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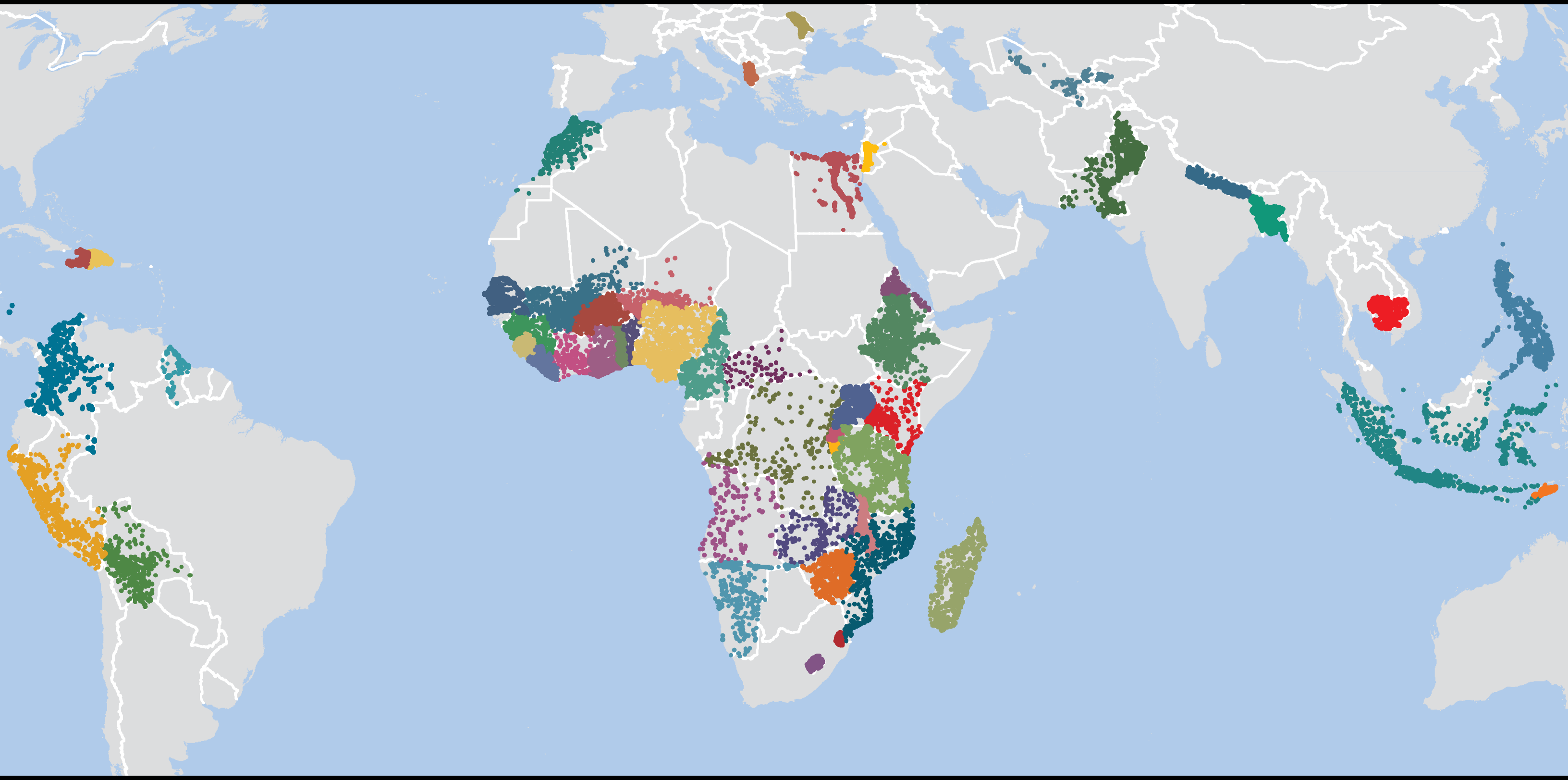
GEOGRAPHIC VARIATION IN KEY INDICATORS OF MATERNAL AND CHILD HEALTH ACROSS 27 COUNTRIES IN SUB-SAHARAN AFRICA

DHS SPATIAL ANALYSIS REPORTS 12



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Geographic Variation in Key Indicators of Maternal and Child Health Across 27 Countries in Sub-Saharan Africa

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Abbreviations

ANC	Antenatal care
CHW	Community health workers
CPR	Contraceptive prevalence
DHS	Demographic and Health Survey
DPT	Diphtheria, pertussis, and tetanus
DRC	Democratic Republic of the Congo
EBF	Exclusive breastfeeding
ESDA	Exploratory spatial data analysis
GIS	Geographic Information System
H4+	An inter-agency mechanism aimed at harmonizing and accelerating actions to improve maternal and newborn health, comprising UNICEF, WHO, The World Bank, and UNFPA.
HIV	Human immunodeficiency virus
MCH	Maternal and child health
MDG	Millennium Development Goals
LISA	Local indicator of spatial association
SBA	Skilled birth attendance
USAID	United States Agency for International Development
WHO	World Health Organization

Preface

The Demographic and Health Surveys (DHS) Program is one of the principal sources of international data on fertility, family planning, maternal and child health, nutrition, mortality, environmental health, HIV/AIDS, malaria, and provision of health services.

The DHS Spatial Analysis Reports supplement the other series of DHS reports to meet the increasing interest in a spatial perspective on demographic and health data. The principal objectives of all DHS report series are to provide information for policy formulation at the international level and to examine individual country results in an international context.

The topics in the DHS Spatial Analysis Reports are selected by The DHS Program in consultation with the U.S. Agency for International Development. A range of methodologies are used, including geostatistical and multivariate statistical techniques.

It is hoped that the DHS Spatial Analysis Reports series will be useful to researchers, policymakers, and survey specialists, particularly those engaged in work in low- and middle-income countries, and will be used to enhance the quality and analysis of survey data.

Sunita Kishor
Director, The DHS Program

Abstract

The Millennium Development Goals expire in 2015. While progress has been made in many areas, it appears that the maternal, newborn and child health goals (MDG 4 and 5) will not be universally achieved. There was early recognition that it could be possible to achieve the health goals while increasing health inequity, because most of the gains might go to the better-off rather than to the very poor. Concerns about health inequity indicate the need for analysis of health indicators in small geographic units, to aid in the identification of hotspots where coverage of key interventions lags behind neighboring areas. This report analyzes the spatial distribution of nine key maternal and child health indicators across 27 countries in sub-Saharan Africa. We created maps with 255 polygons representing each survey region from 27 DHS surveys, joined to indicator estimates. These maps show sub-regional-level autocorrelation for each indicator as well as spatial clusters, and we characterized those clusters in terms of the relationships among neighboring sub-regions. Patterns of substantial differences among contiguous subareas are apparent for different indicators, with some intra-country differences greater than 20 percentage points for all indicators examined. Our analysis shows some cross-border association with groups of high-high or low-low clustering present for all indicators. This analysis facilitates the identification of hotspots of low coverage or high need and can be used to allocate resources effectively to reduce health inequities between and within countries.

Executive Summary

In 2000, the United Nations established the Millennium Development Goals (MDGs), in which all 191 Member States agreed to try to achieve eight development goals by 2015 (United Nations 2000). While progress has been made in many areas, it seems certain that the maternal, newborn, and child health goals (MDGs 4 and 5) will not be universally achieved (Ebener et al. 2015; UNICEF 2015). Shortly after the MDGs were adopted, some recognized that it could be possible to achieve the health goals while increasing health inequity, because most of the gains might go to the better-off rather than to the very poor (Gwatkin 2002). Addressing inequities in maternal and child health (MCH) is seen as a critical strategy to improve health and survival overall (Victora et al. 2003). Geographic inequity in maternal and newborn health outcomes is found at regional, national, and subnational levels, and the location of health services is a key determinant of access to care (Ebener et al. 2015).

Concerns about health inequity indicate the need for analysis of health indicators in small geographic units to aid the identification of hotspots where coverage of key interventions lags behind neighboring areas. Geospatial analysis facilitates the identification of those areas, aiding precise allocation of resources and interventions where they are most needed and ultimately leading to effective health programming (Burgert 2014; Rosero-Bixby 2004).

This report focuses on 27 "Countdown to 2015" priority countries in sub-Saharan Africa: Benin, Burkina Faso, Burundi, Cameroon, Republic of Congo, Côte d'Ivoire, Democratic Republic of Congo (DRC), Ethiopia, Gabon, The Gambia, Ghana, Guinea, Kenya, Liberia, Malawi, Mali, Mozambique, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Tanzania, Togo, Uganda, Zambia, and Zimbabwe. Data from the most recent DHS surveys conducted in these countries from 2008 to 2013 were used to compute nine key indicators (ICF International 2008-2014a): contraceptive prevalence rate (CPR) (any modern method), antenatal care with 4+ visits (ANC), skilled birth attendance (SBA), exclusive breastfeeding (EBF), measles vaccination, DPT3 vaccine coverage, care seeking behavior, stunting prevalence, and under-five mortality rate.

DHS survey region borders were obtained from the Spatial Data Repository (ICF International 2008-2014b). Each country has between 3 and 26 regions, with a mean number of regions of 9.4 and median of 10. Individual country shapefiles were merged into a single feature class in ArcGIS 10.2. The final feature class had 255 polygons representing each survey region from the 27 DHS surveys. Indicator estimates were joined to the polygon dataset from the files created in Stata. The weight matrix defines as spatial neighbors any given areas that are touching either a border (edge) or a corner. All regions had at least one neighbor.

We produced maps that show sub-regional-level exploratory spatial data analysis (ESDA) results for each indicator as well as spatial clusters, and characterized those clusters in terms of the relationships among neighboring sub-regions, i.e., high-high values, high-low values, low-high values, and low-low values. The first measure used in this study is global Moran's *I*, which gives an indication of the overall spatial autocorrelation of a dataset. The second measure is a local indicator of spatial association (LISA) measure of local Moran's *I*, which indicates the "presence or absence of significant spatial clusters or outliers for each location" in a dataset (GeoDa 2015a). In addition to visualizing sub-regional indicator values, the main purpose of this analysis is to look at the value of an area compared with the values of its neighboring areas. The hotspots and coldspots (high-high and low-low clusters respectively) tend to be grouped together in several area units, while the high-low and low-high clusters, which indicate "outliers" compared with their neighbors, are usually a single area unit. An interactive version of each map is available at http://spatialdata.dhsprogram.com/SAR12/ to allow for further exploration and visualization of the results.

The differences in indicator coverage are striking, both at the national level between countries and at the subnational level within a country. We observed patterns of substantial differences among contiguous subareas for different indicators, with some intra-country differences greater than 20 percentage points for all indicators examined. Examples of extreme within-country differences are ANC, SBA, and DPT3 in Ethiopia (greater than 70 percentage points); at the other extreme, Malawi has within-country differences for CPR and ANC of less than 7 percentage points. We observed statistically significant variation between countries for SBA, EBF, DPT3, and stunting. Our analysis shows some cross-border association with groups of high-high or low-low clustering present for all indicators. More analysis could be done to examine all the factors among subnational regions that lead to the large differences in indicator coverage seen in most countries.

To our knowledge, this is the first study that has applied geospatial analysis to a comprehensive set of MCH indicators within and among countries. The spatial autocorrelation analysis presented in this report augments the body of established research that identifies and explores spatial implications for maternal and child health with a new visualization of subnational population averages of key MCH indicators. This analysis facilitates the identification of hotspots of low coverage or high need and can be used to allocate resources effectively to reduce health inequities between and within countries.

This report summarizes a body of research to establish the significance of geography in analyzing health indicator coverage differences. It also illustrates the role of geography as a health determinant in analyzing coverage inequity, and how geospatial analysis can be used to identify areas of low coverage or high mortality or stunting relative to neighboring areas within and between countries. Cross-border patterns of maternal and child health service coverage are uniquely identified by spatial autocorrelation analysis, which can point to the need for further research to reveal underlying reasons for low coverage and to aid efficient targeting of resources. The global community has coordinated multilateral regional responses to malaria, HIV, Ebola Virus Disease, and other outbreaks and health conditions; similar efforts could be considered to address persistently low coverage of maternal and child health indicators.

1 Introduction

In 2000, the United Nations established the Millennium Development Goals (MDGs), in which all 191 Member States agreed to try to achieve eight development goals by 2015 (United Nations 2000). As the deadline for achieving the MDGs nears, however, it is unlikely that the maternal, newborn and child health goals (MDG 4 and 5) will be universally achieved (Ebener et al. 2015), although progress has been made in many areas (UNICEF 2015). In 2013, 289,000 women died due to conditions related to pregnancy or childbirth (WHO 2014). While under-five child mortality is decreasing, neonatal deaths have not decreased as quickly and are now 44 percent of all under-five deaths (UNICEF 2014). The leading causes of under-five deaths are preterm birth complications, pneumonia, birth complications, diarrhea, and malaria, with nearly half of deaths attributable to undernutrition (UNICEF 2014). Estimates suggest that most of the 7.6 million deaths of children under age 5 in 2010 could have been averted by increased coverage of proven interventions, such as exclusive breastfeeding and skilled birth attendance (Chopra et al. 2012).

Shortly after the MDGs were adopted, some recognized that it could be possible to achieve the health goals while increasing health inequity, because most of the gains might go to the better-off rather than to the poor (Gwatkin 2002). Addressing inequities in maternal and child health (MCH) is seen as a critical strategy to improve health and survival overall (Victora et al. 2003). The World Health Organization (WHO) defines health equity as “the absence of avoidable or remediable health differences among groups of people, whether those groups are defined socially, economically, demographically, or geographically” (WHO 2015a). Geographic inequity in maternal and newborn health outcomes is found at regional, national, and subnational levels, and the location of health services is a key determinant of access to care (Ebener et al. 2015). There are concerns about growing inequity among socioeconomic groups within the boundaries of countries or sub-regions that seem to be generally “doing well” in reducing preventable morbidity and mortality (Bhutta and Reddy 2012). While progress has been made over the past decade, significant gaps remain, and new tools or methods are needed to accelerate progress.

Given the spatial dimension of health inequities, it is appropriate to analyze health indicators geographically and to make use of the approaches afforded by Geographic Information Systems (GIS) and geospatial analysis (Johnson et al. 2015). Geospatial analysis has been used to map the urban poor’s access to health services (Adams et al. 2015) and has shown that geographic proximity to health services is an important determinant of child survival in sub-Saharan Africa (Becher et al. 2004; Kadobera et al. 2012; Kazembe et al. 2006; Schoeps et al. 2011). Geo-analytic techniques uncovered residual spatial patterning of infant mortality showing higher concentration (“hotspots”) in certain regions of Nepal (Chin et al. 2011). Concerns about health inequity indicate the need for analysis of health indicators in small geographic units to aid the identification of hotspots where coverage of key interventions lags behind neighboring areas. Geospatial analysis facilitates the identification of those areas, aiding precise allocation of resources and interventions where they are most needed and ultimately leading to effective health programming (Burgert 2014; Rosero-Bixby 2004).

1.1. Spatial Implications for Maternal and Child Health

There has been increasing recognition that achieving the MDGs requires understanding and integrating the spatial dimension (Chirwa 2014). Qayum et al. identified settlement, forest cover, water bodies, rainfall, relative humidity, and temperature as geographic features that can be useful when analyzed together with epidemiological and socioeconomic factors to identify disease or service coverage hotspots (Qayum et al. 2015). Mapping these features helps to identify the spatial distribution of infectious disease and also shows geographic barriers to access to health care and influences on health-related behavior. In addition, because geographic barriers can lead to geographic isolation, they may be associated with delayed expansion of health programs (Victora et al. 2006) and thus be a cause of health inequity at the subnational level.

Climate change is expected to have its worst effects on the poorest people in low- and middle-income countries (Smith and Ezzati 2005). Geospatial and geo-climatic features affect food production and consumption patterns, with clear effects on nutritional status and health in different populations. While many population groups have adapted to seasonal weather patterns and their effects on food availability, prolonged unfavorable weather patterns that restrict access to and availability of food for children, adolescents, and pregnant women can have lasting ill effects on their health, since stunting begins in utero and has a multigenerational effect (Prendergast and Humphrey 2014). Hookworm, malaria, and other infections common to tropical climates and impacted by geographic features can also affect nutritional status and contribute to stunting.

Tanahashi proposed a framework that bridges geographic analysis and health service coverage and use, defining four domains of context-specific service provision: availability, acceptability, accessibility, and quality (Tanahashi 1978). The framework has been adopted by several multi-country initiatives, including H4+, USAID, and WHO (Ebener et al. 2015). It facilitates the identification of geography-related bottlenecks to the use of health services, such as distance from a health facility (Peters et al. 2008). Since there is evidence that actual and theoretical use of services based on distance needed to travel are highly correlated (Noor et al. 2003), the demonstrated inverse relationship between distance from services and use of services indicates an important barrier to access (Hjortsberg 2003) that can be assumed even when data on the use of services are not available. Peters cites several factors associated with geographic accessibility of health services: good roads to transport people and supplies; communication services (subject to weather conditions in remote areas); and more money for supervision and other travel-related expenses for remote health centers (Peters et al. 2008).

Considering geographic barriers to access, facility-based services pose an obvious challenge to coverage of key MCH indicators. Barros and colleagues cited SBA and four or more ANC visits as the interventions with the most inequitable coverage in 54 countries (Barros et al. 2012). Gitimu found that living within five kilometers of a health facility was one determinant of SBA use in Kenya (Gitimu et al. 2015), while Mayhew found that living within 60 minutes travel time was one determinant of SBA use in Afghanistan (Mayhew et al. 2008). In addition, numerous studies show that distance from the nearest health facility is a significant barrier to seeking care for child illness, both because of the direct cost of travel and the indirect cost of time lost during travel (Bennett et al. 2015; Bruce et al. 2014; Feikin et al. 2009; Kassile et al. 2014).

Further, an indicator such as care seeking depends on a "supply and demand" interplay that can be attenuated by geographic access (Peters et al. 2008). Care seeking for child illness depends upon both knowledge and behavior. Caregivers need to recognize illness danger signs in children and decide to seek care within a short timeframe ("demand"), and health care services must be available, acceptable, and of high quality ("supply"), in addition to being an accessible distance or travel time, and cost (Adedini et al. 2014). Providing good-quality care in communities can mitigate the barrier of geographic access (UNICEF 2012) but may require other investments from health systems, such as maintaining education and motivation for caregivers, and training and supervising community-based service providers to ensure the quality of services—all of which can be difficult to provide to remote areas.

Not all maternal and child health indicators rely on facility-based provision of services; spatial analysis of these indicators draws upon the spatial distribution of natural and cultural features, considering "the context of place" (Callaghan 2014). This broader concept of geography extends beyond physical and political boundaries to incorporate social determinants of health (Callaghan 2014). Indicators of health behavior in homes and communities, such as exclusive breastfeeding, benefit from spatial analysis that can identify where support is needed. Suboptimal infant feeding behaviors affect mothers' and children's health (WHO 2011a) and can affect stunting and nutritional status. Since breastfeeding outcomes are better when women are supported in their breastfeeding efforts (Britton et al. 2007), the challenge for health service providers is to ensure that breastfeeding support is not limited to providers at health facilities but extends into communities through community health workers (CHW) and trained peer support groups, to help provide support to all those who need it, where they need it.

Community-based interventions should be prioritized as a way to improve coverage and increase equity (Carrera et al. 2012). Several kinds of health services have been provided in communities to overcome geography-related access barriers and to increase coverage. The Reaching Every District campaign adopted by WHO, UNICEF, and other partners seeks to improve immunization coverage in high-need areas. A key component to improving immunization coverage is to maintain regular outreach services (WHO 2005). In addition, this approach encourages countries and districts within countries to use coverage data to analyze the distribution of unimmunized children and to prioritize areas with poor access and low levels of use (Vandelaer et al. 2008). Community-based distribution of contraceptives has also contributed to increasing their use in different settings, including rural communities and isolated urban neighborhoods (Prata et al. 2005). Community-based interventions challenge health systems to make trained staff and supplies available where people live. Increasing reliance on CHWs to deliver high-quality health services that can overcome geographic barriers to care requires government support for this cadre, whose work has gained recognition as a critical component of ensuring population health (Bhutta et al. 2010).

The spatial autocorrelation analysis presented in this report augments the body of established research that identifies and explores spatial implications for maternal and child health with a new visualization of subnational population averages of key MCH indicators. This analysis facilitates the identification of hotspots of low coverage or high need and can be used to allocate resources effectively to reduce health inequities between and within countries.

1.2. Spatial Distribution of Maternal and Child Health Inequity

Place of residence is a key dimension of health inequity (Gwatkin 2007a). Geographic variations in coverage of maternal and child health indicators can reveal inequities between and within countries. Identifying areas of need is the first step in discovering and addressing causes of inequity, whether political, environmental, cultural, or socioeconomic. In Uganda, for example, a study found that poor geographic access to health care overlapped with poverty, in that the two regions with the worst access to health care were also the regions where large segments of the population (63 percent and 46 percent) lived below the poverty line (Kiwanuka et al. 2008). Distance was a barrier to obtaining health care for 20 percent of the poorest in Uganda compared with only 9 percent of the richest (Odaga 2004). There is some evidence that improving accessibility to health care in low- and middle-income countries can reduce socioeconomic gaps in care (Peters et al. 2008).

WHO reports in The State of Inequality: “Overall, inequalities were to the detriment of women, infants and children in disadvantaged population subgroups; that is, the poorest, the least educated and those residing in rural areas had lower health intervention coverage and worse health outcomes than the more advantaged” (WHO 2015c) p. 1). Research by Victora et al. found an inequitable distribution of child survival interventions within countries; the authors recommended equity analyses based on geographical deployment of interventions to assess whether these interventions reach people most in need (Victora et al. 2006). Gwatkin et al. found large disparities in health conditions and health service use overlapping with geographic health disparities among economic quintiles within 56 countries (Gwatkin et al. 2007b). In addition, there is evidence that where fertility is higher among poor people there will be a higher-than-average proportion of “newborns at risk for infant mortality,” among other adverse health outcomes within poor groups (Gwatkin et al. 2007b).

An example from the Democratic Republic of Congo shows that malnutrition is spatially structured—higher in rural areas than in urban centers—and overlaps with political and economic factors: Malnutrition is high in provinces where mining is the main industry, where there is conflict, and where food is produced, likely due to the economic benefit of selling food versus consuming it (Kandala et al. 2011). These findings showing the spatial distribution of malnutrition and its underlying relationship to poverty have implications for programs designed to improve nutrition status.

Reducing health inequity requires policies tailored to geographic areas. Targeting health interventions to high-need populations can be a cost-effective approach to reducing child mortality and can reduce inequities in coverage between the most and least deprived geographic areas (Carrera et al. 2012), but the strategy requires first knowing where to find high-need populations. Spatial autocorrelation analyses like the analysis presented in this report can identify those areas. Some researchers have recommended the inclusion of geo-referenced information in all surveys (Wirth et al. 2006), to facilitate the identification of such areas. Monitoring progress across geographic and socioeconomic indicators between and within countries can determine if programs and policies are benefiting the poorest people (Tugwell et al. 2007).

1.3. Analytical Rationale for DHS Spatial Analysis Report 12

Maternal and child health are key priorities for the global health community, including the United States Agency for International Development (USAID), WHO, and the United Nations. In addition to the MDGs, in 2011 the UN Commission on Information and Accountability for Women's and Children's Health (the Commission) issued a report, "Keeping Promises, Measuring Results," which identified 11 core indicators to monitor, review, and act on the health of women and children across the continuum of care (WHO 2011b). In 2013 USAID issued its "Global Health Strategic Framework," which establishes the agency's core global health priorities for 2012-2016. These include saving mothers' lives, improving child survival, and enhancing family planning and reproductive health (USAID 2013). These global strategic priorities and indicators underpin our analysis.

Sub-Saharan Africa is a compelling region to examine because of the high need and low coverage of several of the selected indicators and uneven progress on addressing the problem. Our timeframe, determined by using the most recent survey in the last seven years among the countries studied, provides an important check on health equity by examining coverage differences among sub-regions during the second half of the MDG monitoring period.

A systematic review of 621 articles about using geospatial analysis in health research found that studies focusing on particular health problems are less common than studies focusing on disease surveillance, access to care, or environmental risk analysis (Nykiforuk and Flaman 2011). A rapid review by Ebener et al. found 33 articles focused on maternal and neonatal health, with a noticeable increase since 2010 (Ebener et al. 2015; Nykiforuk and Flaman 2011). DHS Spatial Analysis Report 12 augments this body of research by exposing the subnational geographic variability of nine maternal and child health indicators across 27 countries in sub-Saharan Africa and identifying areas of high or low coverage through comparison with neighboring areas, a methodology that is also known as spatial autocorrelation analysis. Identifying subnational geographic areas of high need can inform research on why MCH indicators lag in certain areas, in order to direct resources effectively where they are needed most. Table 1 explains the indicators included in this analysis.

This report summarizes a body of research to establish the significance of geography in analyzing differences in coverage of health indicators by explaining the geographic factors that influence maternal and child health, setting the stage for our analysis of differences in coverage among contiguous political sub-regions. It also illustrates the role of geography as a health determinant in analyzing coverage inequity, and how geospatial analysis can be used to identify areas of low coverage or high mortality or stunting relative to neighboring areas within and between countries. Cross-border patterns of MCH service coverage are uniquely identified by spatial autocorrelation analysis, which can point to the need for further research to reveal underlying reasons for low coverage and to aid efficient targeting of resources. For example, cultural and language connections across country borders may be associated with similar health behaviors (Amin et al. 2002) or illness patterns, and consequently may drive bi-national hotspots, implying a need for coordinated efforts to address them. In addition, infectious diseases do not conform to political boundaries. The global community has coordinated multilateral regional responses to malaria, HIV, Ebola Virus Disease, and other outbreaks and health conditions; similar efforts could be considered to address persistently low coverage of maternal and child health indicators.

Table 1. Maternal and child health indicators in this analysis

Indicator	Definition	Significance	Status
Maternal health indicators			
Contraceptive prevalence (CPR), any modern method	Proportion of women age 15-49 who report current use of a modern contraceptive method[1]	Contraceptive use reduces the risk of maternal mortality and increases child survival (Rutstein 2008; Singh et al. 2010).	From 1990 to 2012, in sub-Saharan Africa the CPR among women married or in union increased from 13 to 26 percent (United Nations 2014).
Antenatal care (ANC) 4+ visits	Proportion of women age 15-49 who made four or more antenatal care visits during their last pregnancy within the last five years	ANC prevents or identifies and treats conditions that could threaten the health of mother and fetus or newborn (Banta 2003). ANC may be positively correlated with SBA in some countries (Mishra and Retherford 2006).	From 1990 to 2012, in sub-Saharan Africa the proportion of ANC attendance at four or more visits increased from 48 to 50 percent (United Nations 2014).
Skilled birth attendance (SBA)	Proportion of most-recent live births during the past five years that were attended by skilled health personnel[2]	SBA reduces risk of maternal and newborn morbidity and mortality (Carlough and McCall 2005).	From 1990 to 2012, in sub-Saharan Africa the proportion of deliveries attended by skilled health personnel increased from 40 to 53 percent (United Nations 2014).
Child health indicators			
Exclusive breastfeeding (EBF)	Proportion of last-born infants under age 6 months who are living with the mother and breastfeeding and have not had any water, liquids, or solids in the day or night preceding the interview	EBF is an effective intervention requiring few system inputs (Roberts et al. 2013). Suboptimal breastfeeding practices increase childhood risks of morbidity and mortality (Lim et al. 2012).	Prevalence of EBF in West and Central Africa increased from 12 percent in 1995 to 28 percent in 2010, and from 35 percent to 47 percent in Eastern and Southern Africa (Cai et al. 2012).
Measles vaccination	Proportion of children age 12-23 months who received the measles vaccination at any time prior to the survey	Although it is preventable with immunization, measles is still a leading cause of death for children under age 5. In addition, serious complications in children under age 5 can lead to severe diarrhea and pneumonia. Measles is highly contagious, and infected pregnant women risk severe complications (WHO 2015b). Herd immunity from measles requires immunization coverage of at least 90 percent (Luna et al. 2014).	Coverage with one dose of vaccine among one-year-olds (two doses are recommended) increased in the WHO Africa Region from 53 percent in 2000 to 74 percent in 2013 (WHO Regional Office for Africa 2015).
DPT3 vaccine coverage	Proportion of children age 12-23 months who received three doses of DPT vaccine at any time prior to the survey	Diphtheria, pertussis, and tetanus (DPT) are vaccine-preventable diseases that cause substantial global disease burden among children under age 5.	As of 2013, DPT3 immunization coverage among one-year-olds across Africa was 75 percent, the lowest among all WHO regions (WHO 2013).
Care seeking behavior	Proportion of children age 0-59 months who had cough, diarrhea, or fever in the last two weeks and sought treatment	Prompt diagnosis and appropriate management of diarrhea, malaria, and pneumonia is crucial for reducing under-five morbidity and mortality (Bennett et al. 2015).	Only 28 percent of children with fever were taken for treatment to a public health facility (Gething et al. 2010). Only 43 percent of children with symptoms of acute respiratory infection in low-income countries were taken to a health care provider (Das et al. 2013). It is likely that many children are not taken for treatment at all, making surveillance and disease management difficult in these countries. Coverage of oral rehydration salts (ORS), used in the treatment of diarrhea, was 35 percent globally between 2008 and 2012 (Bennett et al. 2015).

(Continued)

Table 2. – *Continued*

Indicator	Definition	Significance	Status
Child health indicators			
Stunting prevalence	Proportion of *de facto* children age 0-59 months whose height-for-age z-score is less than 2 standard deviations below the median on the WHO 2006 international reference standard	Stunting is a sign of undernutrition that occurred during pregnancy and the first two years of life. It increases lifetime risks of impaired health and affects educational and economic performance (Dewey and Begum 2011). Stunting is also the best proxy measure for child health inequalities (Wamani et al. 2007).	Stunting prevalence ranges from 12 percent to 30 percent among 16 sub-Saharan African countries (Wamani et al. 2007).
Under-five child mortality rate[3]	Number of deaths among children under age 5 in the five-year period preceding the survey per 1000 live births[3]	Impact indicator	From 1990 to 2012, in sub-Saharan Africa the under-five mortality rate declined from 177 to 98 deaths per 1,000 live births, a decrease of nearly 45 percent. However, this is still the highest regional mortality rate in the world for children under age 5. In 2012, 3.2 million children under age 5 in sub-Saharan Africa died, accounting for nearly half of global under-five deaths (United Nations 2014).

[1]Modern contraceptive methods include female sterilization, male sterilization, the contraceptive pill (oral contraceptives), intrauterine contraceptive device (IUD), injectables (Depo-Provera), implants (Norplant), female condom, male condom, diaphragm, contraceptive foam and contraceptive jelly, lactational amenorrhea method (LAM), country-specific modern methods and other modern contraceptive methods mentioned by the respondent (including cervical cap, contraceptive sponge, and others). Abortion, menstrual regulation, and withdrawal are NOT considered modern contraceptive methods.
[2]The definition of "skilled health personnel" or "skilled birth attendant" can vary by country but commonly includes doctors, nurses, midwives, and auxiliary midwives. See Appendix A for country-specific definitions of skilled birth attendant (SBA).
[3]The DHS Program uses a synthetic cohort life table approach to directly estimate the under-five mortality rate. Details may be found in the Guide to DHS Statistics, pp. 90-95 (http://www.dhsprogram.com/publications/publication-DHSG1-DHS-Questionnaires-and-Manuals.cfm).

1.3.1. Analysis objectives

This report uses the most recent data from DHS surveys conducted in the selected 27 countries, almost all of which occurred in the last five years. The units of analysis are DHS regions, which correspond to administrative level-one areas (e.g. provinces) or a combination of such areas within each survey country (Table 2). The data are statistically representative estimates of each indicator of interest for the population within each DHS region at the time of each survey.

Broadly, the report uses exploratory spatial data analysis (ESDA) methods to visualize and measure the spatial association between and among regions that are spatially contiguous. Specifically, we will:

1. Visualize the spatial patterns of MCH indicators across 27 countries and their sub-regions in sub-Saharan Africa. This analysis provides a quantitative assessment of each indicator both within and across national boundaries.

2. Identify areas with statistically significant clustering of high values (hotspots) or low values (coldspots), as well as spatial outliers, for the selected indicators. This analysis provides a statistical intra- and inter-country assessment of relatively high and low performing areas with respect to geographically proximal areas.

Table 3. Country survey year, type, and number of survey regions included in analysis

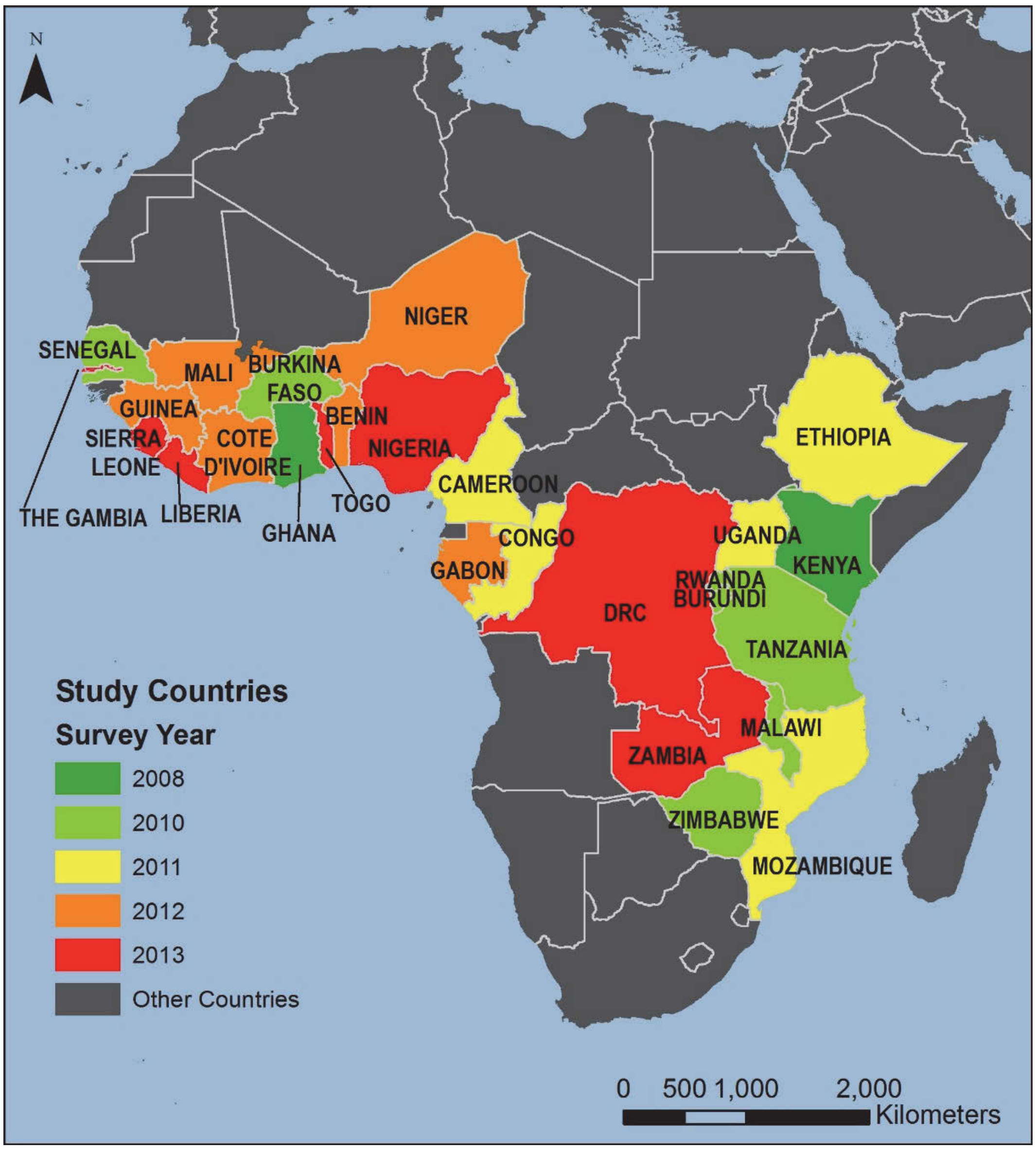
Country	Survey Year	Survey Type	Number of Survey Regions
Benin	2012	DHS	12
Burkina Faso	2010	DHS	13
Burundi	2010	DHS	5
Cameroon	2011	DHS	12
Congo	2012	DHS	12
Cote d'Ivoire	2012	DHS	11
Democratic Republic of the Congo (DRC)	2014	DHS	11
Ethiopia	2011	DHS	11
Gabon	2012	DHS	10
Gambia	2013	DHS	8
Ghana	2008	DHS	10
Guinea	2012	DHS	8
Kenya	2008-09	DHS	8
Liberia	2013	DHS	5
Malawi	2010	DHS	3
Mali	2013	DHS	6
Mozambique	2011	DHS	11
Niger	2012	DHS	8
Nigeria	2013	DHS	6
Rwanda	2010	DHS	5
Senegal	2011	DHS	14
Sierra Leone	2013	DHS	4
Tanzania	2010	DHS	26
Togo	2013-14	DHS	6
Uganda	2011	DHS	10
Zambia	2013	DHS	10
Zimbabwe	2011	DHS	10

2. Methods

2.1. Data

This report focuses on the following 27 countries in sub-Saharan Africa: Benin, Burkina Faso, Burundi, Cameroon, Republic of Congo, Côte d'Ivoire, Democratic Republic of Congo (DRC), Ethiopia, Gabon, The Gambia, Ghana, Guinea, Kenya, Liberia, Malawi, Mali, Mozambique, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Tanzania, Togo, Uganda, Zambia, and Zimbabwe (Figure 1). All of these are considered high-burden priority countries for the Countdown to 2015 (WHO and UNICEF 2012).

Figure 1. Counties included in study by survey year



2.1.1 Survey data

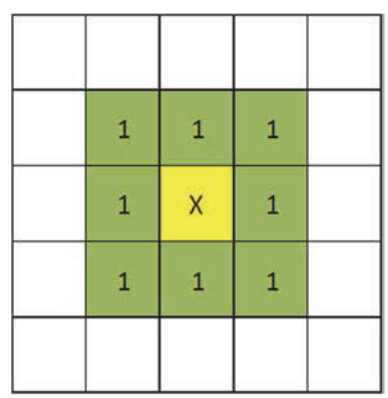
Data from the most recent DHS surveys conducted in these 27 countries between 2008 and 2013 were used to compute the nine key indicators described in Table 1 (ICF International 2008-2014a). These indicators cover three maternal health indicators—contraceptive prevalence (CPR) (any modern method), four or more ANC visits (ANC 4+), and skilled birth attendance (SBA)—and six child health indicators—exclusive breastfeeding (EBF), measles vaccination, DPT3 vaccine coverage, care seeking behavior, stunting prevalence, and under-five mortality rate. All of these indicators have a standardized definition in the DHS, as Table 1 shows, except for SBA, which is a country-specific variable. In 23 out of the 27 countries in this analysis, the "SBA" designation is restricted to a professional cadre, generally including a doctor, nurse, midwife, or trained birth attendant, in line with the generally accepted definition of skilled attendance; however, four countries include other categories of attendants as SBAs. Therefore, comparing this indicator across countries is challenging, and the results should be interpreted cautiously. Appendix A lists the country-specific definitions of SBA.

The key indicators were constructed according to the definitions shown in Table 1 and indicator estimates calculated for the country as a whole as well as for each DHS sample region. For SBA, individuals with missing responses were excluded from the denominator. Sampling weights and the stratified sample design were used to obtain the estimates and their confidence intervals and standard errors using Stata software version 13.0. The standard error or 95% confidence interval width are displayed in the results to provide context for evaluating the precision of the estimates. The micro-level datasets were used instead of data directly from the Spatial Data Repository linked to the STATCompiler database because standard error and confidence intervals are not available for all these indicators in the STATCompiler database

2.1.2 Spatial Data

DHS survey region borders were obtained from the Spatial Data Repository (ICF International 2008-2014b). Each country has between 3 and 26 regions, with a mean number of regions of 9.4 and median of 10. Table 2 summarizes the number of regions per country. Individual country shapefiles were merged into a single feature class in ArcGIS 10.2. Topographic polygon overlap errors were cleaned using ArcGIS, but some small gap slivers were left in the dataset. The final feature class had 255 polygons representing each survey region from the 27 DHS surveys. Indicator estimates were joined to the polygon dataset from the files created in Stata. A spatial weight matrix was constructed in ArcGIS using the Spatial Statistics Tools and a "Contiguity Edges Corners" (i.e. Queen) conceptualization of spatial relationships and row standardization. The ArcGIS approach to creating the spatial weight matrix is more forgiving of topology issues then the method used in GeoDa software. This weight matrix defines as spatial neighbors any given areas that are touching either a border (edge) or a corner. All regions had at least one neighbor. Figure 2 illustrates in green all the first order neighbors for location X (yellow square), these are all contiguity edge corners, or a queen contiguity.

Figure 2. Illustration of queen contiguity

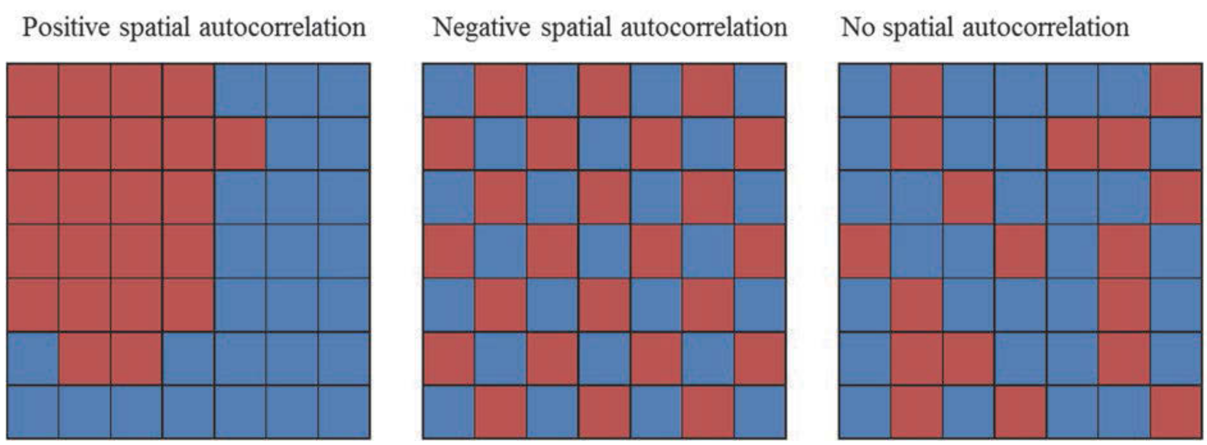


2.2. *Analysis Methods*

This report uses exploratory spatial data analysis (ESDA) techniques to measure the spatial autocorrelation between and among regions that are spatially contiguous. We used two ESDA techniques for this analysis. The first technique is a simple visual inspection of the indicator values displayed on a map in five categories. The category definitions differ between the maps and are defined in each map legend. Several maps have equal interval categories, such as 0-20 percent, 21-40 percent, 41-60 percent, 61-80 percent, and 81-100 percent. This technique has the advantage of being more easily interpretable by non-geospatial specialist but, unlike some other techniques used for displaying continuous data (e.g. jenks natural breaks), may place data that is close in value in different bins instead of breaking the data into groups more closely resembling the actual trends in the dataset.

The second technique uses two measures of spatial autocorrelation—that is, the degree to which one area is similar to or different from its neighboring areas. The Moran's *I* statistic measures clustering in a dataset: Values closer to zero indicate no or random spatial clustering, positive values indicate spatial clustering where neighbors tend to have similar values, and negative values indicate that neighbors tend to have different values. Figure 3 illustrates an example of positive, negative, and no spatial autocorrelation, where each grid square could represent a different subnational region.

Figure 3. Illustration of positive, negative, and no spatial autocorrelation



The first measure used in this study is global Moran's *I*, which gives an indication of the overall spatial autocorrelation of a dataset. The second measure is a local indicator of spatial association (LISA) measure of local Moran's *I*, which indicates the "presence or absence of significant spatial clusters or outliers for each location" in a dataset (GeoDa 2015a). The Global Moran's *I* and LISA analyses were conducted in the software package GeoDa with 99,999 permutations and a pseudo p-value for cluster of <0.05 specified (GeoDa 2015a). GeoDa uses a numerical, data-driven approach to test for statistical significance that does not assume that the underlying distribution of the data is normal. However, this means that the p-value measured is dependent on the number of permutations chosen; in this analysis we chose the maximum number of permutations allowed, which is the most conservative approach. The term "pseudo p-value" refers to its dependence on the number of permutations, rather than its independent selection. Due to the random number selection that is part of this analysis process, the results would be slightly different each time the analysis is run, and thus the results are not exactly replicable.

The LISA analysis results are output in three ways: as a scatter plot; a pseudo p-value spatial layer; and a spatial layer that shows up to five types of spatial association and outliers, as follows (GeoDa 2015b):

- **not significant:** Areas that are not significant at a pseudo p-value level of 0.05.
- **high-high:** High values surrounded by high values. (Note: these values are not "high" in the sense that their absolute value is necessarily high; rather, they are the high values from this dataset.)
- **low-low:** Low values surrounded by low values. (Note: these values are not "low" in the sense that their absolute value is necessarily low; rather, they are the low values from this dataset.)
- **low-high:** Low values surrounded by high values.
- **high-low:** High values surrounded by low values

The three outputs from the LISA analysis show the same results in different ways and with slightly different purposes, and thus we have chosen to show only the spatial association layer in this report, which is most relevant for our study objective.

3. Results

Countries vary widely for all the indicators studied. Figure 4 illustrates the nine key indicators by country, depicting when a country is in the top (green) or bottom (orange) quintile for that indicator, among the counties studied. For most of the indicators high values are “good” while low values are “bad,” except for stunting prevalence and under-five mortality rate, where the opposite is true. Thus, high values for stunting and under-five mortality are highlighted in the bottom quintile, while low values for stunting and child mortality are highlighted in the top quintile. The country point estimates and 95% confidence intervals appear in Appendix B.

There is some difference between the relative ranking of the key indicators for maternal health and those for children’s health. Some countries were most often in the bottom 20 percent of the countries for child health, including Ethiopia, Guinea, Niger, and Nigeria. Others were more likely to be in the top 20 percent for child health indicators, including Burundi, Ghana, Malawi, The Gambia, and Rwanda. For maternal health, the lowest 20 percent often included Ethiopia, Guinea, and Niger, while the highest 20 percent often included Congo and Gabon. Ethiopia is in the bottom quintile for both maternal and child health indicators. Burundi, Malawi, and Rwanda are all relatively high performers for several child health indicators but are also all in the worst quintile for child stunting prevalence.

Figure 4. Summary of key indicators by country

	Benin DHS 2011-2012	Burkina Faso DHS 2010	Burundi DHS 2010	Cameroon DHS 2011	Congo DHS 2011-2012	Cote d'Ivoire DHS 2011-	DRC DHS 2013-2014	Ethiopia DHS 2011	Gabon DHS 2012	Gambia DHS 2013	Ghana DHS 2008	Guinea DHS 2012	Kenya DHS 2008-2009	Liberia DHS 2013	Malawi DHS 2010	Mali DHS 2012-2013	Mozambique DHS 2011	Niger DHS 2012	Nigeria DHS 2013	Rwanda DHS 2010	Senegal DHS 2010-2011	Sierra Leone DHS 2013	Tanzania DHS 2010	Togo DHS 1998	Uganda DHS 2011	Zambia DHS 2013-2014	Zimbabwe DHS 2010-2011
CPR, any modern method	9	14	11	16	22	14	8	19	24	7	14	7	28	21	33	10	12	11	11	25	9	21	24	17	21	33	41
ANC 4+	58	34	33	62	79	44	48	19	78	78	78	57	47	78	46	41	51	33	51	35	50	76	43	57	48	56	65
SBA	85	73	63	68	95	63	81	12	92	59	77	43	48	65	74	61	60	33	40	72	87	74	55	62	61	69	67
EBF	34	25	69	20	21	12	48	52	6	47	63	21	32	55	72	34	41	23	17	85	39	32	53	58	62	73	32
Care seeking behavior	70	87	94	71	75	65	72	56	74	88	90	62	85	74	93	72	82	69	42	95	82	79	85	74	76	85	79
Measles vaccination	62	90	95	68	56	64	61	37	22	88	89	50	86	71	93	63	76	68	38	97	83	78	88	83	72	86	73
DTP3 vaccine coverage	55	61	57	55	59	61	56	29	61	66	64	53	59	73	70	50	60	61	73	47	48	73	76	55	78	71	40
Stunting prevalence	45	35	58	33	24	30	43	44	17	25	28	31	35	32	47	38	43	44	37	44	27	38	42	28	33	40	32
Under-five mortality rate	70	128	96	122	68	108	104	88	65	54	80	123	74	94	112	95	97	127	128	76	72	156	81	88	90	75	84

*For stunting prevalence and under-five mortality high-values are worse, while low values are better

Orange squares indicate countries that are in the worst five countries for that indicator among studied countries

Green squares indicate countries that are in the best five countries for that indicator among studied countries

3.1. Map Interpretation

Regional-level ESDA results for each indicator are shown in Figures 6, 8, 10, 12, 14, 16, 18, 20, and 22. Each figure contains two maps, one larger and one smaller.

The larger map shows indicator values ranging from low values (in yellow) to high (in blue). The univariate LISA output overlays the indicator-level data:

- The high-high spatial clusters (red dot marks) are the hotspots and low-low spatial clusters (orange dot marks) are the coldspots. They represent positive spatial autocorrelation or locations surrounded by neighbors with similar values.
- The high-low (purple hatch marks) and low-high (pink hatch marks) locations are spatial outliers; which represent negative spatial autocorrelation or locations surrounded by neighbors with dissimilar values.
- Locations that do not display any hatch marks are those areas where there is no spatial autocorrelation or significant clustering detected among neighboring regions.

The smaller map shows the standard error or width of the 95% confidence interval (under-five mortality rate only) for the indicator value, ranging from low (light yellow) to high (red). The standard error maps use the same five categories for the data display, which means that some maps do not display data in each category.

The main purpose of this analysis is to look at the value of an area compared with the values of its neighboring areas, rather than the absolute values of areas. The hotspots and coldspots (high-high and low-low clusters respectively) tend to be grouped together in several area units, while the high-low and low-high clusters, which indicate outliers compared with their neighbors, are usually a single area unit. This analysis highlights the relationship of indicator values between and among neighboring areas. As mentioned previously, for all indicators except stunting and under-five mortality, areas of high-high are "good" and areas of low-low are not good; for stunting and under-five mortality it is the opposite. Not all types of spatial associations exist for every indicator. The spatial clustering patterns may at times not seem to be completely matched with the underlying data layer showing the indicator values. This is due to the categorization that is necessary in displaying continuous measures on a one-dimensional map; thus values that might be close in an absolute sense are in different categories depending on how the data were categorized.

An interactive version of each map is available at http://spatialdata.dhsprogram.com/SAR12/ to allow for further exploration and visualization of the results.

3.2. Indicator-Level Results

Overall, the indicator-level results show as wide a distribution of values of the indicators at the subnational level as was observed at the national level (Figure 4, although the national estimates mask large subnational variation in some cases. The lowest subnational region value and highest subnational region value for each country, along with the national estimate, are presented for each indicator respectively in Figures 5, 7, 9, 11, 13, 15, 17, 19, and 21. These figures illustrate the country-level geographic differences in indicator values.

Global Moran's *I* statistics vary across the nine indicators studied. Although the global Moran's *I* may be statistically non-significant, local areas of spatial clustering (i.e., statistically significant local Moran's *I*) may exist at among the countries of sub-Saharan Africa and at subnational levels, highlighting the need to evaluate local as well as global statistics—that is, aggregate statistics for the geographic areas included in the study. A statistically significant positive global Moran's *I* suggests spatial autocorrelation across national borders, highlighting the need to examine across countries and not just within them. A statistically significant negative global Moran's *I* indicates non-random geographical contrasts within the region, highlighting the need to identify the scale and location of these differences. Across the 27 countries, in the maps (Figures 6, 8, 10, 12, 14, 16, 18, 20, and 22) some areas are more consistently in one of the LISA cluster categories, including some areas of the West African Sahel and East Africa. Across indicators, the high-high and low-low clusters often cross national borders, while the outliers often have at least one neighboring area in a different country. The overall standard errors for the estimates are within an acceptable range for all the indicators studied, even those for rare events such as mortality.

3.2.1. Maternal health indicators

Contraceptive prevalence (CPR), any modern method

Use of any modern method of contraception is generally low (≤ 50 percent) throughout and across the countries in this analysis (Figure 5). Most countries have inter-country differences of greater than 10 percentage points, with the exception of Malawi with a difference of 3 percentage points between the highest and lowest regions. In contrast, Kenya has a difference of 40 percentage points between its lowest and highest regions.

The global Moran's *I* statistic indicates no significant spatial clustering at the regional level (Global Moran's *I*: -0.049, p-value: 0.152). The LISA map shows areas of high-high spatial association in the East and Southern Africa while low-low spatial clustering is focused across West and in Central Africa (Figure 6). These spatial clusters cover many area units and several countries. A few areas of low-high outliers in Ethiopia and Mozambique are contiguous to the high-high cluster stretching through eastern and Southern Africa. The standard errors for the prevalence estimates are uniformly low.

Figure 5. Contraceptive prevalence (CPR), any modern method country-level estimate and regional comparison

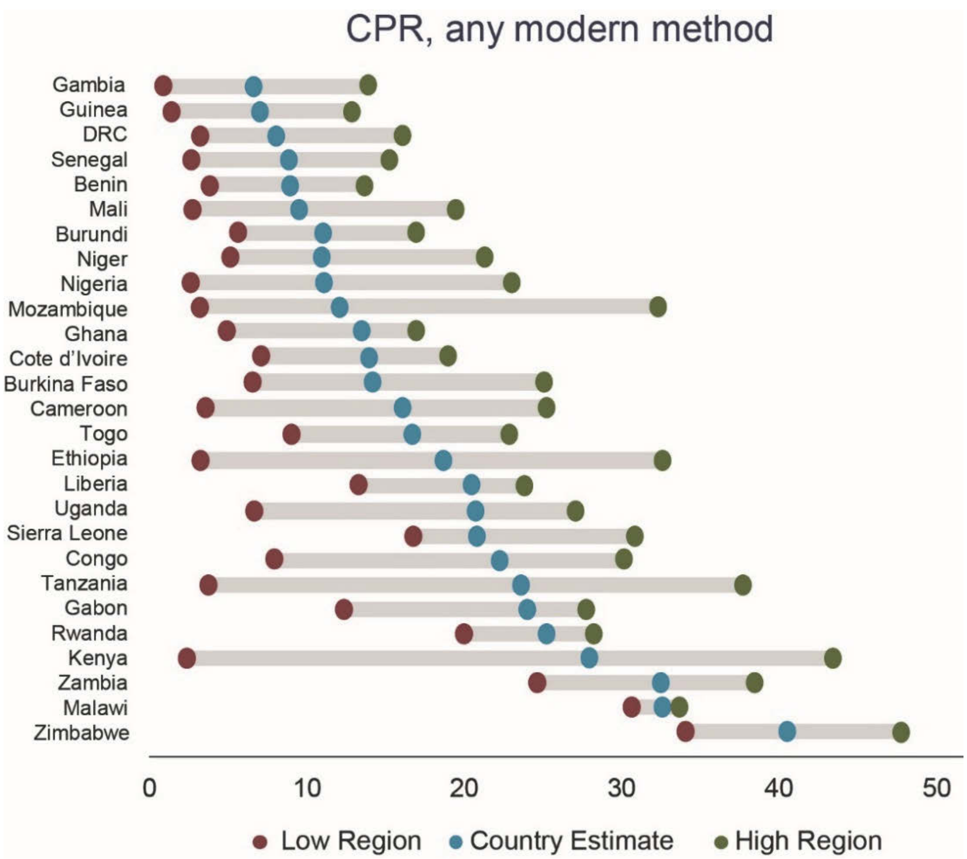
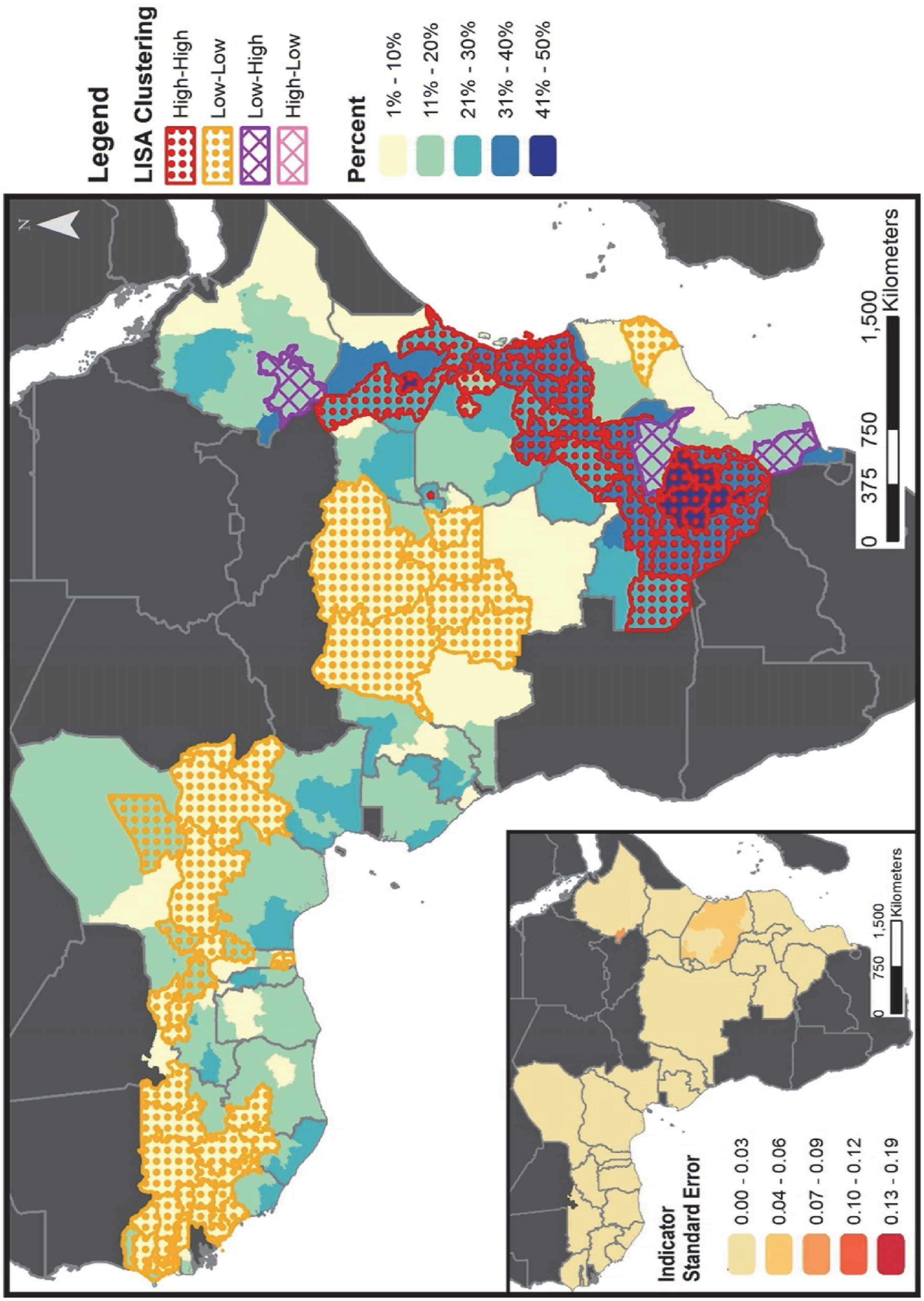


Figure 6. Contraceptive prevalence (CPR), any modern method LISA and standard error maps



Antenatal care, four or more visits (ANC 4+)

ANC 4+ has striking coverage variation among countries in this analysis, as well as large coverage differences within countries. Coverage ranges from 7 percent in the lowest region of Ethiopia to 90 percent in the highest region of Ghana (Figure 7). Some countries, including Ethiopia, have very high intra-country differences (79 percentage points), while others, such as Malawi and Sierra Leone, have less than 7 percentage points between their highest and lowest regions.

There is non-significant positive spatial autocorrelation seen at the regional level (Global Moran's *I*: 0.06, p-value: 0.067). ANC 4+ has high-high spatial association along the coastline of West and Central Africa, and low-low association in both West and eastern Africa inlands (Figure 8). A couple of "belts" of low-low coverage stretch across the Sahel and into the Sahara, and along the horn of Eastern Africa. A few spatial outliers of low-high are present around the high-high clusters in West and Central Africa. There is one area of high-low association, which is contiguous to a low-low cluster in the Great Lakes Region. The standard errors for the coverage estimates are nearly uniformly low.

Figure 7. Antenatal care, four or more visits (ANC 4+) country-level estimate and regional comparison

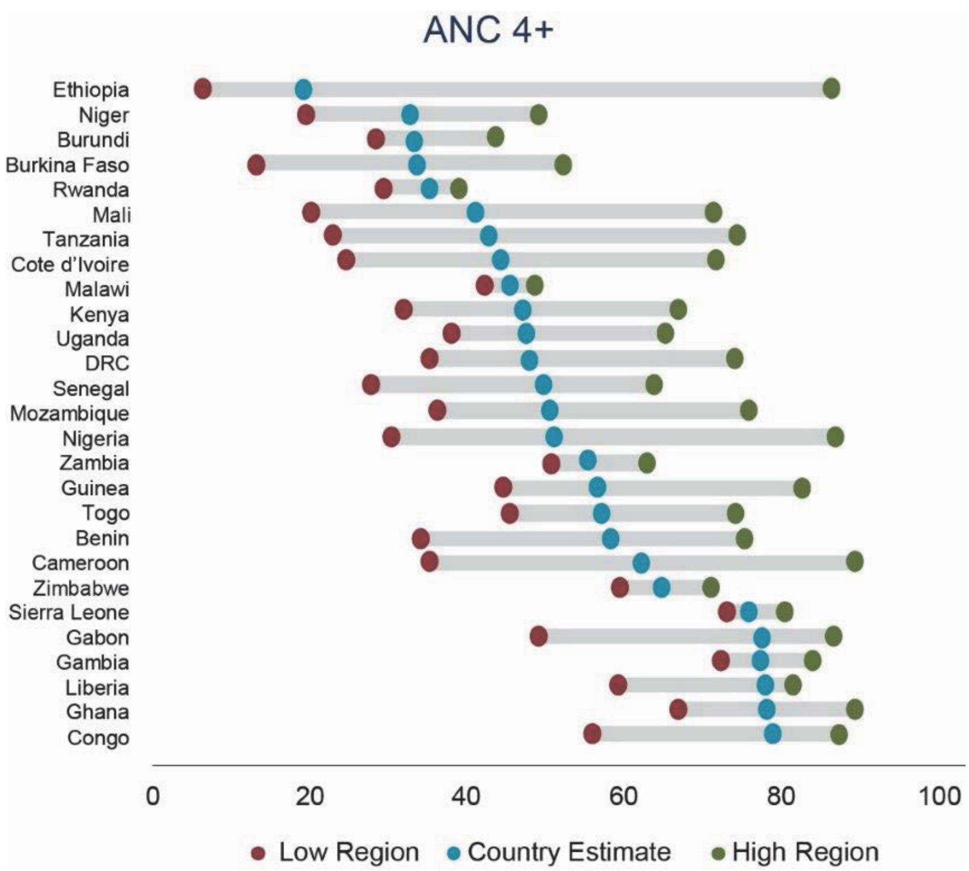
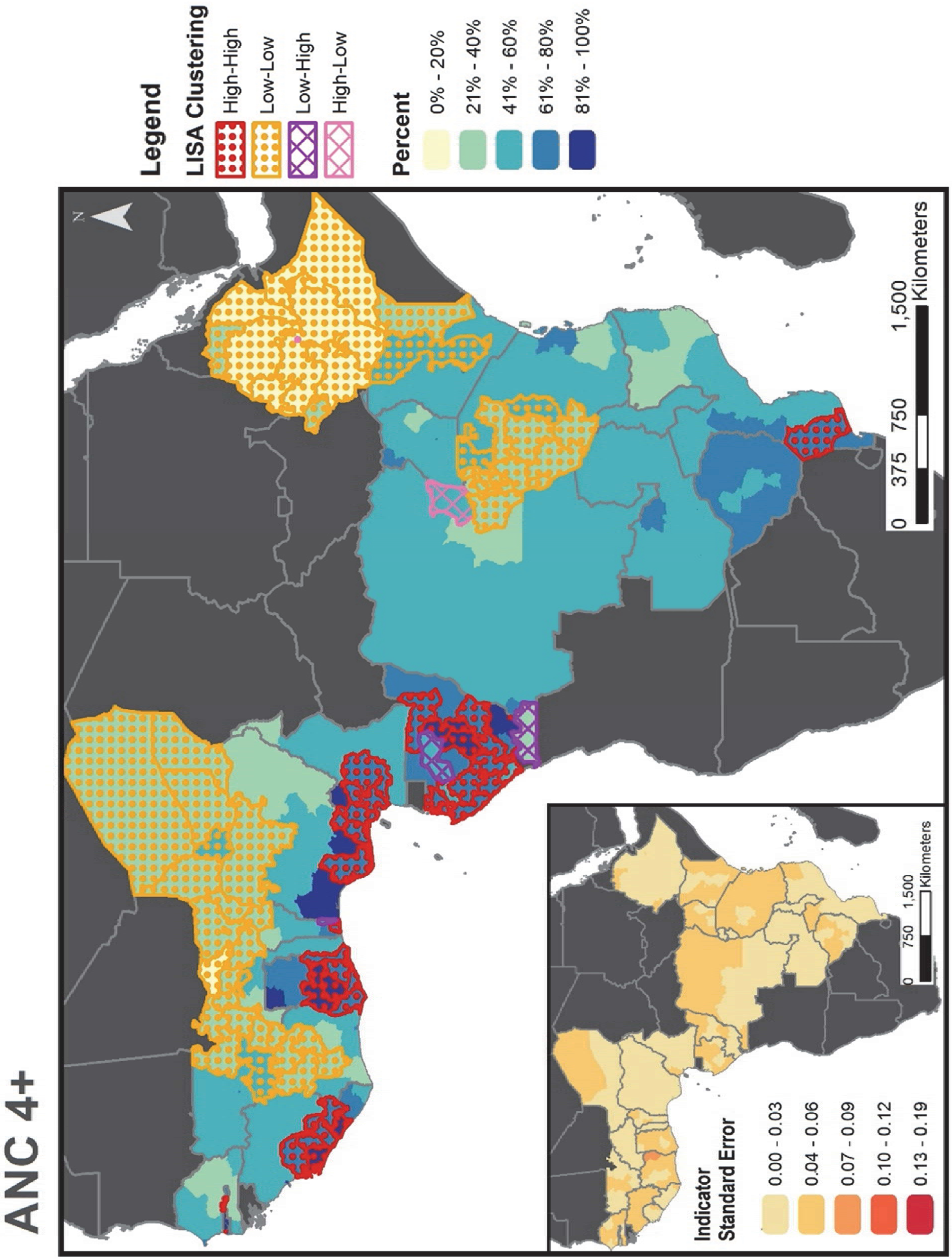


Figure 8. Antenatal care, four or more visits (ANC 4+) LISA and standard error maps



Skilled birth attendance (SBA)

Like ANC 4+, there are large intra-country and inter-country differences in SBA coverage, from 8 percent in Ethiopia to nearly 100 percent in Congo (Brazzaville) (Figure 9). All countries studied have at least one region with SBA coverage higher than 75 percent, while 22 countries have at least one region with coverage less than 60 percent.

There is significant positive spatial autocorrelation seen at the regional level (Global Moran's *I*: 0.125, p-value: 0.002). A belt of moderately high SBA coverage stretches across Central Africa, with a cluster of high-high associations in the western areas of Central Africa, with a few pockets in western Africa (Figure 10). There are large areas of low-low association clustered in western and eastern Africa. There are a few high-low pockets scattered in western and eastern Africa and contiguous to large areas of low-low clustering. It is important to keep in mind that SBA definitions vary among countries, including several of countries with higher SBA coverage with more inclusive definitions, which influences some of the observed differences. There is some variation among the standard errors for these coverage estimates, with generally low standard errors in West and Central Africa and an area of moderately high variability in East Africa.

Figure 9. Skilled birth attendance (SBA) country-level estimate and regional comparison

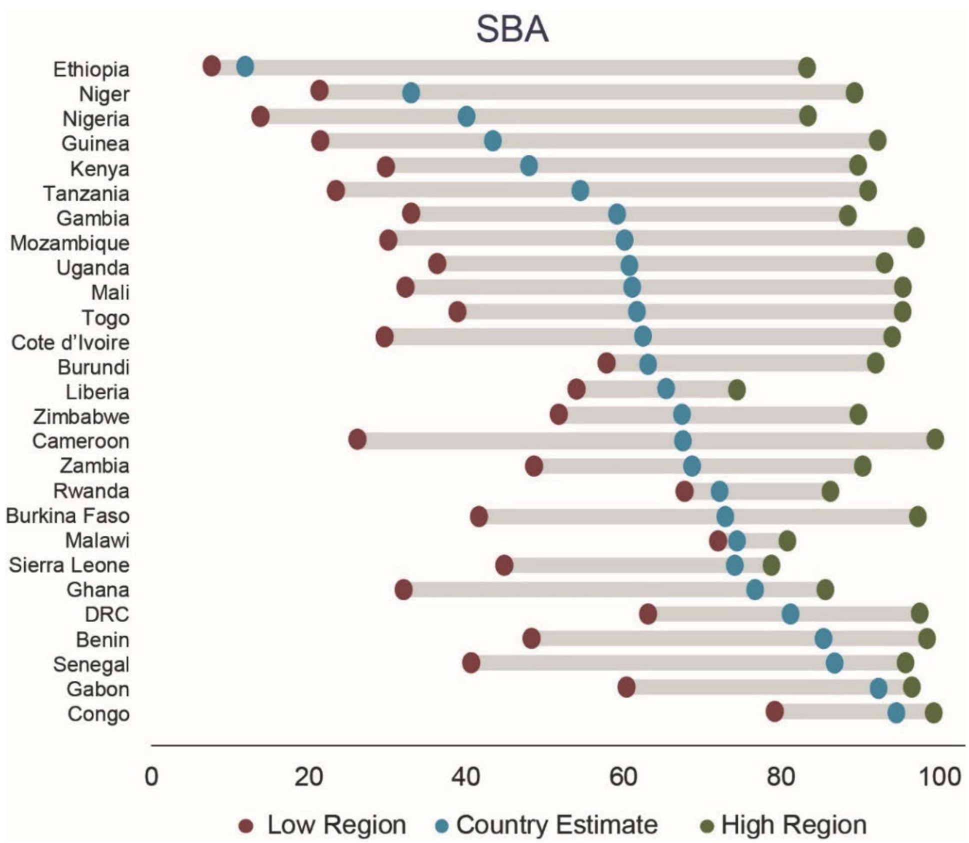
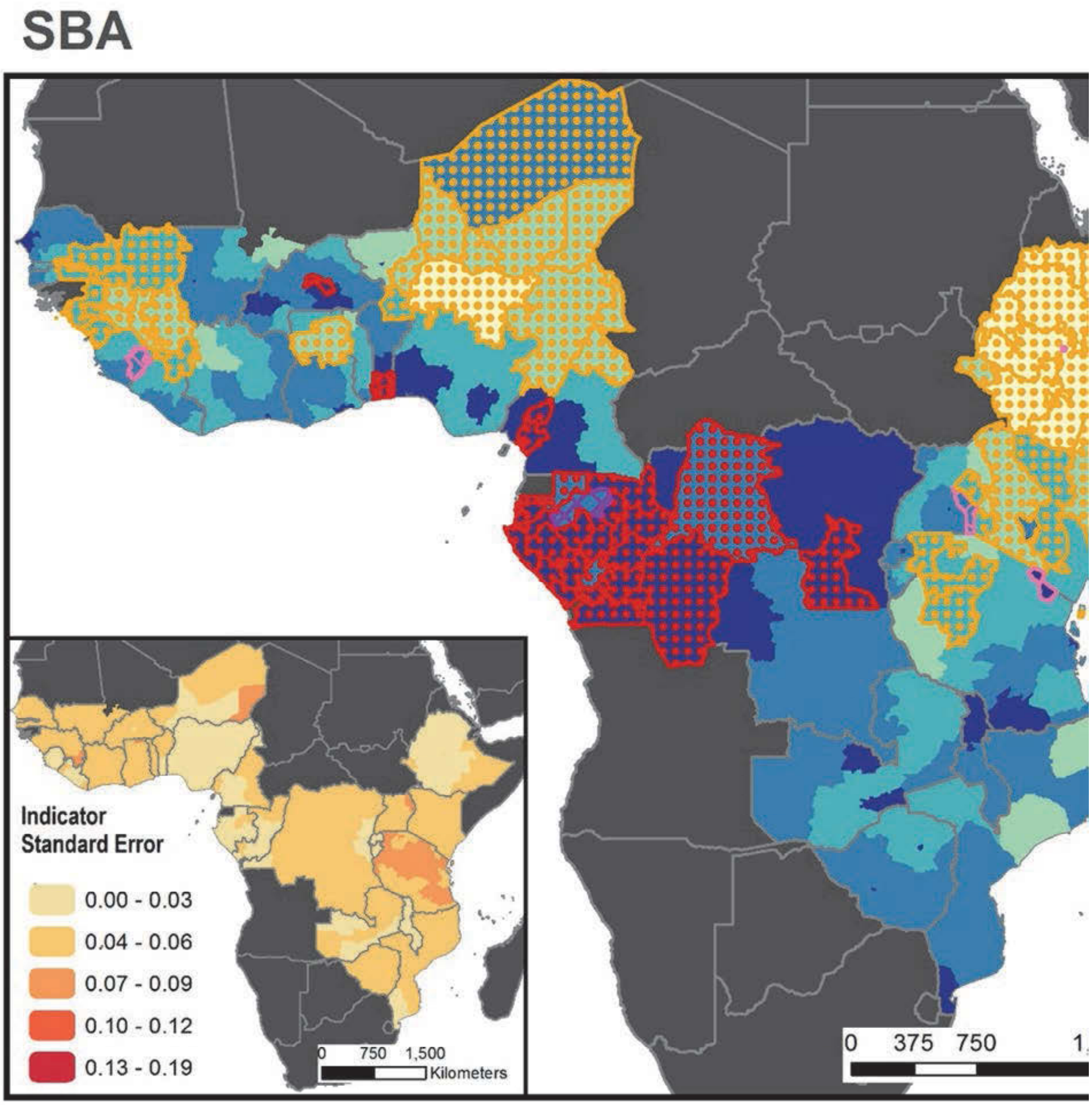


Figure 10. Skilled birth attendance (SBA) LISA and standard error maps



3.2.2. Child health indicators

Exclusive breastfeeding (EBF)

EBF prevalence ranges from 6 to 85 percent among the countries studied, but these national estimates hide substantial subnational regional variation (Figure 11). The majority of countries (22 of 27) have intra-country coverage differences of more than 20 percentage points.

Significant positive spatial autocorrelation exists at the regional level (Moran's *I*: 0.100, p-value: 0.011). Figure 12 shows that there are cross-border similarities apparent between countries, with subnational regions that are adjoining at national borders often being in the same categories. There are high-high clusters in eastern Africa, with a smaller cluster in West Africa, mainly in Ghana. Areas of low-low spatial clustering are mostly in West and Central Africa. There are low-high outliers surrounding the high-high clustering in eastern Africa, while pockets of high-low clustering appear in a few areas contiguous to low-low clusters in West and Central Africa. The standard error map signals that some areas in western Africa and Tanzania have higher standard errors than other areas.

Figure 11. Exclusive breastfeeding (EBF) country-level estimate and regional comparison

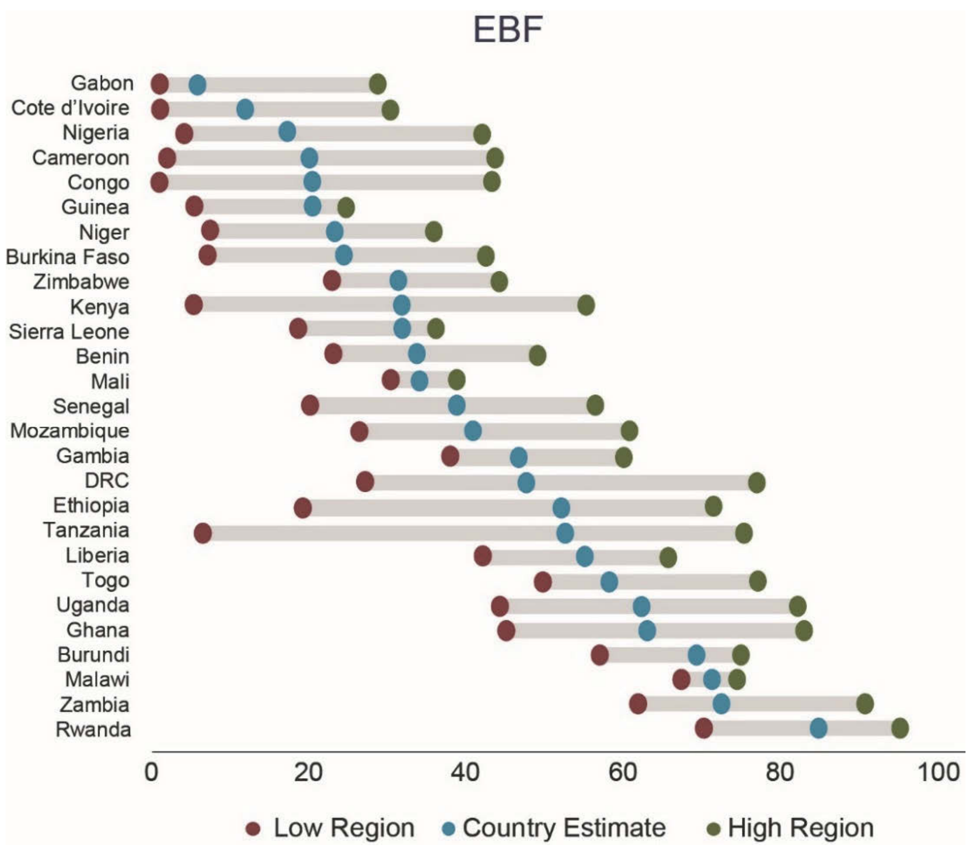
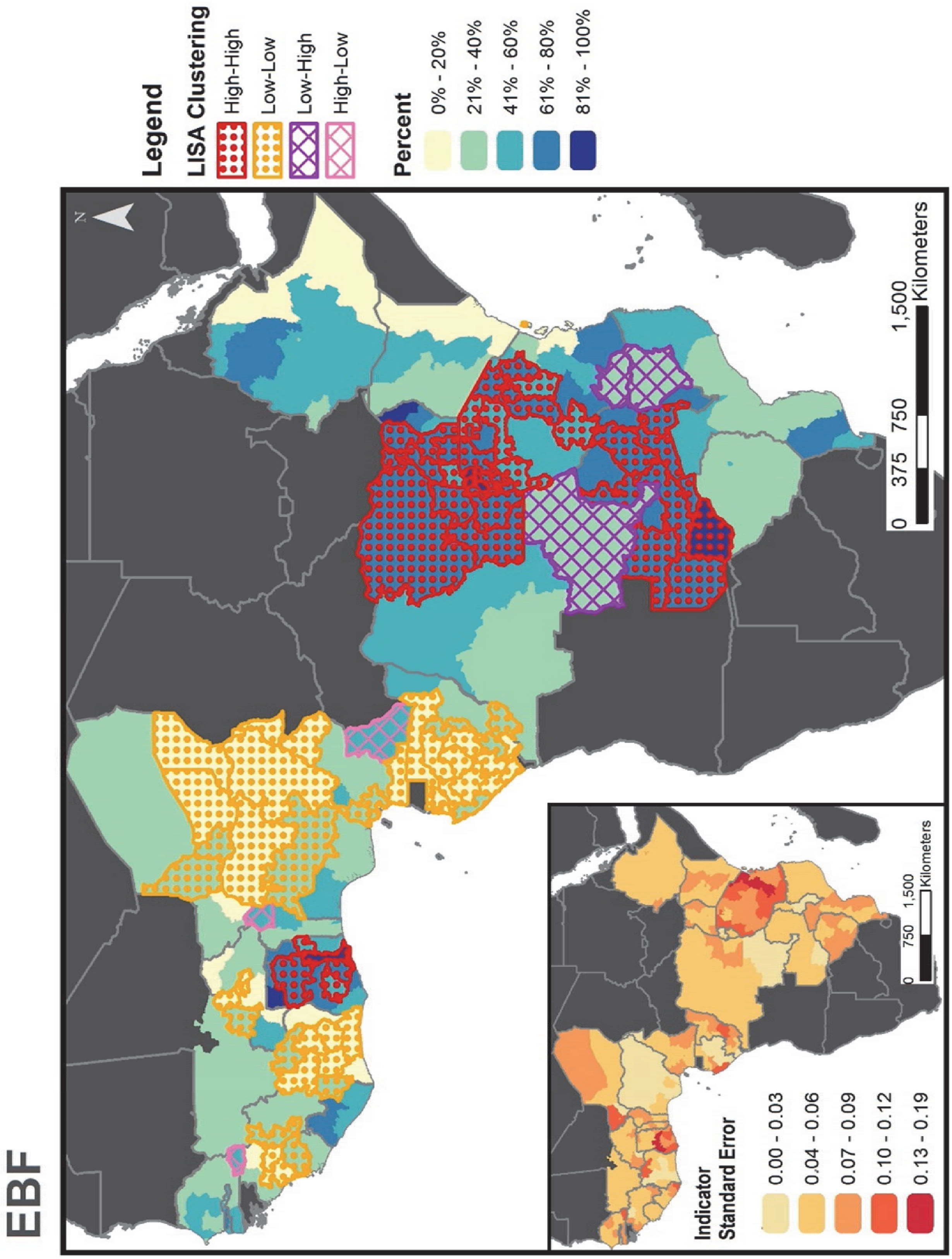


Figure 12. Exclusive breastfeeding (EBF) LISA and standard error maps



Measles vaccination

With a few exceptions, measles vaccination coverage is generally high among the countries studied (Figure 13). The subnational variation remains high in some countries (up to 60 percent points), but in most countries, as coverage increases at the national level, the subnational difference decreases.

No significant spatial autocorrelation was found at the regional level (Global Moran's *I*: 0.014, p-value: 0.325). However, the LISA clustering for coverage of measles vaccination has two large areas of high-high clustering: one in East Africa and one in the center part of West Africa, with smaller areas encompassing Rwanda and Burundi in east-central Africa and The Gambia in West Africa (Figure 14). Low-low clusters appear in West and Central Africa, as well as much of Ethiopia. There are also a few high-low outliers, including areas in Benin, Cameroon, Ethiopia, and Gabon, while there is only a single low-high outlier in the southwestern corner of Uganda. Map 2 shows a few select areas of higher standard error.

Figure 13. Measles vaccination country-level estimate and regional comparison

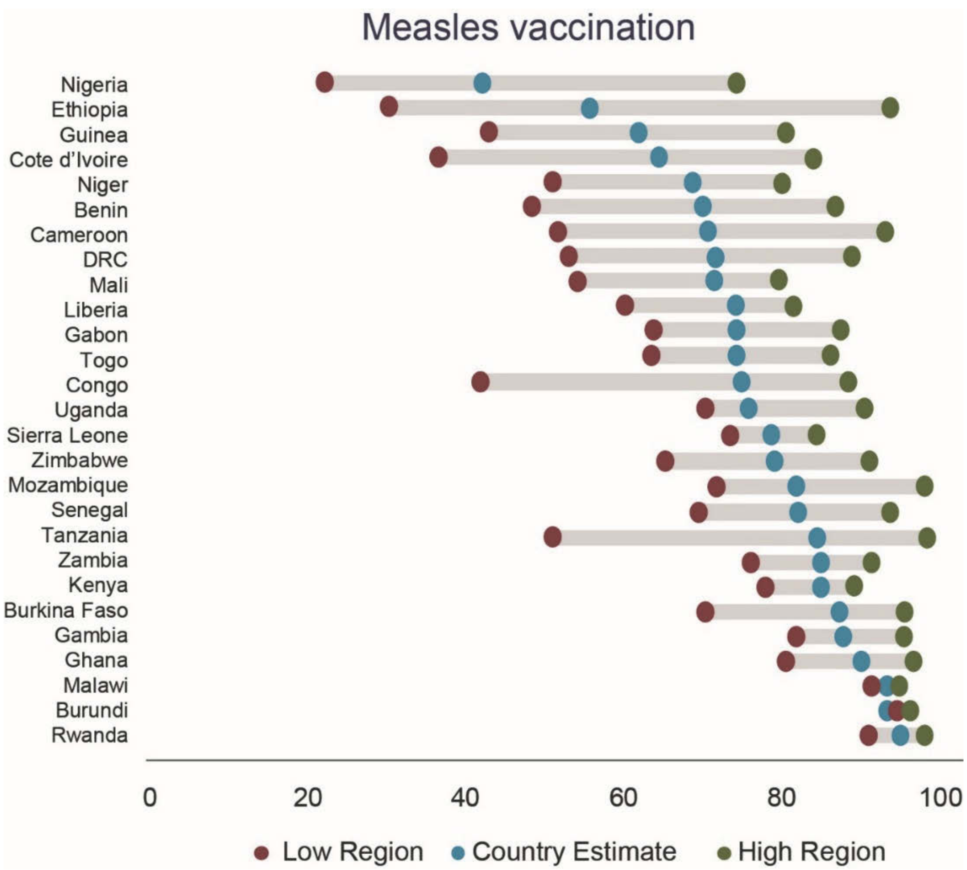
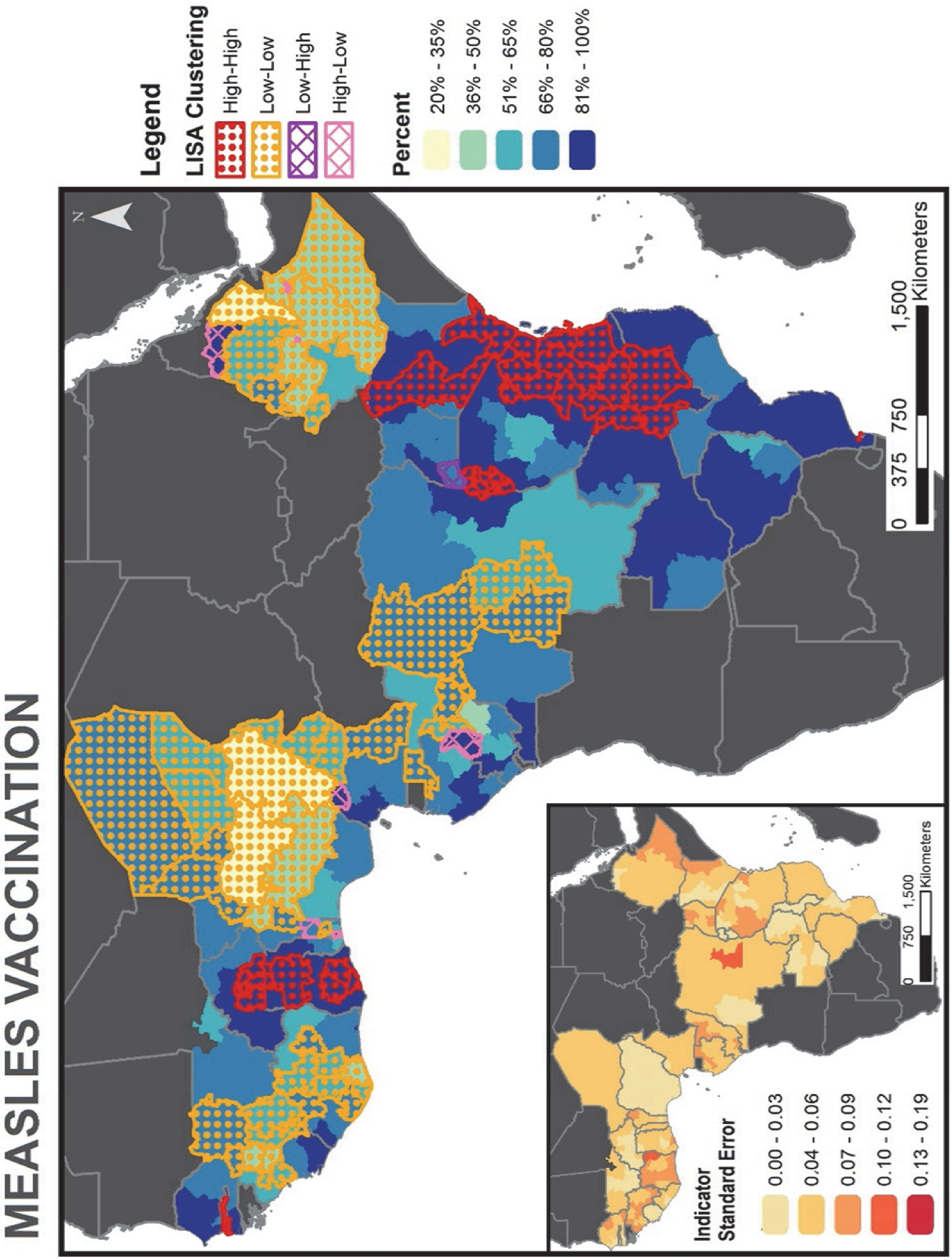


Figure 14. Measles vaccination: LISA and standard error maps



DPT3 vaccine coverage

DPT3 vaccine coverage is generally high among the countries studied, with a few exceptions where coverage is less than 60 percent (Figure 15). Subnational variation, however, remains high, and a majority of countries have a difference of more than 20 percentage points between their lowest and highest regions.

Significant negative spatial autocorrelation exist within the whole DPT3 dataset (Global Moran's *I*: -0.089, p-value: 0.021). The LISA clustering looks similar to that on the Measles map, although the low-low areas comprise a smaller number of units, while the high-high clusters contain more areas and are more contiguous, with a long stretch in eastern Africa and two smaller clusters in western Africa (Figure 16). Low-low areas are concentrated in West and Central Africa, as well as Ethiopia. There are just three areas of high-low outliers: two in Ethiopia and one in Niger. There are no low-high areas visible. Map 2 indicates some areas with relatively high standard error.

Figure 15. DPT3 vaccine coverage country-level estimate and regional comparison

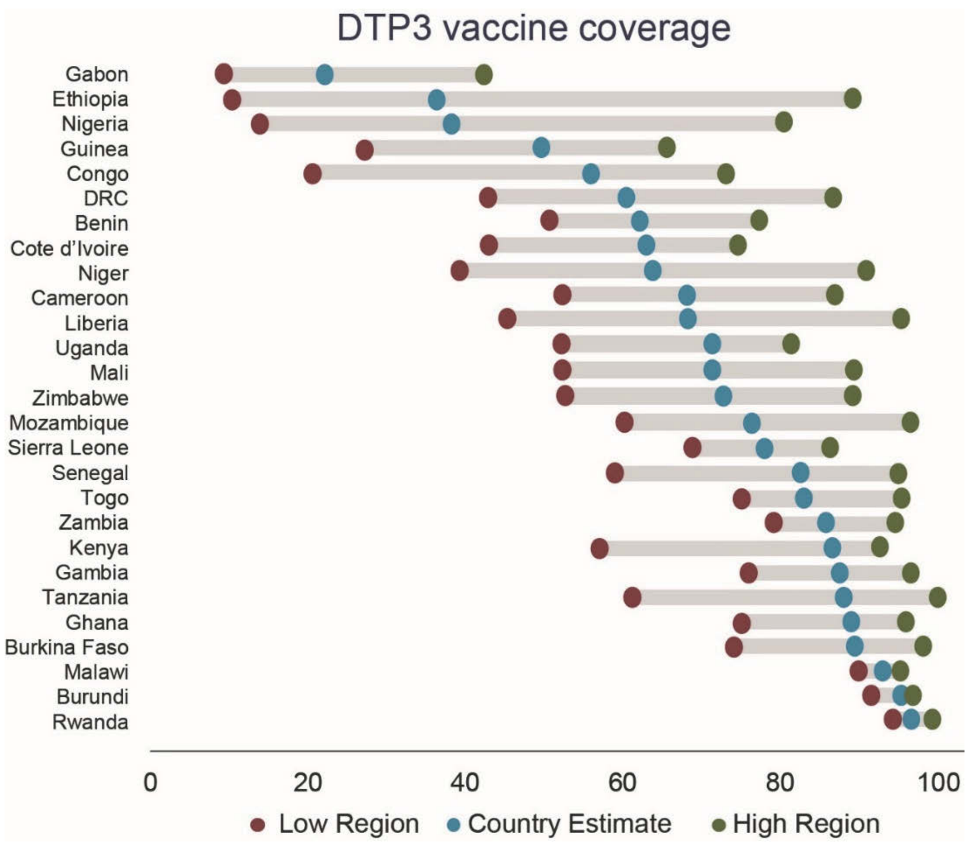
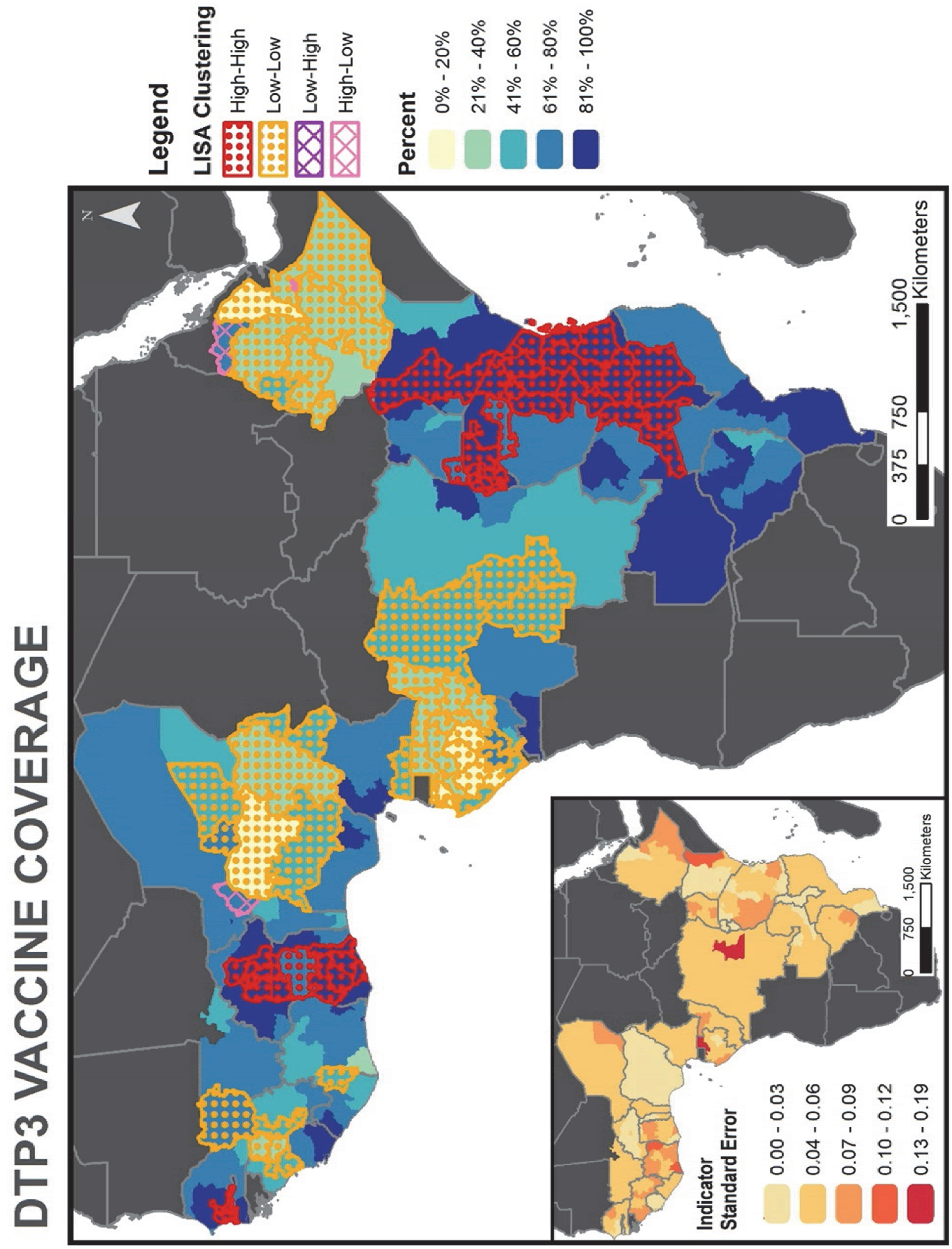


Figure 16. DPT3 vaccine coverage: LISA and standard error maps



Care seeking behavior

The care seeking behavior indicator shows a moderately high prevalence across the countries studied, with most countries at 50-80 percent (Figure 17). Subnational variation is above 20 percentage points in most countries, with a few exceptions.

The global measure of spatial autocorrelation for the care seeking behavior dataset was non-significant (Global Moran's *I*: 0.016, p-value: 0.318). Figure 18 shows that at the local level there are three main areas of high-high spatial association: a stretch in eastern Africa, a cluster in western-central Africa and a cluster in western Africa including parts of Liberia and Sierra Leone. Low-low associations appear mainly in West Africa, Ethiopia, Zimbabwe, and a small section of Central Africa. Low-high outliers are grouped around the high-high areas of East Africa, while a single high-low area is located in Cameroon. Standard errors are consistently low, with a few pockets of higher ranges in western and eastern Africa.

Figure 17. Care seeking behavior country-level estimate and regional comparison

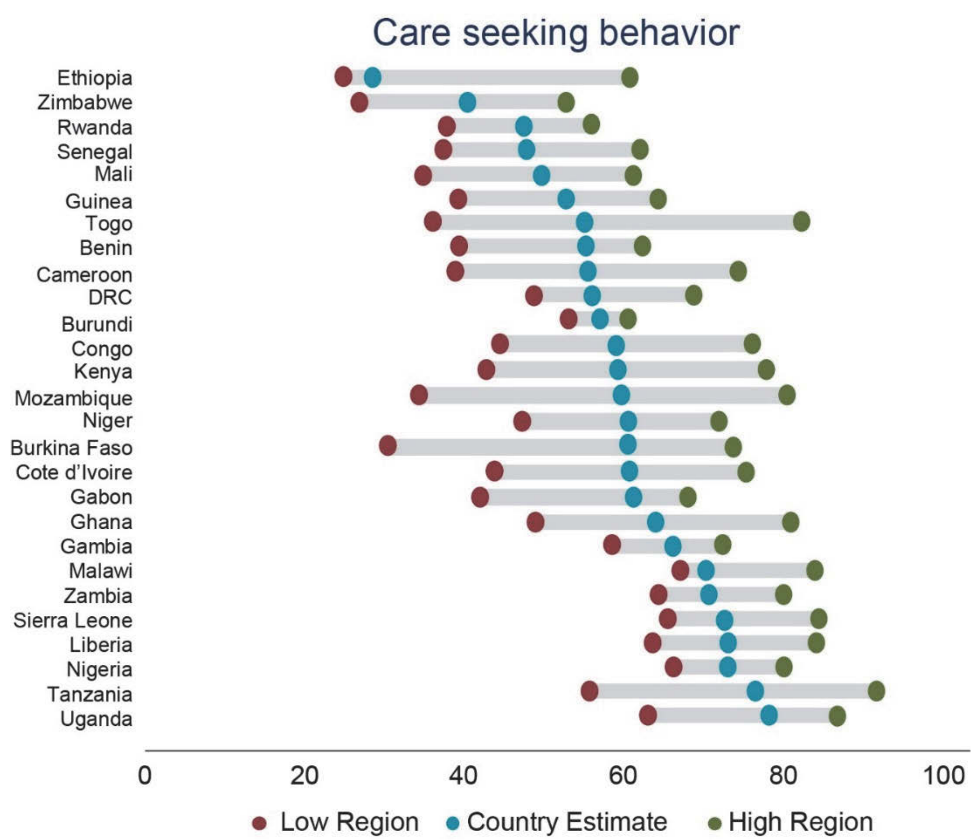
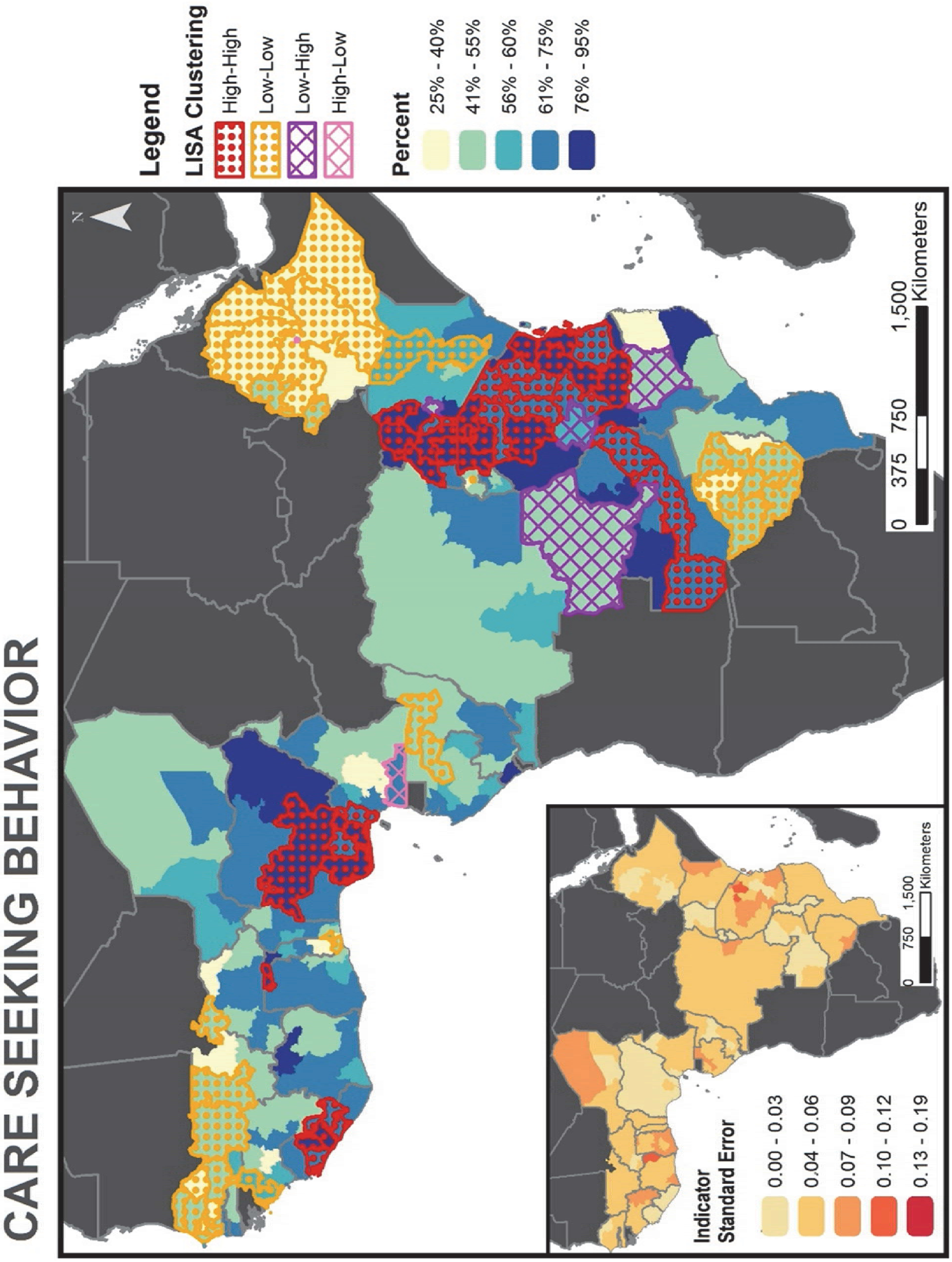


Figure 18. Care seeking behavior: LISA and standard error maps



Stunting prevalence

Stunting prevalence is high in most areas studied (> 20 percent), with some subnational regions below 20 percent. Intra-country variation is high in most countries; Nigeria has regional values ranging from 16 to 55 percent and DRC has regional values ranging from 17 to 53 percent (Figure 19).

Significant negative spatial autocorrelation exist within the whole DPT3 dataset (Global Moran's *I*: -0.090, p-value: 0.021). In the LISA analysis, high-high areas are in Central and East Africa, as well as parts of Niger and Nigeria, and northern Ethiopia (Figure 20). Pockets of low-low clustering appear along the Central and West African coastline. A single low-high area appears in Tanzania, while a few high-low clusters include areas in Ghana and Togo, DRC, Congo, and Senegal. Standard errors are generally uniformly low; low-high and high-low areas seem to be higher in prevalence of stunting compared with other areas.

Figure 19. Stunting prevalence country-level estimate and regional comparison

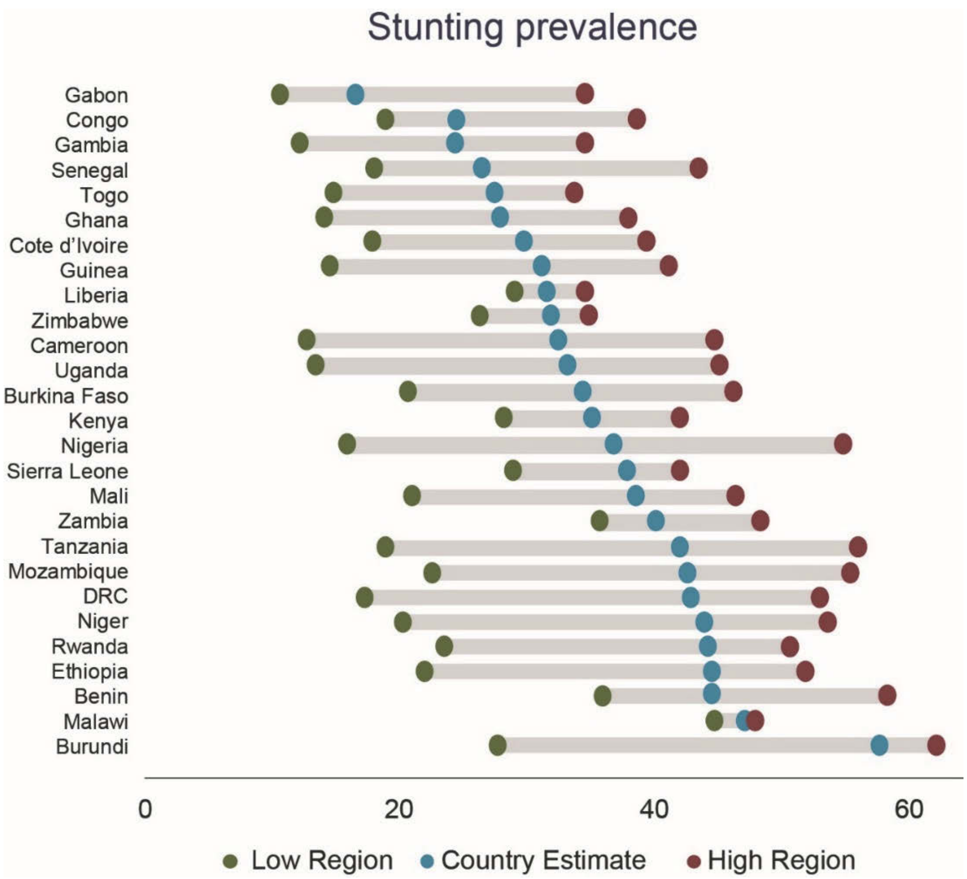
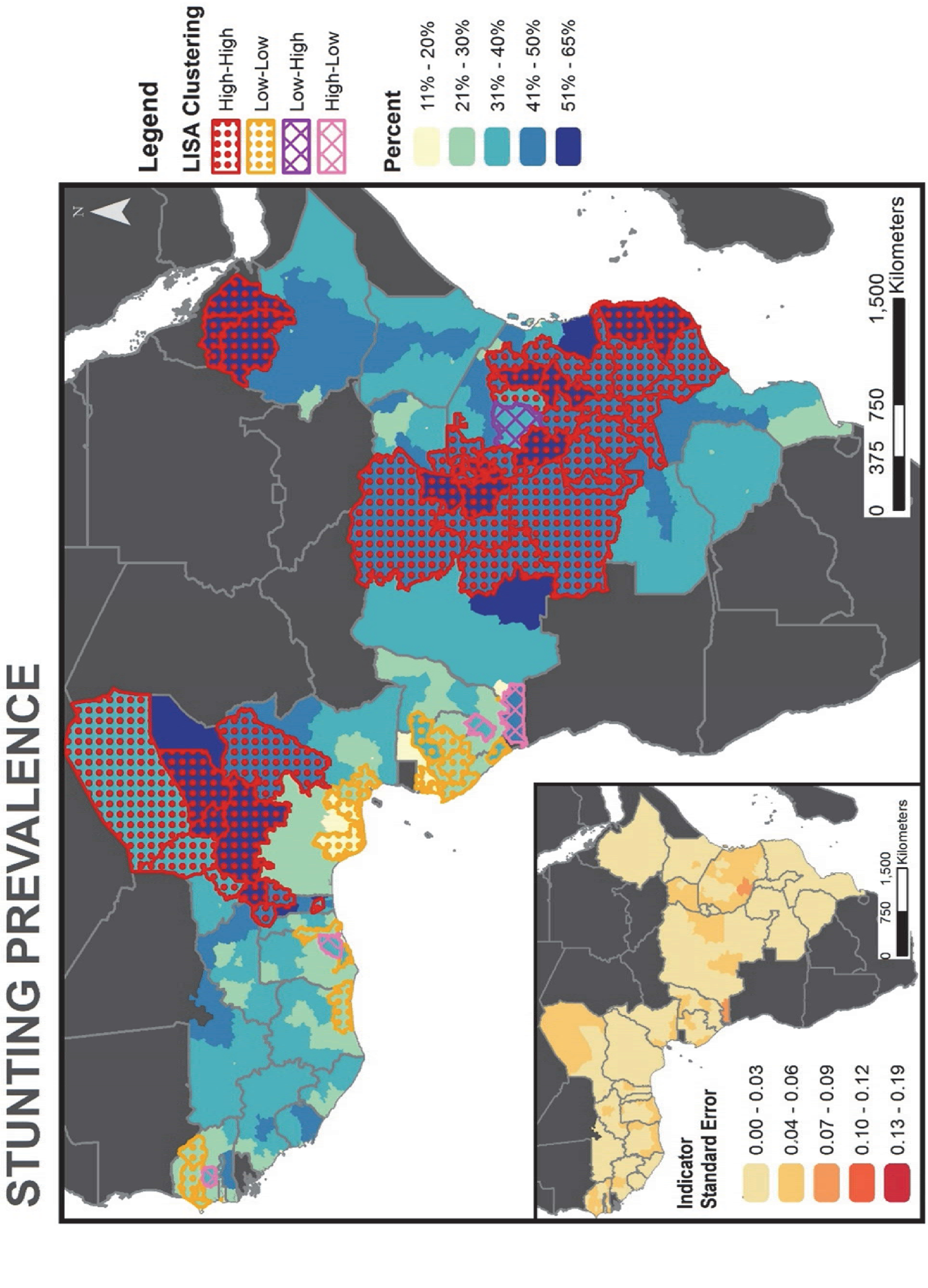


Figure 20. Stunting prevalence LISA and standard error maps



Under-five mortality rate

The under-five mortality rate is moderately high across the countries studied, with a few areas that are very high. Subnational variation is generally high between the lowest and highest regions in each country, except for Malawi (Figure 21).

There is no spatial clustering seen at the regional level for this indicator (Global Moran *I*: 0.067, p-value: 0.055). Figure 22 shows high-high clustering along the West African countries of Niger, Nigeria, Burkina Faso, Mali, Guinea, and Liberia. A few low-low clusters appear in parts of Benin, Gabon, Senegal, Kenya, Tanzania, Zambia, and Zimbabwe. Three small low-high outliers are scattered along the Sahel high-high cluster, while two high-low areas appear in Gabon and Zimbabwe. Precision is more variable for these estimates than for those on the other maps. There are large widths in confidence interval throughout the areas shown, with particularly high variability in pockets of north-central, western coastal, and eastern Africa.

Figure 21. Under-five mortality rate country-level estimate and regional comparison

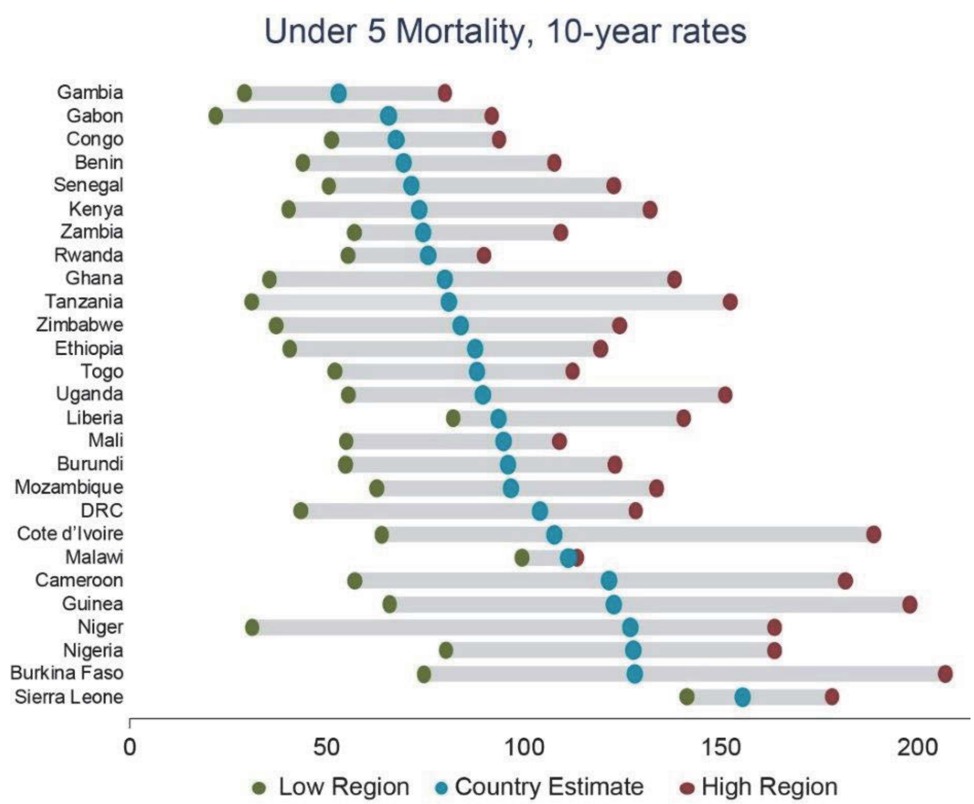
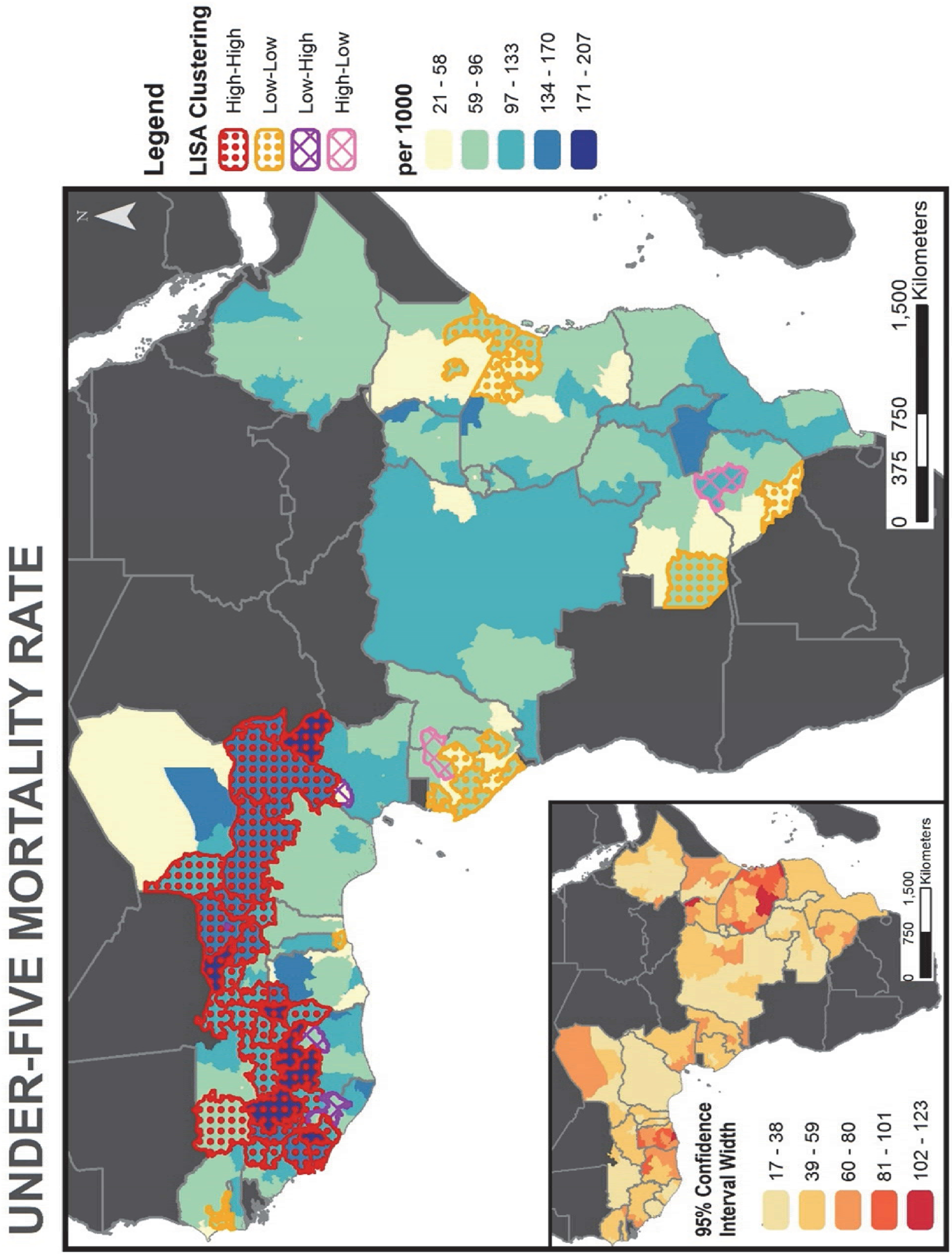


Figure 22. Under-five mortality rate LISA and 95% confidence interval width maps



4. Discussion

To our knowledge, this is the first study to apply geospatial analysis to a comprehensive set of MCH indicators within and among countries. No previous studies using DHS data have focused on the cross-border relationship that may exist in maternal and child health behaviors or service coverage, as well as intra-country variability. A few studies have looked at the spatial autocorrelation present for single or multiple indicators within a single country or within several countries—for example, water and sanitation indicators (Pullan et al. 2014)—but these have not compared indicators among countries. Although this analysis was not designed to examine the underlying reasons for differences in indicator coverage among contiguous sub-regions, in this section we use maternal and child health information to discuss the spatial distributions we observed and to indicate areas for further research.

The differences in indicator coverage are striking, both at the national level between countries and at the subnational level within a country. Intra-country variability is clearly visible for all indicators across all the countries included in the study, with a few exceptions. The observed difference between the highest region and lowest region in a country, often over 20 percentage points, reinforces the recognition that advancements in MDG health indicators might be achieved while increasing health coverage inequity (Gwatkin 2002). More analysis could be done to examine all the factors among subnational regions that lead to the large differences in indicator coverage seen in most countries.

In our analysis, all indicators have some cross-border association with groups of high-high or low-low clustering present. It is not surprising to see these cross-border bands, given the cultural influences that may exist for many of the MCH indicators studied, especially exclusive breastfeeding, stunting, modern contraceptive use, and antenatal care, and the fact that many ethnic groups reside in geographic areas that cross-political boundaries. The political boundaries of most countries in Africa were drawn during the colonial period with little regard for traditional boundaries and thus often divided ethnic groups between two or more countries.

Some indicators have larger multi-country clusters. In particular, estimates of prevalence of exclusive breastfeeding and stunting seem to group together in large areas, such that it is possible to identify bands of similar values that stretch across different countries. Exclusive breastfeeding has a band of low prevalence across West Africa, interrupted by bands of very low prevalence in the same region; a band of moderate prevalence stretching across central to eastern Africa; and bands ranging from very low to moderate prevalence of exclusive breastfeeding stretching north-south through Ethiopia and Kenya. Stunting, too, depends in part on culturally influenced consumption and feeding practices, and we see a great swath of high rates of stunting in north-central Africa as well as Central Africa stretching to East Africa. Since stunting begins in utero, it also reflects mothers' health. Conditions where women have little autonomy, are deprived of human rights related to health and well-being, and are forced to marry young affect maternal health, and thus affect the health of children and societies generally. These conditions point to the need for systemic changes that would affect stunting as well as other health issues. For investments focused on health, researching cultural practices related to maternal health and infant feeding, implementing culturally appropriate interventions, and then sharing knowledge, tools, and lessons learned with other culturally similar areas could achieve broader positive impact than an investment in health with a limited, country-specific geographic focus. This type of regional investment may be more cost-effective over the long-term.

Other indicators with cross-border clustering of high-high or low-low values may be influenced less by culture than by other factors, such as access to goods and services, or wealth. Antenatal care use is higher in coastal areas, in general. Care seeking is also higher in coastal areas, with some exceptions of high coverage for inland areas in eastern Africa. Coastal areas may be more geographically accessible and wealthier due to tourism and fishing. Wealth, both at the area level and individual level, may increase the accessibility of facility-based services, because the costs of transportation and of time away from productive work are not as prohibitive as in poorer areas.

Care-seeking coverage may show improvements in subsequent surveys due to the adoption of policies for community-case management of childhood illness by many countries in sub-Saharan Africa (Rasanathan et al. 2014). Under this policy, community health workers are trained to diagnose and treat pneumonia, diarrhea, and malaria in communities, thereby greatly reducing geographic barriers to care seeking. Modern contraceptive use, measles vaccination, and DPT3 coverage are generally lower in more remote areas of West and Central Africa, while the band of high-high in East and Southern Africa is likely related to factors other than simply access such as culture or government policies. In some countries community health workers are able to distribute contraceptives at the community level. Vaccination campaigns can provide community-level interventions, although they are more often facility-based. However, as the type of available vaccinations increases (pneumonia, rotavirus, etc.) and delivery mechanisms and cold-chain storage needs evolve, community health workers may also be able to provide more vaccinations at the community level.

Environmental factors have been previously associated with the band of high under-five mortality in the West African Sahel region (Balk et al. 2004). The sporadic areas of low under-five mortality seem to be more coastal geographically, or in the case of the two areas in Southern Africa, bordering areas where there were no data and thus may simply be an artifact of the data more than a true low cluster.

Coverage of skilled birth attendance is difficult to compare between countries due to national variations in the definition. The finding of high coverage of skilled birth attendance in otherwise poorly covered areas such as DRC or Congo is suspect. In Congo this may be due in part to the inclusion of auxiliary midwife, trained birth attendant, and community health worker in the definition of skilled birth attendant.

Geographic areas that have high coverage but are surrounded by areas of low coverage and vice versa are of particular interest for all indicators examined. In particular, for indicators where high values indicate "good" outcomes, high areas of coverage surrounded by low areas indicate the need for further study to understand what environmental, cultural, or political barriers make these areas different from their neighbors. The same is true for low areas of stunting or under-five mortality surrounded by high areas. Qualitative research into the "positive deviance" of those outliers may illuminate factors that could be extended to or replicated in neighboring areas. Low areas of coverage surrounded by high areas also point to the need for further investigation to uncover perhaps untapped resources or structural barriers that separate those residents' coverage status from that of their neighbors. In several cases small but densely populated urban areas are very different from the rest of the mostly rural country—for example in Ethiopia, where Addis Ababa and Dire Dawa have good values while the rest of the country has quite poor values for the majority of indicators studied.

Clearly, a study of this kind at the DHS survey region level misses subtleties within the large geographic regions. As household surveys such as the DHS start to have data available at lower geographic levels (administrative 2, district), which in many countries are also the administrative boundaries often used for funding decisions, this type of analysis could prove useful both within individual countries and across the whole continent. Africa is particularly suited for this type of analysis due to its large size and relative geographic continuity. Another region, for example Asia, would be more difficult or nearly impossible to analyze in the same way due to the large expanse of coastlines, with low spatial contiguity along with many island nations. Some more geographically contained sub-regions in Asia would likely be appropriate for an analysis of this type.

There are several limitations in this study. First, the analysis could be biased by the modifiable areal unit problem. This occurs when the areas used in an analysis are "artificial" in their size and the same data could be aggregated into different-sized units, which would result in a different outcome to the analysis. The varied size of the subnational areas across countries could influence the results toward areas with larger size or areas that aggregate larger-sized population. Second, the analysis outcome may be different if they included areas not included in the present analysis, due to not having recent DHS data available. Areas that are on the outer edge of the areas that are being analyzed have only some of their neighbors included in the analysis and thus it is not known if those excluded neighbors might make that area a hotspot or a coldspot, for example. As more data become available, or if a mixture of other sources of data was used, the geographic coverage of the analysis could be expanded in the future. Finally, limitations remain in the timing of surveys, as the estimate for some indicators can be sensitive to specific shocks (drought, epidemics, etc.) or programmatic interventions (mass coverage campaigns, changes in national policy on skilled birth attendance, etc.). In this study all surveys were within a six-year period, and all neighboring countries have indicator values that were calculated within two or three years of each other. This reduces the influence of shocks or interventions on differences in indicators. Although the politics and intervention approaches of each country differ, we did not seek here to analyze the underlying political or socio-cultural reasons why sub-regional values differ, which would require more intensive ESDA, including some multilevel modeling with spatial regression techniques.

4.1. Future Directions to Equitably Improve Maternal and Child Health

Program implementers and health advocates have deliberately pursued equity in strategic ways (Luna et al. 2014). To respond to growing disparities in many countries, governments of the United States, India, and Ethiopia, in partnership with UNICEF, launched the Child Survival Call to Action, calling on countries around the world to "refocus their health systems on scaling up access to high quality services for populations suffering from a disproportionate burden of disease, especially rural, poor, and marginalized populations" and to implement better mechanisms to monitor progress in the most disadvantaged areas (UNICEF 2012, p.4). GIS is a powerful tool to aid focused monitoring of activities because it reveals geographic variation in coverage (Burgert 2014).

Decentralizing health care funding is one way to prioritize disadvantaged areas. Decentralization empowers local levels to use health resources as they choose, and assumes that targeting and monitoring will take place within a focused geographic area. However, analyses that simultaneously stratify by indicator and urban versus rural residence show that allocation to a region does not necessarily reach the most needy. For example, SBA coverage in the Greater Accra region of Ghana is 73 percent, which seems to indicate that resources should be focused on improving SBA coverage in areas of greater need. However, a closer look through sub-regional analysis indicates that urban SBA coverage in Greater Accra is 86 percent, but rural coverage is only 23 percent (Wirth et al. 2008). To advocate for this type of multifactorial analysis, Wirth, et al. acknowledges that poverty has many dimensions, so analysis of wealth should be complemented by analysis of ethnicity, geography, and education. In addition, particular attention should be paid to people in conflict regions, who may not be represented in surveys (Wirth et al. 2008).

Chopra identified promising strategies to improve coverage of effective interventions, including using community health workers, which requires both increasing their numbers and "task shifting" by enabling them to provide communities with services that are typically provided in health facilities (Luna et al. 2014). Harnessing the power of geospatial analysis to identify hotspots of low coverage and high need can help to determine where community health workers and other health programs can have the most impact and to deploy resources accordingly. To realize this potential of geospatial analysis, Ebener et al. (2015) calls for standardizing geospatial information in the health sector; coordinating support to maternal and newborn health programs to strengthen geospatial analysis capacity; integrating capacity building for geospatial analysis as part of strengthening health information systems; and systematically considering geospatial analysis for implementing and monitoring maternal and newborn programs. Investments in increasing the availability of geographic data through geo-referencing facility registries and providers would also facilitate geospatial analysis from the lowest levels. Since some funding mechanisms are now requesting descriptions of the "geographic dimension" of disease with the location of hotspots of transmission along with maps to visualize disease burden and identify areas of high need (Global Fund 2014), Ebener's (2015) call for investment in geographic information systems and the capacity to use and maintain them is timely and important.

5. Conclusion

It is likely that the MDGs focused on maternal, newborn, and child health will not be universally met, even though these are key priorities for the global health community. Geographic barriers to optimal health include distance to health services as well as climatic, social, and economic characteristics that cluster geographically, leading to a spatial distribution of persistent health inequities. This report used Exploratory Spatial Data Analysis (ESDA) techniques to measure the spatial autocorrelation of nine key maternal and child health indicator values between and among regions in 27 sub-Saharan African countries. This type of geospatial analysis can pinpoint areas of need and facilitate effective investments and program targeting to redress health inequities. We observed patterns of substantial differences among contiguous subareas for different indicators, with some intra-country differences greater than 20 percentage points for all indicators examined. Examples of extreme within-country differences are ANC, SBA, and DPT3 in Ethiopia (more than 70 percentage points); at the other extreme, Malawi has within-country differences for CPR and ANC of less than 7 percentage points. We observed statistically significant variation between countries for SBA, EBF, DPT3, and stunting. This analysis was not designed to identify underlying reasons for differences nor specific interventions to increase coverage, but those are the next logical steps.

This report illustrates a preliminary analysis of the possibility and potential for using these spatial analysis techniques across multiple DHS survey countries. Future studies may also investigate the relationship between indicators (e.g. antenatal care and skilled birth attendance; exclusive breastfeeding and stunting; stunting and female autonomy, etc.) and how the indicator estimate relates to the underlying population at risk or population burden. Additionally, further bivariate LISA or spatial regression analyses incorporating information on environment, wealth, education, population density, or government policies, among others, would deepen the understanding of the interplay between health determinants and geography.

References

Adams, A.M., R. Islam, and T. Ahmed. 2015. “Who Serves the Urban Poor? A Geospatial and Descriptive Analysis of Health Services in Slum Settlements in Dhaka, Bangladesh.” *Health Policy Plan* 30(Suppl 1):i32-i45.

Adedini, S.A., C. Odimegwu, O. Bamiwuye, O. Fadeyibi, and N. De Wet. 2014. “Barriers to Accessing Health Care in Nigeria: Implications for Child Survival.” *Global Health Action* 7:doi:10.3402/gha.v7.23499.

Amin, S.B., A.M. Basu, and R. Stephenson 2002. “Spatial Variation in Contraceptive Use in Bangladesh: Looking Beyond the Borders.” *Demography* 39(2):251-267.

Balk, D., T. Pullum, A. Storeygard, F. Greenwell, and Neuman. 2004. “A Spatial Analysis of Childhood Mortality in West Africa.” *Population, Space and Place* 10(3):175-216.

Banta, D. 2003. *What is the Efficacy/Effectiveness of Antenatal Care and the Financial and Organizational Implications?* Health Evidence Network. Copenhagen: WHO Regional Office for Europe. Available at http://www.euro.who.int/Document/E82996.pdf.

Barros, A.J.D., C. Ronsmans, H. Axelson, E. Loaiza, A.D. Bertoldi, G.V.A. França, J. Bryce, J.T. Boerma, and C.G. Victora. 2012. “Equity in Maternal, Newborn, and Child Health Interventions in Countdown to 2015: A Retrospective Review of Survey Data from 54 Countries.” *The Lancet* 379(9822):1225-1233.

Becher, H., O. Müller, A. Jahn, A. Gbangou, G. Kynast-Wolf, and B. Kouyate. 2004. “Risk Factors of Infant and Child Mortality in Rural Burkina Faso.” *Bulletin of the World Health Organization* 82:265-273.

Bennett, A.E., T. Eisele, J. Keating, and J. Yukich. 2015. *Global Trends in Care Seeking and Access to Diagnosis and Treatment of Childhood Illnesses*. DHS Working Papers. Rockville, MD: ICFI.

Bhutta, Z.A., Z.S. Lassi, G. Pariyo, and L. Huicho. 2010. *Global Experience of Community Health Workers for Delivery of Health-Related Millennium Development Goals: A Systematic Review, Country Case Studies, and Recommendations for Integration into National Health Systems*. Geneva: Global Health Workforce Alliance and WHO.

Bhutta, Z.R., and K.S Reddy. 2012. “Achieving Equity in Global Health: So Near and Yet so Far.” *JAMA* 307(19):2035-2037.

Britton, C.M., F.M. McCormick, M.J. Renfrew, A. Wade, and S.E. King. 2007. “Support for Breastfeeding Mothers.” *Cochrane Database of Systematic Reviews* Issue 1: Art. No. CD001141. doi: 10.1002/14651858.CD001141.pub3.

Bruce, N.P., D. Pope, B. Arana, C. Shiels, C. Romero, R. Klein, and D. Stanistreet. 2014. "Determinants of Care Seeking for Children with Pneumonia and Diarrhea in Guatemala: Implications for Intervention Strategies." *American Journal of Public Health* 104(4):647-657.

Burgert, C. 2014. *Spatial Interpolation with Demographic and Health Survey Data: Key Considerations*. DHS Spatial Analysis Reports. Rockville, MD: ICFI.

Cai, X., W. Tessa, and D.W. Brown. 2012. "Global Trends in Exclusive Breastfeeding." *International Breastfeeding Journal* 7(12):1-5.

Callaghan, W.M. 2014. "Geographic Variation of Reproductive Health Indicators and Outcomes in the United States: Place Matters." *Amerucab Journal of Obstetrics and Gynecology* 211(3):278-284.

Carlough, M., and M. McCall. 2005. "Skilled Birth Attendance: What Does it Mean and How Can it Be Measured? A Clinical Skills Assessment of Maternal and Child Health Workers in Nepal." *International Journal of Gynaecology and Obstetrics* 89(2):200-208.

Carrera, C., A. Azrack, G. Begkoyian, J. Pfaffmann, E. Ribaira, T. O'Connell, P. Doughty, K.M. Aung, L. Prieto, K. Rasanathan, A. Sharkey, M. Chopra, and R. Knippenberg. 2012. "The Comparative Cost-effectiveness of an Equity-focused Approach to Child Survival, Health, and Nutrition: A Modelling Approach." *The Lancet* 380(9850):1341-1351.

Chin, B., L. Montana, and X. Basagana. 2011. "Spatial Modeling of Geographic Inequalities in Infant and Child Mortality Across Nepal." *Health Place* 17(4):929-936.

Chirwa, T.F., J.N. Mantempa, F.L. Kinziunga, J.D. Kandala, and N. Kandala. 2014. "An Exploratory Spatial Analysis of Geographical Inequalities of Birth Intervals Among Young Women in the Democratic Republic of Congo (DRC): A Cross-sectional Study." *BMC Pregnancy and Childbirth* 14 (271):doi:10.1186/1471-2393-14-271.

Chopra, M., A. Sharkey, N. Dalmiya, D. Anthony, and N. Binkin. 2012. "Strategies to Improve Health Coverage and Narrow the Equity Gap in Child Survival, Health, and Nutrition." *The Lancet* 380(9850):1331-1340.

Das, J.K., Z.S. Lassi, R.A. Salam, and Z.A. Bhutta. 2013. "Effect of Community Based Interventions on Childhood Diarrhea and Pneumonia: Uptake of Treatement Modalities and Impact on Mortality." *BMC Public Health* 13(Suppl 3):S29.

Dewey, K.G., and K. Begum. 2011. "Long-term Consequences of Stunting in Early Life." *Maternal and Child Nutrition* 7(Suppl 3):5-18.

Ebener, S., M. Guerra-Arias, J. Campbell, A.J. Tatem, A.C. Moran, F. Amoako Johnson, H. Fogstad, K. Stenberg, S. Neal, P. Bailey, R. Porter, and Z. Matthews. 2015. "The Geography of Maternal and Newborn Health: The State of the Art." *International Journal of Health Geographics* 14(19): doi 10.1186/s12942-015-0012-x.

Feikin, D.R., L.M. Nguyen, K. Adazu, M. Ombok, A. Audi, L. Slutsker, and K.A. Lindblade. 2009. "The Impact of Distance of Residence from a Peripheral Health Faciltiy on Pediatric Health Utilisation in Rural Western Kenya." *Tropical Medicine and International Health* 14(1):54-61.

GeoDa. 2015a. *Glossary of Key Terms*. Arizona State University GeoDa Center for Geospatial Analysis and Computation. Available at https://geodacenter.asu.edu/node/390.

GeoDa. 2015b. *Local Spatial Autocorrelation*. Arizona State University GeoDa Center for Geospatial Analysis and Computation. Available at https://geodacenter.asu.edu/node/393.

Gething, P.W., V.C. Kirui, V.A. Alegana, E.A. Okiro, A.M. Noor, and R.W. Snow. 2010. "Estimating the Number of Paediatric Fevers Associated with Malaria Infection Presenting to Africa's Public Health Sector in 2007." *PloS Medicine* 7(7):doi:10.1371/journal.pmed.1000301.

Gitimu, A.H., C. Herr, H. Oruko, E. Karijo, R. Gichuki, P. Ofware, A. Lakati, and J. Nyagero. 2015. "Determinants of Use of Skilled Birth Attendant at Delivery in Makueni, Kenya: A Cross Sectional Study." *BMC Pregnancy and Childbirth* 15(9):doi:10.1186/s12884-015-0442-2.

Global Fund. 2014. *Standard Concept Note Instructions: Investing for Impact Against HIV Tuberculosis and Malaria.* The Global Fund to Fight AIDS, Tuberculosis and Malaria. Available at www.theglobalfund.org

Gwatkin, D.R. 2002. *Who Would Gain Most from Efforts to Reach the Millennium Development Goals for Health?* HNP Discussion Paper. Washington, DC: The World Bank.

Gwatkin, D.R. 2007a. "10 Best Resources on... Health Equity." *Health Policy Plan* 22(5):348-51.

Gwatkin, D.R., S. Rustein, K. Johnson, E. Suliman, A. Wagstaff, and A. Amouzou. 2007b. *Socio-economic Differences in Health, Nutrition, and Population within Developing Countries*. Washington, D.C.: The World Bank.

Hjortsberg, C. 2003. "Why Do the Sick Not Utilise Health Care? The Case of Zambia." *Health Economics* 12(9):755-770.

ICF International. 2008-2014a. *Demographic and Health Surveys (Various) [Datasets]*. Rockville, Maryland: ICF International [Distributor].

ICF International. 2008-2014b. *Spatial Data Repository, The DHS Program (Various) [Datasets]*. Rockville, Maryland: ICF International [Distributor]. Available from spatialdata.dhsprogram.com. [Accessed 8 March 2015]

Johnson, F.A., F. Frempong-Ainguah, Z. Matthews, A.L.P. Harfoot, P. Nyarko, A. Baschieri, P.W. Gething, J. Falkingham, and P.M. Atkinson. 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):doi:10.1371/journal.pone.0120556

Kadobera, D., B. Sartorius, H. Masanja, A. Mathew, and P. Waiswa. 2012. "The Effect of Distance to Formal Health Facility on Childhood Mortality in Rural Tanzania, 2005-2007." *Global Health Action* 5:doi:10.3402/gha.v5i0.19099.

Kandala, N.B., T.P. Madungu, J.B. Emina, K.P. Nzita, and F.P. Cappuccio. 2011. "Malnutrition Among Children Under the Age of Five in the Democratic Republic of Congo (DRC): Does Geographic Location Matter?" *BMC Public Health* 11(261):doi:10.1186/1471-2458-11-261.

Kassile, T.L., R. Lokina, P. Mujinja, and B. Mmbando. 2014. "Determinants of Delay in Care Seeking Among Children Under Five With Fever in Dodoma Region, Central Tanzania: A Cross-Sectional Study." *Malaria Journal* 13(348):1-10.

Kazembe, L.N., I. Kleinschmidt, and B.L. Sharp. 2006. "Patterns of Malaria-related Hospital Admissions and Mortality Among Malawian Children: An Example of Spatial Modelling of Hospital Register Data." *Malaria Journal* 5(93):doi:10.1186/1475-2875-5-93.

Kiwanuka, S.N., E.K. Ekirapa, S. Peterson, O. Okui, M.H. Rahman, D. Peters, and G.W. Pariyo. 2008. "Access to and Utilisation of Health Services for the Poor in Uganda: A Systematic Review of Available Evidence." *Transactions of the Royal Society of Tropical Medicine and Hygiene* 102(11):1067-1074.

Lim, S.S., V. Theo, A.D. Flaxman, G. Danaei, K. Shibuya, H. Adair-Rohani, et al. 2012. "A Comparative Risk Assessment of Burden of Disease and Injury Attributable to 67 Risk Factors and Risk Factor Clusters in 21 Regions, 1990-2010: A Systematic Analysis for the Global Burden of Disease Study 2010." *Lancet* 380(9859):2224-2260.

Luna, J.W., T. Monga, and L. Morgan. 2014. *Equity Matters - Lessons from MCHIP and CSHGP in Measuring and Improving Equity*. Maternal Child Health Integrated Program.

Mayhew, M., P. Hansen, D. Peters, A. Edward, L. Singh, V. Dwivedi, A. Mashkoor, and G. Burnham. 2008. "Determinants of Skilled Birth Attendant Utilization in Afghanistan: A Cross-Sectional Study." *American Journal of Public Health* 98(10):1849-1856.

Mishra, V. and R.D. Retherford. 2006. *The Effect of Antenatal Care on Professional Assistance at Delivery in Rural India*. DHS Working Papers. Calverton, MD: ORC Macro.

Noor, A.M., D. Zurovac, S.I. Hay, S.A. Ochola, and R.W. Snow. 2003. "Defining Equity in Physical Access to Clinical Services Using Geographical Information Systems as Part of Malaria Planning and Monitoring in Kenya." *Tropical Medicine and International Health* 8(10):917-933.

Nykiforuk, C.I., and L.M. Flaman. 2011. "Geographic Information Systems (GIS) for Health Promotion and Public Health: A Review." *Health Promotion and Practice* 12(1):63-73.

Odaga, J. 2004. "Health Inequality in Uganda - the Role of Financial and Non-financial Barriers." *Health Policy and Development* 2(3):192-208.

Peters, D.H., A. Garg, G. Bloom, D.G. Walker, W.R. Brieger, and M.H. Rahman. 2008. "Poverty and Access to Health Care in Developing Countries." *Annals of the New York Academy of Sciences* 1136:161-71.

Prata, N., F. Vahidnia, M. Potts, and I. Dries-Daffner. 2005. "Revisiting Community-based Distribution Programs: Are They Still Needed?" *Contraception* 72(6):402-407.

Prendergast, A.J., and J.H. Humphrey. 2014. "The Stunting Syndrome in Developing Countries." *Paediatrics and International Child Health* 34(4):250-265.

Pullan, R.L., M.C. Freeman, P.W. Gething, and S.J. Brooker. 2014. "Geographical Inequalities in Use of Improved Drinking Water Supply and Sanitation Across sub-Saharan Africa: Mapping and Spatial Analysis of Cross-sectional Survey Data." *PLoS Medicine* 11(4):e1001626.

Qayum, A., R. Arya, P. Kumar, and A.M. Lynn. 2015. "Socio-economic, Epidemiological and Geographic Features Based on GIS-integrated Mapping to Identify Malarial Hotspots." *Malaria Journal* 14(192):doi:10.1186/s12936-015-0685-4.

Rasanathan, K., M. Muniz, S. Bakshi, M. Kumar, A. Solano, W. Kariuki, A. George, M. Sylla, R. Nefdt, M. Young, and T. Diaz. 2014. "Community Case Management of Childhood Illness in sub-Saharan Africa - Findings From a Cross-sectional Survey on Policy and Implementation." *Journal of Global Health* 4(2):doi:10.7189/jogh.04.020401.

Roberts, T.J., E. Carnahan, and E. Gakidou. 2013. "Can Breastfeeding Promote Child Health Equity? A Comprehensive Analysis of Breastfeeding Patterns Across the Developing World and What We Can Learn From Them." *BMC Medicine* 11(254):doi:10.1186/1741-7015-11-254.

Rosero-Bixby, L. 2004. "Spatial Access to Health Care in Costa Rica and its Equity: A GIS-Based Study." *Social Science & Medicine* 58(7):1271-1284.

Rutstein, S.O. 2008. *Further Evidence of the Effects of Preceding Birth Intervals on Neonatal, Infant, and Under-five-years Mortality and Nutritional Status in Developing Countries: Evidence From the Demographic and Health Surveys*. DHS Working Papers Series. ICF Macro.

Schoeps, A., S. Gabrysch, L. Niamba, A. Sie, and H. Becher. 2011. "The Effect of Distance to Health-care Facilities on Childhood Mortality in Rual Burkina Faso." *American Journal of Epidemiology* 173(5):492-498.

Singh, S., G. Sedgh, and R. Hussain. 2010. "Unintended Pregnancy: Worldwide Levels, Trends, and Outcomes." *Studies in Family Planning* 41(4):241-250.

Smith, K.E., and M. Ezzati. 2005. "How Environmental Health Risks Change with Development." *Annual Review of Environmental Resources* 30:291-333.

Tanahashi, T. 1978. "Health Service Coverage and its Evaluation." *Bulletin of the World Health Organization* 56(2):295-304.

Tugwell, P., V. Robinson, and E. Morris. 2007. *Mapping Global Health Inequalities: Challenges and Opportunities*. Mapping Global Inequalities. Center for Global, International and Regional Studies. UC Santa Cruz: Available at http://escholarship.org/uc/item/2f11d67c

UNICEF. 2012*. Chid Survival Call to Action: Ending Preventable Child Deaths.* UNICEF. Available at http://5thbday.usaid.gov/pages/responsesub/roadmap.pdf

UNICEF. 2014. *Levels and Trends in Child Mortality*. UNICEF.

UNICEF. 2015. *Progress for Children: Beyond Averages: Learning from the MDGs*. New York, USA: UNICEF.

United Nations. 2000. *United Nations Millennium Declaration*.

United Nations. 2014. *The Millennium Development Goals Report*. United Nations.

USAID. 2013. *Global Health Strategic Framework*. Available at http://www.usaid.gov/sites/default/files/documents/1864/gh_framework2012.pdf.

Vandelaer, J., J. Bilous, and D. Nshimirimana. 2008. "Reaching Every District (Red) Approach: A Way to Improve Immunization Performance." *Bulletin of the World Health Organization* 86(3):161-240.

Victora, C.G., A. Wagstaff, J.A. Schellenberg, D. Gwatkin, M. Claeson, and J.-P. Habicht. 2003. "Applying an Equity Lens to Child Health and Mortality: More of the Same is Not Enough." *The Lancet* 362(9379):233-241.

Victora, C.G., L. Huicho, J.J. Amaral, J. Armstrong-Schellenberg, F. Manzi, E. Mason, and R. Scherpbier. 2006. "Are Health Interventions Implemented Where They Are Most needed? District Uptake of the Integrated Management of Childhood Illness Strategy in Brazil, Peru and the United Republic of Tanzania." *Bulletin of the World Health Organization* 84:792-801.

Wamani, H., A.N. Astrom, S. Peterson, J.K. Tumwine, and T. Tylleskar. 2007. "Boys Are More Stunted Than Girls in sub-Saharan Africa: A Meta-Analysis of 16 Demographic and Health Surveys." *BMC Pediatrics* 7(17):doi:10.1186/1471-2431-7-17 .

WHO. 2005. *Global Immunization Vision and Strategy*. Available at http://www.who.int/immunization/givs/en/

WHO. 2011a. *Exclusive Breastfeeding for Six Months Best for Babies Everywhere*. World Health Organization. Geneva

WHO. 2011b. *Keeping Promises, Measuring Results*. World Health Organization. Geneva.

WHO. 2013. *DPT3 Data by WHO Region*. Edited by Global Health Observatory Data Repository.

WHO. 2014. *Trends in Maternal Mortality: 1990 to 2013*. World Health Organization. Geneva.

WHO. 2015a. *Equity*. World Health Organization. Available at http://www.who.int/healthsystems/topics/equity/en/.

WHO. 2015b. *Measles Fact sheet*. Available at http://www.who.int/mediacentre/factsheets/fs286/en/.

WHO. 2015c. *State of Inequality: Reproductive, Maternal, Newborn and Child Health*. WHO.

WHO and UNICEF. 2012. *Countdown to 2015: The 2012 report*. Available at http://www.countdown2015mnch.org/reports-and-articles/previous-reports/2012-report.

WHO Regional Office for Africa. 2015. *Measles-containing Vaccine (MCV) Immunization Coverage Among 1-year-olds*. Available at http://www.aho.afro.who.int/en/data-statistics/measles-containing-vaccine-mcv-immunization-coverage-among-1-year-olds.

Wirth, M.E., D. Balk, E. Delamonica, A. Storeygard, E. Sacks, and A. Minujin. 2006. "Setting the Stage for Equity-sensitive Monitoring of the Maternal and Child Health Millennium Development Goals." *Bulletin of the World Health Organization* 84:519-528.

Wirth, M., E. Sacks, E. Delamonica, A. Storeygard, A. Minujin, and D. Balk. 2008. "Delivering on the MDGs?: Equity and Maternal Health in Ghana, Ethiopia and Kenya." *East African Journal Public Health* 5(3):133-141.

Appendix A

Table A.1. Skilled birth attendant (SBA) definitions by country

Country	Definition
Benin	doctor, nurse, midwife, auxiliary nurse, assistant midwife.
Burkina Faso	doctor, nurse, midwife, matron or professional birth attendant, auxiliary professional birth attendant.
Burundi	doctor, nurse, midwife
Cameroon	doctor, nurse, midwife, auxiliary midwife
Congo	doctor, nurse, midwife, auxiliary midwife, trained birth attendant, community health worker
Cote d'Ivoire	doctor, nurse, midwife, auxiliary midwife
Democratic Republic of Congo	doctor, nurse, birth attendant
Ethiopia	doctor, nurse, midwife
Gabon	doctor, nurse, midwife, auxiliary nurse, matron
Gambia	doctor, nurse, midwife
Ghana	doctor, nurse, midwife, auxiliary midwife, community health officer
Guinea	doctor, nurse, midwife, auxiliary nurse, midwife
Kenya	doctor, nurse, midwife
Liberia	doctor, nurse, midwife, physician's assistant
Malawi	doctor, clinical officer, nurse, midwife
Mali	doctor, nurse, midwife, matron, other health professional
Mozambique	doctor, nurse, midwife, auxiliary nurse/midwife
Niger	doctor, nurse, midwife
Nigeria	doctor, nurse, midwife, auxiliary nurse/midwife
Rwanda	doctor, nurse, medical assistant, midwife
Senegal	doctor, nurse, midwife
Sierra Leone	doctor, nurse, midwife, MCH Aide
Tanzania	doctor/AMO, clinical officer, assistant clinical officer, nurse/midwife, MCH aide
Togo	doctor, medical assistant, nurse, midwife, auxiliary midwife
Uganda	doctor, nurse/midwife, medical assistant/clinical officer
Zambia	doctor, clinical officer, nurse/midwife
Zimbabwe	doctor, nurse-midwife, nurse

Appendix B

Table B.1. Country estimate and 95% confidence interval for key indictors

	CPR, any modern method	ANC 4+	SBA	EBF	Measles vaccination	DTP3 vaccine coverage	Care seeking behavior	Stunting prevalence	Under-five mortality rate
Benin DHS 2011-2012	9.0 [8.3,9.6]	58.2 [56.6,59.8]	85.4 [83.6,87.0]	33.9 [31.0,37.0]	70.0 [67.6,72.4]	62.2 [59.5,64.9]	55.3 [52.3,58.2]	44.6 [43.2,46.1]	70.1 [65,75]
Burkina Faso DHS 2010	14.3 [13.4,15.2]	33.7 [32.2,35.2]	72.9 [70.4,75.2]	24.8 [22.1,27.8]	87.3 [85.6,88.9]	89.5 [87.7,91.1]	60.8 [58.5,63.0]	34.6 [33.1,36.1]	128.4 [122,135]
Burundi DHS 2010	11.0 [10.2,11.9]	33.4 [31.5,35.4]	63.1 [60.8,65.4]	69.4 [64.6,73.8]	94.3 [92.8,95.5]	95.4 [93.9,96.5]	57.1 [54.9,59.3]	57.7 [55.7,59.7]	96.1 [88,104]
Cameroon DHS 2011	16.1 [15.3,17.1]	62.2 [60.2,64.2]	67.5 [65.1,69.8]	20.2 [17.6,23.1]	70.6 [67.8,73.2]	68.4 [65.2,71.3]	55.3 [52.7,58.0]	32.5 [31.0,34.0]	121.8 [114,129]
Congo DHS 2011-2012	22.3 [21.0,23.7]	78.9 [77.0,80.7]	94.6 [93.6,95.5]	20.5 [17.0,24.5]	74.9 [71.1,78.4]	55.9 [52.3,59.4]	59.0 [55.8,62.1]	24.4 [22.4,26.4]	67.8 [59,76]
Cote d'Ivoire DHS 2011-2012	13.9 [12.8,15.1]	44.2 [41.6,46.7]	62.5 [59.3,65.7]	12.2 [9.6,15.3]	64.5 [59.8,68.9]	63.8 [59.6,67.8]	60.8 [57.7,63.9]	29.8 [27.7,31.9]	108.0 [99,117]
DRC DHS 2013-2014	8.1 [7.3,9.1]	48.0 [45.8,50.2]	81.2 [78.7,83.5]	47.8 [44.3,51.3]	71.6 [69.1,74.0]	60.5 [57.2,63.8]	55.9 [52.9,58.8]	42.7 [40.9,44.5]	104.2 [98,110]
Ethiopia DHS 2011	18.7 [17.3,20.2]	19.1 [17.3,21.0]	11.8 [10.3,13.4]	52.0 [47.3,56.7]	55.7 [51.5,59.8]	36.5 [32.8,40.3]	28.5 [25.6,31.6]	44.4 [42.7,46.2]	88.0 [80,96]
Gabon DHS 2012	24.0 [22.0,26.0]	77.6 [75.5,79.6]	92.4 [91.0,93.6]	6.0 [3.7,9.7]	74.3 [70.6,77.8]	22.2 [18.3,26.6]	61.3 [57.4,65.1]	16.5 [14.3,18.9]	64.6 [54,75]
Gambia DHS 2013	6.5 [5.7,7.5]	77.6 [75.8,79.4]	59.2 [56.0,62.3]	46.8 [41.8,51.8]	87.8 [83.7,91.1]	87.7 [85.2,89.8]	66.3 [63.1,69.4]	24.5 [22.4,26.7]	53.6 [46,61]
Ghana DHS 2008	13.5 [12.4,14.7]	78.2 [75.7,80.4]	76.7 [74.0,79.2]	63.1 [57.2,68.6]	90.2 [87.0,92.6]	88.8 [85.3,91.5]	63.9 [59.7,67.9]	28.0 [25.8,30.2]	80.0 [69,91]
Guinea DHS 2012	7.0 [6.1,8.0]	56.6 [53.7,59.4]	43.4 [39.8,47.1]	20.6 [16.5,25.4]	61.8 [57.7,65.6]	49.8 [45.4,54.1]	52.8 [48.8,56.7]	31.2 [29.2,33.2]	122.9 [114,132]
Kenya DHS 2008-2009	28.0 [26.5,29.5]	47.1 [44.8,49.5]	48.0 [44.5,51.5]	31.9 [26.7,37.7]	85.0 [81.8,87.7]	86.4 [83.2,89.1]	59.2 [55.6,62.6]	35.3 [33.2,37.4]	73.6 [64,83]
Liberia DHS 2013	20.5 [18.6,22.6]	78.1 [76.1,80.0]	65.3 [62.2,68.3]	55.2 [49.6,60.7]	74.2 [70.6,77.5]	71.4 [67.5,75.1]	73.0 [70.4,75.5]	31.6 [29.3,34.0]	93.8 [84,103]
Malawi DHS 2010	32.6 [31.7,33.6]	45.5 [44.2,46.7]	74.1 [72.5,75.6]	71.5 [68.1,74.6]	93.0 [91.8,94.0]	93.0 [91.7,94.1]	70.2 [68.7,71.7]	47.1 [45.2,49.0]	112.1 [106,118]
Mali DHS 2012-2013	9.6 [8.7,10.6]	41.2 [38.8,43.7]	61.3 [58.1,64.4]	34.2 [30.5,38.1]	71.7 [68.7,74.5]	63.1 [59.8,66.2]	49.6 [46.0,53.2]	38.3 [36.3,40.4]	95.1 [88,102]
Mozambique DHS 2011	12.1 [11.2,13.0]	50.6 [48.7,52.6]	60.1 [57.3,62.8]	41.1 [37.1,45.3]	81.5 [78.8,83.8]	76.2 [73.2,78.9]	59.7 [56.5,62.8]	42.6 [41.0,44.2]	96.9 [90,104]
Niger DHS 2012	11.0 [10.0,12.1]	32.8 [30.9,34.7]	33.0 [30.5,35.6]	23.4 [19.9,27.2]	68.7 [65.8,71.4]	68.1 [64.5,71.4]	60.6 [57.4,63.7]	43.9 [41.9,45.9]	127.2 [120,134]
Nigeria DHS 2013	11.1 [10.5,11.9]	51.1 [49.1,53.1]	40.2 [38.2,42.1]	17.4 [15.6,19.4]	42.1 [39.8,44.4]	38.2 [36.0,40.5]	73.1 [71.2,74.8]	36.8 [35.6,38.0]	128.0 [123,133]
Rwanda DHS 2010	25.2 [24.4,26.1]	35.4 [33.9,37.0]	72.2 [70.6,73.8]	84.9 [81.9,87.5]	95.0 [93.7,96.1]	96.8 [95.6,97.7]	47.4 [45.0,49.9]	44.2 [42.5,46.0]	75.7 [70,81]
Senegal DHS 2010-2011	8.9 [8.2,9.6]	50.0 [48.1,51.9]	86.6 [84.7,88.2]	38.9 [35.6,42.3]	82.1 [79.8,84.2]	82.6 [80.0,84.8]	47.9 [45.5,50.3]	26.5 [24.5,28.7]	71.6 [66,77]
Sierra Leone DHS 2013	20.9 [19.4,22.5]	76.0 [73.7,78.2]	74.1 [71.9,76.2]	32.1 [28.1,36.3]	78.6 [75.8,81.1]	77.9 [75.0,80.5]	72.6 [69.7,75.3]	37.9 [35.9,39.8]	155.8 [148,164]
Tanzania DHS 2010	23.6 [22.3,25.0]	42.8 [40.8,44.8]	54.5 [51.6,57.4]	52.6 [48.5,56.7]	84.5 [81.8,86.9]	88.0 [85.2,90.4]	76.4 [73.9,78.8]	42.0 [40.4,43.6]	81.1 [74,88]
Togo DHS 1998	16.7 [15.6,17.9]	57.2 [55.0,59.3]	61.7 [58.4,64.8]	58.3 [53.5,63.0]	74.3 [70.4,77.7]	82.8 [79.4,85.8]	55.1 [50.4,59.7]	27.5 [25.7,29.4]	88.3 [81,96]
Uganda DHS 2011	20.7 [19.5,21.9]	47.6 [45.5,49.7]	60.6 [57.8,63.3]	62.4 [58.4,66.3]	75.8 [72.7,78.6]	71.5 [68.1,74.6]	78.1 [76.1,80.0]	33.4 [30.9,35.9]	90.0 [82,98]
Zambia DHS 2013-2014	32.5 [31.4,33.5]	55.5 [54.0,57.0]	68.6 [66.9,70.3]	72.5 [69.5,75.4]	84.9 [82.9,86.7]	85.8 [83.8,87.7]	70.5 [68.6,72.4]	40.1 [38.9,41.3]	74.6 [69,80]
Zimbabwe DHS 2010-2011	40.5 [39.2,41.8]	64.8 [62.7,66.8]	67.4 [64.6,70.0]	31.6 [27.6,35.8]	79.1 [75.8,82.1]	72.9 [68.9,76.6]	40.4 [37.2,43.6]	32.0 [30.6,33.4]	84.1 [74,94]