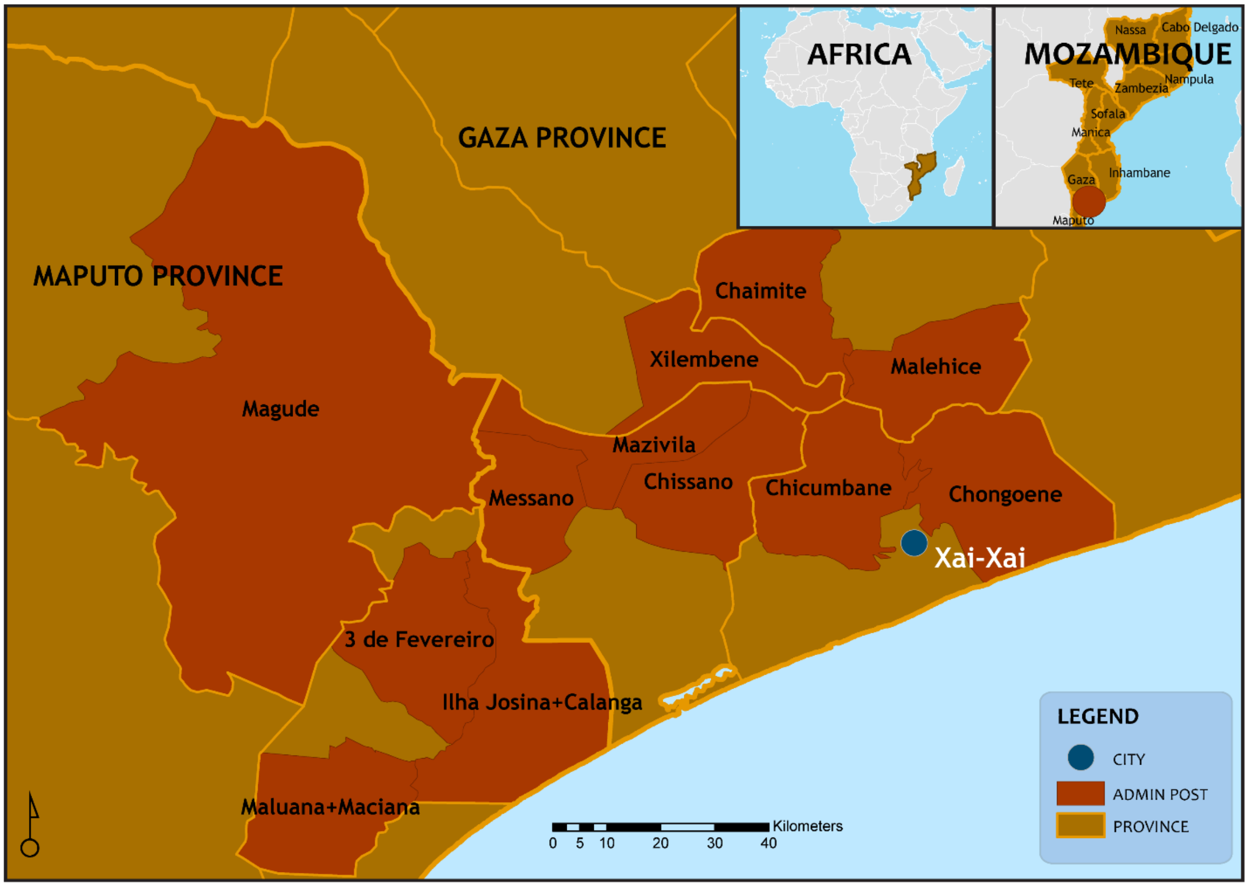


Figure 4.1: Study areas in regions of Gaza and Maputo provinces, Southern Mozambique

There were 4 core aspects of this project: 1) gathering data on the community perspectives of the determinants of maternal health, 2) collecting primary empirical data on these determinants and 3) prioritizing variables through a Delphi consensus and 4) conducting statistical analyses to explore association with adverse maternal outcomes (Figure 4.2).

4.3.2. Community perspectives on the determinants of maternal health

The first step of this project was to go into the communities within the study area to elicit local knowledge on the determinants of maternal health inline with the new global health strategies stated earlier. Ten focus group discussions (FGDs) were conducted in four of the 12 clusters with pregnant women, women of reproductive age, matrons, male partners, community leaders and health workers. The FGDs asked questions on local understandings of the socio-cultural, environmental and economic factors that were related to adverse maternal events (e.g. See Appendix C). Participants for the FGDs were recruited using a sample of convenience and snowballing. Semi structured interviews were also conducted with the administrative post chiefs in all 12 clusters to better understand the historical context (e.g. civil wars, natural disasters, foreign aid, micro finance etc.) of the communities under study and how these could impact maternal health. Both the interviews and FGDs were conducted in a local language (Xichangana), and translated verbatim into Portuguese before a final translation into English. The full details concerning data collection, coding the data and thematic analysis are being presented through a separate publication that was undergoing revisions after an initial peer review process for publication (Firoz et al., 2016).

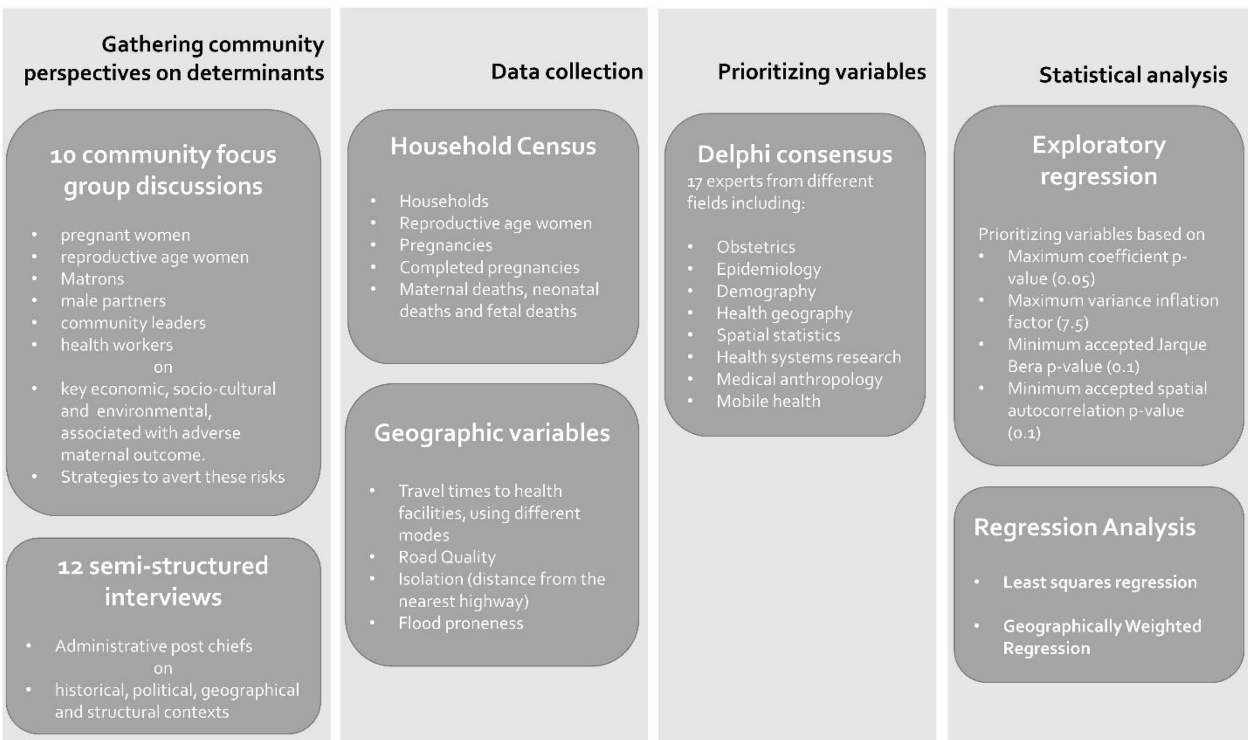


Figure 4.2: Overview of methods used in the study

4.3.3. Data collection

After deciding on the context specific variables potentially associated with adverse maternal outcomes in our study area, we collected data on these through a household census, and also created relevant geographical variables using geographical information systems. Data collected during the baseline census included variables specific to the women (e.g. age, education, and pregnancy history), and some that concerned her household and community characteristics (e.g. availability of the household head and community support initiatives). Data on all pregnancies reported to have occurred in the 12 months prior to the census were recorded during this process. Information on all women of reproductive age deaths were recorded, and a follow up verbal autopsy (World Health Organization, 2012) was conducted to classify maternal deaths. Apart from maternal deaths, the census also captured data on early and late neonatal deaths, miscarriages and stillbirths.

Five sets of geospatial variables were created for the study area. These include travel times using mixed transport modes that included public transport and ambulances to 1) primary health facilities, 2) secondary health facilities and 3) tertiary health facilities. Walking times to the nearest highway (4) were also calculated to measure the degree to which communities were geographically isolated. Finally, an indicator for flood proneness (5) was designed based on flood records from the previous year (Global Flood Observatory, 2016). The impact of floods on reducing access to care was created as a measure for flood proneness. These variables and other community level estimates for the variables captured in the census were calculated for each of the administrative units in the study area as described in Table 3.1. Both the census and geographical data were aggregated into community level averages for each of the chosen variables.

4.3.4. Prioritizing variables

We conducted one round of a Delphi consensus meeting through a teleconference to prioritize the variables for statistical analysis. The Delphi technique helps with "achieving convergence of opinion concerning real-world knowledge solicited from experts within certain topic areas" (Hsu & Sandford, 2007). The meeting consisted of a panel of experts from a range of diverse but relevant backgrounds to our study; including Obstetricians, Epidemiologists, Demographers, Health geographers, spatial statisticians, health systems researchers, medical anthropologists, and mobile health experts. A questionnaire was sent to other member of the Delphi group that could not make the call.

4.3.5. Statistical analysis

The primary outcome for this study was a combined maternal and perinatal outcome (including maternal, fetal and neonatal deaths). A composite outcome was chosen as powering the study for maternal deaths alone would have required a prohibitively large sample size, which was not possible for the study timeline. Nonetheless, there is clinical plausibility in the combined outcome as both fetal and early neonatal outcomes are related to the woman's condition during the antenatal, while her environment and socio-cultural circumstances have an impact late neonatal outcomes (Gardosi, Madurasinghe, Williams, Malik, & Francis, 2013; Oza, Lawn, Hogan, Mathers, & Cousens, 2015).

The spatial statistics module within ArcGIS software was used for exploratory regression to further prioritize variables, and to create the global Ordinary Least Squares (OLS) regression model. The exploratory regression exercise evaluated different combinations of our explanatory variables for their fit for an OLS model, and how these potentially explained trends in our outcome variable. This method implements the exploration by screening variables in a forward stepwise sequence, exploring how the different combinations of variables fit and perform in a regression model. Using a criterion that assessed *p* values significance, multicollinearity measured by the variance inflation factor (VIF), normality of residuals, and clustering of residuals in space (Table 4.1), we selected the variables that best explained the outcome and met the criteria of a well specified regression model and explored these through a more rigorous OLS modelling exercise.

Table 4.1: Criteria for variable selection prior to regression modeling

Criteria	**Description**	**Threshold**
Coefficient p-value	The confidence interval required for p values of coefficients	< 0.05
Variance inflation factor	Measures redundancy of multi-collinearity between the explanatory variables	< 7.5
Jarque Bera p-value	Measures whether the model residuals are normally distributed.	> 0.1
Spatial autocorrelation p-value	Check for spatial clustering of model residuals	> 0.1

Global regression model

The performance of the OLS models chosen from the exploratory regression were assessed based on the magnitude of the adjusted R^2 value. We also checked for significance of p values for the model coefficients. Multicollinearity between different variables in a model was checked for using the a lower VIF threshold of 5. The Koenker statistic ($p < 0.01$) was used to check if the relationships being modelled were consistent (either due to non-stationarity or heteroskadisticity), while the wald statistic was used to assess overall model significance. The Jarque Bera test ($p < 0.01$) was used to check if model predictions were biased, i.e. if the model residuals were normally distributed. The model that performed best and met these criteria was selected for further analysis to create a locally specified model.

Local regression model

The Geographically Weighted Regression (GWR) technique was used to develop a second model, which extended the output from OLS, accounting for spatial structure to estimate local rather than global model parameters (Brunsdon, Fotheringham, & Charlton, 1996; Fotheringham, Brunsdon, & Charlton, 2003). As part of the modelling process, the spatial weights based on the geographic proximity of observation are applied to give more weight to values that are closer together. GWR4 software (Nakaya, 2014) was used for this part of the project. The geographic variability test was conducted to assess if there was significant non-stationarity in the coefficients after applying GWR. This test compares the geographically varying parameter with those in the fixed global model, where a negative difference (abbreviated "DIFF OF CRITERION" in GWR4), indicates significant variation in parameter estimates across space (Nakaya, 2014). We also assessed the performance of the GWR model using the newly calculated values of the adjusted R^2.

4.4. Results

4.4.1. Community perspectives and choice of variables

The full list of community level variables that were considered in this study is presented in Table 4.2. These variables which were gathered from the results of the focus group discussions, the semi-structured interviews, and the Delphi consensus, represent the local perspectives of the factors that matter, expert views and *a priori* study knowledge. A full report of the community perspectives on these determinants of health is being reported through separate publications (Firoz et al., 2016.; Munguambe et al., 2016).

From the focus groups, unemployment was consistently mentioned by women of reproductive age as an important factor contributing to ill health. Most women mentioned that there are no jobs although some were involved in domestic work and growing crops. Unemployment was said to have resulted in financial constraints that limited women's ability to access transport and care, especially to buy medications and pay for costs incurred in facilities. Women described that at times they walked to facilities because they could not afford transport.

Poor relationships with spouses and difficult relationships with in-laws were cited by women as factors that impact their wellbeing in pregnancy. However, neighbors were identified as a vital source of support for pregnant women. In the absence of government health workers in some rural communities, women relied on matrons for advice during pregnancy, assistance during childbirth and accompanying them to health facilities. Matrons mentioned that they were also involved in mediating marital problems and reconciling couples. Women identified that informal community groups were important because without them, women in these communities could not organize structured activities like informal money savings scheme that could potentially be used for pregnancy related emergencies requiring money.

Administrative post chiefs described that the localities had faced several natural disasters including floods, droughts and cyclones. Several study areas were sandy and therefore, required large 4x4 vehicles for transport. Other areas were described as muddy or had potholes also limiting transport options in the region. An important consideration for accessing roads was seasonality, particularly the rainy season when many regions were prone to floods. Many of the administrative post chiefs acknowledged the negative impact of extreme weather conditions poor road infrastructure on adverse maternal outcomes.

Table 4.2: Community level variables potentially associated with the rates of adverse maternal outcomes

Community level variable	**Description** *(Variables calculated for reproductive age women with completed pregnancies)*
<u>Census Variables</u>	
1. Age of reproductive age woman	Average age of reproductive age woman
2. Household head's education	Average number of years that household heads (man or woman) have spent in school *(No schooling = 0; At least Primary = 7; At least secondary = 12; At least a degree = 16; Graduate = 18, post grad = 20)*
3. Household head's availability	Percentage of households where the household head lives in the house
4. Water source score	Percentage of households that have an improved water source
5. Latrine score	Percentage of households that have an improved latrine
6. Private transportation score	Percentage of reproductive age women who live in a house where someone owns a private car
7. Reproductive age women's education	Average number of years that reproductive age women have spent in school *(No Schooling = 0, grade 5 = 5, grade 7 = 7, grade 10 = 10, grade 12 = 12, Bachelors = 16, Graduate = 18, post grad = 20)*
8. Fertility rate	Average number of children born to each woman in the community that had a completed pregnancy
9. Reproductive age women's marital status score	Percentage of reproductive age women in a marital union (monogamous or polygamous) relative to total with completed pregnancies
10. Reproductive age women's unemployment rate	Proportion of reproductive age women that do not work compared with total reproductive age women with a completed pregnancy
11. Family support	Percentage of reproductive age women that would receive financial, transport and emotional help from family or neighbors for a pregnancy related need
12. Community group support	Percentage of reproductive age women that would financial, transport and emotional help from a community based group for a pregnancy related need
13. Financial autonomy in pregnancy	Percentage households where the reproductive age woman is empowered to make financial decision concerning her pregnancy
<u>Geospatial variables</u>	
14. Access to primary health facilities	Average travel time to the nearest primary health facility, using public transport
15. Access to secondary health facilities	Average travel time to the nearest secondary health facility, using a mix of public transport, and an ambulance
16. Access to tertiary health facilities	Average travel time to the nearest tertiary health facility, using a mix of public transport, and an ambulance
17. Isolation	Average travel distance to the nearest highway
18. Flood proneness	The difference between the Road Quality Indicator (RoQI) score on a typical day in the dry season and on the worst day in the wet season. RoQI scores range between 0 and 1 and are a function of the quality of roads in a community

4.4.2. Statistical analysis

Descriptive statistics

A total of 50,652 households were included in the census. These households included 80,509 women of reproductive age (age 12 - 49), 13,563 of whom had been pregnant in 12 months prior to data collection. Nine thousand one hundred and seventy-two women had completed pregnancies within the same time period, with 8,621 of these having resulted in a live born. The maternal verbal autopsy identified 19 women as having died during pregnancy or 42 days after from causes directly or indirectly related to their pregnancy. Ninety-one women reported having early neonatal deaths (within a week of delivery), while 87 reported late neonatal deaths (between one week and one month after delivery). Two hundred and eighty-eight and 475 reproductive age women reported having miscarriages and stillbirths during the same time period. Of the 8,621 women with completed pregnancies, 960 (11%) women were reported to have experienced a severe adverse maternal health outcome.

The geographic pattern for the rates of the combined adverse outcomes is shown in figure 4.3, the localities of Ilha Josina + Calanga, Mazivila, Xilembene and Chissano had the highest rates of outcomes.

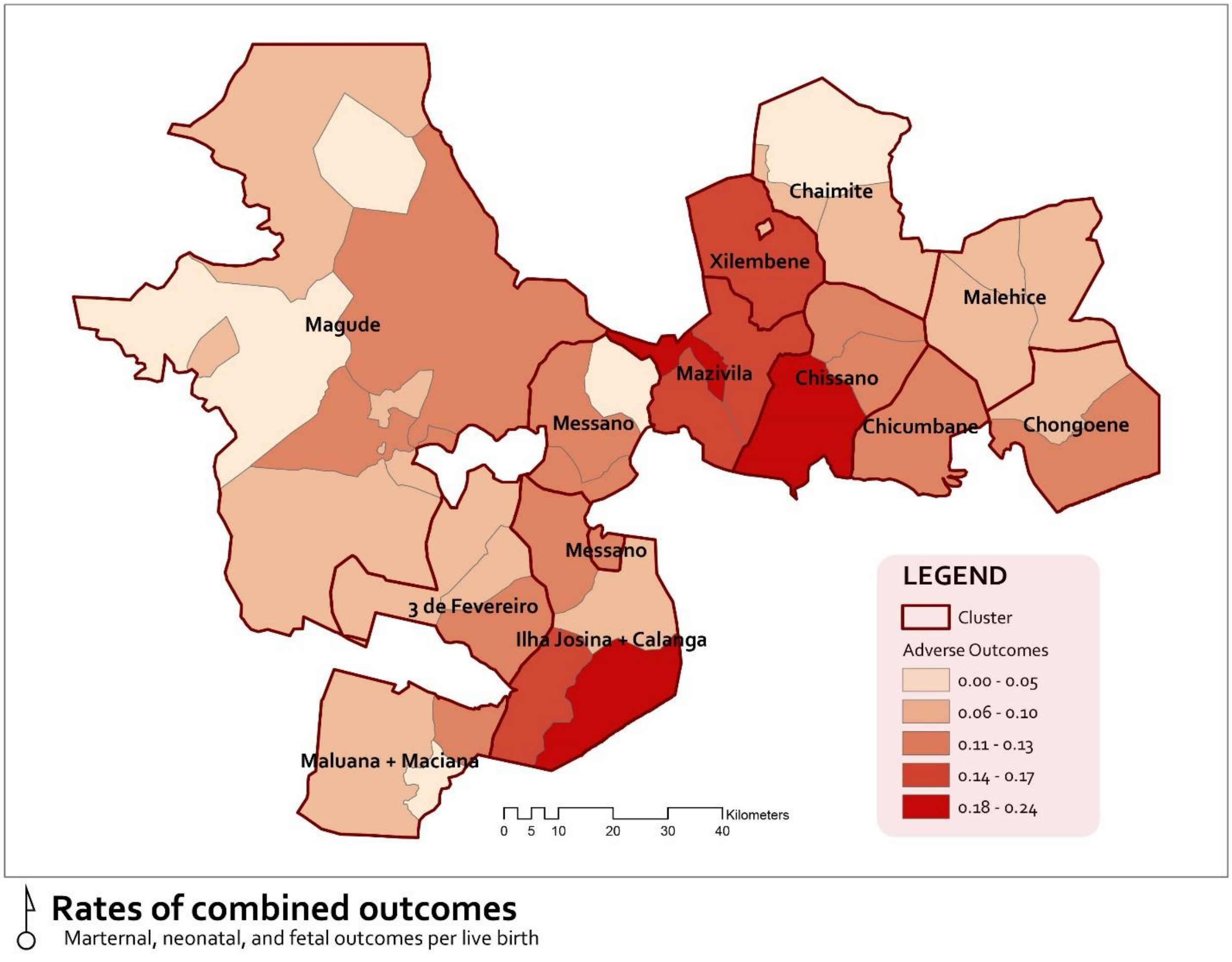


Figure 4.3: Geographic pattern for the rates of the combined adverse outcomes

Community level scores for all census variables for women with completed pregnancies, and geographical variables are summarized in Table 4.3. The average age of women with complete pregnancies was 26. Ninety-one percent of households reported that the household head lived in the household. There was large variability in the percentage of households with an improved water source, with the lowest community level score being 11.9% while the highest was 99%. The number of households with an improve toilet facility was staggeringly low, with the best locality level score for this variable being 31.6%. An average of 5.57% of all households reported owning a private vehicle. Most women reported being in a marital union (70.85%). The reported rates of unemployment were surprisingly low (mean 11%), given how this was perceived as an important risk factors in the focus group discussions. The proportion of women who indicated that they would receive either financial, transport or emotional help from family or a neighbor in the event of a pregnancy related need was 85.61%, while only 3.59% would receive the same from community groups. Twenty-two percent of households indicated that the woman is empowered to make financial decision concerning her pregnancy.

The average travel time to the primary health facilities was 0.61 hours using public transport. For women who were referred to secondary facilities, it was calculated to take an average of 1.2 hours, assuming that they used public transport to primary facilities and an ambulance to secondary facilities. For tertiary facilities, it was calculated to take and average of 2.08 hours using the same transport modes. The most isolated communities were approximately 54km from the nearest highway while the closest were less than one km. The ease of travel through communities reduced by an average of 6.75% as a result of flooding and precipitation during the 12 months prior to the household census.

Table 4.3: Summary statistics

Community level variable	Min	Max	Mean	Std Dev
Census Variables				
1. Reproductive age women's age (Years)	24.30	28.00	26.36	0.90
2. Household head's education (Years)	3.60	7.30	5.47	0.88
3. Household head's availability (proportion)	0.80	1.00	0.91	0.07
4. Water source score (%)	11.90	99.00	54.68	25.97
5. Latrine score (%)	0.00	31.60	15.48	8.35
6. Private transportation score (%)	0.00	12.30	5.57	3.05
7. Reproductive age women's education (Years)	3.80	7.20	5.29	0.95
8. Fertility rate (No. per woman)	2.40	3.80	2.89	0.29
9. Reproductive age women's marital status score (%)	52.40	88.90	70.85	8.47
10. Reproductive age women's unemployment rate (proportion)	0.00	0.40	0.11	0.10
11. Family support (%)	61.30	100.00	85.61	10.46
12. Community support (%)	0.00	17.30	3.59	3.86
13. Financial autonomy in pregnancy (%)	0.00	45.90	22.15	8.43
Geospatial variables				
14. Access to primary health facilities (Hrs)	0.18	1.75	0.61	0.36
15. Access to secondary health facilities (Hrs)	0.29	2.80	1.20	0.54
16. Access to tertiary health facilities (Hrs)	0.97	4.32	2.08	0.74
17. Isolation (km)	0.64	54.12	14.63	15.50
18. Flood proneness (%)	5.61	8.27	6.75	0.67
Rate of adverse outcomes per live birth (Maternal + Neonatal +Miscarriages + Stillbirths) / 100 livebirths	**0.01**	**0.24**	**0.11**	**0.05**

Global model

Through the exploratory regression, we identified six variables that met the pre-specified criteria for significance of p values, multicollinearity, normality and randomness of residuals. The resulting OLS model is illustrated in Table 4.4. An overall adjusted R^2 value of 0.65 was achieved by this model, indicating that the model explains 65% of the variability in the outcome. A full record of the diagnosis for the OLS have been provided as supplementary material (Appendix A). A graduated color classification was used to describe the magnitude of these variables in each of the localities under study, with the lighter colors representing the smaller numbers and the darker colors the larger numbers (Figure 4.4).

Table 4.4: OLS model

Variable	Coefficient	Std Error	t-Statistic	VIF
Intercept	-0.00171	0.23043	-0.00742	--------
Isolation (km)	0.000001 **	0	2.10195	2.3078
Latrine score (%)	-0.001756 *	0.00106	-1.65075	3.27039
Private transportation score (%)	-0.006127 *	0.00259	-2.36438	2.58454
Family support (%)	-0.002683 **	0.00062	-4.36388	1.7135
Age of reproductive age woman (Years)	0.039 ***	0.0102	3.82316	3.50571
Fertility rate (No. of children)	-0.222724 ***	0.0352	-6.32673	4.38403

* $p \leq 0.05$ ** $p \leq 0.01$ *** $p \leq 0.001$

Multiple $R^2 = 0.71$ Adj $R^2 = 0.65$

The OLS model shows that as the degree of isolation increases, there is an effect of increasing rates of adverse outcomes ($p \leq 0.01$). This effect is however modest, as with every 10km distance from the highway the outcome is shown to increase by 0.01%. There is significantly more isolation in the western region of the study area, particularly for localities in the Magude and Ilha Josina + Calanga clusters, making women in these areas more vulnerable to the effect of isolation on the rates of the adverse outcome. Higher rates of availability of an improved latrine are associated with lower rates of the adverse outcome ($p \leq 0.05$), with a 1% increase in improved latrines estimated to decrease the outcome by approximately 0.2%. A similar pattern to that of isolation existed, where localities Magude and Ilha Josina + Calanga had the lowest rates of improved latrines.

Increase in the relative number of personal vehicles available in a locality was associated with decreasing rates of the outcome ($p \leq 0.05$). Magude district has the highest proportion of personal vehicles relative to populations of reproductive age women in the study area, whereas Ilha Josina + Calanga have the lowest. Private transportation thus possibly had a protective effect on the negative impact of isolation in Magude, and is a possible explanation for disparities in rates of adverse outcomes that are observed between Magude and Ilha Josina + Calanga.

Family support emerged as an important characteristic in reducing the rates of adverse outcomes with increasing rates of women who would get either transport, financial or emotional help from family or neighbors in the event of a pregnancy related need ($p \leq 0.05$). Although the levels of family support are relatively high for all localities (mean 85.61%) there is a north-south divide between the communities that have higher and lower rates of family support with Maluana + Maciana, Ilha Josina + Calanga and 3 de Fevereiro having the highest rates while Mazivila, Chissano and the northern region of Magude have lower rates.

Average age of women with completed pregnancy was positively associated with rates of the adverse outcome ($p \leq 0.001$), while fertility rates are negatively associated with the rates of adverse outcomes ($p \leq 0.001$). A one-year increase of the average age of the woman has an effect of increasing the rate of adverse outcomes by 3.9%. An increase in the average fertility rate by 0.1 decreases the outcome by 2.2%.

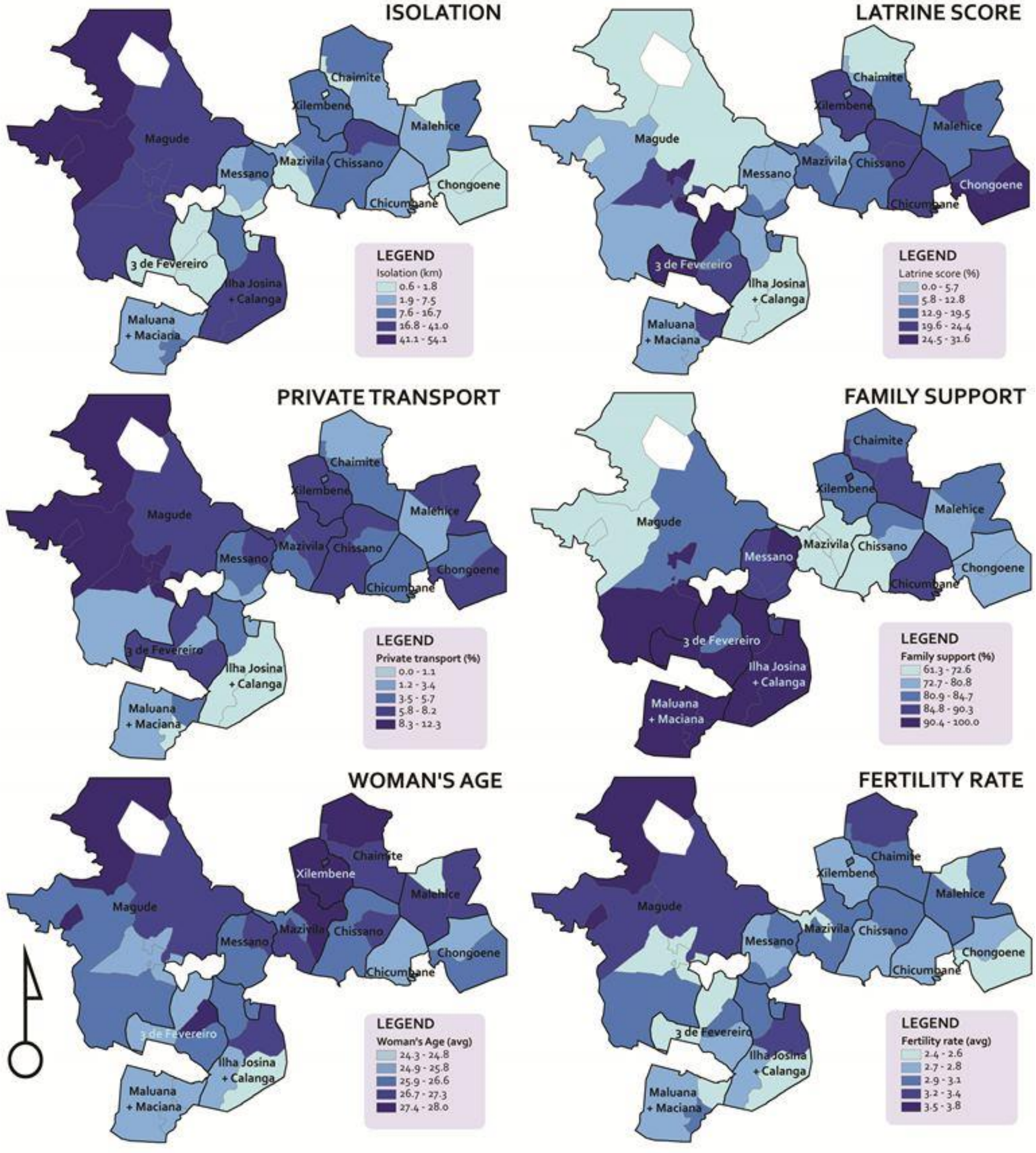


Figure 4.4: geographic patterns in values for the model variables

Local model

THE GWR model indicated that the effect on the combined outcome was geographically non-stationary for all the variables except isolation as indicated by the negative DIFF OF CRITERION values in Table 4.5. The performance of the local model improved from the global model to an adjusted R^2 value of 0.72, explaining a further 7% of the variability in the outcome. A graduated color classification was used to describe the magnitude of the effect in each of the localities under study, with the lighter colors representing modest effect and the darker colors the larger effects for both negative and positive influences on the outcome (Figure 4.4). The transcript of the GWR results are available in Appendix B.

Table 4.5: Results of the geographic variability test

VARIABLE	DIFF OF CRITERION
Intercept	-74.95761
Isolation	4.173562
Latrine score	-0.801706
Private transportation score	-2.715218
Family support	-11.928525
Age of reproductive age woman	-68.868077
Fertility rate	-3.133848

The general direction of the effects in the global model are preserved in local model. The effect of isolation is almost constant across the geographic region as is indicated by the minimal variance in the beta coefficients for this variable (Figure 4.5). Proportion of household with an improved latrine was associated with decreasing the adverse outcomes for all regions under study, though this effect is greatest in magnitude for the eastern region of the study area by a factor of about 2.88. Availability of private transport has more of an effect of decreasing the rates of adverse outcomes in the western region of Magude, Chissano and 3 de Fevereiro than it does for the eastern region by a factor of about 1.6. Family support has a greater effect of reducing the rates of adverse outcomes in the eastern regions by a factor of about 1.7. Average woman's age had the greatest geographic variability in its effect on the outcome, with its effect increasing the outcome by up to 5.5 times more in the west. Great variability in the effect of this variable is also reflected by the high DIFF OF CRITERION value in Table 4.5. The variability in the association of fertility rates to the rates of adverse outcomes is also non-stationary with the highest effect 1.3 times more than the lowest.

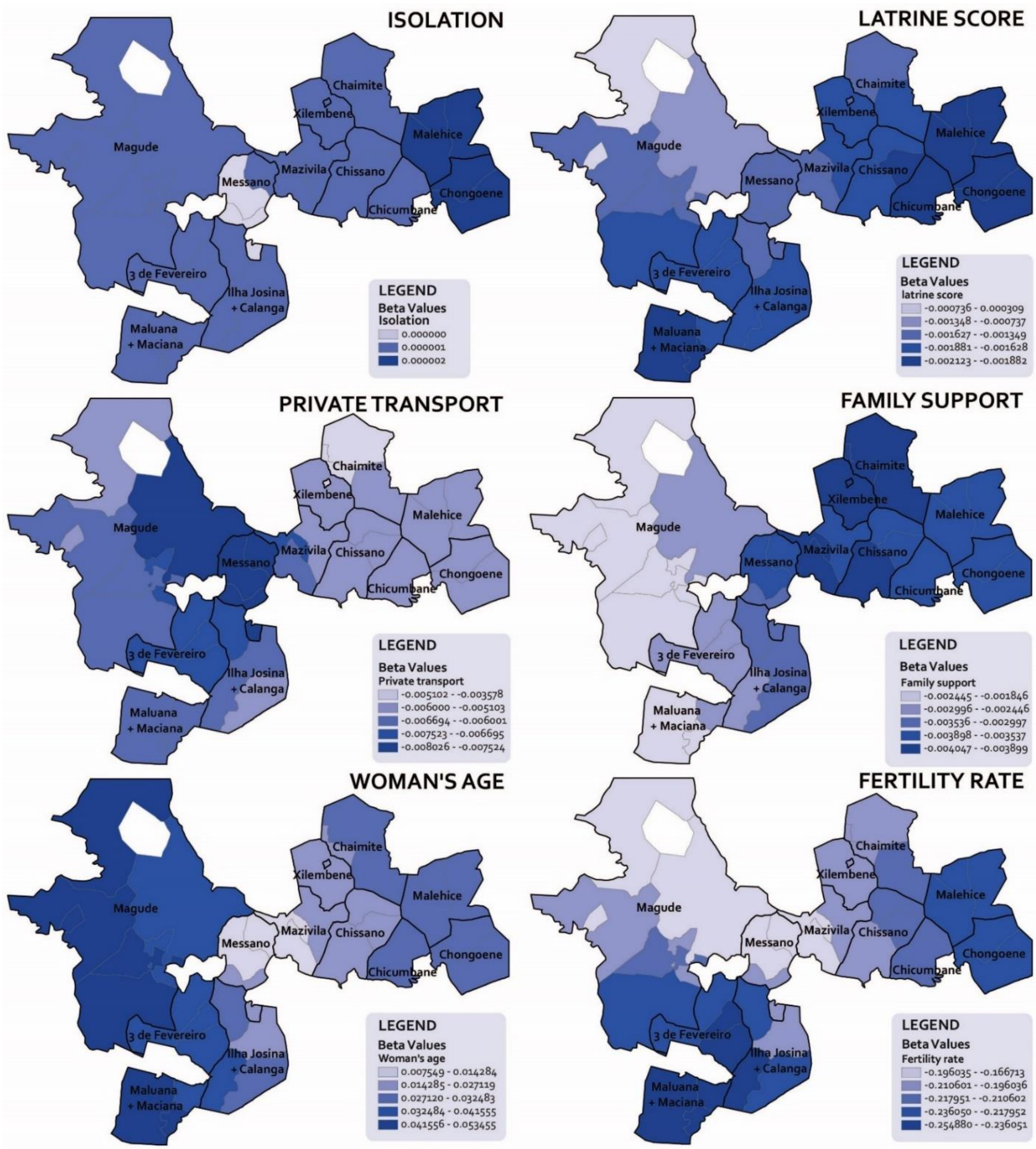


Figure 4.5: Geographic variation of beta coefficients

4.5. Discussion

This study has explored the place specific factors that are associated with rates of adverse maternal outcomes. Information gathered through focus group discussions and semi-structured interviews enabled us to measure the context specific determinants that were thought to be related to adverse maternal outcomes. Some of the variables from the FGDs and interviews were indeed significantly associated with the rates of our combined outcome and include family support, geographic isolation and access to transport. Other noteworthy variables include the proportion of households with an improved latrine, average age of reproductive age women with completed pregnancy and fertility rates. Fertility rates were the only variable where the direction of the effect is contrary to common expectation. However, fertility rate was the most significant variable in both the global model ($p \leq 0.001$) and as a single variable in the exploratory regression, so the observed pattern is unlikely a result of effect modification. Instead it is possible that there are other pervasive factors are at play. The effect of these determinants of the outcome varied between communities though the direction of the effect was largely constant.

This is the first time that the place specific socio-cultural and environmental factors related to adverse maternal outcomes has been explored in this region of Mozambique. Similar methods have been used in the USA (Shoff et al., 2012). However, most of these studies emphasize health systems related variables and how they relate to adverse maternal outcomes. This project's approach of going into communities to meet with local stakeholders is aligned with upcoming strategies within the SDGs for improving maternal health (United Nations, 2015, 2015). Core to these new global health strategies is an emphasis on multi-sectoral interventions that broadly consult multiple local stakeholders to understand the context specific factors that may be related to population level health trends. The value of geographical techniques to these new strategies is demonstrated in two ways in this project.

First we used GIS to design new indicators for some of the context specific variables perceived to be related to adverse maternal outcomes. Our measure of isolation for example (distance from highway) was designed based on local knowledge from the FGDs and interviews and implemented in a GIS. Other GIS variables on access to care were generated based on an understanding from the focus group discussions and relevant literature that most women would either walk or use public transport to other primary facilities and be driven to higher level facilities (Blanford et al., 2012; Munjanja et al., 2012). Second, the use of geographically explicit techniques such GWR enhances the ability to elucidate the spatial structure of the determinants of health and is in line with a drive within global health (expressed through the SDGs) to measure more granular subnational trends in health (United Nations, 2015). Evidence from the local regression model developed for this project highlights that different determinants matter to different extents in different places. This understanding is valuable, particularly for designing and targeting population level interventions for improving maternal and child health, and achieving the greatest impact in a low resource setting like Mozambique (Friberg et al., 2010; Sartorius & Sartorius, 2013).

A key limitation for this study is that the results can only be applied at the population level and should not be used to predict outcomes at the individual woman level. This phenomenon is termed ecological fallacy (Dummer, 2008) and is a key drawback for conducting population level studies like this one. Furthermore, this project created a combined outcome for maternal, fetal and neonatal outcomes. The implication for this is that the results may not mirror the actual associations with any of the three outcomes in the combined outcome if considered separately. However, the observed patterns address more broadly, an approach to improving maternal health along the continuum of care that includes thinking about fetal, newborn and child survival together (World Health Organization, 2015). Furthermore, the combined outcome better captures the true impact on families, as tragedies of death of mothers, fetuses and infants do not happen in isolation.

4.6. Conclusions

A geographic perspective contributes to new strategies for improving global maternal health by providing the tools required to understand local contexts and determinants of maternal health. It also helps to elucidate the place specific associations between these determinants and maternal health outcomes, and this is crucially important for targeting interventions, and can help to operationalize some of the key strategies within the new SDG. While the patterns that characterize the findings of this project are specific to the region of southern Mozambique, and may not be transferable to other settings, the process of doing research could certainly be transferred to help with understanding the local factors that elevate risk for adverse maternal outcomes. It was outside the purview of this research to explore how this evidence could be translated into action on these community specific social determinants, and future work should address this knowledge gap.

4.7. Acknowledgements

Funding: This work was part funded by Grand Challenges Canada- Stars in Global Health program (Grant 0197) and was conducted as part of the PRE-EMPT (Pre-eclampsia/Eclampsia, Monitoring, Prevention and Treatment) initiative supported by the Bill & Melinda Gates Foundation.

Chapter 5. Guidelines for creating framework data for GIS analysis in low- and middle-income countries

This chapter has been published in a special issue on global medical geography in The Canadian Geographer

Citation details: Makanga, P. T., Schuurman, N., Sacoor, C., Boene, H., von Dadelszen, P., & Firoz, T. (2016). Guidelines for creating framework data for GIS analysis in low- and middle-income countries. The Canadian Geographer, In Press.

5.1. Abstract

Health sciences research is increasingly incorporating geographic methods and spatial data. Accessing framework data is an essential pre-requisite for conducting health-related geographic information systems (GIS) research. However, in low- and middle-income countries (LMICs) these data are not readily available—and there is a lack of coordinated data creation and sharing. This paper describes a simple set of strategies for creating high-resolution framework data in LMICs, based on lessons from a maternal health GIS project, "Mapping Outcomes for Mothers", conducted in southern Mozambique. Data gathering involved an extensive search through public online data warehouses and mapping agencies. Freely available satellite image services were used to create road centrelines, while GPS coordinates of households in the study area were used to create community boundaries. Our experience from this work shows that manual digitizing is becoming cheaper and faster, due to increased availability of free satellite image services and open mapping standards that allow for distributed data capture. Involving mapping agencies in data capture processes will likely promote the scaling up of framework data creation in LMICs. This will benefit health GIS research in these settings.

Keywords: framework data, health GIS, data capture, global maternal health, manual digitizing

5.2. Introduction

Framework data for Geographical Information Systems (GIS) analysis have been defined as “geospatial data themes identified as the foundation upon which all other data layers are structured and integrated for analysis and application” (Berendsen, Hamerlinck, Lanning, & Shin, 2010). In most high-income settings, maps and framework GIS data at large scales are readily available. However, for much of the world, these data are largely unavailable, and those data that are available are often stored away in private databases of non-governmental organizations and corporations (Von Hagen, 2007). In low- and middle-income countries (LMICs), particularly in Africa, the lack of good framework GIS data, as well as the cost associated with creating them, have been acknowledged as the major limitations to the use of GIS in health research (Aimone, Perumal, & Cole, 2013; Kim, Sarker, & Vyas, 2016). There have been some efforts to fill these data gaps through programs like the Global Spatial Data Infrastructure (GSDI) initiative (Stevens, Onsrud, & Rao, 2005), Mapping Africa for Africa (Gyamfi-Aidoo, Schwabe, & Govender, 2005), and the United Nations Economic Commission for Africa (Ezigbalike, 2001). Despite all these efforts there remains a glaring need for framework GIS data, as well as new protocols that aid the development and sharing of these data.

There is a rapid growth in the use of geographic thought and spatial analysis techniques within the health sciences (Richardson et al., 2013). Health research typically requires framework GIS data as the basis for overlaying other datasets such as those for health facilities and population-level disease prevalence (Tanser & le Sueur, 2002). Without such data it is difficult to communicate population-level health problems and identify areas with the greatest need for health interventions. Thus, spatial epidemiology is founded on the framework data for the area under investigation. Typically, framework data come from mapping agencies rather than existing health research (Ezigbalike, 2001; Rajabifard, Binns, Masser, & Williamson, 2006). However, in some instances where framework data do not exist, health researchers have had to create their own (e.g. Bailey., P., et al., (2011)). In instances where village health workers access their communities on a regular basis, they can be used to map neighbourhoods in a manner that is cheaper than hiring professional GIS practitioners to do the same (Munyaneza et al., 2014).

Due to the general unavailability of framework data in LMICs, health researchers have sometimes resorted to using more readily and freely available coarse-resolution data to model the geography of health-related issues. For example, 90 m digital elevation models have been used together with land cover data to model access to care using friction surfaces (Fogliati et al., 2015; Masters et al., 2013). Access to health care services has also been modelled by (Friedman et al., 2013) “as the crow flies,” through the creation of buffer zones around health facilities to avoid the process of creating road data required for more precise estimates of travel time. These approaches, while useful at very small scales, produce results that are simply not useful for understanding health trends at the community level. Semi-automated methods such as feature extraction from satellite images have also been explored (Awad, 2013), but the costs associated with post-processing and acquiring the high-resolution satellite images remains a prohibiting factor.

Despite the free availability of coarse-resolution GIS data from public sources, detailed framework data remain essential for modelling geographic patterns in health (Schuurman, Fiedler, Grzybowski, & Grund, 2006), particularly for facilitating targeted community health programming in highly burdened settings that have limited resources. This article introduces a series of strategies for creating framework GIS data in a data-poor setting based on the experiences from the Mapping Outcomes for Mothers (MOM) project in a largely rural region of southern Mozambique. These data creation strategies are an important contribution to the execution of health-related GIS research, spatial mapping, and analysis in LMIC settings where framework data are not readily available.

5.3. Project context and GIS data needs

The MOM project was set in 12 administrative regions in the southern part of Mozambique: four in Maputo province and eight in Gaza province. The overall aim of MOM was to explore the community-specific factors that elevate risk in pregnant women, resulting in maternal deaths or instances of severe maternal morbidity. We also endeavoured to identify community-specific factors that promote healthy pregnancy outcomes. Part of this process included modelling access to maternal health services—as well as how this access was affected by the seasonal floods and wet weather that plague this study region almost every year. MOM was undertaken in partnership with the

Community Level Interventions for Pre-eclampsia (CLIP) cluster randomized control trial [ClinicalTrials.gov ID: NCT01911494], which at the time of writing this paper was evaluating a care package delivered by community health workers in an effort to reduce all-cause maternal mortality and severe morbidity in Pakistan, India, Nigeria and Mozambique. Two key datasets were created as part of the MOM work, including a detailed set of community-level roads for modelling spatial access to maternal care services, and a set of high-resolution community boundaries for quantifying community-specific risk and resilience factors related to maternal outcomes.

5.3.1. Modelling spatial access to maternal care

Modelling potential geographical access to health services is the main application of GIS in maternal health research (Ebener et al., 2015; Makanga et al., 2016). A detailed road network dataset is normally required for this work—in order to trace the actual paths that are potentially used to navigate through space. However, alternate methods for quantifying spatial access to the closest facility that require less detailed data can be used in the absence of good framework road data. Examples include calculating fixed distance buffers around health facilities (Ivers et al., 2008), and creating friction surfaces based on low-resolution and freely available digital elevation models and land use data (Masters et al., 2013). These methods have all been shown to produce comparably accurate results for identifying the closest facilities (Nesbitt et al., 2014). However, it has also been demonstrated that patients do not necessarily access their closest facility (Alford-Teaster et al., 2016), and that there are many other pervasive factors that influence which facility will be used in the time of need. Moreover, patients do not necessarily walk or drive as the crow flies.

The MOM study sought to extend current models of access to care by accounting for the hierarchical nature of travel through the health referral chain (i.e., primary health facilities to secondary health facilities to tertiary health facilities) instead of simply identifying the closest facilities. Modelling potential spatial access using this hierarchical manner more closely matches the reality of women's travel through the health care system and required a more detailed inspection of the pathways of travel used when seeking maternal care—hence our need for a high-resolution network of community-level roads.

We also sought to factor into our analysis the impact of precipitation and floods on access to maternal care. Therefore, we needed a dataset that described the actual roads (and their condition) that women would travel on (e.g., paved/unpaved) to quantify how the road infrastructure would be affected by weather conditions, and also to identify the specific community road segments that would not be usable in the event of flooding.

5.3.2. Modelling community-level risk and resilience in maternal health

The use of geographically explicit statistical techniques is increasingly being recognized in health GIS research as this approach adds value by illustrating how associations with disease patterns change across space (e.g.,(Inmaculada Aguilera et al., 2007; Owoo & Lambon-Quayefio, 2013; Shoff et al., 2012)). These kinds of analyses require data to be aggregated into small geographical units prior to analysis in order to reveal the underlying spatial patterns that are normally masked into single values (e.g., beta coefficients and R^2 values). An example of one of these techniques, which was used in the MOM project, is geographically weighted regression (GWR). Unlike ordinary least squares regression, GWR evaluates the non-stationarity of parameter estimates across space (Shoff et al., 2014). GWR typically requires many data points (neighbourhoods) for the valid estimation of the changing parameter values (Fotheringham et al., 2003).

The MOM study used GWR to explore the spatial epidemiology of maternal ill health in the study area. This entailed elucidating the associations between possible risk and health promotion factors as measured through the baseline study of the CLIP trial, as well as how these associations changed over different communities. A host of socio-cultural variables including financial support, emergency transport availability, and financial decision making were collected for every household in the study area, with the intention of aggregating these to community-level scores. There was, therefore, a need to create high-resolution community boundaries as a basis for the doing further geo-statistical analysis and identifying the place-specific patterns relating the variables to rates of maternal deaths.

5.3.3. Other datasets

Two other datasets were required for this work, including a spatio-temporal dataset for precipitation spanning a retrospective 1-year period starting from the point when the CLIP baseline survey was conducted. We also required data on the flood extent for the same timeframe. These data helped in modelling the seasonal impact of weather elements on access to maternal care services in the study area.

5.4. Data sources and data creation

5.4.1. Existing data sources

The first step for data acquisition was searching through public databases that host spatial data, such as DIVA-GIS and OpenStreetMap, and identifying relevant datasets. We also met with personnel from the Mozambique National Cartography and Remote Sensing Centre (CENACARTA), and other local mapping institutions who shared their available data. The data were assessed to evaluate if they needed re-formatting for our needs. Through this process, we were able to quantify the data gaps that needed to be filled through alternate methods. A key lesson from this data-building process was the importance of liaising with local data stewards as well as drawing on open geodata repositories.

A summary of the freely available public datasets acquired for this project is provided in Table 5.1. There were multiple versions of the same data, none of which had comprehensive metadata to describe how they could be used. Both the street data and administrative boundaries were only available at very small scales; highways and paved main roads were the best roads available, while the best available administrative boundaries were at the administrative post level. Lower level boundaries for localities and neighbourhoods were not available at any of the public data sources or CENACARTA.

Table 5.1: Datasets acquired from public databases and CENACARTA

Data Source	Datasets Acquired
Public Databases (e.g., DIVA-GIS, OpenStreetMap, UN FAO clearinghouse, CENACARTA website)	Street data • Highways Administrative Boundaries • National, provincial, district and administrative post
OpenStreetMap	Street data • Highways, major roads and some minor roads
CENACARTA (National Mapping Agency)	Street data • Highways, major Roads Administrative boundaries • National, provincial, district and administrative post
Bureau of Statistics	None
Health Ministry	Health facility coordinates
CLIP Project	Households • GPS Coordinates • Household IDs
Manhica Research Centre (Local research partner)	List of all neighbourhood IDs linked to neighbourhood names, locality and administrative post Street data • Highways, major Roads Administrative boundaries • National, provincial, district and administrative post
Global Flood Observatory	Daily flood extents for the study area (for quantifying the impact of flooding on access to health facilities)
Famine Early Warning Systems Network (FEWSNET)	Daily precipitation estimates for the study area (for quantifying the seasonal impact of precipitation on access to health facilities)

5.4.2. Capturing road data

Gaps in the road datasets were filled through a process of manual digitization. We set up a custom data capture platform (Figure 5.1) based on the ArcGIS suite of software, that met our data capture needs and also allowed for data capturers to use a familiar software platform. The idea of a custom interface for data capture was also to demonstrate that the process of setting up custom applications has become much quicker, and that researchers who require data capture tools that are not part of the design in existing free platforms (e.g., OpenStreetMap) have an option to make their own.

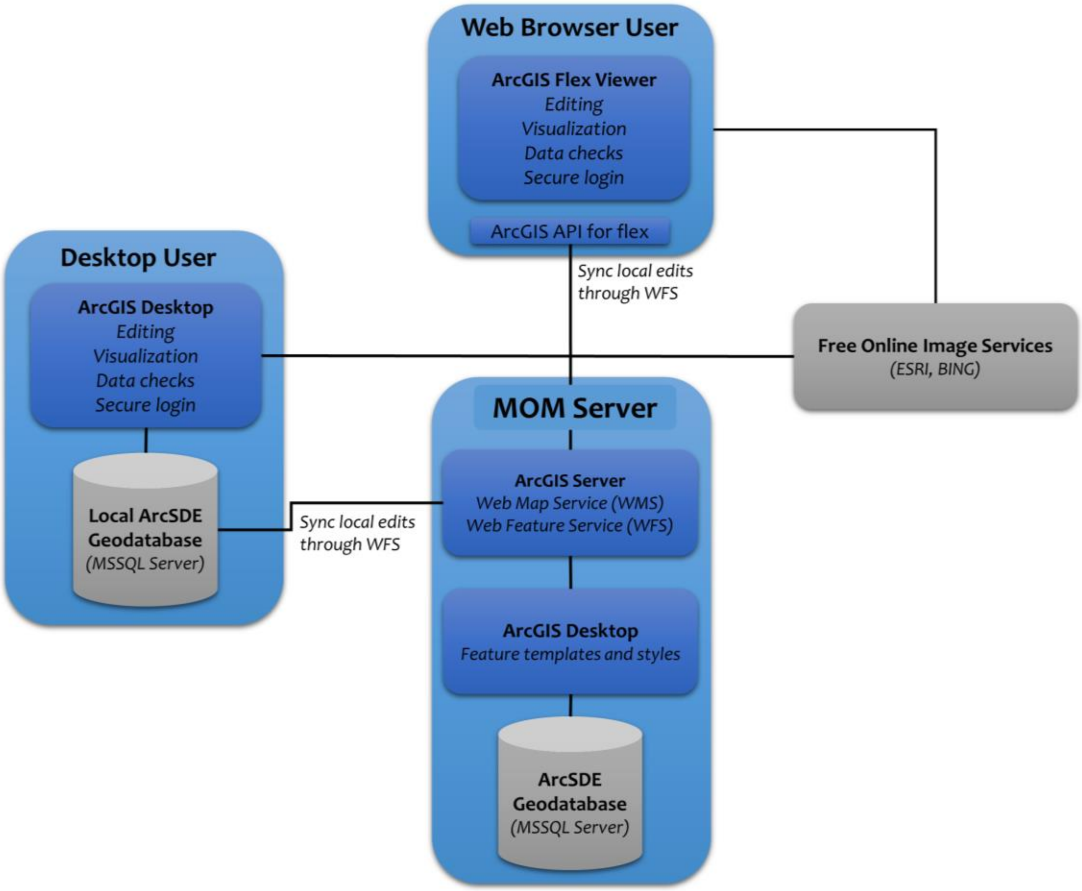


Figure 5.1: Architecture of the data capture platform

An ArcSDE multiuser geodatabase was designed to allow for multiple remote users to digitize the data concurrently and sync the changes centrally to the MOM server in near real time. A freely available satellite image service from Bing Maps was used as reference for tracing out the new road features. The images for the study area were last updated in April of 2012 and were available at 60 cm resolution at the 18th zoom level (Bing Maps, 2016; Microsoft Developer Network, 2016). A Web Feature Service (WFS) was used to render the contents of the geodatabase to the multiple users for editing through the ArcGIS server platform. The WFS is an open standard for rendering and manipulating geographic vector features through the web and independent clients (Open Geospatial Consortium Inc, 2014).

There were two possible ways of accessing the WFS: (1) through secure access from a remote ArcGIS desktop client, or (2) through our custom browser-based MOM application, designed using the ArcGIS viewer for flex (Figure 5.2). In the first instance, the data capturer would set up a local ArcSDE geodatabase that would allow for data to be downloaded onto their computers from the MOM server, for editing. Upon completion of a digitizing session, data would be synced back to the MOM server. In the second instance, users would access the WFS and do all edits through a web browser.

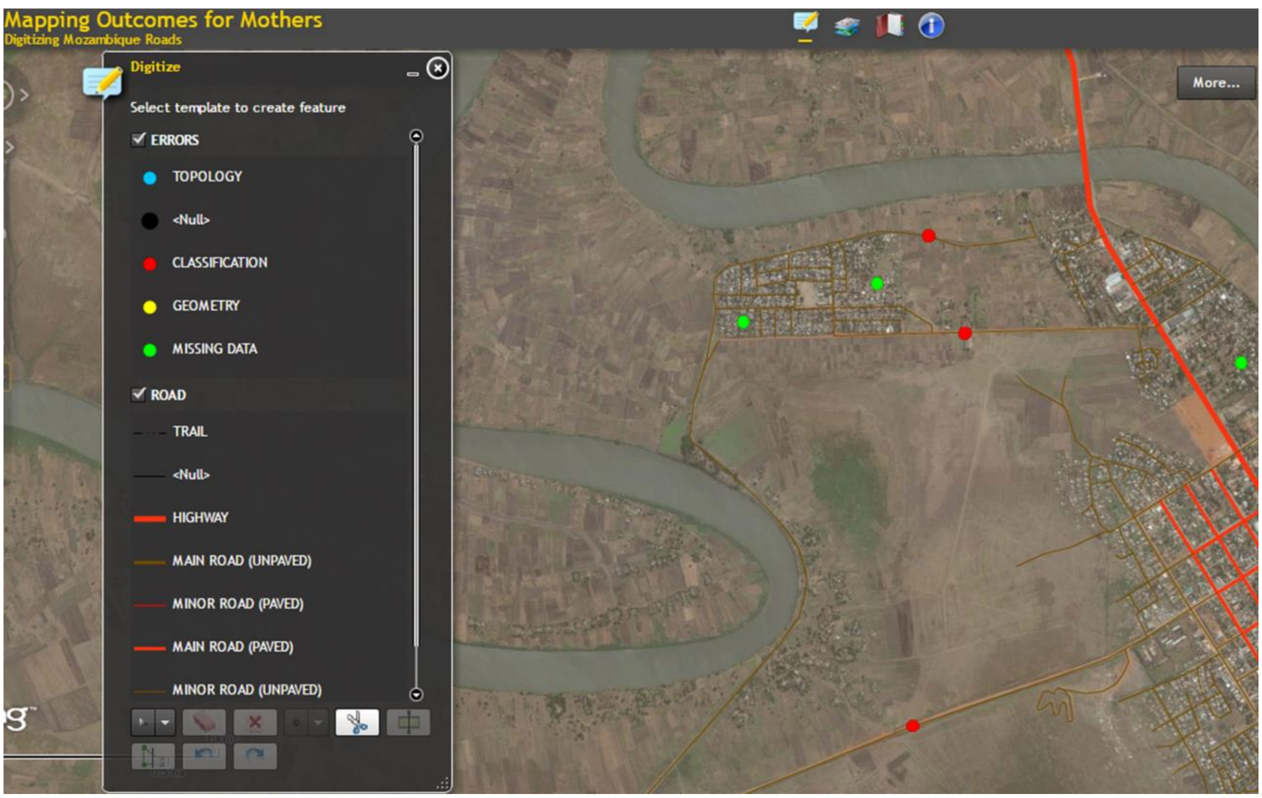


Figure 5.2: Flex based web viewer for digitizing roads data

Twenty-six student volunteers were initially recruited to help with the digitizing. However, we realised early into the data capture process that there were a lot of quality control challenges. We thus chose to work with only four students who were compensated for their time. Estimations of time spent digitizing were based on timestamps attached to each digitized feature. All students were given basic training to minimize data capture errors and to ensure uniform interpretation of imagery during the data capture process. The data capturers also checked each other's work for geometric, topological, and classification errors, as well as omitted roads. One of the data capturers was solely dedicated to checking all the digitized features for these errors. Two staff from CENACARTA also volunteered to check the data. Classification of road types was done by consensus between all participating parties based on local knowledge and interpretation of the imagery.

A total of 15,014.4 km of road length was manually digitized and checked for the data capture errors described earlier (Table 5.2). The roads were classified into 6 themes: highways, paved main roads, unpaved main roads, paved minor roads, unpaved minor roads, and trails—with most of roads (71.2%, 10694.7 km) being unpaved minor roads. The total time for the digitizing process was 179 hours, which translates to roughly 22 8-hour days. This is significantly less time than what we expected for such high-resolution data capture.

Table 5.2: Summary of new roads data

Road classification	Total length (km)	% of all roads
Highway	788.3	5.3
Main road (paved)	610.1	4.1
Main road (unpaved)	1978.4	13.2
Minor road (paved)	479.5	3.2
Minor road (unpaved)	10694.7	71.2
Trail	463.4	3.1
Total length (all roads)	15014.4	
Total time for digitizing (hr)	179.0	

Although OpenStreetMap data have been used in other studies in which these data were confirmed as an accurate representation of what's on the ground (Ferguson, Kemp, & Kost, 2016), this was not the case for our study area, as illustrated by the huge data gaps in Figure 5.3. At the time of writing this paper, arrangements are underway to publish all the new data to the OpenStreetMap platform to serve as a contribution to a wider GIS audience needing access to data in the study area.

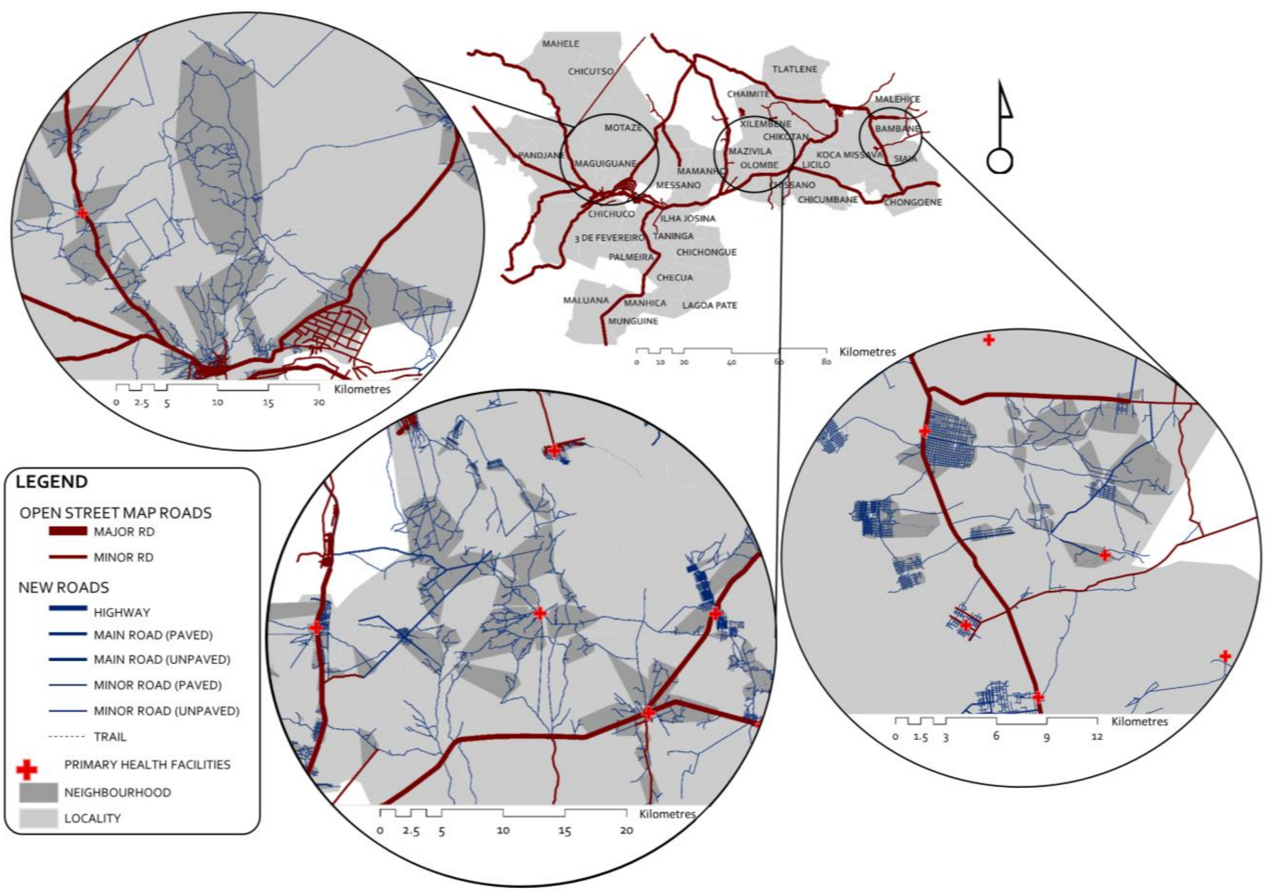


Figure 5.3: Data gaps in open street map that were filled through manual digitizing

5.4.3. Capturing community boundaries

Community boundaries were created from GPS coordinates of households in the study area that were acquired from the CLIP baseline survey. Each household in the study was assigned a unique 10-character household identification (ID) that indicated the administrative post, locality, neighbourhood, and household number (Figure 5.4). A neighbourhood is the smallest administrative unit and the administrative post is the largest administrative unit for this study. Multiple neighbourhoods are contained in a single locality, and multiple localities in an administrative post. Ethics approval for this study only allowed us to access information up to the neighbourhood ID, so we would not be able to identify any of the individual households.

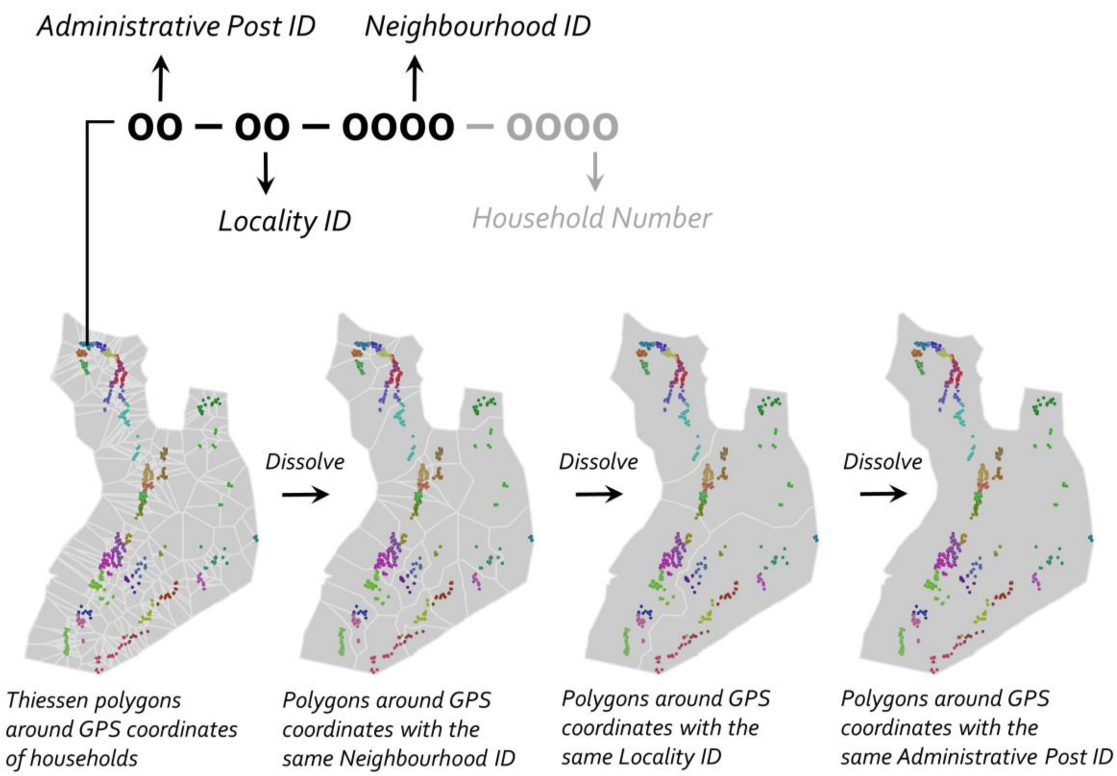


Figure 5.4: Structure of the household ID. Used as basis for mapping community boundaries

Based on this information we created Thiessen polygons around all GPS coordinates and dissolved the Thiessen polygons that had the same IDs for each of the three administrative levels (Figure 5.4). This process created two new sets of smaller community boundaries that did not exist prior to starting this work (in addition to the administrative post data): 36 localities and 425 neighbourhoods (Figure 5.5). While this approach created polygons around points that belonged to the same neighbourhood, locality, or administrative post, a key limitation of this approach is that unpopulated regions (e.g., forests) that lie in between the inhabited sections of neighbourhoods would be shared between these neighbourhoods. This approach, therefore, tends to overestimate the spatial extent of the administrative units.

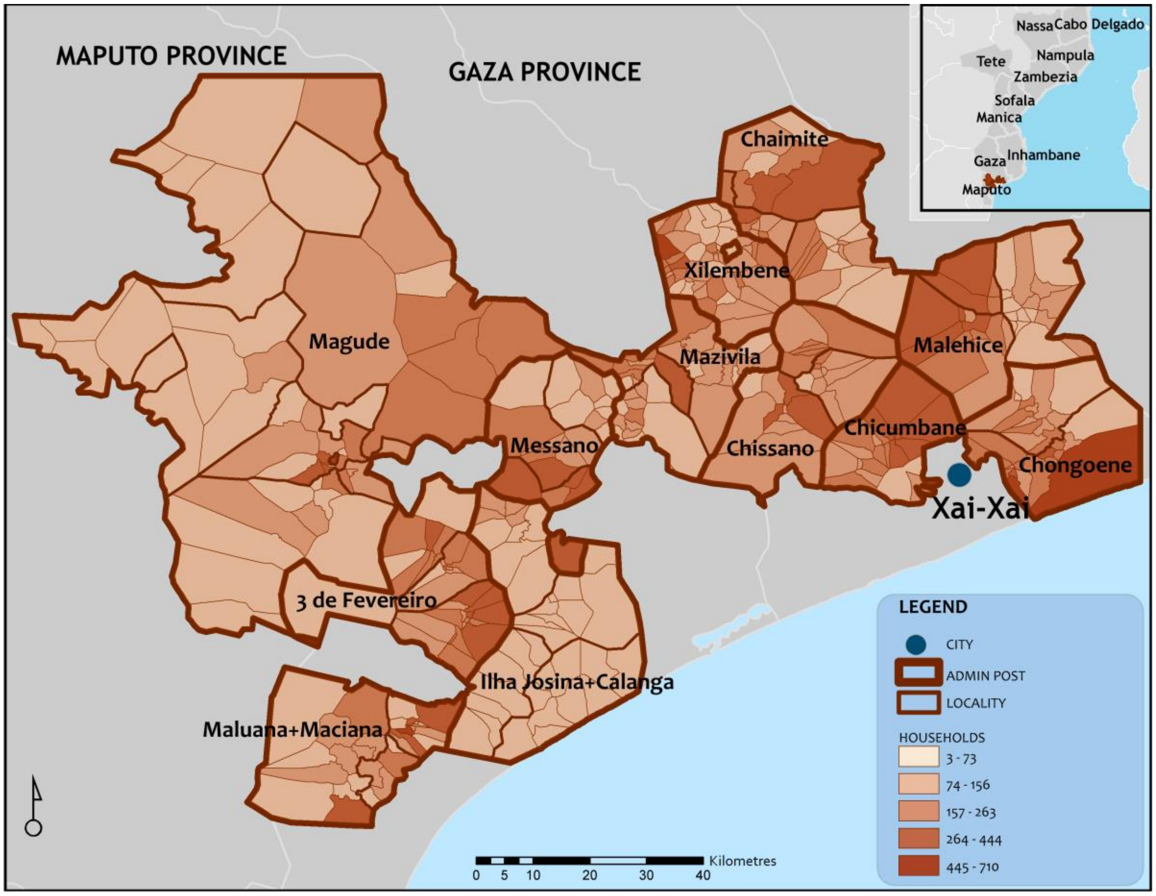


Figure 5.5: Community boundaries dataset

These neighbourhood boundary datasets were used for detailed spatial analysis of community-level access to care, in contrast to the more abstract possibilities that would have been achieved at the administrative post level. As each of the households were assumed to have one or more women of reproductive age (WRA), these data were also used to generate WRA population estimates which are an important component of evaluating access to maternal health services, and identifying marginalized populations of women.

A comparison of the official administrative post dataset with the ones created in this project revealed that 24 of the 425 neighbourhoods (or 2141 of the 50619 households) in the study area were not located within their presumed administrative post boundary by as much as almost 5 kilometres in some of the cases.

5.5. Discussion

This article addresses some of the data challenges that health GIS researchers working in LMIC face and illustrates strategies to address these challenges by drawing on the lessons learned from our health GIS project in southern Mozambique. A set of guidelines that could help health GIS researchers in LMIC face these data challenges is summarized in Table 5.3. We found that although public databases are a good place to start searching for base GIS data, these sources do not provide enough data for high-resolution health-related spatial analysis. While there is not an absolute lack of data in LMIC, decentralized and uncoordinated efforts result in duplication of mapping activities, as indicated by multiple custodians having different versions of the same dataset. It should be recognized that the institutions that are meant to coordinate creation and sharing of spatial data are not leading these initiatives in LMICs (Von Hagen 2007), which is a possible explanation for why most of the available data were acquired from public online sources rather than CENACARTA.

While much of the literature suggests that digitizing is a long, tedious, and expensive process (Awad, 2013; Sipe & Dale, 2003), the time taken to create the data from this work demonstrates that digitizing data is becoming cheaper and faster. This is attributed partly to the availability of free satellite imagery through the geoweb, which eliminates the high cost associated with their purchase. The distributed data capture, enabled through the use of open mapping standards like the WFS, makes the process more efficient. Manual digitizing may be perceived of as a trivial (and old-fashioned) method to many health GIS researchers, but it is an essential part of doing health GIS research at very granular levels in LMIC; it is also essential to sustaining the use of GIS in studying population health problems and targeting health interventions. Complementing the manual digitizing process with semi-automated methods may be helpful in some instances, although currently there are additional costs associated with these methods arising from post-processing and cleaning the data (Cao & Sun, 2014).

Table 5.3: Guidelines for gathering and creating framework GIS data in a typical data-poor setting

1. Determine what publicly accessible spatial data are available from existing data warehouses. This step precedes any decision to acquire base spatial data.
2. Consult local/national mapping agencies or other relevant mapping authorities and acquire datasets relevant to the research project. Inventory the data from all sources to identify data gaps.
3. Use freely available high-resolution satellite data to digitize new vectors that can be extracted from the imagery (e.g., dwellings and roads).
4. Utilize appropriately skilled local personnel with local knowledge to be part of a consensus-based process for data capture. Train all the data capturers how to interpret features from satellite imagery in a manner that is consistent.
5. Use GPS coordinates from previous household surveys or censuses, where available, as the basis for mapping the location of populations and higher-resolution community boundaries.
6. Utilize open geospatial standards for web mapping (e.g., the web feature service) to facilitate for distributed data capture, allowing for multiple users to work on the same centrally managed dataset.
7. Use open standards to document metadata for the created data; e.g., why the data was created, when, for what, by whom, use limitations, etc. This will allow for future users to know how and how not to use the data.
8. Use independent data checkers to validate the captured data for completeness, geometric precision, topological consistency, and classification of features. If possible, involve the mapping agency in this process.
9. Share the data with mapping agencies to add to their data infrastructure and to make data accessible to other researchers.

The MOM data capture platform was designed using proprietary software because it was much easier and quicker to set up compared to other available open source options. The cost of acquiring this software may prohibit other LMICs from implementing a similar design, and we acknowledge this as a possible limitation of this work. However, web computing standards similar to the WFS are also available in most free and open source GIS software, and these could be used instead to achieve the same functionality as the platform presented in this article.

This project has produced high-resolution community boundaries that can be used for fine-grained spatial analysis that could help to better target health programs and inform health policy. It is likely that the generation of these community boundaries will be much faster and more accurate in the future because most countries in Africa are starting to use

GIS and GPS as part of household surveys and censuses (Perez-Heydrich, Warren, Burgert, & Emch, 2013; Yilma, 2015). Point data on household dwellings are also increasingly being used as an alternative to cadastre-based property registers (Hackman-Antwi, Bennett, de Vries, Lemmen, & Meijer, 2013; Statistics South Africa, 2015), and this will open up opportunities to catalyze production of base community maps.

This project also demonstrates that the use of volunteered geographic information may not be ideal for the creation of framework data like roads. Data capturers for such high-precision geodata will require some level of training to achieve the required technical precision (Budhathoki, Bruce, & Nedovic-Budic, 2008). As was the case with the OpenStreetMap initiative, where only a small percentage of the registered users generate most of the content (Heipke, 2010), our experience has shown that data will be captured more efficiently by a few trained individuals who have incentive to participate in the data capture process. Further to that, OpenStreetMap data for our study area, which had been created by other volunteers, was not precise enough for our work (Figure 5.3).

We undertook a participatory approach and involved CENACARTA in our data capture processes. This enabled them to contribute to and validate the process of data creation. We anticipate that this instilled a sense of ownership in the data and its creation process. Intentionally involving members of CENACARTA also exposes them to basic retraining on methods of data capture that are much cheaper than those they currently use. As CENACARTA has the mandate to create and maintain framework spatial data (Rajabifard et al., 2006), working with this agency increases the potential for scaling up mapping work. However, more needs to be done to convert these methods into standard procedures that could be incorporated into routine mapping exercises by CENACARTA. Ultimately, it should be the role of the mapping agency to create and manage the fundamental GIS datasets and make them centrally accessible to different stakeholders, including health GIS researchers.

5.6. Conclusion

With the increasing inclusion of geographic thought and use of spatial techniques in health research, there is a growing demand for high-resolution framework spatial datasets. This article illustrates some of the key considerations for health GIS researchers working in settings where the required data may not be readily available. The processes presented in this article are a quick fix to the data challenges in most LMICs, and there is a need for more coordinated and sustainable efforts for data creation and sharing. Involving mapping agencies in data capture processes has the potential to sustain rapid scale-up of mapping efforts, using some of the low cost strategies presented in this article.

5.7. Acknowledgements

Funding: This work was part funded by Grand Challenges Canada- Stars in Global Health program (Grant 0197) and was conducted as part of the PRE-EMPT (Pre-eclampsia/Eclampsia, Monitoring, Prevention and Treatment) initiative supported by the Bill & Melinda Gates Foundation. I would also like to thank Valódia Cármen Cufanhane and Antonio Maimbo from CENACARTA for volunteering to check the data and advise on data capture processes.

Chapter 6. Conclusion

6.1. Summary

The global health vision of improving the health of everyone, everywhere is grand. However, there are unprecedented levels of political will at the highest level of global governance within the United Nations and the World Health Organization to make this dream a reality (United Nations, 2015, 2015). There is an underlying premise behind the new global health, that the disparities in health that exists in the world are indeed unfair. New strategies for improving global health thus recognize that while clinical measures that seek to deliver treatment of disease and avert premature deaths have worked in the MDGs, there is a parallel need to further address the structural inequities that generate these disparities to further accelerate progress towards a healthier world (United Nations, 2015). The paradigm of reducing structural inequalities requires innovative frameworks for equalizing the social determinants of health. This dissertation contributes to this discourse by exploring how the methods within the discipline of health geography can elucidate the social determinants of maternal health, and be used to complement (not replace) current clinical strategies that are known to work. This dissertation has demonstrated the value of using spatial data and analyses to understanding the place specific character of these determinants in how they influence health outcomes. Although this dissertation has applied geographic methods to identify the local determinants of maternal health in Mozambique, I would like to propose that much of the lessons from this work could be applied to many other health issues, in different settings.

In the following sections I reflect back on the larger objectives of this dissertation, and describe the key contribution that each paper adds. I then conclude this dissertation by highlighting some of the limitations of this work, as well as future research directions.

6.2. Research contributions

6.2.1. Overall contributions

This dissertation aimed to implement geographic methods in identifying and measuring the context relevant determinants of maternal ill-health, as well as to elucidate the geographic nature of associations between these determinants and maternal health outcomes. The key contribution of this work is a demonstration of how geographic methods can be used to operationalize the social determinants of health. Throughout the dissertation it becomes clear that challenges exist concerning the social determinants of health, including identifying the determinants that matter in specific places and the extent to which these determinants actually generate the disease patterns that are observed. The approach used in this research included entering communities and understanding their perspectives on their own socio-cultural and environmental characteristics. This helped to generate new evidence for the context specific determinants of maternal health in the region of interest in southern Mozambique. The use of GIS helped to further quantify these determinants and explore the spatial structure of their associations with maternal health. While the need to take action on the social determinants has now been widely accepted, and reflected in substantive policy related to health within the SDGs, the frameworks for identifying the determinants, measuring their impact on health outcomes and addressing them to eventually improve health are still under development. The geographic perspective highlighted in this dissertation contributes to that end.

The contribution of this work also extends to the ongoing space vs place debates between medical and health geographers, by illustrating the merits of a unified geographies of health. Part of the reason for the call to a reformed medical geography was the position that medical geographers appeared to undervalue the social context within which health occurred (Kearns, 1993). However, medical geographers claimed to share this same principle of valuing context, through the disease ecology and biopsychosocial frameworks (Mayer, 1994, 1996). The apparent difference between the two streams of thought lies in the suite of methods that seem to preferred. Health geographers largely use qualitative methods while medical geographers largely use quantitative methods. This dissertation has demonstrated the value of both perspectives through adopting the use of qualitative techniques to explore the community perceptions of the determinants of maternal health. This was coupled with a quantitative exploration of these associations using geostatistical techniques in a manner that validated the qualitative findings. This research therefore illustrates the merits of analysing the characteristics of a place, using spatial techniques.

The specific contributions of each paper are described in the following section.

6.2.2. Contributions of each paper

The first paper in this dissertation (chapter 2) described how GIS has been used in maternal health within global health literature, and contributes to the use of geographic methods in maternal health by highlighting the knowledge gaps that exist in the use of GIS. This review was conducted early in my doctoral studies, and the knowledge gaps that were identified in the process contributed to forming the thematic premise for the subsequent studies. Two key knowledge gaps that were identified include the inadequacy of current methods of evaluating potential geographical access to maternal health services in typical sub-Saharan Africa contexts, and a general underutilization of available spatially explicit techniques in relating the determinants of maternal health with adverse maternal outcomes. Both knowledge gaps are an important illumination of current limitations in existing geographical approaches that aim to describe the determinants of maternal health. Apart from highlighting these knowledge gaps, as a standalone publication the scoping review is intended to serve as a resource for policy makers and researchers in global maternal health needing to know how GIS has, and could be used as part of the maternal health policy.

Chapter 3 contributes to the methods of measuring potential geographical access to maternal health services; a well-known determinant for adverse maternal outcomes. This was achieved by extending current models of spatio-temporal access to account for 1) the seasonal variation in access using empirical data on precipitation and floods, and 2) the daily transport realities that characterise women journeys in the study area, based on the transport options available to them. This approach illustrates the value of incorporating local knowledge (e.g. transport realities) and context specific data (e.g.

floods and precipitation records) as part of creating context specific measures for the determinants of health and contributes to the first objective of this dissertation. Furthermore, the access model developed in this paper is methodologically superior as it more readily incorporates the realities of travel to health facilities. It does so by utilizing a design that respects the hierarchy of the facility referral network, as women mostly travel to higher level facilities after having been referred from lower ones, not directly. This study is the first of its kind to incorporate empirical records of floods and precipitation, together with data on pregnancies and mixed transport modes as part of modeling the seasonal impact on spatial access to maternal care.

Chapter 4 relates to both objective 1 and 2, and contributes by highlighting the value of eliciting local perspectives as part of knowing and measuring the context specific determinants of health. The chapter illustrates the use of geographically explicit techniques and how these help to understand the determinants that matter in specific places, adding to a knowledge gap identified in the scoping review. This process of conducting this research contributes to the discussion on how to operationalize some of the emerging global health strategies concerning multi-sectoral approaches and disaggregating analyses of the determinants of health and health outcomes. A multi-sectoral approach to understanding the local determinants of health was illustrated through how this project consulted multiple stakeholders; including pregnant women, health professionals, local leaders, male partners and matrons to elicit their perceptions on the local determinants. This approach directly contributed to our criteria for knowing which variables to measure. Further, the Delphi consensus broadened the reach of our consultations by getting input from 17 professionals from different parts of the world who had worked in relevant disciplines. The statistical significance of the variables derived from this broad consultation validates the process of doing this research. The use of geographic boundaries to organize the data collected in this project is consistent with the new policy priorities for disaggregating health data to understand patterns that are normally masked into single values like national MMRs. Likewise, the use geographically weighted regression identified the place specific effects of the statistically significant variables on the combined outcome, and contributes to methods of generating evidence to support targeted interventions on the determinants of health.

Finally, chapter 5 presented a set of guidelines for generating framework GIS data. Availability of good quality framework data was identified as an obstacle to applying GIS to maternal health in LMICs in the scoping review. This paper provides much needed strategies and protocols for developing datasets that are fundamental for implementing the geographical analyses used in this dissertation. In this paper I challenged the common narrative around the tediousness of manual digitization of data and illustrated that this process is becoming quicker and cheaper due to wide availability of free and recent satellite imagery. The paper also described how to quickly set up a platform for data capture that is based on open mapping standards. A simple process of creating high resolution community boundaries using geocoded census data was designed as part of this work and contributed to the discourse on moving beyond national averages and performing high resolution geographically disaggregate analysis and reporting are a priority within the new SDGs. In writing this paper, it is my hope that global health researchers needing to do GIS work in LMIC will use these guidelines to overcome some of the data challenges that they will likely face.

6.3. Limitations and future research

The limitations of this work form the basis for future research topics. The first has to do with the generalizability of findings. As was highlighted in the scoping review, geographic approaches tend to produce results that are largely applicable to the specific areas where the research is conducted. Therefore, while this dissertation created new knowledge concerning the determinants of maternal health in Mozambique, whether this knowledge can be directly translated to design health interventions in other places remains an empirical question. In other words, the determinants of maternal health that have been show to matter in this region of Mozambique, may not matter in other countries. Nonetheless, this works approach of eliciting multi-stakeholder perspectives on these determinants, measuring them and exploring the place specific nature of association could be replicated in other settings to elaborate on the context specific determinants of health.

While most maternal deaths occur in the lower income regions of the world, the new global health policy drive that calls for disaggregate reporting of subnational trends in maternal health will likely reveal that there exist pockets of communities within high income countries that also have high MMRs. Canada is a case in point, where First Nations communities have disproportionately higher MMRs and face challenges of poor access to maternal health services due to geographic isolation and severe winter weather, similar to mozambique. The solutions developed in poor countries will need to be adapted for these contexts. This process of reverse innovation which "seeks to make use of low-income country health innovations within high-income country settings" (Syed, Dadwal, & Martin, 2013), is a future research area of interest.

The other limitation of using geographic methods to elucidate the determinants of health has to do with the limitations of ecological approaches to understanding health trends. Most geographic analyses in health are done with aggregate level data in order to protect the privacy of individual patient record. The results therefore cannot be used to explain or predict patterns for the individual (Dummer, 2008). For maternal deaths in particular, the units of analysis require to be large in order to adequately power any meaningful statistical analysis, as there are normally very few deaths in small regions. However, the underlying patterns in the determinants of health become convoluted as the scale becomes smaller, making it harder to draw solid parallels between the trend in the determinants and the outcomes.

While the dissertation created a context specific measure of access to maternal health, and further evidence on the associations between determinants and maternal outcomes, improving maternal health will require action on these determinants. Generating this evidence is an important step for designing interventions. However, future research should explore how to translate such evidence on the place specific influences for maternal health into targeted action.

References

ACIS. (2011). Decree-Law 1/2011 of 23 March - THE ROAD TRAFFIC CODE. Retrieved from http://www.mcli.co.za/mcli-web/downloads/docs/acis_road_code_decree_law_1-2011.pdf

Adegoke, A., Utz, B., Msuya, S. E., & van den Broek, N. (2012). Skilled Birth Attendants: Who is Who? A Descriptive Study of Definitions and Roles from Nine Sub Saharan African Countries. *PLoS ONE*, *7*(7), e40220. http://doi.org/10.1371/journal.pone.0040220

Aguilera, I., Sunyer, J., Fernández-Patier, R., Hoek, G., Aguirre-Alfaro, A., Meliefste, K., … Brunekreef, B. (2007). Estimation of outdoor NO x, NO2, and BTEX exposure in a cohort of pregnant women using land use regression modeling. *Environmental Science & Technology*, *42*(3), 815–821.

Ahmed, S., Li, Q., Liu, L., & Tsui, A. O. (2012). Maternal deaths averted by contraceptive use: an analysis of 172 countries. *The Lancet*, *380*(9837), 111–125.

Aimone, A. M., Perumal, N., & Cole, D. C. (2013). A systematic review of the application and utility of geographical information systems for exploring disease-disease relationships in paediatric global health research: the case of anaemia and malaria. *International Journal of Health Geographics*, *12*(1), 1–13. http://doi.org/10.1186/1476-072X-12-1

Alegana, V. A., Wright, J. A., Pentrina, U., Noor, A. M., Snow, R. W., & Atkinson, P. M. (2012). Spatial modelling of healthcare utilisation for treatment of fever in Namibia. *International Journal of Health Geographics*, *11*(1), 1.

Alford-Teaster, J., Lange, J. M., Hubbard, R. A., Lee, C. I., Haas, J. S., Shi, X., … Tosteson, A. N. (2016). Is the closest facility the one actually used? An assessment of travel time estimation based on mammography facilities. *International Journal of Health Geographics*, *15*(1), 1.

Alvarez, J. L., Gil, R., Hernández, V., & Gil, A. (2009). Factors associated with maternal mortality in Sub-Saharan Africa: an ecological study. *BMC Public Health*, *9*(1), 1–8. http://doi.org/10.1186/1471-2458-9-462

Arksey, H., & O'Malley, L. (2005). Scoping studies: towards a methodological framework. *International Journal of Social Research Methodology*, *8*(1), 19–32. http://doi.org/10.1080/1364557032000119616

Audet, C. M., Chire, Y. M., Vaz, L. M., Bechtel, R., Carlson-Bremer, D., Wester, C. W., … Gonzaléz-Calvo, L. (2015). Barriers to male involvement in antenatal care in rural Mozambique. *Qualitative Health Research*, 1049732315580302.

Awad, M. M. (2013). A Morphological Model for Extracting Road Networks from High-Resolution Satellite Images. *Journal of Engineering*, *2013*, 1–9.

Bailey, P. E., Keyes, E. B., Parker, C., Abdullah, M., Kebede, H., & Freedman, L. (2011). Using a GIS to model interventions to strengthen the emergency referral system for maternal and newborn health in Ethiopia. *International Journal of Gynecology & Obstetrics*, *115*(3), 300–309. http://doi.org/10.1016/j.ijgo.2011.09.004

Bailey, P. E., Keyes, E., Moran, A. C., Singh, K., Chavane, L., & Chilundo, B. (2015). The triple threat of pregnancy, HIV infection and malaria: reported causes of maternal mortality in two nationwide health facility assessments in Mozambique, 2007 and 2012. *BMC Pregnancy and Childbirth*, *15*(1), 1.

Banta, J. E. (2001). From international health to global health. *Journal of Community Health*, *26*(2), 73–76.

Berendsen, M. E., Hamerlinck, J. D., Lanning, S. G., & Shin, S. (2010). *Developing NSDI Framework Data:ANSI Framework Data Content Standards Guidance Document*. Federal Geographic Data Committee: Wyoming Geographic Information Science Center, University of Wyoming, Laramie, Wyoming USA.

Bhutta, Z. A., & Black, R. E. (2013). Global maternal, newborn, and child health—so near and yet so far. *New England Journal of Medicine*, *369*(23), 2226–2235.

Bhutta, Z. A., & Reddy, S. (2012). Achieving equity in global health: so near and yet so far. *J Am Med Assoc*, *307*. http://doi.org/10.1001/jama.2012.4659

Bing Maps. (2016). Bing image analyzer. Retrieved from http://mvexel.dev.openstreetmap.org/bing/.

Blanford, J. I., Kumar, S., Luo, W., & MacEachren, A. M. (2012). It'sa long, long walk: accessibility to hospitals, maternity and integrated health centers in Niger. *International Journal of Health Geographics*, *11*(1), 1–15.

Boene, H., Vidler, M., Sacoor, C., Nhama, A., Nhacolo, A., Bique, C., … Munguambe, K. (2016). Community perceptions of pre-eclampsia and eclampsia in southern Mozambique. *Reproductive Health*, *13*(1), 27–37. http://doi.org/10.1186/s12978-016-0135-y

Boerma, J. (1987). Maternal Mortality in Sub-Saharan Africa: Levels Causes and Interventions.

Boulos, M. N. K. (2004). Towards evidence-based, GIS-driven national spatial health information infrastructure and surveillance services in the United Kingdom. *International Journal of Health Geographics*, *3*(1), 1–50. http://doi.org/10.1186/1476-072X-3-1

Braun, R., Catalani, C., Wimbush, J., & Israelski, D. (2013). Community Health Workers and Mobile Technology: A Systematic Review of the Literature. *PLoS ONE*, *8*(6), e65772. http://doi.org/10.1371/journal.pone.0065772

Braveman, P., Egerter, S., & Williams, D. R. (2011). The Social Determinants of Health: Coming of Age. *Annual Review of Public Health*, *32*(1), 381–398. http://doi.org/10.1146/annurev-publhealth-031210-101218

Brown, C. A., Sohani, S. B., Khan, K., Lilford, R., & Mukhwana, W. (2008). Antenatal care and perinatal outcomes in Kwale district, Kenya. *BMC Pregnancy and Childbirth*, *8*(1), 1.

Brown, S., Richards, M., & Rayburn, W. (2012). Geographical information systems (GIS) mapping indicates access to tertiary care perinatal centers in the United States is regionally maldistributed. *American Journal of Obstetrics and Gynecology*, *206*(1), S304–S304.

Brown, T. M., Cueto, M., & Fee, E. (2006). The World Health Organization and the Transition From "International" to "Global" Public Health. *American Journal of Public Health*, *96*(1), 62–72. http://doi.org/10.2105/AJPH.2004.050831

Brunsdon, C., Fotheringham, A. S., & Charlton, M. E. (1996). Geographically weighted regression: a method for exploring spatial nonstationarity. *Geographical Analysis*, *28*(4), 281–298.

Budhathoki, N., Bruce, B., & Nedovic-Budic, Z. (2008). Reconceptualizing the role of the user of spatial data infrastructure. *GeoJournal*, *72*(3–4), 149–160. http://doi.org/10.1007/s10708-008-9189-x

Buse, K., & Hawkes, S. (2015). Health in the sustainable development goals: ready for a paradigm shift? *Globalization and Health*, *11*(1), 1–8. http://doi.org/10.1186/s12992-015-0098-8

Cao, C., & Sun, Y. (2014). Automatic road centerline extraction from imagery using road GPS data. *Remote Sensing*, *6*(9), 9014–9033.

Chapman, R. R. (2003). Endangering safe motherhood in Mozambique: prenatal care as pregnancy risk. Social Science & Medicine, 57(2), 355–374. http://doi.org/10.1016/S0277-9536(02)00363-5

Chapman, R. R. (2006). Chikotsa—Secrets, silence, and hiding: Social risk and reproductive vulnerability in central Mozambique. Medical Anthropology Quarterly, 20(4), 487–515.

Charreire, H., & Combier, E. (2006). Socio-spatial equity of access to perinatal care in urban area: Use of the geographical techniques for health care planning Equite socio-spatiale d'acces aux soins perinatals en milieu urbain: Utilisation des techniques geographiques pour la planification sanitaire. *Espace-Populations-Societes*, (2–3), 313–327.

Cheng, J., Schuster-Wallace, C., Watt, S., Newbold, B., & Mente, A. (2012). An ecological quantification of the relationships between water, sanitation and infant, child, and maternal mortality. *Environmental Health*, *11*(1), 4.

Collender, G., Gabrysch, S., & Campbell, O. M. (2012). Reducing maternal mortality: better monitoring, indicators and benchmarks needed to improve emergency obstetric care. Research summary for policymakers. *Tropical Medicine & International Health*, *17*(6), 694–696.

Colston, J. M., & Burgert, C. R. (2014). USING GEOSPATIAL ANALYSIS TO INFORM DECISION MAKING IN TARGETING HEALTH FACILITY-BASED PROGRAMS.

Conde-Agudelo, A., Rosas-Bermúdez, A., & Kafury-Goeta, A. C. (2007). Effects of birth spacing on maternal health: a systematic review. *American Journal of Obstetrics and Gynecology*, *196*(4), 297–308. http://doi.org/10.1016/j.ajog.2006.05.055

Cowen, D. J. (1988). GIS versus CAD versus DBMS: What are the differences? *Photogramm. Eng. Remote Sens.*, *54*(11), 1551–1555.

Cueto, M. (2004). The origins of primary health care and selective primary health care. *American Journal of Public Health*, *94*(11), 1864–1874.

Cullinan, J., Gillespie, P., Owens, L., & Dunne, F. (2012). Accessibility and screening uptake rates for gestational diabetes mellitus in Ireland. *Health & Place*, *18*(2), 339–348. http://doi.org/10.1016/j.healthplace.2011.11.001

Curtis, A. (2008). From healthy start to hurricane Katrina: using GIS to eliminate disparities in perinatal health. *Statistics In Medicine*, *27*(20), 3984–3997. http://doi.org/10.1002/sim.3260

David, E., Machungo, F., Zanconato, G., Cavaliere, E., Fiosse, S., Sululu, C., … Bergström, S. (2014). Maternal near miss and maternal deaths in Mozambique: a cross-sectional, region-wide study of 635 consecutive cases assisted in health facilities of Maputo province. *BMC Pregnancy and Childbirth*, *14*(1), 1–8. http://doi.org/10.1186/s12884-014-0401-3

de Andrade, L. O. M., Filho, A. P., Solar, O., Rígoli, F., de Salazar, L. M., Serrate, P. C.-F., … Atun, R. (2015). Social determinants of health, universal health coverage, and sustainable development: case studies from Latin American countries. *The Lancet*, *385*(9975), 1343–1351. http://doi.org/10.1016/S0140-6736(14)61494-X

Dedele, A., Grazuleviciene, R., & Aleksandras Stulginskis, U. (2011). Nitrogen Dioxide Exposure Dispersion Modelling for Assessment of Preterm Birth Risk. In *Rural Development in Global Changes, Vol 5, Book 2* (Vol. 5, pp. 400–406). Akademija: Aleksandras Stulginskis University. Retrieved from ://WOS:000304698500070

Dummer, T. J. B. (2008). Health geography: supporting public health policy and planning. *Canadian Medical Association Journal*, *178*(9), 1177–1180. http://doi.org/10.1503/cmaj.071783

Ebener, S., Guerra-Arias, M., Campbell, J., Tatem, A. J., Moran, A. C., Amoako Johnson, F., … Matthews, Z. (2015). The geography of maternal and newborn health: the state of the art. *International Journal of Health Geographics*, *14*(1), 1–10. http://doi.org/10.1186/s12942-015-0012-x

ESRI. (2016a). Closest facility analysis. Retrieved from http://desktop.arcgis.com/en/desktop/latest/guide-books/extensions/network-analyst/closest-facility.htm

ESRI. (2016b). Service area analysis. Retrieved from http://desktop.arcgis.com/en/desktop/latest/guide-books/extensions/network-analyst/service-area.htm

Evjen-Olsen, B., Hinderaker, S. G., Lie, R. T., Bergsjø, P., Gasheka, P., & Kvåle, G. (2008). Risk factors for maternal death in the highlands of rural northern Tanzania: a case-control study. *BMC Public Health*, *8*(1), 1.

Ezigbalike, C. (2001). The future orientation of geoinformation activities in Africa. *Commisioned by Committee on Development Information (Geo-Information Subcommittee) Development Information Services Division (DISD) United Nations Economic Commission for Africa*.

Ferguson, W. J., Kemp, K., & Kost, G. (2016). Using a geographic information system to enhance patient access to point-of-care diagnostics in a limited-resource setting. *International Journal of Health Geographics*, *15*(1), 1.

FEWSNET. (2016). Famine Early Warning Systems Network - Precipitation GIS Data. Retrieved January 17, 2016, from ftp://ftp.cpc.ncep.noaa.gov/fews/fewsdata/africa/arc2/geotiff/

Firoz, T., Chou, D., von Dadelszen, P., Agrawal, P., Vanderkruik, R., Tuncalp, O., … Say, L. (2013). Measuring maternal health: focus on maternal morbidity. *Bulletin of the World Health Organization*, *91*, 794–796.

Firoz, T., Vidler, M., Makanga, P., Boene, H., Sevene, E., Magee, L., … Mungambe, K. (2016). Community Perspectives on the Determinants of Maternal Health in Rural Southern Mozambique: A Qualitative Study. BMC Reproductive Health, In Press.

Fogliati, P., Straneo, M., Brogi, C., Fantozzi, P. L., Salim, R. M., Msengi, H. M., … Putoto, G. (2015). How Can Childbirth Care for the Rural Poor Be Improved? A Contribution from Spatial Modelling in Rural Tanzania. *PLoS ONE*, *10*(9), e0139460. http://doi.org/10.1371/journal.pone.0139460

Fotheringham, A. S., Brunsdon, C., & Charlton, M. (2003). *Geographically weighted regression: the analysis of spatially varying relationships*. John Wiley & Sons.

Friberg, I. K., Kinney, M. V., Lawn, J. E., Kerber, K. J., Odubanjo, M. O., Bergh, A.-M., … Black, R. E. (2010). Sub-Saharan Africa's mothers, newborns, and children: how many lives could be saved with targeted health interventions? *PLoS Med*, *7*(6), e1000295.

Friedman, J. M., Hagander, L., Hughes, C. D., Nash, K. A., Linden, A. F., Blossom, J., & Meara, J. G. (2013). Distance to hospital and utilization of surgical services in Haiti: do children, delivering mothers, and patients with emergent surgical conditions experience greater geographical barriers to surgical care? *The International Journal of Health Planning and Management*, *28*(3), 248–256.

Gabrysch, S., Cousens, S., Cox, J., & Campbell, O. M. R. (2011). The influence of distance and level of care on delivery place in rural Zambia: a study of linked national data in a geographic information system. *Plos Medicine*, *8*(1), e1000394–e1000394. http://doi.org/10.1371/journal.pmed.1000394

Gabrysch, S., Zanger, P., Seneviratne, H. R., Mbewe, R., & Campbell, O. M. R. (2011). Tracking progress towards safe motherhood: Meeting the benchmark yet missing the goal? An appeal for better use of health-system output indicators with evidence from Zambia and Sri Lanka. *Tropical Medicine and International Health*, *16*(5), 627–639. http://doi.org/10.1111/j.1365-3156.2011.02741.x

Gage, A. J., & Guirlène Calixte, M. (2006). Effects of the physical accessibility of maternal health services on their use in rural Haiti. *Population Studies*, *60*(3), 271–288.

Gardosi, J., Madurasinghe, V., Williams, M., Malik, A., & Francis, A. (2013). Maternal and fetal risk factors for stillbirth: population based study. *BMJ*, *346*. http://doi.org/10.1136/bmj.f108

Gething, P. W., Johnson, F. A., Frempong-Ainguah, F., Nyarko, P., Baschieri, A., & Aboagye, P. (2012). Geographical access to care at birth in Ghana: a barrier to safe motherhood. *BMC Public Health*, *12*. http://doi.org/10.1186/1471-2458-12-991

Gjesfjeld, C. D., & Jung, J.-. K. (2011). How far?: Using geographical information systems (GIS) to examine maternity care access for expectant mothers in a rural state. *Soc Work Health Care*, *50*. http://doi.org/10.1080/00981389.2011.575537

Global Flood Observatory. (2016). Dartmouth Flood Observatory - Space-based Measurement, Mapping, and Modeling of Surface Water For Research, Humanitarian, and Water Management Applications. Retrieved January 17, 2016, from http://floodobservatory.colorado.edu/

Goodwin, K., & Tobler, L. (2008). Community health workers. *Communities*, *1*, 2.

Grzybowski, S., Kornelsen, J., & Schuurman, N. (2009). Planning the optimal level of local maternity service for small rural communities: a systems study in British Columbia. *Health Policy*, *92*(2), 149–157.

Grzybowski, S., Stoll, K., & Kornelsen, J. (2011). Distance matters: a population based study examining access to maternity services for rural women. *BMC Health Services Research*, *11*(1), 147.

Gyamfi-Aidoo, J., Schwabe, C., & Govender, S. (2005). Determination of the fundamental Geospatial datasets for Africa through a user needs analysis,ÄìA synthesis report.

Hackman-Antwi, R., Bennett, R., de Vries, W., Lemmen, C., & Meijer, C. (2013). The point cadastre requirement revisited. *Survey Review*, *45*(331), 239–247.

Hardee, K., Gay, J., & Blanc, A. K. (2012). Maternal morbidity: Neglected dimension of safe motherhood in the developing world. *Global Public Health*, *7*(6), 603–617. http://doi.org/10.1080/17441692.2012.668919

Heaman, M. I., Sword, W., Elliott, L., Moffatt, M., Helewa, M. E., Morris, H., … Cook, C. (2015). Barriers and facilitators related to use of prenatal care by inner-city women: perceptions of health care providers. *BMC Pregnancy and Childbirth*, *15*(1), 1–13. http://doi.org/10.1186/s12884-015-0431-5

Heipke, C. (2010). Crowdsourcing geospatial data. *ISPRS Journal of Photogrammetry and Remote Sensing*, *65*(6), 550–557.

Hogan, M. C., Foreman, K. J., Naghavi, M., Ahn, S. Y., Wang, M., Makela, S. M., … Murray, C. J. (2010). Maternal mortality for 181 countries, 1980–2008: a systematic analysis of progress towards Millennium Development Goal 5. *The Lancet*, *375*(9726), 1609–1623.

Hranac, R., Sterzin, E., Krechmer, D., Rakha, H. A., Farzaneh, M., & Arafeh, M. (2006). Empirical studies on traffic flow in inclement weather.

Hsu, C.-C., & Sandford, B. A. (2007). The Delphi technique: making sense of consensus. *Practical Assessment, Research & Evaluation*, *12*(10), 1–8.

Hunger, C., Kulker, R., Kitundu, H., Massawe, S., & Jahn, A. (2007). Assessing unmet obstetric need in Mtwara region, Tanzania. *Tropical Medicine & International Health*, *12*(10), 1239–1247. http://doi.org/10.1111/j.1365-3156.2007.01909.x

Instituto Nacional de Estatística, & MeasureDHS. (2011). Mozambique Demographic Health Survey (DHS). Retrieved from http://dhsprogram.com/publications/publication-FR266-DHS-Final-Reports.cfm

Irwin, A., & Scali, E. (2007). Action on the social determinants of health: a historical perspective. *Global Public Health*, *2*(3), 235–256.

Ivers, L. C., Garfein, E. S., Augustin, J., Raymonville, M., Yang, A. T., Sugarbaker, D. S., & Farmer, P. E. (2008). Increasing access to surgical services for the poor in rural Haiti: surgery as a public good for public health. *World Journal of Surgery*, *32*(4), 537–542.

Jambai, A., & MacCormack, C. (1996). Maternal Health, War, and Religious Tradition: Authoritative Knowledge in Pujehun District, Sierra Leone. *Medical Anthropology Quarterly*, *10*(2), 270–286. http://doi.org/10.1525/maq.1996.10.2.02a00090

Jamisse, L., Songane, F., Libombo, A., Bique, C., & Faúndes, A. (2004). Reducing maternal mortality in Mozambique: challenges, failures, successes and lessons learned. *International Journal of Gynecology & Obstetrics*, *85*(2), 203–212.

Joharifard, S., Rulisa, S., Niyonkuru, F., Weinhold, A., Sayinzoga, F., Wilkinson, J., … Thielman, N. M. (2012). Prevalence and predictors of giving birth in health facilities in Bugesera District, Rwanda. *BMC Public Health*, *12*, 1049–1049. http://doi.org/10.1186/1471-2458-12-1049

Johnson, F. A., Frempong-Ainguah, F., Matthews, Z., Harfoot, A. J., Nyarko, P., Baschieri, A., … Atkinson, P. M. (2015). Evaluating the impact of the community-based health planning and services initiative on uptake of skilled birth care in Ghana. *PloS One*, *10*(3), e0120556.

Kearns, R. A. (1993). Place and Health: Towards a Reformed Medical Geography*. *The Professional Geographer*, *45*(2), 139–147. http://doi.org/10.1111/j.0033-0124.1993.00139.x

Kelly, M. P., & Bonnefoy, J. (2007). *The social determinants of health developing an evidence base for political action*. NHS.

Kickbusch, I., Silberschmidt, G., & Buss, P. (2007). Global health diplomacy: the need for new perspectives, strategic approaches and skills in global health. *Bulletin of the World Health Organization*, *85*(3), 230–232.

Kim, D., Sarker, M., & Vyas, P. (2016). Role of spatial tools in public health policymaking of Bangladesh: opportunities and challenges. *Journal of Health, Population and Nutrition*, *35*(1), 1–5. http://doi.org/10.1186/s41043-016-0045-1

Kirk, M., Tomm-Bonde, L., & Schreiber, R. (2014). Public health reform and health promotion in Canada. *Global Health Promotion*, 1757975913512157.

Koplan, J. P., Bond, T. C., Merson, M. H., Reddy, K. S., Rodriguez, M. H., Sewankambo, N. K., & Wasserheit, J. N. (2009). Towards a common definition of global health. *The Lancet*, *373*(9679), 1993–1995. http://doi.org/10.1016/s0140-6736(09)60332-9

Krieger, N. (2001). Theories for social epidemiology in the 21st century: an ecosocial perspective. *International Journal of Epidemiology*, *30*(4), 668–677.

Kruk, M. E., & Freedman, L. P. (2008). Assessing health system performance in developing countries: A review of the literature. *Health Policy*, *85*(3), 263–276. http://doi.org/10.1016/j.healthpol.2007.09.003

Kuruvilla, S., Bustreo, F., Kuo, N., Mishra, C., Taylor, K., Fogstad, H., … Thomas, J. (2016). The Global strategy for women's, children's and adolescents' health (2016–2030): a roadmap based on evidence and country experience. *Bull World Health Organ*, *94*(5), 398–400.

Labonté, R., & Schrecker, T. (2007a). Globalization and social determinants of health: Introduction and methodological background (part 1 of 3). *Globalization and Health*, *3*. http://doi.org/10.1186/1744-8603-3-5

Labonté, R., & Schrecker, T. (2007b). Globalization and social determinants of health: The role of the global marketplace (part 2 of 3). *Globalization and Health*, *3*. http://doi.org/10.1186/1744-8603-3-6

Lawn, J. E., Blencowe, H., Pattinson, R., Cousens, S., Kumar, R., Ibiebele, I., … Stanton, C. (2011). Stillbirths: Where? When? Why? How to make the data count? *The Lancet*, *377*(9775), 1448–1463.

Lehmann, U., & Sanders, D. (2007). Community health workers: What do we know about them? The state of the evidence on programmes, activities, costs and impact on health outcomes of using community health workers. *World Health Organization*, *2*, 1–42.

Leroy, J. L., Habicht, J.-P., Pelto, G., & Bertozzi, S. M. (2007). Current Priorities in Health Research Funding and Lack of Impact on the Number of Child Deaths per Year. *American Journal of Public Health*, *97*(2), 219–223.

Locker, D., & Scambler, G. (2008). Social determinants of health and disease. *Sociology as Applied to Medicine*, 18–37.

Makanga, P. T., Schuurman, N., von Dadelszen, P., & Firoz, T. (2016). A scoping review of geographic information systems in maternal health. *International Journal of Gynecology & Obstetrics*.

Makanga, P. T., Schuurman, N., Sacoor, C., Boene, H., von Dadelszen, P., & Firoz, T. (2016). Guidelines for creating framework data for GIS analysis in low- and middle-income countries. The Canadian Geographer, In Press.

Marmot, M. (2005). Social determinants of health inequalities. *The Lancet*, *365*(9464), 1099–1104. http://doi.org/10.1016/S0140-6736(05)71146-6

Marmot, M., Friel, S., Bell, R., Houweling, T. A. J., & Taylor, S. (2008). Closing the gap in a generation: health equity through action on the social determinants of health. *The Lancet*, *372*(9650), 1661–1669. http://doi.org/10.1016/s0140-6736(08)61690-6

Marmot, M., Friel, S., Bell, R., Houweling, T. A., Taylor, S., & Commission on Social Determinants of Health. (2008). Closing the gap in a generation: health equity through action on the social determinants of health. *The Lancet*, *372*(9650), 1661–1669.

Masters, S. H., Burstein, R., Amofah, G., Abaogye, P., Kumar, S., & Hanlon, M. (2013). Travel time to maternity care and its effect on utilization in rural Ghana: a multilevel analysis. *Social Science & Medicine*, *93*, 147–154.

Maternity Worldwide. (2014). Saving lives at Childbirth: How many women die in Childbirth? Retrieved December 22, 2014, from http://www.maternityworldwide.org/

Mayer, J. D. (1994). A reformed medical geography reconsidered. *Professional Geographer*, *46*(1), 103.

Mayer, J. D. (1996). The political ecology of disease as one new focus for medical geography. *Progress in Human Geography*, *20*, 441–456.

McLafferty, S., & Grady, S. (2004). Prenatal care need and access: a GIS analysis. *Journal Of Medical Systems*, *28*(3), 321–333.

McLafferty, S., Widener, M., Chakrabarti, R., & Grady, S. (2012). Ethnic Density and Maternal and Infant Health Inequalities: Bangladeshi Immigrant Women in New York City in the 1990s. *Annals of the Association of American Geographers*, *102*(5), 893–903. http://doi.org/10.1080/00045608.2012.674901

Meng, G., Thompson, M. E., & Hall, G. B. (2013). Pathways of neighbourhood-level socio-economic determinants of adverse birth outcomes. *International Journal of Health Geographics*, *12*. http://doi.org/10.1186/1476-072x-12-32

Microsoft Developer Network. (2016). Understanding scale and resolution. Retrieved from https://msdn.microsoft.com/en-us/library/aa940990.aspx

Mozambique News Agency. (2014). Incomati flood laps at edges of EN1. Retrieved from http://www.poptel.org.uk/mozambique-news/newsletter/aim481.html#story3

Munguambe, K., Boene, H., Vidler, M., Bique, C., Sawchuck, D., Firoz, T., … Sevene, E. (2016). Barriers and facilitators to health care seeking behaviours in pregnancy in rural communities of southern Mozambique. *Reproductive Health*, *13*(1), 83–97. http://doi.org/10.1186/s12978-016-0141-0

Munjanja, S. P., Magure, T., & Kandawasvika, G. (2012). 11 Geographical Access, Transport and Referral Systems. *Maternal and Perinatal Health in Developing Countries*, 139.

Munyaneza, F., Hirschhorn, L. R., Amoroso, C. L., Nyirazinyoye, L., Birru, E., Mugunga, J. C., … Ntaganira, J. (2014). Leveraging community health worker system to map a mountainous rural district in low resource setting: a low-cost approach to expand use of geographic information systems for public health. *International Journal of Health Geographics*, *13*(1), 1–8. http://doi.org/10.1186/1476-072X-13-49

Murray, C. J. L. (2015). Shifting to Sustainable Development Goals — Implications for Global Health. *New England Journal of Medicine*, *373*(15), 1390–1393. http://doi.org/10.1056/NEJMp1510082

Murray, C. J. L., & Lopez, A. D. (2013). Measuring the Global Burden of Disease. *New England Journal of Medicine*, *369*(5), 448–457. http://doi.org/10.1056/NEJMra1201534

Mwaniki, P., Kabiru, E., & Mbugua, G. (2002). Utilisation of antenatal and maternity services by mothers seeking child welfare services in Mbeere District, Eastern Province, Kenya. *East African Medical Journal*, *79*(4), 184–187.

Nakaya, T. (2014). GWR4 User Manual: Windows application for geographically weighted regression modelling. Retrieved from https://geodacenter.asu.edu/drupal_files/gwr/GWR4manual.pdf

Nesbitt, R. C., Gabrysch, S., Laub, A., Soremekun, S., Manu, A., & Kirkwood, B. R. (2014). Methods to measure potential spatial access to delivery care in low- and middle-income countries: a case study in rural Ghana. *Int J Health Geogr*, *13*. http://doi.org/10.1186/1476-072x-13-25

Nour, N. N. (2011). Maternal health considerations during disaster relief. *Reviews in Obstetrics and Gynecology*, *4*(1), 22.

Oestergaard, M. Z., Inoue, M., Yoshida, S., Mahanani, W. R., Gore, F. M., Cousens, S., … Mathers, C. D. (2011). Neonatal mortality levels for 193 countries in 2009 with trends since 1990: a systematic analysis of progress, projections, and priorities. *PLoS Med*, *8*(8), e1001080.

O'Hare, B. A. M., & Southall, D. P. (2007). First do no harm: the impact of recent armed conflict on maternal and child health in Sub-Saharan Africa. *JRSM*, *100*(12), 564–570. http://doi.org/10.1258/jrsm.100.12.564

Okafor, U. V., Efetie, E. R., & Ekumankama, O. (2009). Eclampsia and seasonal variation in the tropics-a study in Nigeria. *Pan African Medical Journal*, *2*(1).

Olowonyo, T., Oshin, S., & Obasanjo-Bello, I. (2005). Registering in a health facility for delivery protects against maternal mortality in a developing country setting. *Journal of Obstetrics and Gynaecology*, *25*(7), 638–641.

Open Geospatial Consortium Inc. (2014). *OpenGIS Web Feature Service 2.0 Interface Standard – With Corrigendum*. Panagiotis (Peter) A. Vretanos.

Open Street Map. (2016). openstreetmap. Retrieved from https://www.openstreetmap.org/#map=9/-24.8864/33.5413

Osorio, A. M., Tovar, L. M., & Rathmann, K. (2014). Individual and local level factors and antenatal care use in Colombia: a multilevel analysis. *Cadernos de Saúde Pública*, *30*(5), 1079–1092.

Ostfeld, R. S., Glass, G. E., & Keesing, F. (2005). Spatial epidemiology: an emerging (or re-emerging) discipline. *Trends in Ecology & Evolution*, *20*(6), 328–336. http://doi.org/10.1016/j.tree.2005.03.009

Östlin, P., Schrecker, T., Sadana, R., Bonnefoy, J., Gilson, L., Hertzman, C., … Vaghri, Z. (2011). Priorities for Research on Equity and Health: Towards an Equity-Focused Health Research Agenda. *PLoS Med*, *8*(11). http://doi.org/10.1371/journal.pmed.1001115

Owoo, N. S., & Lambon-Quayefio, M. P. (2013). National health insurance, social influence and antenatal care use in Ghana. *Health Economics Review*, *3*(1), 19–19. http://doi.org/10.1186/2191-1991-3-19

Oza, S., Lawn, J. E., Hogan, D. R., Mathers, C., & Cousens, S. N. (2015). Neonatal cause-of-death estimates for the early and late neonatal periods for 194 countries: 2000_2013. *Bulletin of the World Health Organization*, *93*, 19–28.

Pereira, C., Cumbi, A., Malalane, R., Vaz, F., McCord, C., Bacci, A., & Bergström, S. (2007). Meeting the need for emergency obstetric care in Mozambique: work performance and histories of medical doctors and assistant medical officers trained for surgery. BJOG: An International Journal of Obstetrics & Gynaecology, 114(12), 1530–1533. http://doi.org/10.1111/j.1471-0528.2007.01489.x

Perez-Heydrich, C., Warren, J. L., Burgert, C. R., & Emch, M. (2013). *GUIDELINES ON THE USE OF DHS GPS DATA: DHS SPATIAL ANALYSIS REPORTS*. Maryland.

Porter, G. (2012). Transport services and their impact on poverty and growth in rural sub-Saharan Africa: Literature review. Report to the Africa Community Access Programme, London.

Potvin, L. (2009). Yes! More research is needed; but not just any research. *International Journal of Public Health*, *54*(3), 127–128.

Rajabifard, A., Binns, A., Masser, I., & Williamson, I. (2006). The role of sub-national government and the private sector in future spatial data infrastructures. *International Journal of Geographical Information Science*, *20*(7), 727–741.

Rakha, H., Farzaneh, M., Arafeh, M., Hranac, R., Sterzin, E., & Krechmer, D. (2007). *Empirical studies on traffic flow in inclement weather*. Virginia Tech Transportation Institute.

Ranson, M. K., & Bennett, S. C. (2009). Priority setting and health policy and systems research. *Health Research Policy and Systems*, *7*, 27–27. http://doi.org/10.1186/1478-4505-7-27

Richardson, D. B., Volkow, N. D., Kwan, M.-P., Kaplan, R. M., Goodchild, M. F., & Croyle, R. T. (2013). Spatial turn in health research. *Science*, *339*(6126), 1390–1392.

Ronsmans, C., & Graham, W. J. (2006). Maternal mortality: who, when, where, and why. *The Lancet*, *368*(9542), 1189–1200. http://doi.org/10.1016/s0140-6736(06)69380-x

Sachs, J. D., & McArthur, J. W. (2005). The millennium project: a plan for meeting the millennium development goals. *The Lancet*, *365*(9456), 347–353.

Sartorius, B., & Sartorius, K. (2013). Identifying and Targeting Mortality Disparities: A Framework for Sub-Saharan Africa Using Adult Mortality Data from South Africa. *Plos One*, *8*(8). http://doi.org/10.1371/journal.pone.0071437

Schuurman, N., Fiedler, R. S., Grzybowski, S. C., & Grund, D. (2006). Defining rational hospital catchments for non-urban areas based on travel-time. *International Journal of Health Geographics*, *5*(1), 43.

Scott, S., & Ronsmans, C. (2009). The relationship between birth with a health professional and maternal mortality in observational studies: a review of the literature. *Tropical Medicine & International Health*, *14*(12), 1523–1533.

Sevean, P., Dampier, S., Spadoni, M., Strickland, S., & Pilatzke, S. (2009). Patients and families experiences with video telehealth in rural/remote communities in Northern Canada. *Journal of Clinical Nursing*, *18*(18), 2573–2579. http://doi.org/10.1111/j.1365-2702.2008.02427.x

Shah, N., Hossain, N., Shoaib, R., Hussain, A., Gillani, R., & Khan, N. H. (2009). Socio-demographic characteristics and the three delays of maternal mortality. *J Coll Physicians Surg Pak*, *19*(2), 95–8.

Shoff, C., Chen, V. Y.-J., & Yang, T.-C. (2014). When homogeneity meets heterogeneity: the geographically weighted regression with spatial lag approach to prenatal care utilisation. *Geospatial Health; Vol 8, No 2 (2014)*. Retrieved from http://geospatialhealth.net/index.php/gh/article/view/45

Shoff, C., Yang, T.-C., & Matthews, S. (2012). What has geography got to do with it? Using GWR to explore place-specific associations with prenatal care utilization. *GeoJournal*, *77*(3), 331–341. http://doi.org/10.1007/s10708-010-9405-3

Simoes, P. P., & Almeida, R. (2011). Geographic accessibility to obstetric care and maternal mortality in a large metropolitan area of Brazil. *International Journal of Gynecology & Obstetrics*, *112*(1), 25–29. http://doi.org/10.1016/j.ijgo.2010.07.031

Sipe, N. G., & Dale, P. (2003). Challenges in using geographic information systems (GIS) to understand and control malaria in Indonesia. *Malaria Journal*, *2*(1), 1–8. http://doi.org/10.1186/1475-2875-2-36

Smith, D. J. (2004). Contradictions in Nigeria's fertility transition: the burdens and benefits of having people. *Population and Development Review*, *30*(2), 221–238.

Statistics South Africa. (2015). Dwelling Frame. Retrieved October 15, 2015, from http://mapserver2.statssa.gov.za/geographywebsite/Projects/dwellFrame.html

Stevens, A. R., Onsrud, H. J., & Rao, M. (2005). Global Spatial Data Infrastructure (GSDI): Encouraging SDI Development Internationally (pp. 14–16). Presented at the ISPRS Workshop on Service and Application of Spatial Data Infrastructure, XXXVI (4/W6), Oct.

Subramaniam, V. (2007). Seasonal variation in the incidence of preeclampsia and eclampsia in tropical climatic conditions. *BMC Women's Health*, *7*(1), 18.

Sudhof, L., Amoroso, C., Barebwanuwe, P., Munyaneza, F., Karamaga, A., & Zambotti, G. (2013). Local use of geographic information systems to improve data utilisation and health services: mapping caesarean section coverage in rural Rwanda. *Trop Med Int Heal*, *18*. http://doi.org/10.1111/tmi.12016

Syed, S. B., Dadwal, V., & Martin, G. (2013). Reverse innovation in global health systems: towards global innovation flow. *Globalization and Health*, *9*(1), 1.

Tanser, F. C., & le Sueur, D. (2002). The application of geographical information systems to important public health problems in Africa. *International Journal of Health Geographics*, *1*(1), 1–9. http://doi.org/10.1186/1476-072X-1-4

Tatem, A. J., Campbell, J., Guerra Arias, M., Bernis, L., Moran, A., & Matthews, Z. (2014). Mapping for maternal and newborn health: the distributions of women of childbearing age, pregnancies and births. *Int J Health Geogr*, *13*. http://doi.org/10.1186/1476-072x-13-2

Teela, K. C., Mullany, L. C., Lee, C. I., Poh, E., Paw, P., Masenior, N., … Lee, T. J. (2009). Community-based delivery of maternal care in conflict-affected areas of eastern Burma: Perspectives from lay maternal health workers. *Social Science & Medicine*, *68*(7), 1332–1340. http://doi.org/10.1016/j.socscimed.2009.01.033

Thaddeus, S., & Maine, D. (1994). Too far to walk: Maternal mortality in context. *Social Science & Medicine*, *38*(8), 1091–1110. http://doi.org/10.1016/0277-9536(94)90226-7

Tomintz, M. N., Clarke, G. P., Rigby, J. E., & Green, J. M. (2013). Optimising the location of antenatal classes. *Midwifery*, *29*(1), 33–43. http://doi.org/10.1016/j.midw.2011.10.010

Tulenko, K., Mgedal, S., Afzal, M. M., Frymus, D., Oshin, A., Pate, M., … Zodpey, S. (2013). Community health workers for universal health-care coverage: from fragmentation to synergy. *Bulletin of the World Health Organization*, *91*(11), 847–852.

United Nations. (2015). *The Global strategy for women's, children's and adolescents' health (2016–2030)*. New York. Retrieved from http://www.who.int/life-course/partners/global-strategy/globalstrategyreport2016-2030-lowres.pdf?ua=1

United Nations. (2015). *The Millennium Development Goals Report (2015)*. New York: United Nations. Retrieved from http://www.un.org/millenniumgoals/2015_MDG_Report/pdf/MDG%202015%20rev%20(July%201).pdf

United Nations. (2015). Transforming our world: the 2030 Agenda for Sustainable Development. *See, Related, The Global Initiative Against Transnational Organized Crime,"Organized Crime: A Cross-Cutting Threat to Sustainable Development"(Geneva: January 2015)*.

United Nations Commission on Information and Accountability. (2013). Countdown to 2015 Maternal, Newborn and Child Survival. Mozambique. Retrieved August 29, 2016, from http://www.countdown2015mnch.org/documents/2013Report/Mozambique_Accountability_profile_2013.pdf

United Nations Office of the Coordination of Humanitarian Affairs. (2013). MOZAMBIQUE: Flood Displaced Accommodation Centres as of 26 January 2013. Retrieved from http://reliefweb.int/sites/reliefweb.int/files/resources/Mozambique%20Flood%20Displaced%20Accommodation%20Centres%20as%20of%2026%20January%202013.pdf

Urdal, H., & Che, C. P. (2013). War and Gender Inequalities in Health: The Impact of Armed Conflict on Fertility and Maternal Mortality. *International Interactions*, *39*(4), 489–510. http://doi.org/10.1080/03050629.2013.805133

von Dadelszen, P., Ansermino, J. M., Dumont, G., Hofmeyr, G. J., Magee, L. A., Mathai, M., … Roberts, J. M. (2012). Improving maternal and perinatal outcomes in the hypertensive disorders of pregnancy: a vision of a community-focused approach. *International Journal of Gynecology & Obstetrics*, *119*, S30–S34.

Von Hagen, C. (2007). Towards a spatial data infrastructure for Somalia using open source standards. *Journal of Spatial Science*, *52*(1), 157–169.

Wall, L. L. (1998). Dead Mothers and Injured Wives: The Social Context of Maternal Morbidity and Mortality among the Hausa of Northern Nigeria. *Studies in Family Planning*, *29*(4), 341–359.

World Health Organization. (2004). *International statistical classification of diseases and related health problems* (Vol. 1). World Health Organization.

World Health Organization. (2012). Verbal autopsy standards: the 2012 WHO verbal autopsy instrument. *Geneva: WHO*.

World Health Organization. (2013). Post Flood Health Assessment - Report Gaza Province-Mozambique. Retrieved from http://www.who.int/hac/crises/moz/sitreps/mozambique_health_assessment_30january2013.pdf

World Health Organization. (2014). Mozambique country cooperation at a glance. Retrieved August 29, 2016, from http://www.who.int/countryfocus/cooperation_strategy/ccsbrief_moz_en.pdf

World Health Organization. (2015). Strategies towards ending preventable maternal mortality (EPMM).

Yilma, A. D. (2015). Geospatially Enabled Census: Perspective for African Countries. Presented at the Africa Geospatial Forum.

Zhang, X., Alexander, L., Hegerl, G. C., Jones, P., Tank, A. K., Peterson, T. C., … Zwiers, F. W. (2011). Indices for monitoring changes in extremes based on daily temperature and precipitation data. *Wiley Interdisciplinary Reviews: Climate Change*, *2*(6), 851–870.

Appendix A.

Summary of OLS diagnostics

Variable definition

DIST_HWY	Isolation (Distance to the nearest highway)
LATRINE_RT	Latrine score
PRVTRANS_RT	Private transportation score
FAMSUPP_RT	Family support
WRAAGE_RT	Age of woman of reproductive age
FERTRATE	Fertility rate

Summary of OLS Results - Model Variables

Variable	Coefficient [a]	StdError	t-Statistic	Probability [b]	Robust_SE	Robust_t	Robust_Pr [b]	VIF [c]
Intercept	-0.001710	0.230434	-0.007420	0.994132	0.249095	-0.006864	0.994572	--------
DIST_HWY	0.000001	0.000000	2.101954	0.044678*	0.000000	3.084686	0.004552*	2.307797
LATRINE_RT	-0.001756	0.001064	-1.650745	0.109963	0.000733	-2.394796	0.023566*	3.270388
PRVTRANS_RT	-0.006127	0.002591	-2.364379	0.025231*	0.002274	-2.694305	0.011789*	2.584540
FAMSUPP_RT	-0.002683	0.000615	-4.363876	0.000156*	0.000780	-3.438337	0.001850*	1.713498
WRAAGE_RT	0.039000	0.010201	3.823164	0.000673*	0.009792	3.982781	0.000439*	3.505708
FERTRATE	-0.222724	0.035204	-6.326731	0.000001*	0.032481	-6.857144	0.000000*	4.384027

OLS Diagnostics

Input Features:	LOCALITY_COMPLETEDPREG1	Dependent Variable:	NEOMATSTILMIS_RT
Number of Observations:	35	Akaike's Information Criterion (AICc) [d]:	-135.637782
Multiple R-Squared [d]:	0.713920	Adjusted R-Squared [d]:	0.652618
Joint F-Statistic [e]:	11.645805	Prob(>F), (6,28) degrees of freedom:	0.000002*
Joint Wald Statistic [e]:	144.946266	Prob(>chi-squared), (6) degrees of freedom:	0.000000*
Koenker (BP) Statistic [f]:	20.007248	Prob(>chi-squared), (6) degrees of freedom:	0.002761*
Jarque-Bera Statistic [g]:	0.387205	Prob(>chi-squared), (2) degrees of freedom:	0.823986

Notes on Interpretation

* An asterisk next to a number indicates a statistically significant p-value ($p < 0.01$).

[a] Coefficient: Represents the strength and type of relationship between each explanatory variable and the dependent variable.

[b] Probability and Robust Probability (Robust_Pr): Asterisk (*) indicates a coefficient is statistically significant ($p < 0.01$); if the Koenker (BP) Statistic [f] is statistically significant, use the Robust Probability column (Robust_Pr) to determine coefficient significance.

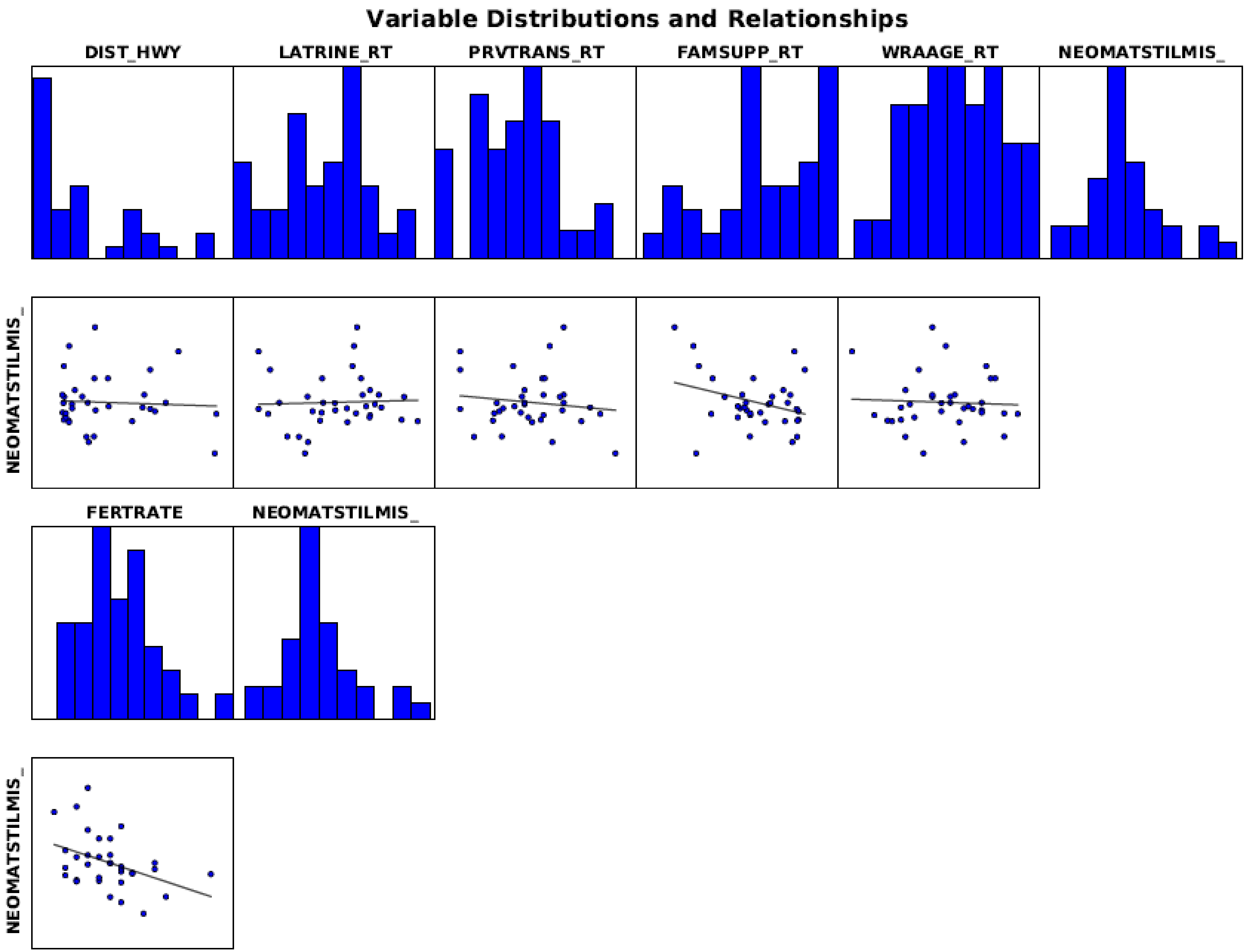
[c] Variance Inflation Factor (VIF): Large Variance Inflation Factor (VIF) values (> 7.5) indicate redundancy among explanatory variables.

[d] R-Squared and Akaike's Information Criterion (AICc): Measures of model fit/performance.

[e] Joint F and Wald Statistics: Asterisk (*) indicates overall model significance ($p < 0.01$); if the Koenker (BP) Statistic [f] is statistically significant, use the Wald Statistic to determine overall model significance.

[f] Koenker (BP) Statistic: When this test is statistically significant ($p < 0.01$), the relationships modeled are not consistent (either due to non-stationarity or heteroskedasticity). You should rely on the Robust Probabilities (Robust_Pr) to determine coefficient significance and on the Wald Statistic to determine overall model significance.

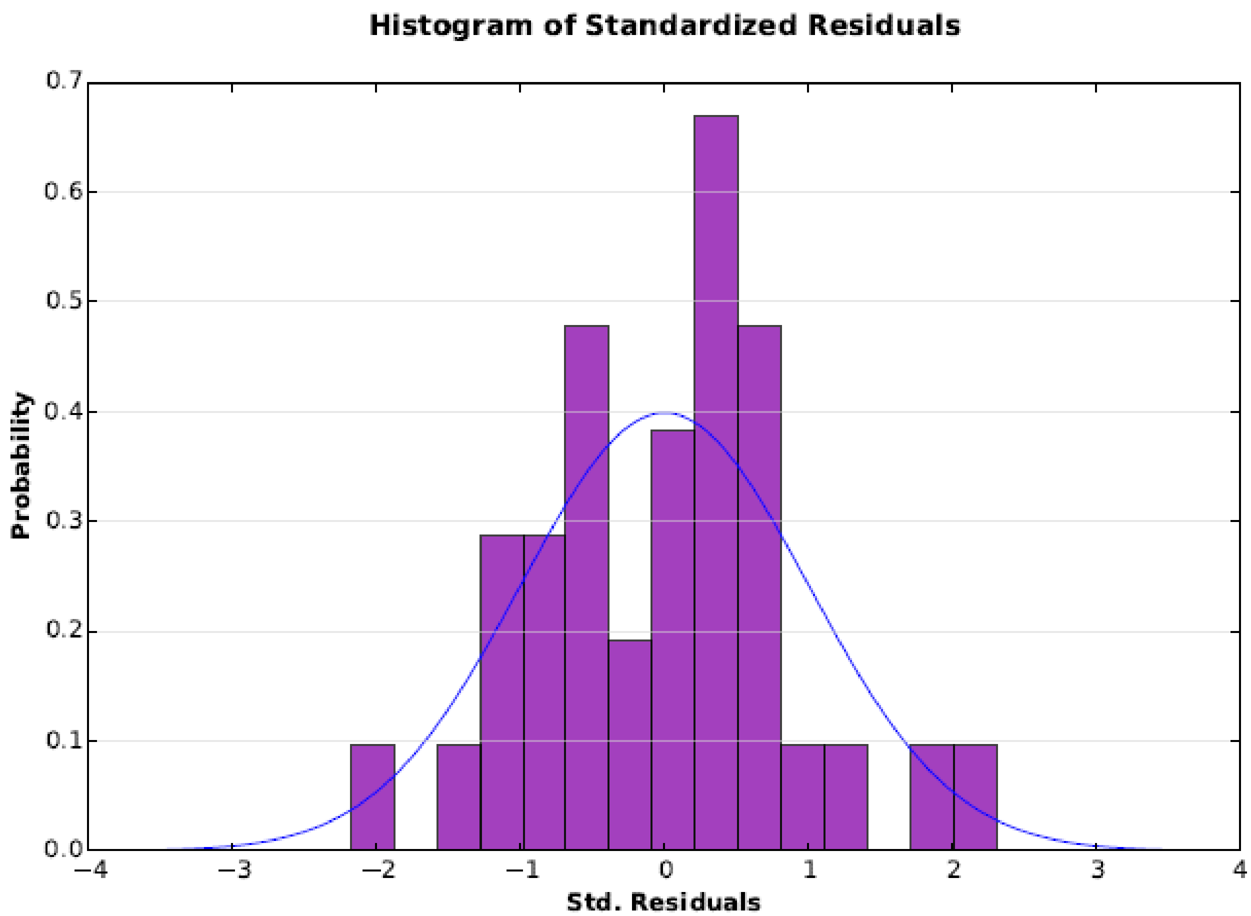
[g] Jarque-Bera Statistic: When this test is statistically significant ($p < 0.01$) model predictions are biased (the residuals are not normally distributed).


Variable Distributions and Relationships
DIST_HWY
LATRINE_RT
PRVTRANS_RT
FAMSUPP_RT
WRAAGE_RT
NEOMATSTILMIS_
NEOMATSTILMIS_
FERTRATE
NEOMATSTILMIS_
NEOMATSTILMIS_

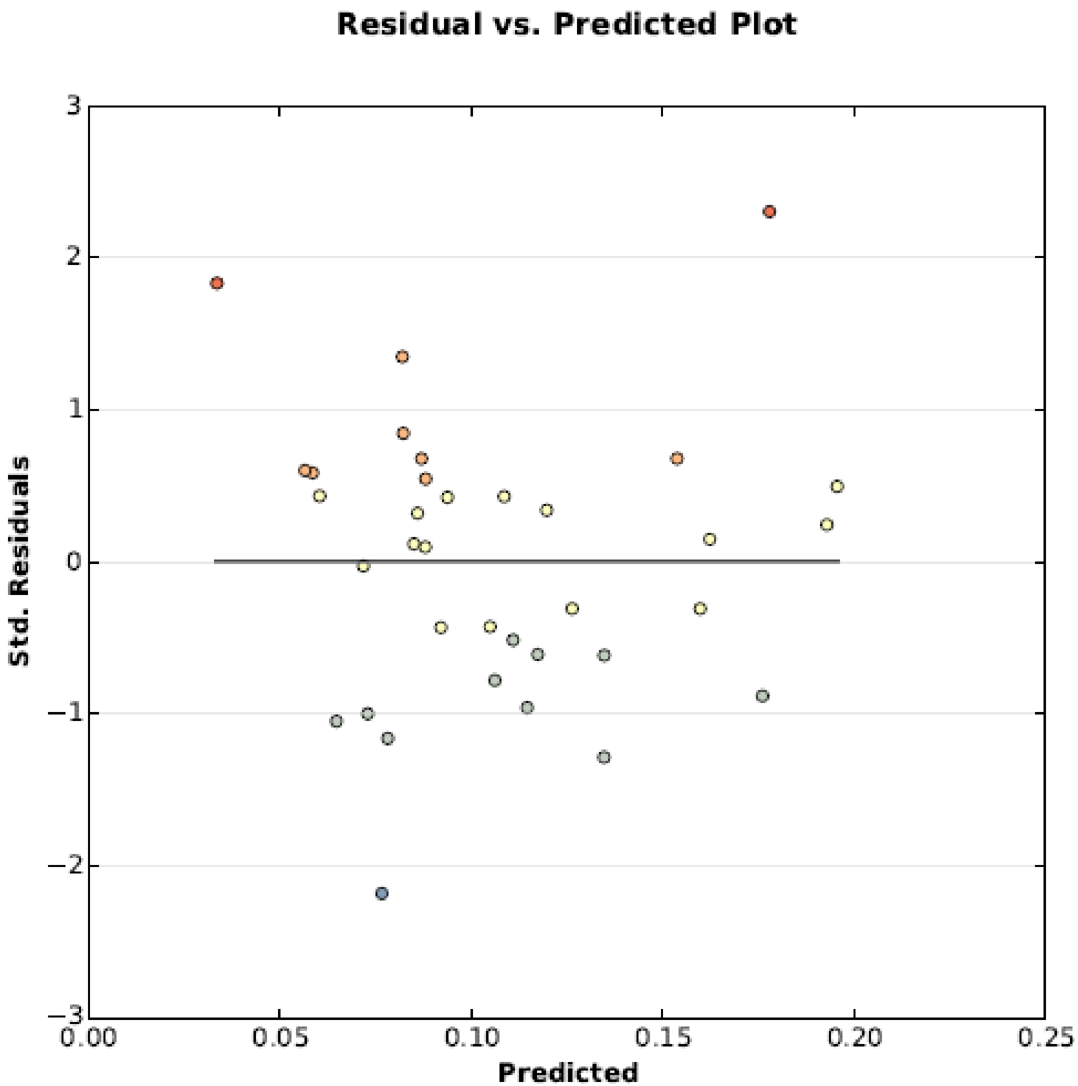
Variable Distributions and Relationships (Cont.)

The above graphs are Histograms and Scatterplots for each explanatory variable and the dependent variable. The histograms show how each variable is distributed. OLS does not require variables to be normally distributed. However, if you are having trouble finding a properly-specified model, you can try transforming strongly skewed variables to see if you get a better result.

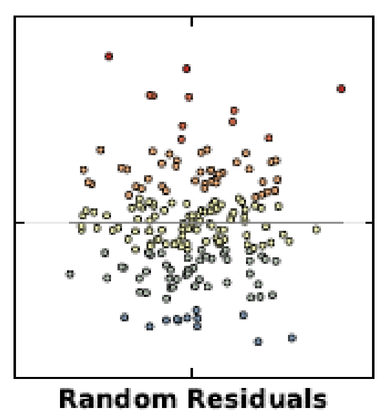
Each scatterplot depicts the relationship between an explanatory variable and the dependent variable. Strong relationships appear as diagonals and the direction of the slant indicates if the relationship is positive or negative. Try transforming your variables if you detect any non-linear relationships. For more information see the Regression Analysis Basics documentation.



Ideally the histogram of your residuals would match the normal curve, indicated above in blue. If the histogram looks very different from the normal curve, you may have a biased model. If this bias is significant it will also be represented by a statistically significant Jarque-Bera p-value (*).



This is a graph of residuals (model over and under predictions) in relation to predicted dependent variable values. For a properly specified model, this scatterplot will have little structure, and look random (see graph on the right). If there is a structure to this plot, the type of structure may be a valuable clue to help you figure out what's going on.



Appendix B.

Summary of GWR results

Model settings---------------------------------

Model type: Gaussian

Geographic kernel: adaptive bi-square

Method for optimal bandwidth search: Golden section search

Criterion for optimal bandwidth: AICc

Number of varying coefficients: 7

Number of fixed coefficients: 0

****

GWR (Geographically weighted regression) result

****

Bandwidth and geographic ranges

Bandwidth size: 30.000000

Coordinate	Min	Max	Range
X-coord	3616601.398000	3768895.758000	152294.360000
Y-coord	-2920426.694000	-2791357.504000	129069.190000

Diagnostic information

Residual sum of squares:	0.012040
Effective number of parameters (model: trace(S)):	13.459566
Effective number of parameters (variance: trace(S'S)):	10.888771
Degree of freedom (model: n - trace(S)):	21.540434
Degree of freedom (residual: n - 2trace(S) + trace(S'S)):	18.969639
ML based sigma estimate:	0.018547

Unbiased sigma estimate:	0.025193
-2 log-likelihood:	-179.794727
Classic AIC:	-150.875595
AICc:	-127.995999
BIC/MDL:	-128.385937
CV:	0.001334
R square:	0.850091
Adjusted R square:	0.716360

****

<< Geographically varying (Local) coefficients >>

****

Summary statistics for varying (Local) coefficients

Variable	Mean	STD
Intercept	0.221617	0.301727
DIST_HWY	0.000001	0.000000
LATRINE_RT	-0.001586	0.000429
PRVTRANS_R	-0.005944	0.000973
FAMSUPP_RT	-0.003135	0.000736
WRAAGE_RT	0.029786	0.010397
FERTRATE	-0.204228	0.024069

Variable	Min	Max	Range
Intercept	-0.626351	0.788107	1.414458
DIST_HWY	0.000000	0.000002	0.000001
LATRINE_RT	-0.002123	0.000309	0.002433
PRVTRANS_R	-0.008026	-0.003578	0.004448

FAMSUPP_RT	-0.004047	-0.001846	0.002201
WRAAGE_RT	0.007549	0.053455	0.045906
FERTRATE	-0.254880	-0.166713	0.088167

Variable	Lwr Quartile	Median	Upr Quartile
Intercept	0.000741	0.308334	0.387369
DIST_HWY	0.000001	0.000001	0.000001
LATRINE_RT	-0.001882	-0.001677	-0.001500
PRVTRANS_R	-0.006918	-0.006062	-0.005630
FAMSUPP_RT	-0.003859	-0.003537	-0.002512
WRAAGE_RT	0.025811	0.029927	0.038405
FERTRATE	-0.227504	-0.213048	-0.198427

Variable	Interquartile R	Robust STD
Intercept	0.386628	0.286604
DIST_HWY	0.000001	0.000001
LATRINE_RT	0.000383	0.000284
PRVTRANS_R	0.001288	0.000955
FAMSUPP_RT	0.001347	0.000998
WRAAGE_RT	0.012594	0.009336
FERTRATE	0.029076	0.021554

(Note: Robust STD is given by (interquartile range / 1.349))

****

GWR ANOVA Table

****

Source	SS	DF	MS	F
Global Residuals	0.023	28.000		
GWR Improvement	0.011	9.030	0.001	
GWR Residuals	0.012	18.970	0.001	1.908140

****

Geographical variability tests of local coefficients

****

Variable	F	DOF for F test		DIFF of Criterion
Intercept	146.579403	1.442	21.540	-74.957610
DIST_HWY	0.368867	0.773	21.540	4.173562
LATRINE_RT	4.740815	0.699	21.540	-0.801706
PRVTRANS_R	6.656507	0.724	21.540	-2.715218
FAMSUPP_RT	21.370457	0.551	21.540	-11.928525
WRAAGE_RT	127.603391	1.341	21.540	-68.868077
FERTRATE	6.108694	1.163	21.540	-3.133848

Note: positive value of diff-Criterion (AICc, AIC, BIC/MDL or CV) suggests no spatial variability in terms of model selection criteria.

F test: in case of no spatial variability, the F statistics follows the F distribution of DOF for F test.

Appendix C.

Sample guide for focus group discussions

PRE-eclampsia-Eclampsia Monitoring, Prevention & Treatment

Reducing the global burden of maternal, fetal & infant death & disease related to pre-eclampsia

CLIP Mozambique

Community Level Interventions for Pre-eclampsia

FOCUS GROUP DISCUSSION

Reproductive Age Women

Introduction

I am ____________________ from Manhica Research Centre, Manhica. I welcome you to this focus group discussion. I will be the moderator for this focus group and Mr/Ms. ________________ also from Manhica Research Centre will be taking notes and recording audio during this discussion.

You have been invited for this focus group discussion because your input is essential in understanding the experience of pregnancy and birth in your community.

Purpose

Many factors can affect a pregnant woman's health. During this focus group, we will explore your perspectives on factors in your local community that influence women's health during pregnancy. Specifically, we will be discussing your perspectives on your local healthcare services and social and environmental aspects that influence health.

This focus group is expected to take 1-1.5 hours.

Participants

Women from local communities who are between the ages of 15 – 49 and who are currently pregnant or have been Pregnant before

Ground Rules

We will be recording this focus group to ensure we do not miss any of the responses or discussion. The note taker will also be taking notes throughout the discussion for backup. All information recorded will be kept confidential and you will not be identified by name. You may choose not to respond at any time.

Everybody will be given an equal chance to speak. We will follow these rules:

- All participants will have the chance to respond if desired All participants will wait for their turn to speak
- All participants will respect each other's' point of view

REPORTING

Focus Group Characteristics				
Focus group nr				
Cluster				
Participant type (group)				
Methods for selecting participants	Purposive	Convenience	Consecutive	Snowball
Number of women approached				
Number of women refused to participate?				

Date *(DDMMYYYY)*	
Venue	
Start time *(HH:MM)*	
End time *(HH:MM)*	
Name of moderator	
Name of note taker	
Cluster coordinator contact	Name Cell phone #

Participant Characteristics					
ID	Age	Number of years of schooling	Marital Status 1 Single 2 Married/ with partner 3 Divorced 4 Separated 5 Widowed	Occupation 1 Housewife 2 Seasonal agricultural worker 3 Permanent agricultural worker 4 Non-agricultural worker 5 Self employed 6 Unemployed 7 Other, specify	Maternal Status 1 Currently pregnant 2 Previously has been pregnant
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					

13					
14					

FOCUS GROUP DISCUSSION GUIDE

Opening Questions

Who are the most vulnerable group of pregnant women in your community?

PROBES: widowed, separated, divorced, poor, sick, disabled, unemployed, large families, geographically isolated

THEME I: Social Factors

1. What kinds of relationships are important for a pregnant woman to have so that she can have a healthy pregnancy?

   PROBES: relationships with other women, neighbours, friendships

2. How do you think that a woman's marital status and relationship with her husband affects her pregnancy?

   PROBES: single, divorced, widowed, violence

3. What community groups or support networks that you know of that can help pregnant women and how?

   PROBES:women's groups, microfinance

4. How do you think a woman's education level affects her pregnancy?

   PROBES: illiterate, formally educated, pregnancy knowledge

5. Who makes decisions about care seeking in pregnancy?

   PROBES: woman, husband, mother in law, other family member, money and finances

THEME II: Economic Factors

6. How do you think finances or money can affect a woman's pregnancy?

   PROBES: money for: medications, transport, medical services

7. Does the type of work a woman does affect her pregnancy?

   PROBES: unemployed, manual labour, physical labour, short term employment

THEME III: Environmental Factors

8. How do the physical conditions of a woman's house affect her pregnancy?

   PROBES: sanitation, cooking fuels, materials for walls

9. What factors in a woman's neighbourhood or village affect her pregnancy?

   PROBES: agriculture, access to roads, transport, animals

THEME IV: Health Care Knowledge and Care Seeking

10. Who are the key people in your neighbourhood or village who can help with problems in pregnancy?

    PROBES: matrons, traditional birth attendant, nurses, community health workers

11. What should a woman know about to have a healthy pregnancy?

    PROBES: danger signs, bleeding, seizures, knowing when to go to hospital, traditional behaviours in pregnancy, traditional medicine

12. What preparation or plans should a woman make to have a healthy pregnancy?

PROBES: saving money, identifying transport, identifying place of birth, having a place to stay after birth

13. What do you think are the barriers in the health care system that might affect pregnancy?

PROBES: medication stock outs, availability of health care staff, hours that the facility is open, cost, subsidies, quality of facility care, treated with respect at facility, transport

We will end with two more questions:

14. What do you consider a healthy pregnancy?

15. How can women have healthy pregnancies and avoid problems?

END OF FOCUS GROUP

Closing Comments

I am very thankful for your participation in this important discussion and for sparing your valuable time. Your comments are very important to guide us in understanding the experience of pregnancy and childbirth in your community. Please feel free to ask me any questions you may have.