Spatio-temporal child and maternal mortality patterns and associations with health interventions and health systems performance in sub-Saharan Africa

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A la mémoire de mon très cher Papa, ***MILLOGO Dié Abdoul Malick***

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List of abbreviations

ACT	**Artemisinin based-combination therapy**
ANC	Antenatal care
ARC	Annual rate of change
ARR	Annual rate of reduction
BCI	Bayesian credible interval
CAR	Conditionally autoregressive
CHERG	Child Health epidemiology reference group
CRSN	Centre de recherche en santé de Nouna
CRVS	Civil registration and vital event
CSPS	Centre de santé et de promotion sociale
DHS	Demographic and health survey
EPI	Expanded program of immunization
EVI	Enhanced vegetation index
FAOC-G	Global first axis ordering consistency
FBH	Full birth history
FEWS	Famine early warning system
GAVI	Global alliance for vaccines and immunization
GDP	Gross domestic product
GNI	Gross national income
HDI	Human development index
HF	Health facility
HMIS	Health management and information system
HRR	Hazard rate ratio
ICD	International classification of diseases
ICPD	International conference on population and development
IMCI	Integrated management of child illness
IMR	Infant mortality rate
IPTg	Intermittent treatment of malaria in pregnancy
IRSP	Institut régional de santé publique
ITNs	Insecticide-treated nets
LICs	Low-income countries
LLINs	Long lasting Insecticide-treated nets
LMICs	Low-and middle-income countries
LST	Land surface temperature
LTR	Lifetime risk of maternal death
LTR	Life time risk
MCA	Multiple correspondence analysis
MCMC	Markov chain Monte Carlo
MDGs	Millennium development goals
MICS	Multiple indicator cluster survey
MMR	Maternal mortality rate
MMrate	Maternal mortality rate
MNCH	Maternal, new-born and child health
MODIS	Moderate resolution imaging spectroradiometer
MoH	Ministry of Heath
NDVI	Normalized difference vegetation index
PCA	Principal component analysis
PEPFAR	President’s emergency plan for AIDS relief
PMDF	Proportion of maternal deaths among female deaths
PMI	President’s malaria initiative

PMNCH	Partnership for maternal, new-born and child Health
PNUD	Programme des Nations Unies pour le développement
R4D	Research for development
RAMOS	Reproductive age mortality studies
RDT	Rapid diagnostic test
SBH	Summary birth history
SDGs	Sustainable development goals
SEDAC	Socioeconomic data and applications center
SNSF	Swiss National Science Foundation
SPA	Service provision assessment
U5MR	Under-5 mortality rate
UN	United Nations
UNICEF	United Nations Children's Fund
WB	World Bank
WHO	World Health Organization

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Summary

Background:

In 2000, the international community adopted eight Millennium Development Goals (MDGs). Three were devoted to health (reducing child mortality; improving maternal health; and combating HIV/AIDS, malaria, and other diseases). The MDGs facilitated the mobilisation of funds, implementation and assessment of cost-effective health interventions to reverse the high burden of diseases, particularly in low-and middle-income countries (LMICs). Indeed, under-5 and maternal mortality rates were unacceptably high, the pandemic of HIV/AIDS in full blow and the prevalence and incidence of malaria and other infectious diseases was rampant. The increase of financial and technical support in sub-Saharan Africa led to the scaling up of maternal and child health interventions. Furthermore, technical support enabled synergised efforts, regular monitoring of the progress and impact assessment. The "Countdown to 2015" initiative was set up to track the progress towards MDG 4 (reduce by two-thirds, between 1990 and 2015, the under-five mortality rate (U5MR) and MDG 5 (reduce by three-quarters, between 1990 and 2015, the maternal mortality ratio (MMR)). A set of 20 priority health interventions targeting life stages (from pregnancy to childhood) was promoted in several high burdened low-and middle-income countries to achieve the MDGs 4 and 5 by 2015. The fundament of these selected set of health interventions was the concept of the "continuum of care" which integrates the life cycle and place of provision of health care. At the end of 2015, the coverage of maternal and child health interventions such as skilled birth attendance, antenatal care visit, family planning, post-natal care, exclusive breastfeeding, micronutrients, supplementation, immunization, use of insecticide-treated nets (ITNs) had increased significantly. Consequently, U5MR and MMR declined substantially. However, most sub-Saharan Africa countries did not achieve MDG 4 and MDG 5. Several weaknesses of their health systems hindered the optimal implementation of the cost effective-interventions. Furthermore, a lack of reliable data prevent efficient tracking of the progress.

In LMICs, U5MR and MMR are most often derived from household surveys conducted every 3 to 5 years. Data from health services are not as reliable because they are based on attendances of health facilities and exclude events occurring in the community. Data from demographic and health surveillance systems (DHSS) are reliable but they only cover the HDSS area. Besides, most data analysis are limited to national averages ignoring local heterogeneities.

Like most sub-Saharan countries, the scaling up of the priority health interventions, health system reforms (removal of user fees, subsidization, strengthening of infrastructure and equipment) improvements of access to water, sanitation and education significantly improved health indicators during the MDGs era in Burkina Faso. However, the country failed to achieve MDGs 4 and 5.

In 2015, the international community set up new global objectives namely the Sustainable Development Goals (SDGs). The ambitious SDGs 3.1 and 3.2 related to mother and under-5 aimed at reducing the global maternal mortality ratio to less than 70 per 100,000 live births and the under-5 mortality rate to at least as low as 25 per 1,000 live births by 2030, respectively. Taking advantages of lessons learned

from the MDG era, there is a need to increase the pace of annual reduction in U5MR and MMR mortality rates to achieve child and women related SDGs by 2030. As mortality rates are reducing and clustering, the subnational scale estimates become most important to optimize the health intervention's impact.
To this end, local factors driving mortalities such as climatic and environmental factors, economic, educational individual as well as community and family level risks should be taken into account. Furthermore, health system performance and health interventions coverages also influence the distribution of mortality rate within the country and their incorporation in the statistical analysis could benefit decision-making.

Goal and objectives:
The U5MR and MMR are extremely high in Burkina Faso. We aimed to contribute to accelerating their reduction by advanced statistical analysis providing evidence for decision-making. The overreaching goal was to assess the spatio-temporal mortality patterns and associations with health system performance and interventions in Burkina Faso. The specific objectives were (1) to assess the spatial distribution of child mortality and its associations with child, maternal and household health interventions in Burkina Faso; (2) to assess the spatial distribution of child mortality and its associations with child main causes of mortality; (3) to assess the association between malaria-related health service readiness and malaria mortality in under-5 years old in Burkina Faso; (4) to assess temporal changes in the association of malaria-related health service readiness and malaria mortality in under-5 years old between 2012 and 2014 in; and (5) assess the effect of maternal, socio-economic, education and health system factors on maternal mortality across sub-Saharan Africa.

Methods: In chapter 2, we fit Bayesian geostatistical Weibull proportional hazards survival models with spatially varying coefficients. Sixteen maternal, child and household health interventions were assessed to quantify their effect on under-5 survival at the national as well at the subnational scale (administrative regions). In chapter 3, we applied the same method to assess the associations between under-5 mortality and childhood diseases. The analyses were adjusted for health interventions, climatic and environmental confounders. In both chapters, we assumed spatially structured covariate effects at the regional level. That is, the effects of health interventions or diseases are more alike in regions close to each other than those far away. Conditionally autoregressive (CAR) models modeled the spatial structure of the effects. In chapter 4 and chapter 5, we analyzed nationally representative health facility survey to assess the readiness of health facilities to perform malaria services. Specifically, in Chapter 4, we identified firstly from malaria and general service items of the service availability and readiness assessment (SARA) survey of 2014, the most important tracer items related to malaria deaths. The items are binary with the presence of the item corresponding to "1" and "0" if the item is absent. We fit Bayesian geostatistical variable selection using stochastic search and adopting a spike and slab prior distributions for the regression coefficients. The variables selection' were applied to two separated groups of health facilities namely peripheral health centres (low level) and medical centres (high level). Multiple correspondence

analysis (MCA) was applied on the selected items of each level. The creation of the composite readiness score followed the approach proposed by Asselin to create a composite poverty index. The methodology ensures the monotone increasing or decreasing condition of the score for all indicators. The number of the factorial axes to be included is determined when a factorial axis has been selected for each indicator. The factorial axes with higher discrimination measure are those that are selected.

In Chapter 5, we combined the data of the SARA surveys of 2012 and 2014. We, again grouped the health facilities into 2 levels and followed the process of Chapter 4 to create the composite readiness score.

In both Chapters 4 and 5, we split the readiness score into 3 categorical ordered levels as readiness index. A geostatistical negative binomial model was fitted to assess the effect of the facility readiness index on malaria mortality adjusted for facility characteristics (type of health facility location and administrative status).

Finally, in chapter 6 we fit a negative binomial model to assess the association of maternal mortality rate with the change in the coverage of health intervention, socio-economic covariates, health financing and health human resources indicators within two rounds of demographic and health survey (DHS). We linked the mean count of maternal death and the covariates with the number of exposure years to death as offset via a log-linear regression equation.

Results: The results of chapter 2 showed uneven spatial distribution of the associations between U5MR and health interventions. At the national level, DPT3, immunization, and baby post-natal check within 24 hours after birth had the most important effect on U5MR (hazard ratio (HR)=0.89, 95% Bayesian credible interval (BCI): 0.86-0·98 and HR=0.89, 95% BCI: 0·86-0·92, respectively). At the subnational level, the most effective interventions were skilled birth attendance, and improved drinking water, followed by baby post-natal check within 24 hours after birth, vitamin A supplementation, antenatal care visit, and all-antigens immunization (including BCG, Polio3, DPT3, and measles immunization). Centre-Est, Sahel, and Sud-Ouest were the regions with the largest number of effective interventions. There was no intervention with a significant effect on child survival in the region of Hauts Bassins.

Concerning chapter 3, malaria positive parasitemia stands as the predominant childhood condition that affects the survival of under-5 in 6 regions out of 13. It was followed by low birth weight (4 regions) and severe anemia (3 regions). The regions of Centre and Centre-Est had the lowest under-five mortality rates and there was no association with none of the selected childhood diseases.

The results of chapter 4 and 5 showed that the composite readiness index captures more variability in the dataset than the first component. That is, in chapter 4, the composite score explained 30% of variability compared to 14% when used the first axis of MCA for medical centres. For peripheral health centres, the composite score explained 53% whereas the first axis explained 18%. Peripheral health centres with the higher readiness score were associated with a 59% of reduction of malaria mortality compared to the lowest level of readiness.

In Chapter 5, the readiness of malaria service increase from 2012 to 2014 for both health facilities levels. Peripheral health centres with higher readiness index were associated with a 52% of reduction of malaria mortality compared to the lowest level. For medical centres, the middle and highest level of readiness index were associated with 28 and 38% of reduction of mortality rate compared to the lowest readiness index group.

In chapter 6, our results revealed that the temporal trend of the decreasing of the MMR was associated with the increase of the coverage of skilled birth attendance, family planning and female education rate in 24 sub-Saharan countries.

Conclusion: The crucial implication of our results from Chapters 2 and 3, is the need of shifting from the nationally and uniformly allocation of resources to targeted subnational allocation. Indeed, our results show the administrative regions that lack the effectiveness of health interventions and regions with a high burden of diseases. Furthermore, we stressed the most important health interventions to be scaled up.

In Chapters 4 and 5, the clear effect of malaria related-service readiness to reduce malaria burden in under-5 years old suggests a need for a national policy of strengthening the health system, which is lacking. Importantly, all health programmes or projects should incorporate health system reinforcement as a core component. Undoubtedly, this policy will beneficiate to others health programme to reduce morbidity and mortality of other important diseases in under-5 as well in others population groups.

Our results in Chapter 6 suggest a need for multi-sectoral synergies at each country level to reduce optimize health interventions effects. Indeed, women empowerment (education), an alternative to health financing such as insurances, removal or subsidization of user's fees related to maternal health services could increase the coverage of maternal health interventions that, in turn, will accelerate progress toward the attainment of SDG 3.1.

Chapter 1: Introduction

1.1 Trends of maternal and under-5 mortalities

Under-5 and maternal mortality rates are two important indicators of population health and social development (AbouZahr and Wardlaw, 2001; Silva, 2012). In the past 30 years, under-5 year's old and women health's were priorities in the global development agenda because of the high burden of morbidity and mortality particularly, in sub-Saharan Africa (Rosenfield and Maine, 1985). Awareness of the magnitude of the maternal mortality tragedy rose at the beginning of the 1980s and culminated in 1987 with the establishment of the safe motherhood initiative (Starrs, 2006). The commitment to reduce MMR was reaffirmed by the international community at the International Conference on Population and Development (ICPD) in Cairo in 1994 (United Nations, 1994). Likewise, several initiatives have been set up concerning under-5 health. The Alma Atta Conference in 1978 set up the first rather vague goals to improve under-5 health. In 1989, the United Nations (UN) convention on children rights established the right to health care for children. In 1990, the international community marked its commitment to improving the under-5 health particularly in low-income countries (LICs) (WHO, 1978; Pebley, 1993; Rios-Kohn, 1997).

The Millennium Development Goals (MDGs) 4 (reduce by two-thirds, between 1990 and 2015, the U5MR) and 5 (reduce by three quarters, between 1990 and 2015, the maternal mortality ratio) in 2000 were the benchmark of the will to reduce maternal and under-5 mortality burden (UN General Assembly, 2000). MDGs led to a significant increase of technical and financial resources and the scaling up of cost-effective health interventions for mothers and children in sub-Saharan Africa. This led to a revitalization of the concept of "the continuum of care", with a conceptual framework and specific content. It consists of connections of mothers, babies and children sequential health care throughout lifespan and place of caregiving (Kerber et al., 2007). Approximately 190 health cares have been grouped into eight packages. The "Countdown to 2015 initiative" was established to track the progress of the scaling up of selected interventions from this continuum of care in some prioritized countries, mostly in Africa (Victora et al., 2016). Unprecedented and remarkable success has been achieved regarding MDGs 4 and 5 at the end of 2015. Globally, U5MR declined from 77.8 to 42.5 per 1,000 live births. More than 4 million under-5 deaths were prevented between 2000 and 2015 (Liu et al., 2016; WHO, 2016). MMR declined by 44% (WHO, 2016). However, most sub-Saharan Africa countries failed to meet their MDG 4 and MDG. MMR and U5MR remained high. In 2015, Africa landed the 10 countries with the highest U5MR, one in 12 children did not reach his fifth birthday and two-thirds of maternal deaths occurred therein (WHO, 2016). Africa remains the part of the world bearing the highest burden of U5MR and MMR (Figures 1.1 and 1.2).

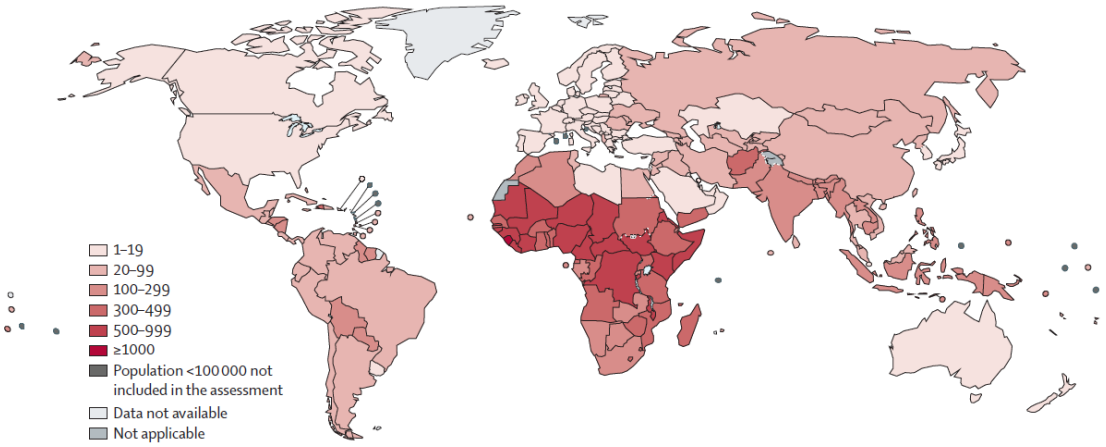

Figure 1.1: Maternal mortality ratio (MMR; number of deaths per 100,000 livebirths) for countries and territories, 2015 (Alkema et al., 2016).

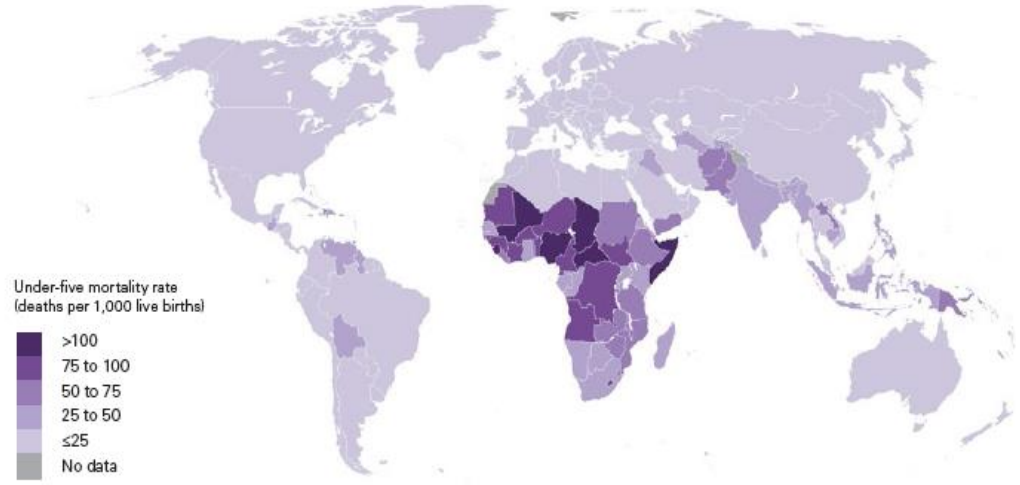

Figure 1.2: Under-five mortality rate (deaths per 1,000 live births) by country, 2017 (UNICEF, World Bank, WHO, 2018).

Taking advantage of the achievements and the shortcomings of the MDGs era, the international community has set up the Sustainable Development Goals (SDGs). SDG targets 3.1 and 3.2 aiming at reducing the global MMR to less than 70 per 100,000 live births and the U5MR to less than 25 per 1,000 live births by the end of 2030 (WHO, 2016). Political, financial and technical commitments need to be maintained to scale up the coverage of maternal and child health interventions. To achieve the SDG target 3.1, an annual reduction rate of 7.3% would be required; which is 3 times higher compared to the reduction rate during the MDG era. Overall, the rate of reduction of the MDGs' period will make it possible to reach the target for under-5 mortality by the end of 2030, but efforts will vary from one country to another.

1.2 Maternal and child health in Burkina Faso

Burkina Faso failed to meet its maternal and child health-related MDGs in 2015. The country was among the prioritized countries by the World Health Organization (WHO) in the early 2000s to track the progress of the scaling up of appropriate health interventions (Bhutta et al., 2010). The country has intensified the efforts over the past 15 years through different initiatives, reforms and strategies to improve maternal and child health. The country removed user's fees for antenatal care (ANC) services in 2002, created in 2002 the Directorate of Nutrition (Direction de la Nutrition), adopted the management of obstetrical emergencies without prepayment in public hospitals and the integrated management of childhood illness (IMCI) in 2003, subsidised the costs of delivery by 80% and by 100% for the poorest in 2007, and eliminated the poorest from payment of all user fees for all curative and preventive health services in 2009, removed user's fees for children and women in 2016 (Ridde et al., 2011; Belaid and Ridde, 2012). New vaccines have been introduced in the Expanded program of immunization (EPI). In 2009 and 2014, mass distributions of ITNs were conducted; artemisinin based-combination therapy (ACT) and rapid diagnostic tests (RDTs) for malaria management were introduced in the same period at health facilities and community levels. The country is implementing performance-based payment since 2011 and is underway to set up universal health insurance. Despite these reforms, the subnational coverages of maternal health interventions throughout the country are uneven. . For example, in the Sahel and the Sud-Ouest regions', the coverage of most of the health interventions are below the national averages (Ministère de la Santé, 2017). Also, the coverages of the interventions such as family planning, at least 4 antenatal care visits and exclusive breastfeeding, are very low (Countdown to 2030, 2015; Ministère de la Santé, 2017). Taken together, the annual reductions rates of MMR and U5MR were below the required rates to achieve the related MDGs. In 2015, MMR was as high as 400 for a target of 190 per 100,000 live births. U5MR was at 89 for a fixed objective of 67 per 1,000. Furthermore, the reductions hide heterogeneities within the country. The regions of Sahel and Sud-Ouest had a U5MR of 235 and 195 per 1,000 respectively while the region of Centre-Est registered a U5MR rate of 80 and the national average is 129 per 1000 live births (Ministère de l'Économie et des Finances, 2010).

To meet the SDGs, Burkina Faso needs evidence-based decision to increase the impact of cost-effective health interventions. Thus, more resources should be allocated to areas and groups of population in the highest needs, to reduce inequities, improve the quality of care and strengthen the health systems. As mentioned above, in addition to the suboptimal coverage of health interventions, there are disadvantaged regions such as the regions of Sahel, Est, and Sud-Ouest where the poverty rate is higher than the national average, health infrastructures are weak and security concerns (Ministère de l'Économie et des Finances, 2010).

1.3 Causes of maternal and under-5 deaths

1.3.1 Causes of maternal deaths

Maternal death is defined as the death of a woman while pregnant or within 42 days of termination of pregnancy, irrespective of the duration and site of the pregnancy, from any cause related to or aggravated by the pregnancy or its management, but not from accidental or incidental causes (ICD-10) (Ronsmans and Graham, 2006). This definition distinguishes two types of causes: direct (obstetric complications, interventions, omissions or incorrect treatment, or a chain of events resulting from any of the above) and indirect (maternal death resulting from previously existing disease or disease that developed during pregnancy and that was not due to direct obstetric causes, but that was aggravated by physiological effects of pregnancy) (WHO, 2006). The majority of maternal deaths occur close to the delivery period. Approximately three-quarter of maternal deaths is attributable to direct causes with haemorrhage, hypertension disorder and sepsis as leading causes (Murray et al., 2014; WHO, 2016).

In addition to these direct and indirect causes, some situations that contribute to precarious maternal health. These include low economic and cultural empowerment of women. Indeed, poor women are less prone to seek health care than those with acceptable economic status or educated (Grown et al., 2005; Larsson and Stanfors, 2014). Besides, early pregnancy (mean related to early marriage) among adolescents exposes to pregnancy and delivery complications such as abortion, haemorrhages, uterine rupture, systemic infection and lead to maternal deaths of neonatal deaths (Mayor, 2004; Ganchimeg et al., 2016). Women living in remote areas also face a high risk of death related to pregnancy, delivery and post-delivery period. Lack of health infrastructure and emergency transportation may delay health-seeking and consequently increase the mortality hazard (Kinney et al., 2010).

Several studies have demonstrated the influence of macro-economic indicators such as the gross national product, the expenditure in health, the out-pocket percentage in purchasing health care on MMR. Alvarez et al. (2009) found a correlation between low MMR and high skilled birth and antenatal attendance rates, educational and economic indicators between 1997 and 2006. In Nepal, Shrestha et al. (2014) reported that the improvement of maternal health interventions alongside four DHS rounds led to MMR decline.

In Burkina Faso, in 2017, the main causes of maternal death in health facilities were haemorrhage (23%), infections (14%), eclampsia (10%) and complications of abortion (7%) (Ministère de la Santé, 2017). Several studies have emphasised 3 delay factors (delays of seeking, reaching and receiving care) leading to high MMR in Burkina Faso. Somé et al. (2013) highlighted the financial barrier for women and the need for husband approval before seeking care. Using verbal autopsies, D'Ambruoso et al. (2010) mentioned that the 3 delays factors were reported by more than two-thirds by relatives of women who died in Burkina Faso. Weak empowerment of women (economic, decision-making) and the socio-cultural and educational factors prevent women from undertaking their will to seek antenatal care, delivery and family planning. The quality of obstetric care is not optimal and issues are related to shortages of skilled health workers, equipment for transfusion, caesarean, lack of emergency transportation (Hounton et al., 2008; Nikiema et al., 2010).

1.3.2 Causes of under-5 deaths

The first five years of life is a fragile period with many risk factors varying from intrinsic (biological) to external risk factors related to the physical, social, political and health system environment. Hence, under-5 mortality is an important indicator of population health and development. This period can be subdivided into the neonatal period (from birth to 1 month of life), the post-neonatal (from 1 month to 1 year of life), the infant (from birth to 1 year of life), and the juvenile (from 1 to 5 years of life) periods. As indicated in Figure 1.3, the neonatal period accounts for 45% of total deaths among under-5 years old. The leading causes are preterm birth complications (18%), pneumonia (15.5%), and intrapartum-related events (11.6%).

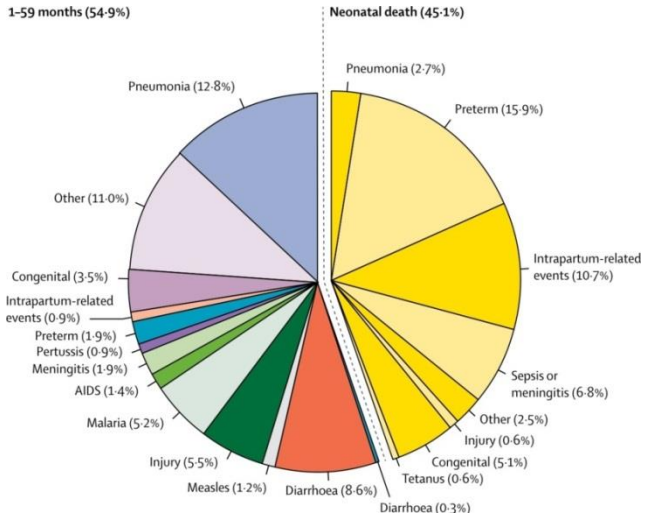

Figure 1.3: Global causes of under-5 deaths in 2015 (Liu et al., 2016).

The neonatal period is crucial for reducing U5MR. A performant health system with qualified health providers and good health infrastructures are required to respond adequately to populations needs.

Most of the causes of maternal and under-5 deaths are preventable. Indeed, the implementation of effective care could prevent at least 60% of deaths.

In Burkina Faso, infectious diseases lead to the causes of childhood deaths. In 2017, malaria and acute respiratory infections were responsible for 36% and 16% of under-5 years deaths, respectively in peripheral health facilities (Ministère de la Santé, 2018). The picture is similar in higher levels of health facilities (regional, national and teaching hospitals).

The burden of these leading causes is heterogeneous within the country. The regions of Sahel and Sud Ouest show the highest rates of U5M (Ministère de la Santé, 2018). In consequence, the allocation of the scarce resources must target the high burdened regions to accelerate the reduction of U5MR in Burkina Faso.

Socio-economic and demographic factors influence and shape the distribution of U5MR at the subnational level. The poorest households have higher disease risk due to delay of care-seeking, poor hygiene and sanitation conditions, malnutrition and limited access to preventive care. Likewise, mothers

education, marital status (single), short birth interval are associated with U5MR (Nkonki et al., 2011; Malderen et al., 2013; Kanmiki et al., 2014).

Climatic and environmental factors are important determinants of the magnitude of under-five survival in Burkina Faso. Two distinct climatic periods characterize the countries; the wet season (May to September) and the dry season (October to April). Accordingly, malaria peaks during the wet season while all diseases related to respiratory track increase in the dry season (Ministère de la Santé, 2018). Despite the evident effect of climatic and environmental factors on child survival, few studies take into account the confounding effects of climate in the estimation of health interventions.

1.4 Sources of maternal mortality estimation

The estimation of mortality rates (any age) requires data collected through a system of registration of births and deaths as they occur. Such a system of recording vital events is absent or incomplete in most African countries (Ye et al., 2012; AbouZahr et al., 2015; Mikkelsen et al., 2015). WHO and its partners produce regularly updated global, regional and national estimates of MMR and U5MR since 2000 (You et al., 2015). These estimates are based on models that compile data from the most common sources listed below (figure 1.4) across countries with both reliable and weak registration of vital events.

Civil registration and vital statistics data

Civil registration and vital statistics (CRVS) represents the most reliable and accurate source of data for estimating both MMR and U5MR. They record continuously life events such as date of birth, date of death, survival status, age, sex and causes of death as they occur. Unfortunately, functional CRVS are lacking where maternal mortality and under-5 mortalities are the highest, especially in sub-Saharan Africa. However, few low-and middle-income countries (LMICs) have derived MMR estimates from CRVS (Hamza, 2005; Kestler and Ramírez, 2000; Phillips et al., 2015).

Census and survey data

Population census, demographic and health surveys (DHS), multiple indicator cluster surveys (MICS) and reproductive age mortality studies (RAMOS) are common data sources that are used to derive MMR and U5MR estimates in most LMICs, particularly in Africa. In sub-Saharan Africa, DHS employ full birth history (FBH) and the direct sisterhood method to estimate U5MR and MMR, respectively (WHO and UNICEF, 1997; Hill et al., 2012). The RAMOS approach is carried out in two steps. The first step is the identification of death of women at reproductive age and the second step consists of investigations of deaths (using verbal autopsy, health facility reports or medical record reviews death certificates with medical cause and interview with household members and relatives) to ascertain whether there are pregnancy-related or maternal deaths (Mgawadere et al., 2016a). Malawi, Sudan and Ghana estimate MMR using the RAMOS method (Zakariah et al., 2009; Mohammed et al., 2011; Mgawadere et al., 2016).

Health and demographic surveillance system data

The health and demographic surveillance system is a geographical limited community-based information system. After an initial census, core demographic events i.e. birth, death, migration and key health indicators are collected periodically. The registration of the vital events allow deriving directly mortality rates. Furthermore, the causes of death are attributed by verbal autopsy (Baiden et al., 2007). Senegal and Kenya have used such data sources to derive MMR (Ba et al., 2003; Ziraba et al., 2009) as well as U5MR (Shabani et al., 2010; Deribew et al., 2016).

Health management and information system data

Health facilities or sentinel sites routinely collect data on maternal death for many LMICs. However, the quality of these data is questionable because of the small proportion of deaths occurring in health facilities. Nevertheless, they are widely used in many countries as they are locally generated and continuously available (Lema et al., 2005; Agan et al., 2010; Bergsjø et al., 2010).

A summary of the different types of data sources used to estimate MMR as indicated in the Figure 1.4.

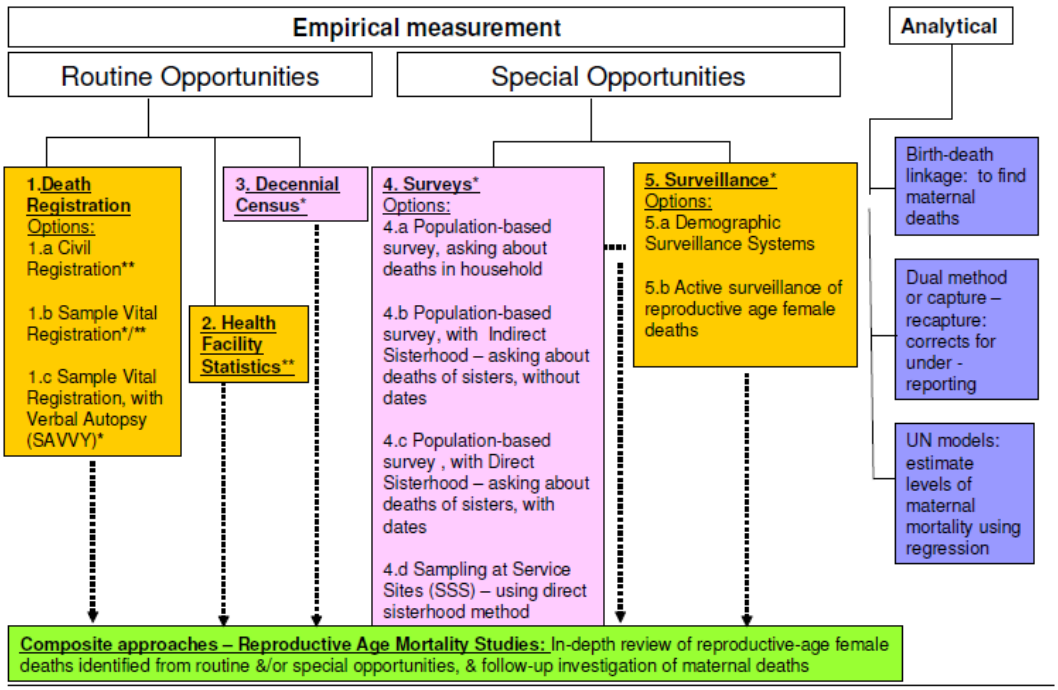

Figure 1.4: Types and source of measurement of maternal mortality (Graham et al., 2008).

Opportunities and options for measuring maternal mortality. Color key: Orange = longitudinal and continuous capture of deaths; Pink = cross-sectional capture; Green = mixed approach; Blue = no new capture of deaths. *Deaths actively sought by measurement option **Deaths passively recorded, as dependent on relatives or health providers to notify death (Graham and al., *BMC Medicine* 2008, **6**:12).

1.5 Data sources and maternal mortality measures

Four indicators are frequently used to estimate maternal mortality from population census and surveys. The ***maternal mortality ratio*** **(MMR)** is defined as the number of maternal deaths per 100,000 live births during a given period (Graham et al., 2008; Alkema et al., 2016).

$$MMR = \frac{number\ of\ maternal\ deaths}{number\ of\ live\ births} * 100{,}000$$

The ***maternal mortality rate (MMRate)*** expresses the risk of a woman dying during reproductive age. It is calculated by the number of maternal deaths per 100,000 women of reproductive age, or woman-years of risk exposure, in a given period (Graham et al., 2008; Alkema et al., 2016).

$$MMrate = \frac{number\ of\ maternal\ deaths}{number\ of\ persons - year\ of\ exposure} * 1{,}000$$

The link between MMR and MMRate is $MMR = \frac{MMRate}{General\ fertility\ rate\ (GFR)}$

The ***lifetime risk of maternal death (LTR)*** is the probability of maternal death across a woman's reproductive life. It is usually expressed in terms of odds (Graham et al., 2008; Alkema et al., 2016).

$$LTR = \frac{T_{15} - T_{50}}{l_{15}} * \left(\frac{MMRate}{1{,}000}\right)$$

Where T_{15}, T_{50} are life table person-years lived above ages 15 and 50 years (starting and ending ages of reproduction) respectively, and l_{15} is survivors to age 15 years.

The ***proportion of maternal deaths among female deaths (PMDF)*** expresses the maternal deaths as a proportion of all female deaths of reproductive age, usually defined as 15–49 years, in a given period (Graham et al., 2008).

$$PMDF = \frac{number\ of\ maternal\ deaths}{total\ deaths\ of\ women\ at\ reproductive\ age}$$

The above estimates are based on the direct or indirect sisterhood method of collecting maternal deaths related data.

In the indirect method, adult respondents are asked four questions on the survival of all their adult sisters born by the same mother. The method consists of identifying any death that occurred during pregnancy, childbirth or the postpartum period. Thus, PMDF determines pregnancy-related rather than true maternal death. It was developed in the 1980s by Brass et al. (Graham et al., 2008; Rutenberg and Sullivan, 1991). The direct sisterhood method refined the four questions of the indirect sisterhood approach detailing the questionnaire with information on the timing of death about the pregnancy, childbirth and postpartum (Rutenberg and Sullivan, 1991; WHO and UNICEF, 1997).

From CRVS, MMR, as well as U5MR, are directly derived because of the completeness of the registration of vital events. Furthermore, causes of death are attributed and allow cause-specific mortality estimates.

1.6 Data sources and measures of under-5 mortality rate

The countries with functioning CRVS, the U5MR and infant mortality rate (IMR) are derived from a standard abridged life table. Let D_0, D_1, P_0, and P_1 be the numbers of deaths for age group < 1 year, of death for age group 1-4 years and of the mid-year populations for the corresponding age groups,

respectively. Let also ${}_nq_x$ be the probability of dying between age x and age $x+n$, $\mathrm{M}_0 = {}^{\mathrm{D}_0}/_{\mathrm{P}_0}$, is the death rate for age < 1, and $\mathrm{M}_1 = {}^{\mathrm{D}_1}/_{\mathrm{P}_1}$, is the death rate for age $1-4$ years.

Then ${}_1q_0 = \frac{M_0}{[1+(1-a)*M_0]}$ a is the fraction of year lived by an infant. $a = 0.1$ for low mortality country and $a = 0.3$ for high mortality country. ${}_5q_0 = 1-(1-{}_1q_0)(1-{}_4q_1)$, where ${}_4q_1 = \frac{4*1}{[1+4(1-0.4)*M_1]}$

IMR is defined as the probability of dying from birth to 1 year of age. It is expressed as well as U5MR in term of 1,000 lives birth. $IMR = {}_1q_0 * 1{,}000$. $U5MR = {}_5q_0 * 1{,}000$

Full details of the method are provided by the United Nations Inter-agency Group for Child Mortality Estimation (UN Inter-agency Group for Child Mortality Estimation, 2018).

From census and survey, U5MR is estimated via two ways of data collection. The indirect or summary birth history (SBH) method requires the number of women of reproductive age ever had given birth to and those that are still alive. The method was pioneered by Brass and estimates the child mortality based on information aggregated by women classified according to different age groups (Brass method) or grouped by time since first birth, or marital duration. SBH contains no information on the date of birth. Thus, direct estimation of mortality is impossible. Instead, indirect estimation is carried out using the mother's age (or duration since first birth or marriage) as the exposure time of their children to die. Then, a model life table (United Nation or Coale-Demeny) serve to convert the proportions dead of children ever borne by women in a group into a standard life table function

The exposure of the child to death is approximated by the mother's age in the Brass method. The method requires (1) that the age group of the mother must exhibit neither age pattern of fertility nor child mortality; (2) independence between the mother survivorship and mortality risk and, (3) recent fluctuation in child mortality (conflicts, epidemic…). Several steps are required to derive the different mortality rates and details are provided in "Tools for Demographic Estimation" (Moultrie et al., 2013).

The **direct method** or full birth history (FBH) requires more information (date of birth, survival status, age at death) on each child a woman has given birth to during her lifetime. This method was initiated by the World Fertility Survey (1975–1984) and sill is the one used by the Demographic and Health Surveys (DHS) in LMICs. To reduce sampling errors, the estimates are often presented as period rates for five years preceding the survey (Hill et al., 2012). A synthetic cohort method developed by the DHS is used to compute period rates in several steps: imputing date of birth and age at death, location of death in the target year, derivation of exposure risk, weighting and cumulating events and exposure time, calculating probabilities of dying from age-specific mortality rates.

That is, weighting and cumulating events and exposure time: $M(x,j) = \frac{\sum_{i=1}^{N} D(i,x,j)*wgt(i)}{\sum_{i=1}^{N} E(i,x,j)*wgt(i)}$,

where, $M(x,j)$ is the mortality rate at age x and year j $D(i,x,j)$ is a binary variable indicating the death of child i at age x in year j (1 if the death occurs, 0 otherwise), $E(i,x,j)$ is the exposure time of child i at age x in year j, and $wgt(i)$ is the sample weight (mean 1.0) of child i.

Then, the probabilities of dying at age specific are calculated: $q(x,j) = \frac{\frac{M(x,j)}{12}}{1+\frac{M(x,j)}{24}}$

Survivorship from birth to any age for example at 5 years from birth is derived by

${}_5q_0^j = 1 - \prod_{x=0}^{59}(1 - q(x,j))$

Full details of the direct estimation of U5MR are also provided in "Tools for Demographic Estimation" (Moultrie et al., 2013).

1.7 Maternal and under-5 key interventions

1.7.1 Health sector interventions

Mothers, babies and children are intimately connected in life. Their health care and services are related as well. However, the interconnection has not always been the case and health programmes and strategies targeted them separately. Continuum of care is a concept of care introduced in the 1970s and was mostly applied to elderly health. Until the 2000s, it was associated with individual care and very little related to public health interventions. The continuum of care brings together two dimensions: time and place. It is a comprehensive integration of maternal, newborn and child health care (MNCH) so that care is connected throughout the lifespan from adolescence, pregnancy, childbirth, post-natal period to childhood. Therefore, care should be provided continuously from the family and community level, ambulatory services to health facilities (de Graft-Johnson et al., 2005).

Figures 1.5 and 1.6 highlight the lifespan key periods and places of provision of eight packages of health interventions that should be provided to mothers, babies, children and adolescents. The continuum of care had served as the foundation of the conceptual framework for initiatives related to MNCH such as the Partnership for Maternal, the Newborn and Child Health (PMNCH) and Opportunities for Africa's Newborns (WHO, 2005; Lawn and Kerber, 2006).

The challenges are to reach mothers and babies at birth as most of the deaths are concentrated around the birth and early post neonatal periods. Thus, the subdivision of places of care with functional links between allows for example at community and family levels to provide health care and services such as awareness of danger signs, references of pregnant women, childbirth preparation, exclusive breastfeeding, case management by community health workers and nutrition (Schiffman et al., 2010; Bahl et al., 2010; Bhutta et al., 2010; Lee et al., 2012).

After the adoption of the MDGs, several initiatives were set to monitor maternal and under-5 mortality trends as well as MNCH interventions coverage. The Countdown to 2015 initiative was assigned to produce trends of coverage of the MNCH interventions (Victora et al., 2016). The Child Health Epidemiology Reference Group (CHERG) was established to improved U5MR estimates, methodological issues and the impact of health interventions on U5MR (Boschi-Pinto et al., 2010). The United Nation Inter-Agencies Groups for Child and Maternal mortalities estimations updated global, regional and national level of maternal and under-5 mortality rates (You et al., 2015; Alkema et al., 2016).

Globally at the end of the MDGs era, maternal and child health care coverage has increased, but not at the same pace everywhere. Interventions such as immunization programme and antenatal consultation (one visit) had coverage above 80%, unlike the coverages intermittent preventive treatment of malaria during pregnancy, post-natal visit, children sleeping under ITNs, malaria treatment by ACTs were below expectations (Victora et al., 2016).

Likewise, the picture is similar at the country level. In Burkina Faso, MNCH interventions related to immunization have been carried out for a decade and had a high level of coverage. However, interventions such as breastfeeding, post-natal/antenatal visit and ITNs whose implementation has been revitalized thanks to the MDGs are still weak. Moreover, the coverage of these interventions is heterogeneous at the subnational level (Ministère de l'Économie et des Finances, 2010).

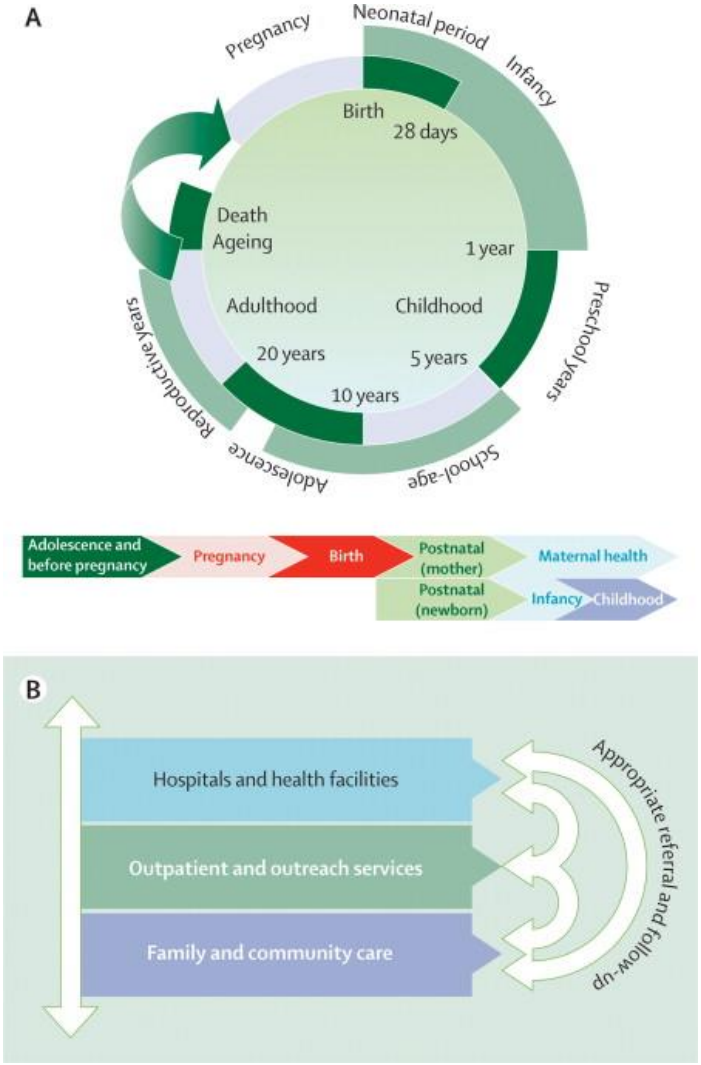

Figure 1.5: Continuum of care: connecting care during the lifecycle (A) and at places of caregiving (B) (Kerber et al., 2007)

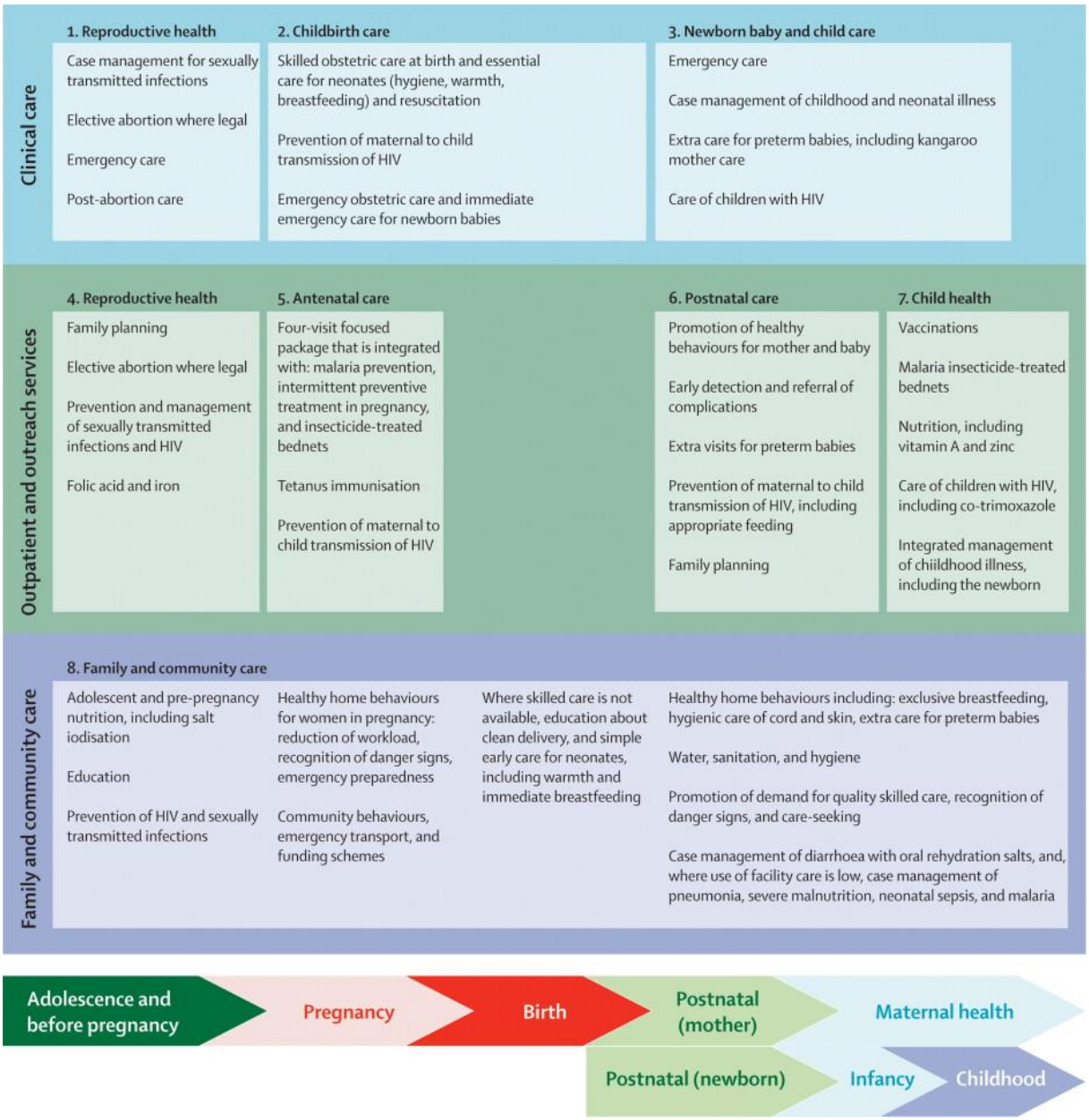

Figure 1.6: Integrated packages for health of mothers, new-born babies, and children, with evidence-based interventions along the continuum of care, organised by lifecycles and place of service-delivery (Kerber et al., 2007)

1.7.2 Interventions out of health sector

Health is multifactorial and particularly maternal and child health' are associated with factors not related to health sector. Governance, water and sanitation, economic growth and educational level positively influence the child and maternal health in LMICs (Alvarez et al., 2009; Fink et al., 2011; Cheng et al., 2012; Kipp et al., 2016; Taylor et al., 2017). In general, these factors influence health care-seeking behavior.

1.8 Health system performance

According to the WHO, the health system is defined as "all the activities whose primary purpose is to promote, restore, or maintain health" (WHO, 2000). A strong health system is a cornerstone to achieve health goals particularly in LMICs such as Burkina Faso. Indeed, human resources shortage, drugs and supply disruption, weak governance and health information prevent health system to implement efficiently lifesaving intervention for mothers and children (Travis et al., 2004). Consequently, the WHO assess the health system performance of all WHO countries members in 2000 (WHO, 2000). Later, the WHO proposed a conceptual framework to assess health system performance. It consists of six building blocks; namely (i) service delivery; (ii) health workforce; (iii) health information system; (iv) access to essential medicines; (v) financing; and (vi) leadership/governance (WHO, 2010). The framework consists of four goals: (i) improve health (level and equity); (ii) health system responsiveness, social and financial risk protection; and (iii) improved efficiency systems. de Savigny and al., (2009) proposed a dynamic framework to highlight the interplay and interaction between the six building blocks. Nevertheless, the assessment of the performance of the health system is obvious because of the complexity of the interrelations between the different components, the definition and approaches (Swanson et al., 2010). Therefore, several approaches were proposed to assess the performance and strength of the health systems (Jee and Or, 1999; WHO, 2000; De Savigny and Adam, 2009; Storeng, 2014).

The health systems in sub-Saharan African countries are mostly oriented towards increasing the coverage of health interventions to reach the maximum of people. They devote very little room to the assessment of their performance. Due to the complexity of the performance assessment based on proposed frameworks, WHO proposed the service availability and readiness assessment (SARA) and the service provision assessment (SPA). They consist of assessing the ability and the readiness of the health system to provide adequate and required care and services to the populations. (The DHS Program, 2012; WHO, 2015).

Both approaches can be thought of as proxies to the assessment and strengthening of the health system. The SARA survey is a health facility-based survey designed to assess and monitor the service availability and readiness of the health services and care. It generates evidence to support the planning and management of the system. It is a precondition to achieving universal health coverage which aims to provide everyone with healthcare services of good quality that meet their needs without the risk of financial hardship (WHO, 2010). The assessment of the availability of general and specific health services or programme concerns the physical presence of items (tracer indicators) necessary for the delivery of service on the survey day. It takes into account the health infrastructure, health human resources and service utilisation. The items are grouped by domains. Indicators are calculated for individual tracer item (average score of presence), for the domain as composite measures and for the whole health service or programme (O'Neill et al., 2013).

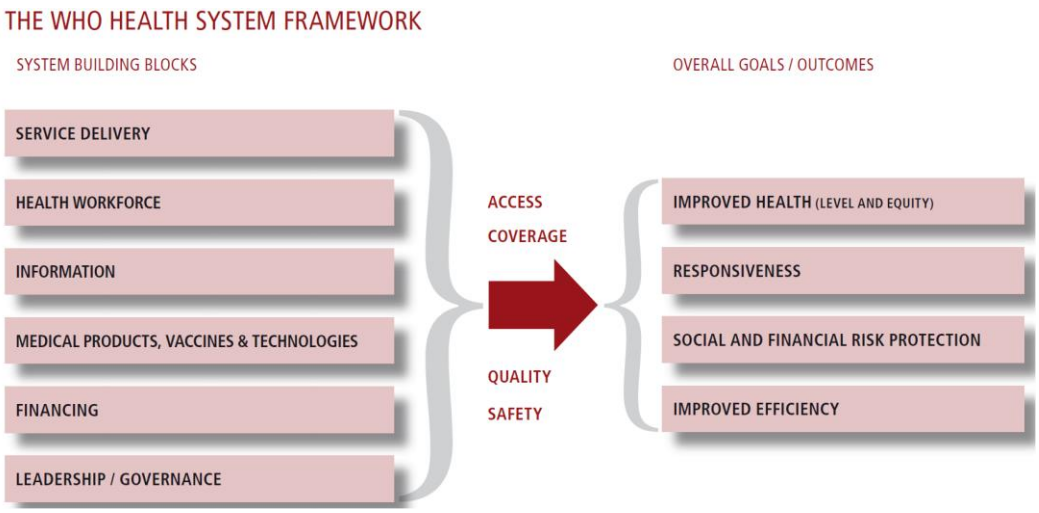

Figure 1.7: The WHO health system framework (WHO, 2007)

From 1960 to 1979, the health system of Burkina Faso was characterised by vertical programmes against local endemic such as leprosy, onchocerciasis and implementation of mobile immunization campaigns. Provision of care was mostly centralised in the major cities. From 1980 to 1991, after the adoption of primary health care and the Initiative of Bamako, the country began to decentralise the health system by creating provincial health care directorates'. This decentralisation was reinforced between 1991 and 2000 by the creation of 53 health districts and 11 regional directorates of health. The structure of the health system of the country is nowadays pyramidal with 3 levels. The health district is the most decentralised level and comprises two grades of health facilities: the "Centre de Santé et de Promotion Sociale" (CSPS) and the district hospital. The second level consists of the regional hospital and the third one is formed by the national and teaching hospitals. The country is partitioned into 70 health districts and elaborates every 10 years a national health policy and national health development plans (Ministère de la Santé, 2010). In terms of governance, health is a right for everyone. Institutional laws, mechanisms and instruments are in place to rule out the entire system.

Health financing is the component with the most reforms in recent years. Indeed, the government does not fulfil the goal of the Abuja conference, which requires that 15% of the budget to be allocated to health. Nearly 40% of the costs of care are provided by households (WHO, 2011). To overcome the financial barrier, the Ministry of Health (MoH) implemented the subsidy of neonatal care and deliveries (2007), the performance-based payment (2010) and the complete removal of user fees for pregnant women and children under 5 years of age (2016). Universal health insurance is in the process to be established (Agier et al., 2018).

The health information is mostly based on the routine HMIS. The main weaknesses are the multiplicity of data collection forms leading to fragmentation, incoherence and lack of completeness and promptness of information. Furthermore, the HMIS lack of private-sector report that reduces the consistency and validity of the national statistics. Estimates of health outcomes and the coverage of health interventions are mostly based on household surveys or statistical modelling.

The building block related to drugs and supply is made up by the existence of centralised system of provision for all public health facilities since 1994. The policy is based on essential and generic medicines.

The health human resource density is far from the WHO standards. In 2017, there were 1/15 836 and 1/7 378 for physicians and midwives, respectively (Ministère de la Santé, 2017). Overall, the density of physicians, nurses and midwives is approximately 8 for 10,000 population, while the WHO requirement is 23 per 10,000 population (Gupta et al., 2011).

Service delivery is a crucial component to reduce U5MR and MMR. However, as explained above, health facilities are mostly operating under weak conditions with a lack of equipment, insufficient human resources, unevenly distributed health infrastructures, lack of emergency transportation. Consequently, health facilities readiness and performance are below expectation and therefore, communities are hesitant to frequent health facilities in the first instance.

1.9 Rational of the study

Financial and technical resources for health interventions have increased in the past 15 years in sub-Saharan Africa. This stemmed from the commitment to the MDGs in 2000 and the SDGs in 2015. At the global level, organisations such as the Bill & Melinda Gates Foundation, the Vaccine Alliance (Gavi), the Global Fund to Fight AIDS, Tuberculosis and Malaria, the US President's Emergency Plan for AIDS Relief (PEPFAR) and the President’s Malaria Initiative (PMI) have emerged and contributed to increasing funding for health (Dieleman et al., 2016; Pallas and Ruger, 2017). Local governments and stakeholders have followed the pace.

Funding raised the demand for accountability at the global and local level and increased the need for accurate data to track the progress. Additionally, limited resources required optimal approaches to allocate and increase the impact of health interventions to reduce the mortality and morbidity burden especially in children under-5 years and women in sub-Saharan Africa. Substantial progress has been made during the MDGs era, but MMR and U5MR remained unacceptably high in sub-Saharan Africa (WHO, 2018). Effective health interventions do exist, but inefficient health systems and weak health information systems prevent optimal implementation of life-saving interventions. Decision-makers face challenges to take into account different factors such as equity, donor pressure, efficiency (maximizing population health), fairness (minimizing differences) and utility (the greatest good for the greatest number) (Baltussen and Niessen, 2006; Youngkong et al., 2009; Guindo et al., 2012). Regular monitoring of the progress is essential to determine gaps and to reorientate adequately the resources.

National representative household surveys are regularly carried out to overcome the lack of reliable data. These surveys provide data to assess the burden of diseases as well as mortality. However, most of the analyses are limited to national averages, overlooking regional and smaller scale heterogeneities and disparities. There is limited use of the data in evaluating the geographical distribution of the effects of interventions because existing analyses do not relate variations in the health indicators, health system performance and implementation of interventions at the local scale (Bicaba et al., 2009; Masanja et al.,

2008; Midekisa et al., 2012).

In Burkina Faso, national surveys highlighted regional variations of U5MR as well as the coverage of health interventions. In the rural district of Nouna, the U5MR declined by more than 50% during the past 25 years; however, this decline was heterogeneous within the district most likely due to disparities of the risk factors and the coverage of health interventions (Becher et al., 2016). Similarly, the coverage of child and maternal interventions has increased at the national level. However, there are large regional disparities within the country. For example, household ownership of at least one LLIN was more than 90% in the regions of Plateau Central and Nord, while it was only 41% in the region of Centre-Nord (Ministère de l'Économie et des Finances, 2010). The rate of breastfeeding within one hour after birth varied from 27% to 67%. Regional variations also exist in the skilled antenatal and birth attendance rates. The Malaria Indicator Survey (MIS) in 2014 showed that in the region of Centre and Centre Ouest, around 2% of children received an ACT the same or the next day after the onset of the fever, in contrary, in the region of Cascades, ACT coverage was much higher (42%) (Ministère de l'Economie et des Finances, Burkina Faso, 2014). Moreover, data from routine health management information system confirm the same heterogeneity observed in the MIS data (Ministère de l'Economie et des Finances, Burkina Faso, 2014). The variability of the coverage of health interventions is related to external factors including deficiencies in the health system, which affect their effectiveness. Very few studies in the country have assessed the effects of health interventions on U5MR at the subnational level and these studies have covered only a subset of interventions (Munos et al., 2016).

Up-to-date, high-resolution estimates of disease burden are needed to maximize the effects of scarce resources. These estimates should reflect the current situation of diseases, which may be influenced by ongoing interventions, climatic, health systems-related and socio-economic factors.

Bayesian statistical modelling is the state of the art to assess the spatial heterogeneity of diseases burden, to quantify the effects of health interventions and health system performance on mortality from national survey data. Beyond, the lack of advanced statistical expertise in the control programme and readily available software to perform routinely geostatistical analyses for surveillance limits the use of the methods to statisticians or specialist in epidemiologists.

1.10 Goal and objectives

The overarching goal of this PhD thesis was to assess at the national as well as at subnational level the spatio-temporal distribution of mortality and its associations with specific health interventions and health system performance indicators in Burkina Faso and sub-Saharan Africa more broadly.

This goal was addressed through the following interrelated specific objectives:

1. Assess the spatial distribution of child mortality and its associations with child, maternal and household health interventions in Burkina Faso.
2. Assess the spatial distribution of child mortality and its associations with child main causes of mortality in Burkina Faso.

3. Assess the association between malaria-related health service readiness and malaria mortality in under-5 years old in Burkina Faso.
4. Assess temporal changes in the association of malaria-related health service readiness and malaria mortality in under-5 years old between 2012 and 2014.
5. Assess the effect of maternal, socio-economic, education and health system factors on maternal mortality across sub-Saharan Africa.

Chapter 2: Geographical variation in the association of child, maternal and household health interventions with under-five mortality in Burkina Faso

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Abstract

Background

Over the past 15 years, scaling up of cost-effective interventions resulted in a remarkable decline of under-five mortality rates (U5MR) in sub-Saharan Africa. However, the reduction showed considerable spatial heterogeneity. We estimated the association of child, maternal, and household interventions with U5MR in Burkina Faso at national and subnational levels and identified the regions with the least effective interventions.

Methods

Data on health-related interventions and U5MR were extracted from the Burkina Faso Demographic and Health Survey (DHS) carried out in 2010. Bayesian geostatistical proportional hazards models with a Weibull baseline hazard were fitted on the mortality outcome. Spatially varying coefficients were considered to assess the geographical variation in the association of the health interventions with U5MR. The analyses were adjusted for child, maternal, and household characteristics, as well as climatic and environmental factors.

Findings

The average U5MR was as high as 128 per 1,000, ranging from 81 (region of Centre-Est) to 223 (region of Sahel). At national level, DPT3, immunization, and baby post-natal check within 24 hours after birth showed the strongest association with U5MR (hazard rates ratio (HRR)=0.89, 95% Bayesian credible interval (BCI): 0.86-0.98 and HRR=0.89, 95% BCI: 0.86-0.92, respectively). At subnational level, the most effective interventions were the skilled birth attendance, and improved drinking water, followed by baby post-natal check within 24 hours after birth, vitamin A supplementation, antenatal care visit and all-antigens immunization (including BCG, Polio3, DPT3, and measles immunization). Centre-Est, Sahel, and Sud-Ouest were the regions with the highest number of effective interventions. There was no intervention that had a statistically important association with child survival in the region of Hauts Bassins.

Interpretation

The geographical variation in the magnitude and statistical importance of the association between health interventions and U5MR raises the need to deliver and reinforce health interventions at a more granular level. Priority interventions are DPT3 immunization, skilled birth attendance, baby post-natal visits in the regions of Sud-Ouest, Sahel, and Hauts Bassins, respectively. Our methodology could be applied to other national surveys, as it allows an incisive, data-driven, and specific decision-making approach to optimize the allocation of health interventions at subnational level.

***Key words**: Bayesian inference Burkina Faso, child mortality, geostatistical modelling, health intervention, proportional hazards model.*

2.1 Introduction

Under-five mortality remains a major public health issue in sub-Saharan Africa, despite a remarkable decline during the Millennium Development Goal (MDG) era from 2000 to 2015 (You et al., 2015). The under-5 mortality rate (U5MR) estimates in 2016 suggest that one in 12 children of sub-Saharan Africa did not reach their fifth birthday (WHO, 2016). Pneumonia, preterm birth complications, intrapartum events, and diarrhoea constitute the main causes of under-5 deaths in sub-Saharan Africa (Liu et al., 2016). Indirect factors related to child, maternal, family, community, and the environment are also strongly associated with under-5 mortality, and hence underlie theses direct causes (Sartorius and Sartorius, 2014; Liu et al., 2016; Dedefo et al., 2016). Most of the direct and indirect causes are preventable. During the MDG era, facilitated by the commitment of donors, local governments, and other stakeholders, cost-effective interventions were scaled up. The effects of the interventions show considerable spatial heterogeneity.

Since 2006, Burkina Faso scaled up child health interventions consisting of subsidy of deliveries, artemisinin-based combination therapies (ACTs), rapid diagnostic tests (RDTs) for malaria at health facility and community levels, and universal distribution of long lasting insecticidal nets (LLINs). Furthermore, new vaccines have been included in the Expanded Programme of Immunization (EPI). The U5MR declined from 146.9 per 1000 to 88.6 per 1000 between 1998 and 2015 (The DHS Program, 2010). Likewise in other Sub-Saharan Africa countries the reduction was heterogeneous between and within the different administrative regions of the country (Barros et al., 2012; Pullan et al., 2014; Requejo et al., 2015; Becher et al., 2016; Burke et al., 2016). For example, the Demographic and Health Survey (DHS) 2010 data showed that the U5MR in the region of Sahel was four times higher than that of Centre-Est (The DHS Program, 2010). In the rural district of Nouna, the U5MR declined by more than 50% during the past 25 years, however strong disparities in mortality have been observed within the district, which are likely to be related to disparities in risk factors and coverage of health interventions (Becher et al., 2016). Even though the coverage of child and maternal interventions has increased globally at national level, there are large regional disparities within the country. For example, household ownership of at least one LLIN was more than 90% in the regions of Plateau Central and Nord, while it was only 41% in the Centre-Nord region (The DHS Program, 2010). The breastfeeding rate within one hour after birth varied from 27% to 67%. Regional variation also exists in the skilled antenatal and birth attendance across the country. Results of the Malaria Indicator Survey (MIS) in 2014 showed that in the region of Centre and Centre-Ouest, around 2% of children received an ACT on the same or the next day after the onset of fever, while in the region of Cascades, ACT coverage was much higher (42%) (The DHS Program, 2014). Moreover, data from routine health management information system confirm the same heterogeneity observed in the MIS data (The DHS Program, 2014). The variability in the coverage of health interventions is related to external factors, including deficiencies in the health system, which affect their effectiveness. In Burkina Faso, very few studies have assessed the association between health interventions and U5MR at subnational level. The few available studies

assessed a subset of interventions (Munos et al., 2016).

Our aim was to assess the magnitude of association between child, maternal and household health interventions and under-five mortality at national and subnational levels. We hypothesize that there is a geographical variation in the effects of health interventions and we aim to identify the interventions and the regions where there is a statistically important association between intervention coverage and child mortality. Our data will support decision making for delivering the most effective interventions in those regions where the highest rate were predicted.

2.2 Methods

2.2.1 Study area

Burkina Faso is a country in West Africa, with an estimated population of 18.5 millions inhabitants in 2015. Around 40.1% of the population lives below the poverty threshold and the Human Development Index (HDI) is 0.402. The population is relatively young with 21% and 54% below 5 and 18 years, respectively. The country is part of the Sudanian zone with a dry tropical climate and two seasons: a dry season from November to June characterised by a peak of respiratory diseases and a wet season from July to October with malaria as the most important communicable disease.

2.2.2 Data source

U5MR and health intervention data were extracted from the Burkina Faso DHS carried out in 2010. The data were collected from a two-stage cluster design and are representative at the national level, for urban and rural areas and for the 13 administrative regions. The survey was carried out in 574 georeferenced clusters and included 17,087 women of reproductive age who provided information for 15,375 lives births in the 5 years before the survey.

We extracted information of selected key health interventions of the countdown to 2015 initiative with less than 15% of missing values (Victora et al., 2016). In particular, we included the following child-related health interventions: all antigens, measles, and DPT3 immunization, vitamin A supplementation, use of LLINs, malaria treatment by any anti-malarial, exclusive breastfeeding, immediate breastfeeding after birth, and baby post-natal check. We considered maternal interventions, such as skilled birth and antenatal care, post-natal check, family planning and intermittent preventive treatment of malaria during pregnancy (IPTp). The household specific interventions included in the study were improved drinking water source and sanitation, wealth index, and ownership of LLIN. We include malaria interventions (sleeping under insecticide-treated net (ITN), household ownership of ITNs and malaria treatment) in the list of child health intervention because children under-5 years old are at high risk of morbidity and mortality in malaria endemic countries, such as Burkina Faso. Data measuring coverage of health interventions were aggregated at regional level. A description of the health intervention coverage indicators used in this study is given in Table A.2.1 in the appendix. Furthermore, we extracted information on socio-demographic characteristics of mothers and children under-5years of age such as birth order, sex, and place of delivery, mother's age at first birth, her educational attainment, as well as

the number of live births.

Environmental and climatic factors, such as land surface temperature (LST), vegetation indices (enhanced vegetation index (EVI) and normalized difference vegetation index (NDVI)), distance to water bodies, and type of land cover were compiled from satellite sources. Day and night LST and rainfall data were averaged for year the 2010. Permanent water bodies were obtained from the land cover category. Details on the source of climatic data and their spatio-temporal resolution are given in appendix (Table A.2.2).

2.2.3 Statistical analysis

Bayesian geostatistical proportional hazard models with a Weibull baseline hazard were fitted on child mortality data to assess the association between child, maternal, and household health interventions and U5MR. The models were adjusted for child, maternal, socio-demographic characteristics, climatic and environmental factors. Spatial correlation was introduced by a Gaussian process, adopted on cluster-specific random effects with an exponential correlation function of the distance between survey clusters. Spatially varying regression coefficients for the interventions were used to capture the geographical variation of the association at subnational level and they were modelled by regional random effects with a conditional autoregressive (CAR) prior distribution. That is, let $s = \{s_1, s_2, \dots, s_m\}, s_i \in D \subset R^2$ be the set of locations at which mortality data are observed; $t_j(s_i)$ be the time to death or the censoring time (in months) for child j at location s_i; $\boldsymbol{X_j}(s_i)$ be the vector of child, maternal, socio-demographic, and climatic factors; and $Z(s_i)$ be the coverage of a given intervention at location s_i. We modelled the mortality hazard as, $h\big(t_j(s_i)\big) = h_0\big(t_j(s_i)\big)\exp(\boldsymbol{\beta}^T\boldsymbol{X_j}(s_i) + \big(a + w_{q(i)}\big)Z(s_i) + \varphi(s_i))$ and assumed a Weibull baseline hazard, i.e. $h_0\big(t_j(s_i)\big) = \delta(t_j(s_i))^{\delta-1}$, where δ is the shape parameter, $\boldsymbol{\beta}^T = \big(\beta_1, \dots, \beta_p\big)$ is the vector of regression coefficients with $\exp(\beta_l), l = 1, \dots p$, corresponding to the hazard ratio (HR). $\varphi(s_i)$ is a cluster-specific random frailty which captures spatial correlation in mortality, i.e. clusters in closer proximity are expected to have similar mortality hazard due to common exposures. We modelled $\boldsymbol{\varphi}(s) = (\varphi(s_1), \varphi(s_2), \dots, \varphi(s_m))^T$ by a Gaussian process, i.e. $\boldsymbol{\varphi}(s) \sim N(0, \sigma^2 R)$, with an exponential correlation function of the distance d_{kl} between locations s_k and s_l, that is $R_{kl} = \exp(-d_{kl}\rho)$. The parameter σ^2 corresponds to the variance of the spatial process and ρ controls the rate of correlation decay with distance. For the exponential correlation function, $\frac{-\log(0.05)}{\rho}$ determines the distance at which the correlation drops to 0.05 (i.e. effective range of spatial process). The geographical variation in the association between interventions and U5MR was modelled by the spatially varying coefficients, $a + w_{q(i)}$, where a quantifies the magnitude of the association at global (national) level and $\boldsymbol{w} = \big(w_1, \dots, w_Q\big)^{\boldsymbol{T}}$ are the varying effects at regional (subnational) levels $q = 1, \dots Q$ with $q(i)$ indicating the region q corresponding to the location s_i. We introduced spatial dependence among the regions via a CAR prior for $\boldsymbol{w}$, that is $\boldsymbol{w} \sim N(\boldsymbol{0}, \sigma_q^2 R_q)$ with $R_q = (I - \gamma C)^{-1} D$. σ_q^2 is the variance of the spatially varying intervention coefficients, D is a diagonal matrix with entries $D_{kk} = {g_k}^{-1}$ where g_k

is the number of neighbours of region k, γ measures overall spatial dependence and C is a proximity matrix with normalized entries that is $C_{kl} = \omega_{kl}/g_k$, ω_{kl} is 1 if region k neighbours l and 0 otherwise (Banerjee et al., 2014). To complete Bayesian model formulation, we assumed inverse gamma priors for all spatial variances with known parameters, i.e. $\sigma^2, \sigma_q^2 \sim IG(2.01, 1.01)$, a uniform prior distribution for $\rho \sim U(a, b)$, where a and b chosen such as the effective range is within the maximum and minimum distances of the observed locations and a uniform prior for $\gamma \sim U(\lambda_1^{-1}, \lambda_2^{-1})$, where λ_1, λ_2 are the smallest and largest eigenvalue of $D^{-1/2}CD^{1/2}$. The shape parameter was assigned an exponential prior $\delta \sim exp(0.01)$. Non-informative normal priors were adopted for the regression coefficients $\beta_l, a \sim N(0, 10^3)$ for $l = 1, \ldots p$.

Model parameters were estimated using Markov chain Monte Carlo (MCMC) simulation. We run a two chain algorithm for 300 000 iterations with an initial burn-in of 15,000 iterations. Convergence was assessed by the Gelman and Rubin diagnostic (Gelman and Rubin, 1992).

Prior to Bayesian spatial analysis, bivariate, non-spatial, and Weibull proportional hazards models were fitted to identify potential child, maternal, and socio-economic confounders. Variables with p-value less than 0.15 were included in the geostatistical model.

The statistical analyses were carried out in STATA version 14 (StataCorp.; College Station, TX, USA) and OpenBUGS version 3.2.3 (Imperial College and Medical Research Council; London, UK). Maps were produced in ArcGIS version 10.2.1 (Esri Inc.; Redlands, CA, USA) and graphs in R (R Core Team; Vienna, Austria).

2.2.4 Ethical approval

We used secondary data that were made available by the MEASURE Demographic Health Survey (DHS) Program based in the USA. According to the survey report (The DHS Program, 2010), ethical approval was obtained by the institutional review board of ICF of Calverton (Maryland, USA) and the national ethics committee for health research of Burkina Faso under deliberation N°2014-7-072. The survey was anonymous. Blood samples were taken from all eligible children for whom parents or legal guardians had given their informed consent.

2.3 Results

Our sample included 541 (94.3%) clusters and 13,505 (87.8%) children under the age of 5 years, after removing clusters with missing coordinates. In total, 1209 (9%) children died before their fifth birthday owing to an estimate for U5MR of 128 per 1,000. The geographical distribution of U5MR is shown in Figure 2.1. The highest U5MRs were observed in the regions of Est, Sahel, and Sud-Ouest with respective U5MR of 172, 197, and 223 per 1,000. The Centre-Est had the lowest rate of 81per 1,000.

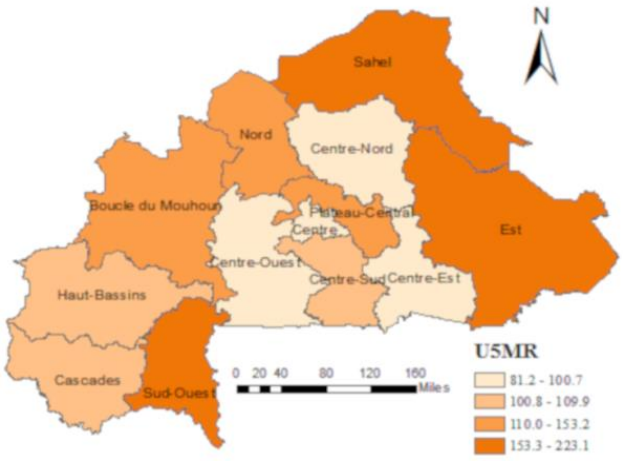

Figure 2.1: Regional distribution U5MR in Burkina Faso based on DHS 2010

Approximately two-third of the children were born in health facilities and 86% lived in rural areas. About 5% of mothers were younger than 19 years of age, two-third gave their first birth before age 19 years and 84% were not educated. Around one quarter of the respondents have more than five children and about 44% of the households were relatively poor (i.e. household asset in the first two quintiles). The socio-demographic characteristics of the sample are summarised in Table 2.1.

Coverage estimates of the child, maternal, and household health interventions used in the study, stratified by region, are given in Table 2.2. The corresponding intervention coverage maps are shown in Figure A.2.1 and A.2.2 in the appendix.

Table 2.1: Child, maternal, and household characteristics and hazard rates ratio estimated by bivariate Weibull proportional hazards models.

Covariate	Percentage (%) N=13,505	Number of death (%)	Hazards rates ratio (95% CI)	P value
Children characteristics				
Sex				
Female	49.1	566 (8.5)	1.00	
Male	50.9	643 (9.4)	1.12 (0.99-1.25)	0.063
Place of residence				
Urban	13.6	104 (5.7)	1.00	
Rural	86.4	1,105 (9.5)	1.71 (1.40-2.10)*	<0.001
Place of delivery				
Health facility	66.3	650 (7.3)	1.00	
Home	32.7	559 (12.3)	1.57 (1.40-1.76)*	<0.001
Birth order				
1-5	75.3	863 (8.5)	1.00	
>5	24.7	346 (10.4)	1.26 (1.11-1.43)*	<0.001
Mothers characteristics				
Age group (years)				
< 19	4.6	76 (12.3)	1.00	
20-35	75.3	870 (8.6)	0.48 (0.38-0.61)*	<0.001
>35	20.1	262 (9.7)	0.51 (0.40-0.69)*	<0.001
Age at first birth				
≤19	66.0	850 (9.5)	1.00	
>19	34.0	359 (7.8)	1.22 (1.07-1.39)*	0.001
Number of live birth				
1-5	71.0	750 (7.8)	1.00	
>5	29.0	459 (11.7)	1.47 (1.31-1.65)*	<0.001
Mother education level				
Primary and above	14.0	104 (5.5)	1.00	
No education	86.0	111 (9.5)	1.72 (1.41-2.11)*	<0.001
Households characteristics				
Asset index				
Richest	33.7	301 (6.6)	1.00	
Middle	22.5	280 (9.2)	1.41 (1.20-1.67)*	<0.001
Poorer	43.8	628 (10.6)	1.62 (1.42-1.86)*	<0.001

*: Statistically significant effect (i.e. P-value<5%)

Table 2.2: U5MR and coverage of child, maternal and household health interventions, stratified by region, as assessed by the Burkina Faso DHS 2010

Health Intervention (%)	Administrative regions													
	Boucle du Mouhoun	Cascades	Centre	Centre-Est	Centre-Nord	Centre-Ouest	Centre-Sud	Est	Hauts Basins	Nord	Plateau Central	Sahel	Sud-Ouest	National level
Child interventions														
Use of ITNs by under-5 years old	42.6	49.8	33.1	35.9	32.0	46.6	38.2	46.0	36.2	65.7	73.5	37.3	44.7	43.4
Malaria treatment	22.5	19.2	36.1	47.9	23.1	36.8	45.7	42.2	42.0	42.0	40.5	20.1	31.7	35.7
Exclusive breastfeeding	6.7	10.1	2.4	8.8	8.6	6.8	7.3	9.0	7.3	6.0	7.3	5.2	5.9	7.0
Breastfeeding after birth within 24 h	36.4	45.6	55.3	26.6	36.1	29.7	45.4	55.4	38.6	46.8	66.9	35.4	37.1	41.4
Baby post-natal check within 24 hours	15.0	18.1	15.2	31.8	20.7	19.5	27.7	30.8	4.5	21.5	19.7	5.4	9.0	18.3
Measles immunization	90.3	90.5	96.8	95.2	95.6	85.9	94.9	75.3	88.5	91.7	95.3	79.2	85.4	88.5
DPT3 immunization	97.0	79.2	93.7	98.1	97.6	91.6	96.2	83.0	87.8	93.6	96.1	82.0	92.0	91.3
All-antigen* immunization	86.9	71.7	88.0	93.0	94.9	82.8	92.4	69.6	81.1	88.8	90.1	74.0	81.0	83.7
Vitamin A	75.7	49.2	59.8	80.6	83.4	41.2	89.2	46.0	64.1	72.4	70.8	36.5	65.4	63.6
Maternal interventions														
Skilled birth attendance	64.5	77.5	96.4	84.6	73.5	60.7	86.4	55.4	73.1	61.4	80.8	40.1	42.9	67.1
Antenatal visits	93.4	95.5	98.7	99.6	97.1	95.2	99.3	92.4	96.0	94.8	98.7	88.3	92.5	95.1
Family planning	12.9	16.5	32.2	8.4	8.7	8.8	16.8	12.0	28.3	9.0	13.9	7.8	10.0	14.0
Intermittent preventive treatment of malaria in pregnancy	36.4	43.8	32.3	52.2	46.9	47.2	51.3	32.3	29.6	40.0	53.2	19.9	58.1	39.2
Household's interventions														
Improved sanitation	24.3	33.2	76.9	15.0	22.4	16.8	11.1	5.1	27.5	25.7	39.7	9.2	8.2	22.5
Improved drinking water	62.5	89.6	94.6	87.3	86.9	65.0	83.7	65.2	76.4	64.3	93.4	61.6	47.6	73.2
Household ownership of ITNs	73.3	81.5	72.7	62.7	52.8	74.0	62.8	83.2	63.3	98.1	95.4	81.5	71.2	74.3
U5MR (per 1000)	117	106	85	81	93	101	110	172	101	153	151	197	223	128

*: include BCG, Polio3, DPT3, and measles immunization

Among the child health interventions, those related to immunization had coverage above 80%, the required level for the universal health coverage (Countdown to 2030 Collaboration, 2018). Baby post-natal check 24 hours after birth and exclusive breastfeeding had the weakest coverage; 18% and 7%, respectively.

The coverage of maternal health interventions related to family planning, intermittent preventive treatment of malaria during pregnancy, and antenatal care visit were 14%, 39% and 95%, respectively. Household-based interventions for safe drinking water and ownership of at least one insecticide-treated net (ITN) were covering each around 73%. The proportion of households in the country with access to improved sanitation was low; around 20%. The distribution of the health interventions within the 13 regions showed strong heterogeneity. In general, the Sahel, Sud-Ouest, Est, and the Centre-Est were the regions with the lowest coverage of most interventions. Geographical disparities were observed in socio-economic proxies, such as the household asset index and the mothers' education level. Figure 2.2 indicates that the wealthiest and the most educated tended to have high coverage of child health interventions.

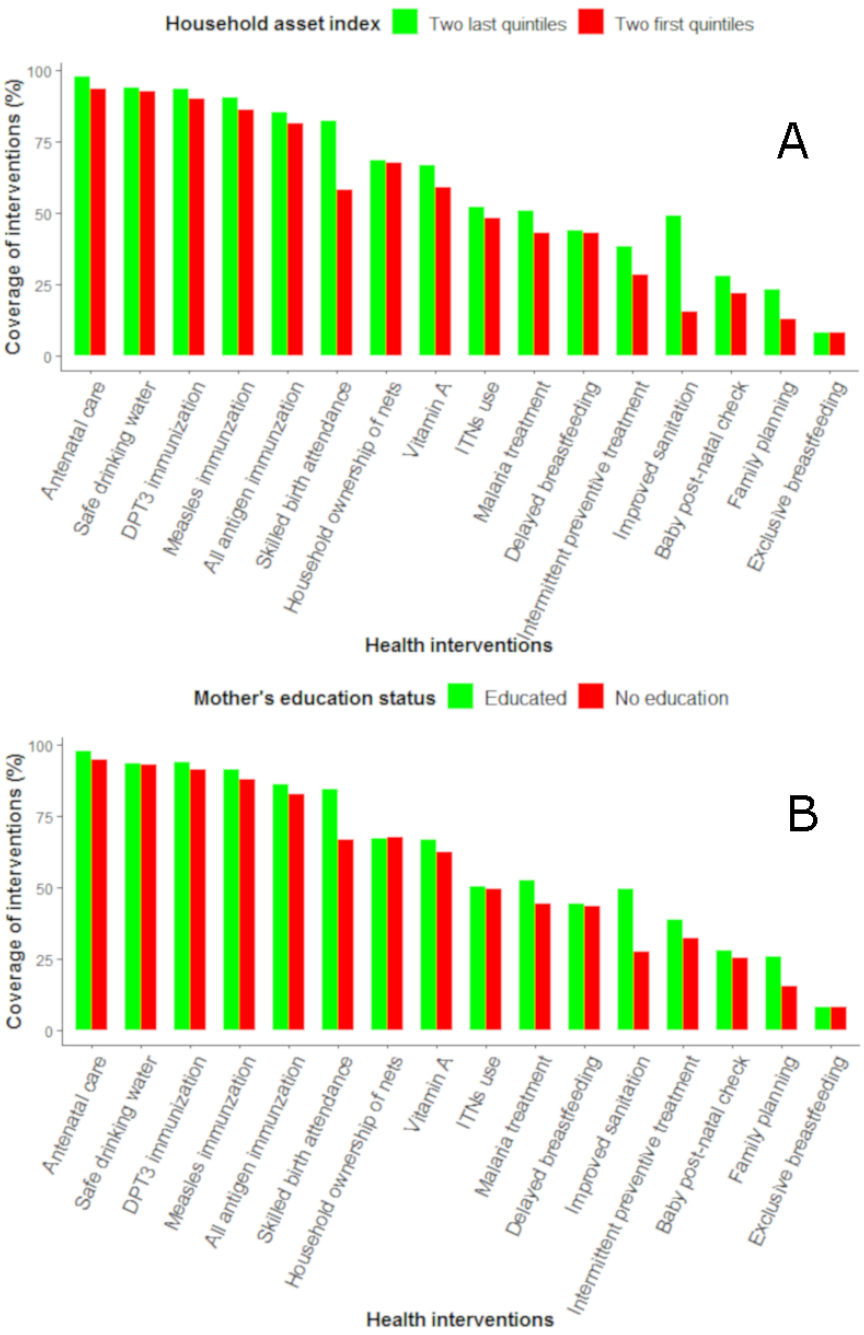

Figure 2.2: Frequency distribution of the coverage of child health intervention by household asset index (A) and by mothers' education level (B) in Burkina Faso based on DHS 2010.

Results of the bivariate survival analysis in Table 1 indicate that all child, maternal, and household socio-demographic covariates (except sex) were associated with child survival. Tables 3 and 4 show the hazard rate ratios (HRR) of child, mother, and household-specific interventions, estimated by Bayesian geostatistical models, adjusted for socio-economic and climatic covariates. HRR are also provided graphically in Figure 2.3 and as maps in figures A.2.3 and A.2.4 in the appendix.

Table 2.3: Estimates (posterior median and 95% Bayesian credible intervals(BCI)) of the effects of child health interventions at national and subnational levels obtained by Bayesian geostatistical Weibull proportional hazards models with spatially varying regression coefficients for the intervention coverage covariates.

	All antigen Immunization	DPT3 immunization	Measles immunization	ITN use by under five	Malaria treatment	Breastfeeding within 24 hours	Exclusive breastfeeding	Baby post-natal check within 24 hours	Vitamin A
	Hazard rates ratio (95% BCI)	Hazard rates ratio (95% BCI)	Hazard rates ratio (95% BCI)	Hazard rates ratio (95% BCI)	Hazard rates ratio (95% BCI)	Hazard rates ratio (95% BCI)	Hazard rates ratio (95% BCI)	Hazard rates ratio (95% BCI)	Hazard rates ratio (95% BCI)
Geographical scale									
National	0·92 (0·87-0·96)*	0·89 (0·86-0·98)*	0·91 (0·89-0·95)*	0·95 (0·90-0·97)*	1·02 (0·93-1·05)	1·07 (0·98-1·16)	0·90 (0·81-0·93)*	0·89 (0·86-0·92)*	0·94 (0·89-0·98)*
Regions									
Boucle du Mouhoun	0·99 (0·81-1·10)	0·97 (0·83-1·22)	0·87 (0·82-1·00)	0·99 (0·89-1·17)	1·04 (0·83-1·34)	1·14 (0·85-1·48)	0·99 (0·81-1·16)	0·79 (0·65-1·03)	1·01 (0·81-1·03)
Cascades	0·97 (0·78-1·40)	1·11 (0·87-1·28)	0·91 (0·73-0·92)*	0·87 (0·61-1·00)	1·17 (0·91-1·49)	1·34 (0·93-1·93)	0·85 (0·63-1·00)	0·82 (0·71-0·87)*	0·92 (0·82-0·96)*
Centre	1·09 (0·84-1·50)	0·93 (0·78-1·11)	1·09 (0·80-1·29)	0·99 (0·89-1·03)	1·04 (0·83-1·22)	1·17 (0·88-1·60)	1·05 (0·79-1·34)	0·98 (0·71-1·18)	1·00 (0·69-1·06)
Centre-Est	0·74 (0·64-0·90)*	0·72 (0·61-0·82)*	0·81 (0·72-0·89)*	0·84 (0·75-0·99)*	1·04(0·86-1·32)	1·25 (0·89-1·76)	0·83 (0·68-0·93)*	0·86 (0·73-0·99)*	0·94 (0·72-0·96)*
Centre-Nord	0·85 (0·69-1·04)	0·79 (0·61-0·95)*	1·09 (0·76-1·11)	1·17 (0·84-1·31)	1·15 (0·85-1·35)	1·11 (0·81-1·55)	0·81 (0·62-0·88)*	0·87 (0·76-1·06)	0·96 (0·67-1·06)
Centre-Ouest	0·82 (0·68-0·97)*	0·82 (0·69-0·95)*	1·14 (0·79-1·15)	1·13 (0·91-1·14)	1·11 (0·72-1·20)	0·93 (0·66-1·27)	0·99 (0·74-1·20)	1·21 (0·99-1·36)	1·11 (0·96-1·14)
Centre-Sud	1·10 (0·80-1·60)	1·00 (0·73-1·33)	1·11 (0·86-1·17)	1·30 (0·89-1·40)	0·96 (0·70-1·28)	1·02 (0·71-1·46)	0·73 (0·55-0·90)*	1·03 (0·82-1·19)	1·21 (0·95-1·27)
Est	0·97 (0·84-1·05)	0·83 (0·71-1·01)	0·95 (0·81-1·05)	0·88 (0·73-0·93)*	1·16 (0·84-1·34)	0·93 (0·72-1·21)	0·95 (0·73-1·11)	0·81 (0·69-1·38)	1·16 (0·97-1·19)
Hauts Bassins	1·10 (0·78-1·21)	1·05 (0·95-1·54)	0·98 (0·80-1·10)	1·36 (0·94-1·37)	1·11 (0·86-1·26	1·10 (0·75-1·62)	1·25 (0·96-1·63)	1·14 (0·84-1·21)	1·06 (0·82-1·30)
Nord	0·96 (0·74-1·19)	0·99 (0·81-1·24)	1·06 (0·80-1·12)	0·86 (0·68-0·89)	0·89 (0·72-0·96)*	1·05 (0·82-1·38)	0·85 (0·73-1·12)	0·97 (0·85-1·31)	0·85 (0·74-0·93)*
Plateau Central	0·91 (0·60-0·97)*	0·83 (0·65-1·00)	0·92 (0·80-1·09)	1·08 (0·77-1·16)	1·04 (0·78-1·12)	0·98 (0·73-1·30)	0·82 (0·63-1·01)	0·96 (0·70-1·04)	1·11 (0·87-1·17)
Sahel	0·96 (0·80-1·15)	0·94 (0·76-1·12)	0·93 (0·85-1·05)	0·78 (0·62-0·81)*	1·30 (1·04-1·36)	1·14 (0·81-1·50)	0·89 (0·64-0·99)*	0·70 (0·47-0·86)*	0·82 (0·67-0·85)*
Sud-Ouest	0·80 (0·66-0·90)*	0·96 (0·82-1·14)	0·74 (0·68-0·76)*	1·00 (0·80-1·26)	0·72 (0·48-0·91)*	0·93 (0·70-1·24)	1·04 (0·70-1·20)	0·61 (0·55-0·95)*	1·00 (0·76-1·14)
Spatial parameters	Median (95% BCI)	Median (95% BCI)	Median (95% BCI)	Median (95% BCI)	Median (95% BCI)	Median (95% BCI)	Median (95% BCI)	Median (95% BCI)	Median (95% BCI)
Range (km)	17·7 (15·0-59·6)	34·5 (14·3-39·3)	27·6 (19·7-37·0)	37·6 (29·0-47·4)	49·3 (22·6-71·4)	56·0 (8·2-69·5)	39·0 (20·1-64·7)	29·9 (9v6-66·0)	36·4 (8·2-42·5)
Spatial variance	0·37 (0·32-0·41)	0·16 (0·14-0·23)	0·16 (0·12-0·19)	0·15 (0·13-0·23)	0·16 (0·12-0·23)	0·19 (0v11-0·33)	0·13 (0·10-0·16)	0·15 (0·13-0·17)	0·16 (0·12-0·34)
Variance of spatially varying effect	0·56 (0·36-0·63)	0·17 (0·11-0·20)	0·27 (0·15-0·47)	0·34 (0·20-0·48)	0·33 (0·25-0·57)	0·23 (0·11-0·56)	0·19 (0·12-0·41)	0·31 (0·15-0·37)	0·14 (0·11-0·29)

* Statistically important effect.

Table 2.4: Estimates (posterior median and 95% Bayesian credible intervals (BCI)) of the effects of maternal and household health interventions at national and subnational levels obtained by Bayesian geostatistical Weibull proportional hazards models with spatially varying regression coefficients for the intervention coverage covariates

	Skill birth attendance	**Antenatal visit**	**Family planning**	**IPT**	**Improved drink water**	**Improved sanitation**	**Household ownership of nets**
	Hazard rates ratio (95% BCI)	**Hazard rates ratio (95% BCI)**	**Hazard rates ratio (95% BCI)**	**Hazard rates ratio (95% BCI)**	**Hazard rates ratio (95% BCI)**	**Hazard rates ratio (95% BCI)**	**Hazard rates ratio (95% BCI)**
Geographical scale							
National	0·93 (0·88-0·96)*	0·95 (0·92-0·98)*	0·91 (0·85-0·94)*	1·01 (0·94-1·08)	1·01 (0·90-1·03)	1·00 (0·96-1·04)	1·09 (0·95-1·13)
Regions							
Boucle du Mouhoun	0·95 (0·72-1·02)	1·02 (0·82-1·09)	0·94 (0·71-1·06)	1·11 (0·88-1·48)	0·92 (0·82-1·18)	0·90 (0·69-0·97)*	1·33 (0·87-1·75)
Cascades	1·03 (0·81-1·29)	1·11 (0·96-1·42))	1·01 (0·85-1·22)	0·98 (0·79-1·24)	1·31 (0·85-1·40)	1·18 (0·95-1·21)	0·87 (0·67-1·00)
Centre	1·03 (0·85-1·33)	0·86 (0·58-1·19)	0·89 (0·71-0·96)*	1·01 (0·81-1·51)	0·96 (0·72-1·05)	1·11 (0·88-1·22)	1·44 (0·73-1·77)
Centre-Est	0·81 (0·60-0·88)*	0·68 (0·62-0·90)*	1·17 (0·84-1·55)	0·80 (0·69-0·96)*	0·73 (0·62 -0·99)*	1·08 (0·77-1·11)	1·15 (0·84-1·24)
Centre-Nord	1·08 (0·90-1·14)	1·01 (0·88-1·13)	0·90 (0·75-1·19)	0·96 (0·66-1·20)	0·96 (0·71-0·99)*	1·17 (0·86-1·27)	1·27 (0·97-1·47)
Centre-Ouest	1·11 (0·88-1·25)	0·99 (0·82-1·29)	0·92 (0·75-0·96)	1·04 (0·79-1·23)	0·86 (0·59-0·91)*	1·19 (0·87-1·25)	0·98 (0·80-1·16)
Centre-Sud	1·12 (0·91-1·37)	1·15 (0·70-1·47)	0·88 (0·60-1·01)	1·09 (0·89-1·57)	1·23 (0·95-1·41)	1·16 (0·89-1·31)	1·43 (0·96-1·75
Est	0·79 (0·66-0·91)*	0·76 (0·71-0·83)*	1·09 (0·88-1·19)	0·93 (0·69-1·06)	1·05 (0·84-1·17)	1·12 (0·91-1·32)	1·05 (0·75-1·22)
Hauts Bassins	1·07 (0·83-1·18)	1·19 (0·92-1·73)	0·89 (0·68-1·23)	1·17 (0·89-1·56)	1·12 (0·90-1·15)	1·04 (0·88-1·11)	1·11 (0·78-1·32)
Nord	0·85 (0·74-0·94)*	1·04 (0·82-1·09)	1·10 (0·83-1·33)	1·23 (0·91-1·52)	0·98 (0·79-1·03)	0·83 (0·71-0·98)*	0·96 (0·79-1·10)
Plateau Central	1·02 (0·79-1·17)	1·01 (0·79-1·39)	0·73 (0·58-0·87)*	1·02 (0·71-1·35)	0·92 (0·71-0·97)*	1·29 (0·96-1·41)	1·12 (0·82-1·21)
Sahel	0·80 (0·73-0·89)*	0·89 (0·79-0·97)*	1·12 (0·72-1·35)	0·75 (0·57-0·97)*	0·91 (0·74-0·97)*	0·89 (0·80-0·98)*	1·13 (0·79-1·28)
Sud-Ouest	0·73 (0·58-0·85)*	0·90 (0·82 0·95)*	0·70 (0·50-0·75)*	1·16 (0·83-1·71)	1·73 (1·35-3·20)	0·88 (0·75-1·15)	0·98 (0·66-1·04)
Spatial parameters	Median (95% BCI)	Median (95% BCI)	Median (95% BCI)	Median (95% BCI)	Median (95% BCI)	Median (95% BCI)	Median (95% BCI)
Range (km)	38·1 (21·0-53·5)	31·2 (23·9-50·3)	30·0 (18·3-68·4)	53·3 (42·2-71·1)	58·9 (33·9-68·9)	37·4 (15·4-70·1)	37·7 (12·4-69·6)
Spatial variance	0·13 (0·13-0·16)	0·15 (0·13-0·20)	0·17 (0·12-0·23)	0·16 (0·11-0·19)	0·15 (0·11-0·18)	0·14 (0·10-0·17)	0·16 (0·11-0·22)
Variance of spatially varying effect	0·18 (0·11-0·43)	0·23 (0·16-0·37)	0·21 (0·18-0·98)	0·22 (0·11-0·45)	0·33 (0·22-0·53)	0·19 (0·15-0·40)	0·28 (0·13-0·39)

* Statistically important effect.

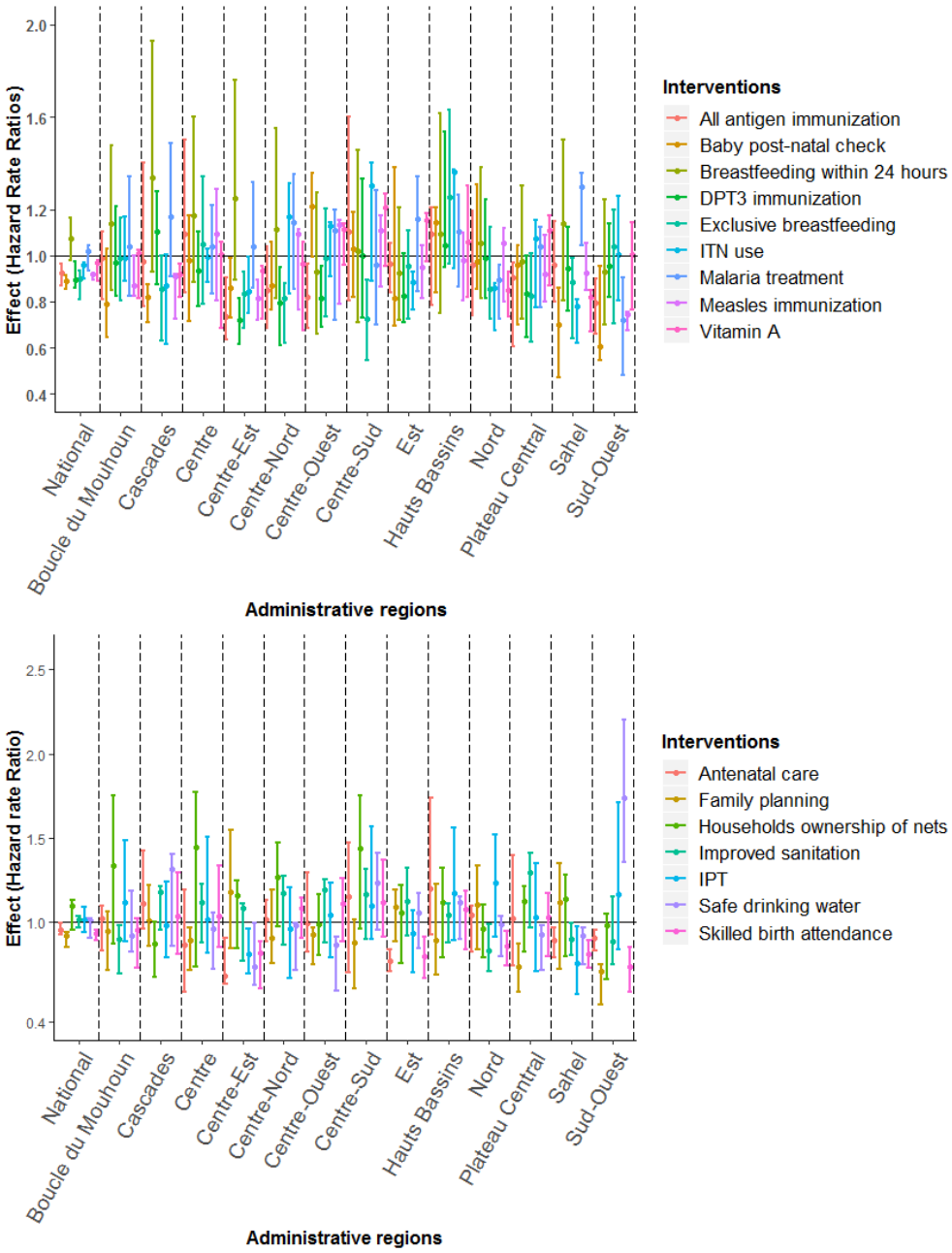

Fig 2.3: Hazard rate ratios (posterior median and 95% BCI) of child (A) maternal and household (B) health interventions estimated by Bayesian geostatistical Weibull proportional hazards models with spatially varying regression coefficients for the intervention coverage covariates. DHS 2010, Burkina Faso. The horizontal line corresponds to a HRR equal to one.

Breastfeeding within 24 hours after birth and household ownership of ITNs did not have an important association neither at national nor at regional level. At national level, DPT3 immunization and baby post-natal check within 24 hours were associated with a reduction of U5MR (HRR=0.89, 95% BCI: 0.86-0.98 and HRR=0.89, 95% BCI: 0.86-0.92, respectively).

There was a considerable variation in the magnitude of the association between the interventions and U5MR within the country. The number of interventions by region associated with a reduction of U5MR ranged from zero to 11 with a median number of 3. The regions, with the highest number of statistically important interventions were Centre-Est, Sahel, and Sud-Ouest having 11, 8, and 7 interventions, respectively. A second group of regions is composed by Cascades, Plateau Central, Nord, Centre-Ouest, Centre-Nord, and Est with 3-4 interventions associated with child survival. The remaining regions had at most one intervention with a statistically important regression coefficient. No important intervention was identified in the region of Hauts Bassins. The combination of interventions with statistically important coefficients varied by region.

Four out of 13 regions had child-specific interventions with protective effects: all-antigen immunization (Centre-Est, Centre-Ouest, Plateau Central, and Sud-Ouest), exclusive breastfeeding (Centre-Est, Centre-Nord, Centre-Sud, and Sahel), vitamin A supplementation (Cascades, Centre-Est, Nord, and Sahel) and baby post-natal check (Cascades, Centre-Est, Sahel, and Sud-Ouest). Use of ITNs (Centre-Est, Est, and Sahel), measles (Cascades, Centre-Est and Sud-Ouest) and DPT3 immunization (Centre-Est, Centre-Nord, and Centre-Ouest) were associated with U5MR in three regions. Intermittent preventive treatment of malaria in pregnant women was not associated with mortality hazard at national level; however, it was associated with mortality hazard in the regions of Centre-Est and Sahel. Among all child interventions at regional level, baby post-natal check showed the strongest negative association with U5MR in the Sud-Ouest region (HRR=0.61, 95% BCI: 0.55-0.95). Skilled birth delivery, antenatal care attendance, and family planning are maternal interventions with statistically important coefficients at both national and regional levels. Antenatal care had the highest association with U5MR in Centre-Est (HRR = 0.68, 95% BCI: 0.62-0.90). At national level, none of the interventions related to household was associated with child survival. However, improved drinking water is associated with a reduction in U5MR in five regions (Centre-Est, Centre-Nord, Centre-Ouest, Plateau Central, and Sahel) while improved sanitation in three (Boucle du Mouhoun, Nord, and Sahel) (Figure 2.3B).

Malaria is one of the main causes of high U5MR in Burkina Faso. Use of ITNs and treatment with any antimalarial showed a protective effect on U5M in three (i.e. Centre-Est, Est, and Sahel) and two regions (i.e. Nord and, Sud-Ouest), respectively.

Association between U5M with socio-demographic characteristics remained the same across the health interventions. That is, male, born at home, birth order higher than five, first birth younger than 19 years, lack of education, mother's age less than 19 or above 35 years, and poorer household were associated with higher mortality (Table A.2.3 and A.2.4 in the appendix).

The models with spatially varying coefficients for IPT and improved drinking water have the highest estimates (i.e. posterior median) of their range parameters suggesting that the spatial correlation in their residuals extend over longer area compared to that in the rest of the models. This implies a weaker spatial correlation structure for the corresponding interventions. However, the credible intervals of parameter estimates across the different health interventions are overlapping; indicating that there are

no statistically important differences in the spatial correlation of the intervention coverage indicators. The same result is also observed in the variance parameter of the Gaussian process estimated by the models.

2.4 Discussion

This is the first study to assess geographical variation in the association of child, maternal and household health interventions with child survival in Burkina Faso at regional level, taking into account socio-demographics characteristics and climatic disparities. The geographical distribution of the coverage of the health interventions showed considerable heterogeneity. Interventions with the highest coverage (> 80%) are those related to child immunization and antenatal care visits. Skilled birth attendance, improved drinking water, and vitamin A supplementation had coverage of 60-80% at country level. The promotion of the above mentioned health interventions have history of several decades. Conversely, interventions with national coverage of less than 40% are those whose implementation was strengthened only from 2000 onwards. These include treatment of malaria with ACTs, exclusive breastfeeding, and early breastfeeding after childbirth.

In our analysis, the child and maternal socio-demographic factors associated with child survival (place of residency, place of delivery, number of live birth, mother's education level, age at first birth, and age group) are similar to those reported by several authors (Ezeh et al., 2014; Kanmiki et al., 2014). Our findings showed that boys under-5 years old have higher mortality hazard than girls as some studies have found in low-and middle-income countries (Sawyer, 2012). The mother's characteristics (number of live birth, education level, age at first birth, and age group) are interrelated with the household socio-economic status. In African settings, the poorest exhibit highest child mortality because poverty influences their health seeking behaviour. Women from poorer households are most often less educated, less autonomous, and make less use of maternal and child care services (Ahmed et al., 2010). This is highlighted in Figure 2.2. Socio-economic status is associated with failure to complete immunization, which is an effective child intervention (Schoeps et al., 2013). The Ministry of Health has addressed the financial barriers by subsidizing childbirth and new-born care in 2006 and removed completely the users' fees for children under-5 years old in 2016. As a result, the use of health services by the mothers has been increased (De Allegri et al., 2011). The high proportion of home delivery in Burkina Faso can be explained by the high proportions of poorest households and of women not educated or living in remote rural areas. As known, home delivery exposes to asphyxia and neonatal sepsis. Several studies reported that women delivering at young age are at higher risk of preterm birth and complicated delivery (Koné et al., 2018; Lawn et al., 2005). These are major causes of neonatal mortality which accounts for 44% of under-five mortality (Lawn et al., 2005; Liu et al., 2016). Multiple parity (more than five live births) is another risk factor and must be taken into account during antenatal care visit. Multiple parity leads to weak reconstitution of the mother's nutritional stock, and hence children with higher birth order are prone to low birth weights which impact negatively their survival. Climatic and environmental

factors are linked to child malnutrition, family's income and the development of water-borne diseases in sub-Saharan Africa (Dos Santos and Henry, 2008; Henry and Dos Santos, 2013).

Burkina Faso has two main seasons; a wet season (from June to September) and dry season (from October to May). Malaria and water-borne diseases are prominent during the wet season. Acute respiratory infections and meningitis are more prevalent during the dry season. Low precipitation may be protective in the Sud-Ouest region of the country, which receives most rain, but might be associated with increased mortality in the dry north (Dos Santos and Henry, 2008) Rainfall is protective in our analyses. We also found a positive association between distance to water bodies and mortality hazard. Similar findings have been reported with regard the spatial distribution of malaria risk in the country (Diboulo et al., 2016). A possible explanation could be that people living in close proximity to open surface water bodies are more aware about the risks and then protect themselves.

The interventions assessed in the current study are, with a few exception, those whose implementation have been regularly monitored at country level to evaluate progress towards the attainment of MDGs (Victora et al., 2016) They are effective at national and subnational level except the household ownership of net and breastfeeding within 24 hours after birth which did not show any impact on child mortality hazard at subnational level.

The variation of the association between the health interventions and U5MR in Burkina Faso may be explained by factors related to health system performance (such as health workers density, quality of care, accessibility of health facilities, availability of drugs and supplies), variations in the coverage of interventions and of the climatic and environmental differences across the country. Centre-Est, Sahel, and Sud-Ouest are the regions with more than 7 interventions with protective effect on child mortality. U5MR is low in Centre-Est but high in the Sahel and Sud-Ouest. Geographically, the three regions belong to the three climatic areas of the country. The Sahel is the driest region and is part of the Sahelian zone, the Centre-Est belongs to the intermediate Sudano-sahelian zone, while the Sud-Ouest belongs to the Sudanian part with the highest rainfall. Furthermore, in 2010, the Sahel and the Sud-Ouest were the poorest regions, while the Centre-Est was one of the richest. In Sahel and Sud-Ouest, even if the interventions are effective, their coverage is below the national average. The financial barrier might play a crucial role in the uptake of health services and care by the population. On the contrary in the wealthiest region of Centre-Est the population makes better use of the health programme.

Cascades, Plateau Central, Nord, Centre-Ouest, Centre-Nord, and Est have 3-4 interventions with protective effect and the U5MR in these regions is above 100 per 1,000 (with the exception of the region of Centre-Nord). These regions present weak coverage of various interventions: malaria treatment in Cascades, and Centre-Nord; immunization, skilled birth, antenatal attendance, improved drinking water and sanitation in Est; family planning in Centre-Nord and Nord. They belong to the Sudano-sahelian and Sudanian climatic areas. Furthermore, Est, Nord, Centre-Ouest, and Centre-Nord have high proportion of poor households. The health interventions with protective effects are mostly immunization, malaria-related interventions, vitamin A, baby post-natal check, skilled birth, and

antenatal attendance. The finding in Plateau Central region is rather surprising. All interventions showed higher coverage than at national level; however the U5MR is among the highest in the country at around 151 per 1,000. The interventions with important effects are family planning, improved drinking water and all antigen immunization. Plausible explanations for those results may be a long delay in health seeking behaviour and a low quality of health care in this region.

Centre, Boucle du Mouhoun, and Centre-Sud have only 1 intervention with protective effect, while there was no intervention associated with U5MR in Hauts Bassins. The U5MRs in these regions are below the national rate of 128 per 1,000. Centre and Hauts Bassins are the wealthiest regions of Burkina Faso with the highest availability of health infrastructures. In Centre region, family planning is the only intervention associated with a reduction in U5MR. The mortality rate in Hauts Bassins is 20 per 1,000 higher than Centre, and the average coverage of health interventions is higher, however, no health intervention showed a statistically important association with U5MR. Emphasis should be put on ITNs, baby post-natal check within 24 hours, and IPT, as their coverage are below the national average. It is conceivable that the reinforcement of these interventions might positively affect child survival. Boucle du Mouhoun and Centre-Sud belong to regions with high proportion of households in the lower wealth index category. Only improved sanitation in Boucle du Mouhoun and exclusive breastfeeding in Centre-Sud are associated with the reduction of U5MR. These regions have low coverage of improved drinking water (in Boucle du Mouhoun), use of ITNs and improved sanitation (in Centre-Sud).

Child mortality is also influenced by health system related factors, such as the density of health professional, availability of medical products, and quality of health care. It is interesting to note that Centre and Hauts Bassins that have only one or no intervention associated with child survival, respectively, have the highest density of health professionals in the country, although they cover about a quarter of total population (Burkina Faso; Ministère de la Santé, 2018). Our results are in the same direction with previous studies that proved association of ACTs with malaria parasitaemia at regional level in Centre-Est, Nord and Sahel (Diboulo et al., 2016). Several authors have highlighted the protective effect of net ownership on child mortality, which, however could not be confirmed in the current study (Lim et al., 2011). A possible explanation is that the DHS was carried out after a mass distribution of nets, but the mortality estimates are covering the 5-year period prior to the survey and therefore they are not influenced by the household ownership of nets. Breastfeeding within 24 hours after birth was a second health intervention not associated with U5MR. In the literature, early initiation of breastfeeding (less than 1 hour after birth) is related to reduced neonatal mortality (Smith et al., 2017). Our indicator included a delay of 24 hours which may explain the above finding.

A limitation of our study is that the coverage of health interventions is based on self-reporting information, therefore, the measurement may be prone to recall bias. Our analysis assumed that there is no systematic bias recall neither for a given health intervention nor for a given specific region. There are two more limitations which may have led to under-estimation of the association between the intervention coverage and U5MR. In particular, the mortality data are covering the 5-year period prior

to the survey. During the latest years the coverage of interventions has increased. The analysis could not take into account the study period because there were no year specific data available. Data were also aggregated at regional level. The few regions in the analysis most likely contributed to a reduced geographical variation in the coverage of interventions. A more appropriate approach would have been to further disaggregate the regions according to rural/urban type.

Concluding, the most effective interventions related to U5MR at national level is the DPT3 immunization, followed by the baby post-natal check within 24 hours, exclusive breastfeeding, measles immunization, all antigen immunization, and vitamin A. Low coverage of DPT3 immunization was observed in Cascades, Plateau Central, and Est; of baby post-natal check in Cascades, Centre Est, and Sud-Ouest; and of exclusive breastfeeding in Centre, Sud-Ouest, Boucle du Mouhoun, and Hauts Bassins. Skilled birth and antenatal care attendance are the most effective maternal interventions and should be reinforced in the regions of Sahel, Sud-Ouest, Nord, and Est. Child survival can be enhanced by increasing the coverage of improved drinking water in Sahel, Sud-Ouest, and Boucle du Mouhoun and the coverage of improved sanitation in Est, Centre-Sud, Sahel, and Sud-Ouest.

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2.6 Appendix

Table A.2.1: Description of the intervention coverage indicators used in the study

Interventions	Definition
Child interventions	
Use of ITN by under-five years	Proportion of children under 5 years in a household who slept under an ITN the previous night of the survey
Malaria treatment	Proportion of children under 5 years in a household who received any antimalarial in the two before the survey
Exclusive breastfeeding	Proportion of infants exclusively breastfed during the first six months after birth
Breastfeeding within 24 hours	Proportion of infants who started breastfeeding within one day after birth
Baby post-natal check within 24 hours	Proportion of infants who have been checked within one day after birth
Measles immunization	Proportion of children who received vaccination of measles
DPT3 immunization	Proportion of children who received vaccination of DPT3
All antigen immunization	Proportion of children who received vaccination of BCG, Polio3 DPT3 and measles
Vitamin A supplementation	Proportion of children receiving vitamin A supplements in the past 6 months
Maternal health interventions	
Skilled birth attendance	Proportion of births that took place with the assistance of a skilled provider
Antenatal care visits	Proportion of pregnant mothers receiving ANC from a skilled provider
Family planning	Proportion of married women using any family planning method
Intermittent preventive treatment (IPT)	Proportion of women who received intermittent preventive treatment for malaria during pregnancy
Household health interventions	
Improved sanitation	Proportion of households using improved sanitation facilities
Improved drinking water	Proportion of households with improved source of drinking water
Household ownership of nets	Proportion of household with at least one net

Table A.2.2: Climatic covariates, sources and spatial and temporal resolution. Data were extracted during the year of 2010.

Data Type	Source	Spatial resolution	Temporal resolution
Day/Night Land surface Temperature (LST)	MODIS/Terra[1]	1x1 km^2	8 days
Normalized Difference Vegetation Index (NDVI)	MODIS/Terra[1]	1 x 1 km^2	16 days
Land Cover	MODIS/Combined[1]	0·5 x 0·5 km^2	NA
Rainfall	FEWS NET[2]	8x8 km^2	10 days
Urban rural extent	Global Rural and Urban Mapping project (GRUMP)[3]	1 x 1 km^2	NA

[1]Moderate Resolution Imaging Spectroradiometer (MODIS):
[2]Famine Early Warning System (FEWS) Network: https://earlywarning.usgs.gov/
[3]Socioeconomic Data and Applications Center (SEDAC): http://sedac.ciesin.columbia.edu/data/set/grump-v1-settlement-points

Table A.2.3: Hazard rates ratio (posterior median and 95% Bayesian credible intervals) of child, maternal, household socio-demographic and climatic factors used to adjust the association between child health interventions and U5MR. Estimates are obtained by Bayesian geostatistical Weibull proportional hazards model with spatially varying regression coefficients for the intervention coverage covariates.

Covariates		All antigen immunization	DPT3 immunization	Measles immunization	Malaria treatment	ITN use	Baby post-natal check within 24h	Breastfeeding within 24 hours	Exclusive breastfeeding	Vitamin A
Child characteristics		HR (95% BCI)[1]	HR (95% BCI)	HR (95% BCI)	HR (95% BCI)	HR (95% BCI)	HR (95% BCI)	HR (95% BCI)	HR (95% BCI)	HR (95% BCI)
Sex	*Male*	1·16 (1·89-1·28)	1·16 (1·02-1·21)	1·14 (1·01-1·29)	1·13 (1·07-1·19)	1·17 (1·05-1·21)	1·09 (0·94-1·22)	1·16 (1·01-1·18)	1·13 (1·04-1·19)	1·20 (1·07-1·26)
Place of residence	*Rural*	1·99 (1·76-2·16)	4·10 (3·35-4·27)	1·83 (1·20-2·25)	1·11 (1·06-1·31)	1·98 (1·52-2·18)	1·32 (1·23-1·65)	1·36 (1·03-1·57)	1·35 (1·23-1·45)	1·49 (1·31-1·86)
Place of birth	*Home*	1·36 (1·19-1·45)	1·21 (1·16-1·32)	1·28 (1·14-1·47)	1·26 (1·18-1·45)	1·28 (1·12-1·29)	1·22 (1·12-1·35)	1·40 (1·04-1·49)	1·32 (1·27-1·40)	1·20 (1·19-1·41)
Birth order	*< 5*	0·66 (0·57-0·71)	0·66 (0·49-0·70)	0·66 (0·54-0·79)	0·61 (0·52-0·73)	0·64 (0·59-0·77)	0·64 (0·59-0·80)	0·70 (0·58-0·75)	0·62 (0·51-1·15)	0·73 (0·67-0·73)
Maternal characteristic										
Age at first birth (years)	*>19*	0·98 (0·84-1·02)	0·94 (0·83-1·06)	0·98 (0·86-1·06)	0·93 (0·86-1·14)	0·96 (0·93-1·00)	0·88 (0·84-0·98)	0·95 (0·87-1·00)	0·95 (0·92-1·03)	1·03 (0·87-1·07)
Number of live births	*>5*	2·71 (2·50-3·47)	2·97 (2·50-3·56)	2·64 (2·25-3·09)	2·89 (2·47-3·03)	2·65 (2·00-2·68)	2·52 (2·37-2·72)	2·77 (2·57-2·90)	2·81 (1·77-3·18)	2·59 (1·83-2·66)
Age group (years)	*<19*	1·93 (1·79-2·35)	1·89 (1·59-1·97)	1·78 (1·55-2·05)	1·92 (1·56-1·99)	1·77 (1·58-1·78)	1·66 (1·53-1·79)	1·83 (1·62-1·92)	1·86 (1·51-2·13)	1·64 (1·31-1·76)
	>=35	1·61 (1·48-1·79)	1·64 (1·39-1·70)	1·57 (1·34-1·85)	1·67 (1·26-1·84)	1·51 (1·29-1·56)	1·46 (1·25-1·58)	1·68 (1·58-1·82)	1·70 (1·42-1·72)	1·51 (1·32-1·69)
Education	*No education*	1·37 (1·27-1·44)	1·22 (1·02-1·37)	1·29 (1·00-1·60)	1·16 (1·13-1·50)	1·34 (1·20-1·38)	1·35 (1·20-1·45)	1·22 (1·06-1·47)	1·31 (1·07-1·59)	1·32 (1·27-1·49)
Household characteristics										
Asset index	*Middle*	0·90 (0·80-1·00)	0·82 (0·74-1·18)	0·89 (0·76-1·02)	0·84 (0·75-0·95)	0·83 (0·74-1·14)	0·86 (0·72-1·11)	0·97 (0·78-1·03)	0·83 (0·77-0·88)	0·76 (0·74-1·18)
	Poorer	1·00 (0·88-1·06)	1·11 (1·04-1·26)	0·99 (0·87-1·14)	0·98 (0·89-1·10)	1·23 (1·17-1·39)	0·98 (0·88-1·21)	1·05 (1·02-1·09)	0·94 (0·84-1·08)	0·93 (0·82-1·25)
Climatic covariates										
Land cover type	*Savannah vs grass*	1·18 (1·10-1·35)	1·15 (0·92-1·25)	1·09 (0·92-1·30)	1·24 (1·05-1·28)	1·09 (0·99-1·12)	0·96 (0·92-1·14)	1·10 (0·97-1·31)	1·34 (1·08-1·36)	1·09 (0·92-1·37)
LSTD		1·03 (0·99-1·14)	0·96 (0·84-1·11)	0·96 (0·84-1·07)	1·00 (0·83-1·10)	0·95 (0·88-1·01)	1·00 (0·91-1·12)	0·94 (0·88-1·05)	0·91 (0·84-0·95)	1·05 (0·95-1·05)
LSTN		1·77 (1·53-1·94)	1·05 (0·86-1·53)	1·43 (1·08-1·59)	0·35 (0·29-0·65)	4·44 (2·65-4·94)	1·06 (0·96-1·23)	2·02 (1·80-2·47)	1·70 (1·46-1·84)	0·71 (0·59-0·78)
NDVI		1·18 (1·06-1·30	1·52 (1·25-1·93)	0·09 (0·07-0·12)	1·54 (1·45-1·83)	0·30 (0·21-0·41)	1·35 (1·23-1·85)	0·49 (0·39-0·54)	0·66 (0·57-0·72)	1·52 (1·24-1·72)
Rainfall		0·91 (0·88-1·01)	0·94 (0·91-1·04)	0·92 (0·84-1·02)	0·91 (0·84-0·93)	0·97 (0·92-1·00)	0·92 (0·81-1·03)	0·92 (0·88-0·99)	0·96 (0·90-1·00)	0·98 (0·92-0·98)
Distance to water body		0·99 (0·95-1.03)	1·05 (0·96-1·13)	1·04 (0·96-1·12)	1·07 (0·98-1·08)	1·05 (0·96-1·11)	1·08 (1·00-1·09)	1·01 (0·97-1·07)	1·04 (0·97-1·06)	1·07 (0·96-1·09)

[1] HR: Hazard ratio, BCI: Bayesian credible interval; [2]Bold numbers indicate a statistically important effect

Table A.2.4: Hazard rates ratio (posterior median and 95% Bayesian credible intervals) of child, maternal, household socio-demographic and climatic factors used to adjust the association between maternal and household health interventions and U5MR. Estimates are obtained by Bayesian geostatistical Weibull proportional hazards models with spatially varying regression coefficients for the intervention coverage covariates.

Covariates		SBA	ANC	Family planning	IPT	Safe drinking water	Sanitation	Household ownership of nets
Child characteristics		HR (95% BCI)	HR (95% BCI)	HR (95% BCI)	HR (95% BCI)	HR (95% BCI)	HR (95% BCI)	HR (95% BCI)
Sex	*Male*	1·14 (1·07-1·24)	1·14 (1·01-1·16)	1·16 (1·10-1·24)	1·10 (0·97-1·23)	1·12 (1·06-1·13)	1·15 (0·95-1·22)	1·13 (1·02-1·22)
Place of residence	*Rural*	1·69 (1·45-2·01)	1·16 (1·06-1·26)	0·92 (0·85-1·20)	1·13 (1·03-1·32)	1·22 (1·12-1·63)	0·85 (0·67-1·11)	0·10 (1·08-1·12)
Place of birth	*Home*	1·15 (1·06-1·17)	1·30 (1·14-1·42)	1·25 (1·13-1·33)	1·30 (1·09-1·40)	1·28 (1·15-1·37)	1·25 (1·10-1·38)	1·36 (1·18-1·39)
Birth order	*< 5*	0·64 (0·52-0·77)	0·65 (0·61-0·84)	0·61 (0·52-0·70)	0·68 (0·56-0·78)	0·69 (0·63-0·75)	0·66 (0·57-0·81)	0·67 (0·60-0·70)
Maternal characteristic								
Age at first birth	*>19*	1·01 (0·87-1·06)	1·01 (0·84-1·03)	0·95 (0·85-1·06)	0·94 (0·88-1·08)	0·97 (0·89-1·07)	0·95 (0·84-1·06)	0·95 (0·85-1·00)
Number of live births	*>5*	2·75 (2·26-2·87)	2·65 (2·37-2·80)	2·78 (2·24-3·31)	2·49 (2·14-2·88)	2·41 (2·26-2·41)	2·62 (2·19-3·35)	2·43 (2·28-2·85)
Age group (years)	*<19*	1·60 (1·46-1·65)	1·64 (1·60-1·74)	1·86 (1·48-2·04)	1·65 (1·44-1·90)	1·70 (1·50-1·86)	1·72 (1·55-2·13)	1·66 (1·41-1·83)
	>=35	1·42 (1·29-1·51)	1·47 (1·38-1·67)	1·63 (1·44-1·87)	1·54 (1·34-1·84)	1·53 (1·38-1·57)	1·64 (1·44-1·85)	1·42 (1·26-1·79)
Education	*No education*	1·25 (1·15-1·42)	1·17 (1·09-1·32)	1·19 (1·11-1·53)	1·26 (1·17-1·33)	1·43 (1·28-1·58)	1·32 (1·17-1·51)	1·24 (1·26-1·79)
Household characteristics								
Asset index	*Middle*	0·78 (0·73-1·10)	0·84 (0·79-1·15)	0·81 (0·72-0·88)	0·84 (0·68-1·05)	0·76 (0·72-0·87)	0·82 (0·71-1·06)	0·80 (0·71-0·85)
	Poorer	1·16 (1·02-1·34)	0·89 (0·77-1·20)	1·11 (1·04-1·27)	0·90 (0·76-1·19)	0·94 (0·81-1·02)	0·96 (0·86-1·10)	0·94 (0·85-1·00)
Climatic covariates								
Land cover type	*Savannah vs grass*	1·10 (1·00-1·19)	1·12 (1·06-1·24)	1·11 (0·99-1·27)	1·07 (0·96-1·19)	1·14 (0·99-1·26)	1·12 (0·95-1·23)	1·08 (0·97-1·20)
LSTN		0·99 (0·87-1·04)	0·97 (0·82-1·07)	0·87 (0·79-0·92)	0·89 (0·82-1·04	0·89 (0·86-0·94)	0·94 (0·83-1·07)	0·97 (0·84-1·00)
LSTD		1·67 (1·47-2·53)	1·89 (1·18-2·05)	5·28 (4·56-5·70)	0·13 (0·10-0·19)	1·02 (0·65-1·11)	1·06 (0·96-1·24)	1·12 (1·05-1·32)
NDVI		1·45 (1·23-1·86)	1·05 (0·96-1·16)	0·20 (0·18-0·23)	8·30 (5·67-10·18)	1·88 (1·53-1·96)	1·47 (1·32-1·96)	1·76 (1·64-2·21)
Rainfall		0·94 (0·91-1·01)	0·99 (0·96-1·05)	0·86 (0·79-0·90)	0·95 (0·90-1·01)	0·91 (0·85-0·97)	0·94 (0·86-1·00)	0·93 (0·85-1·00)
Distance to water body		1·06 (1·00-1·10)	1·05 (1·03-1·11)	1·04 (1·00-1·08)	1·03 (0·95-1·11S)	1·04 (0·99-1·12)	1·04 (0·96-1·14)	1·03 (0·96-1·08)

[1]HR: Hazard ratio, BCI: Bayesian credible interval; [2]Bold numbers indicate a statistically important effect

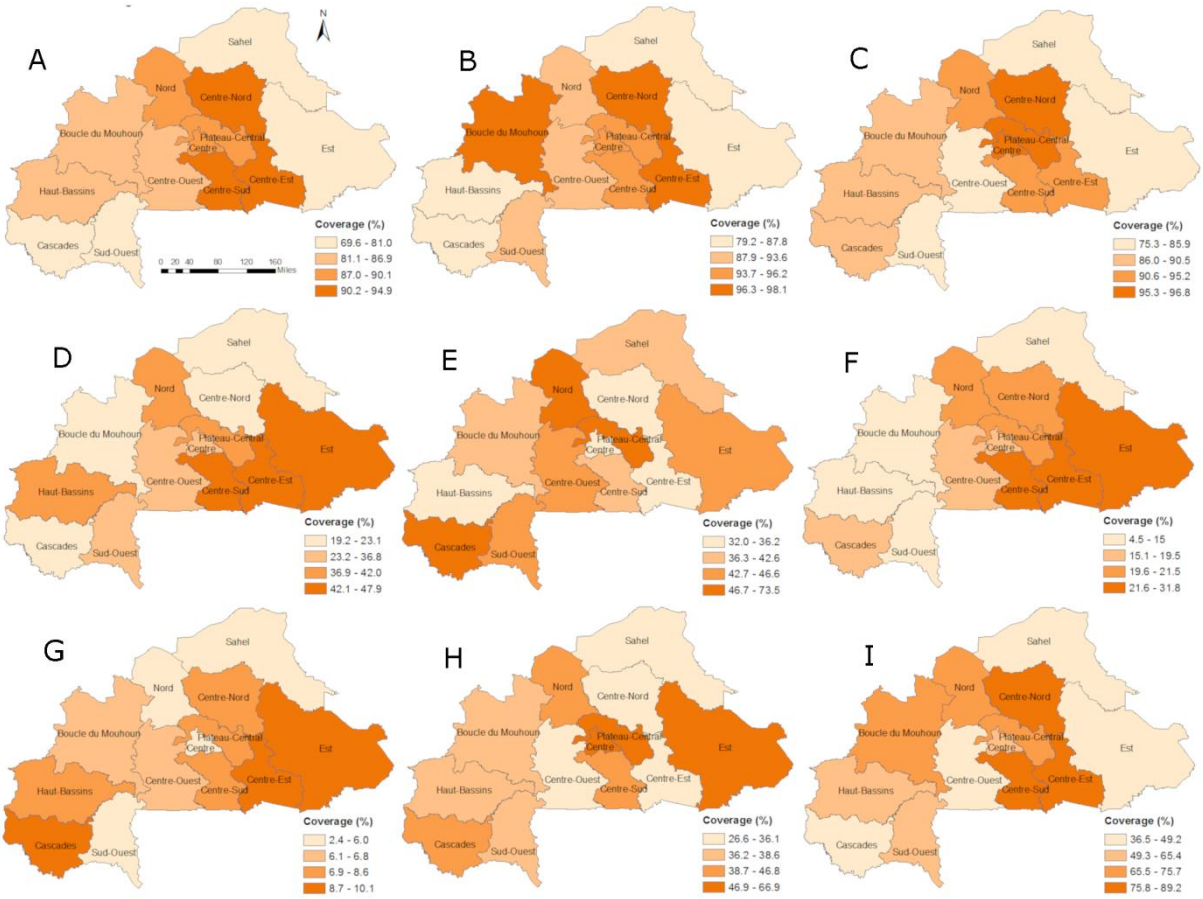

Figure A.2.1: Geographical distribution of the coverage of child health interventions. The coverage are based on quartile cut-offs: (A) all antigen immunization, (B) DPT3 immunization, (C) measles immunization, (D) malaria treatment, (E) ITN use, (F) baby post-natal check, (G) exclusive breastfeeding, (H) breastfeeding within 24 hours, (I) vitamin A supplementation.

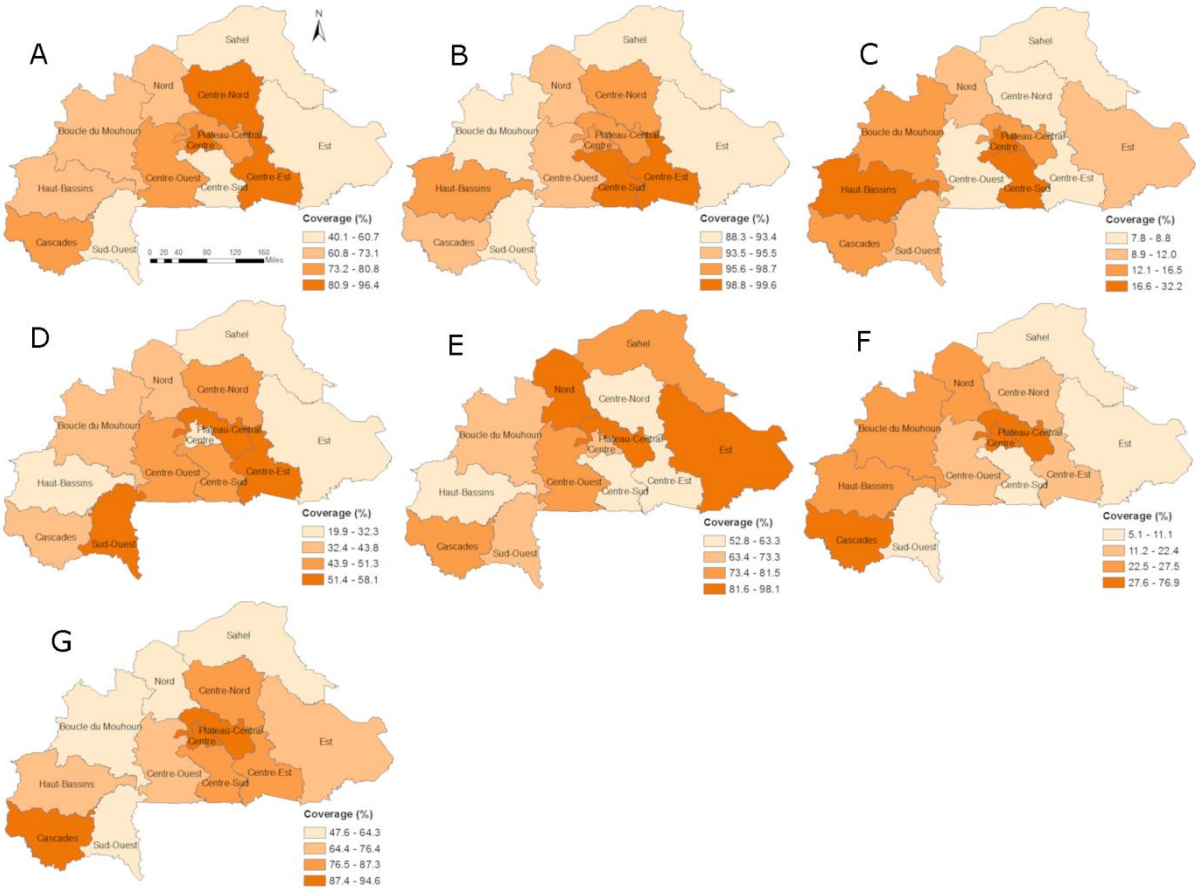

Figure A.2.2: Hazard rates ratio (posterior median and 95% BCI) of child (A) and maternal and household (B) health interventions estimated by Bayesian geostatistical Weibull proportional hazards models with spatially varying regression coefficients for the intervention coverage covariates. Data from DHS 2010, Burkina Faso. The horizontal line corresponds to a HRR equal to one.

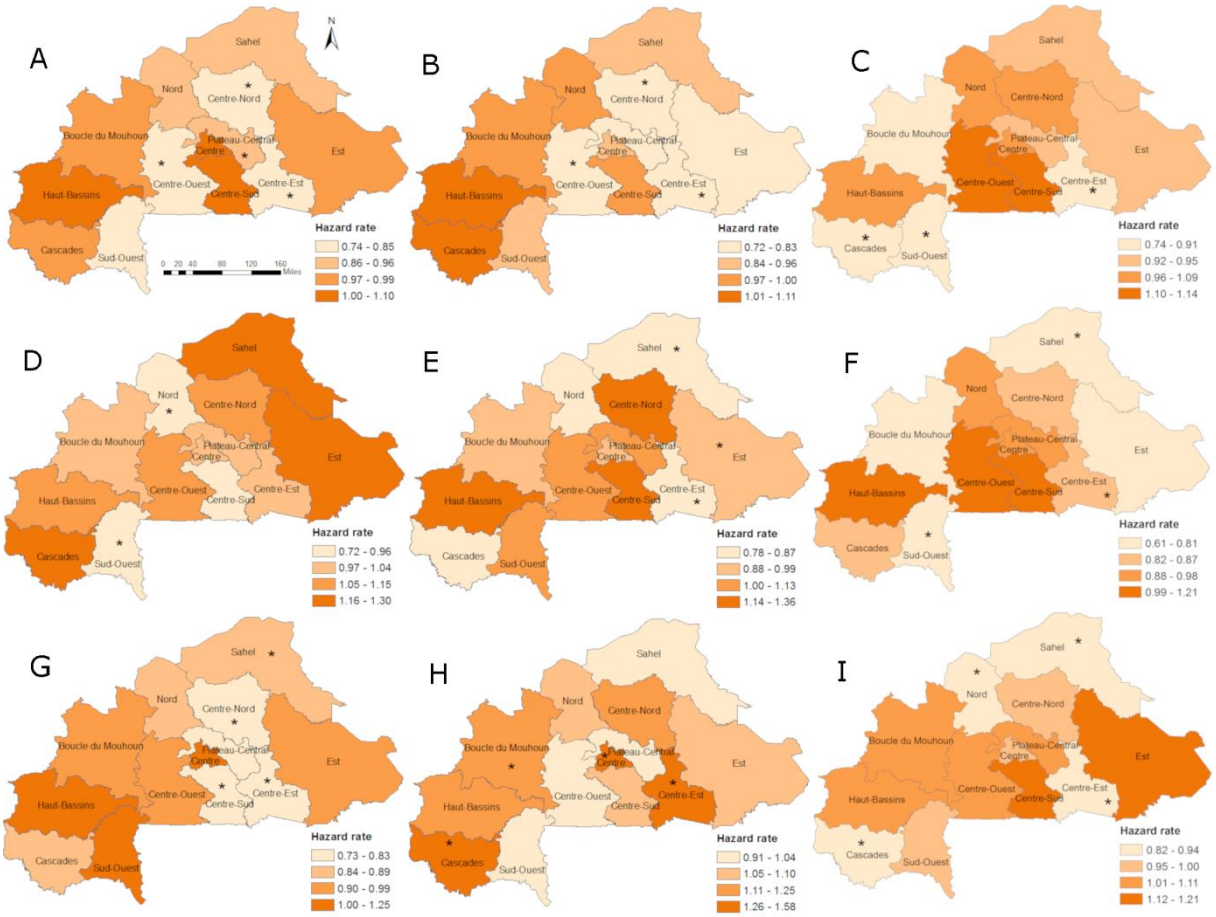

Figure A.2.3: Spatially varying effects of child health interventions on U5MR. Hazard rates ratio estimates (posterior median) obtained by Bayesian geostatistical Weibull proportional hazards model with spatially varying regression coefficients for the intervention coverage covariates. The distribution of the hazard rates ratio are based on quartile cut-offs: (A) all antigen immunization, (B) DPT3 immunization, (C) measles immunization, (D) malaria treatment, (E) ITN use, (F) baby post-natal check, (G) exclusive breastfeeding, (H) breastfeeding within 24 hours, (I) vitamin A supplementation.

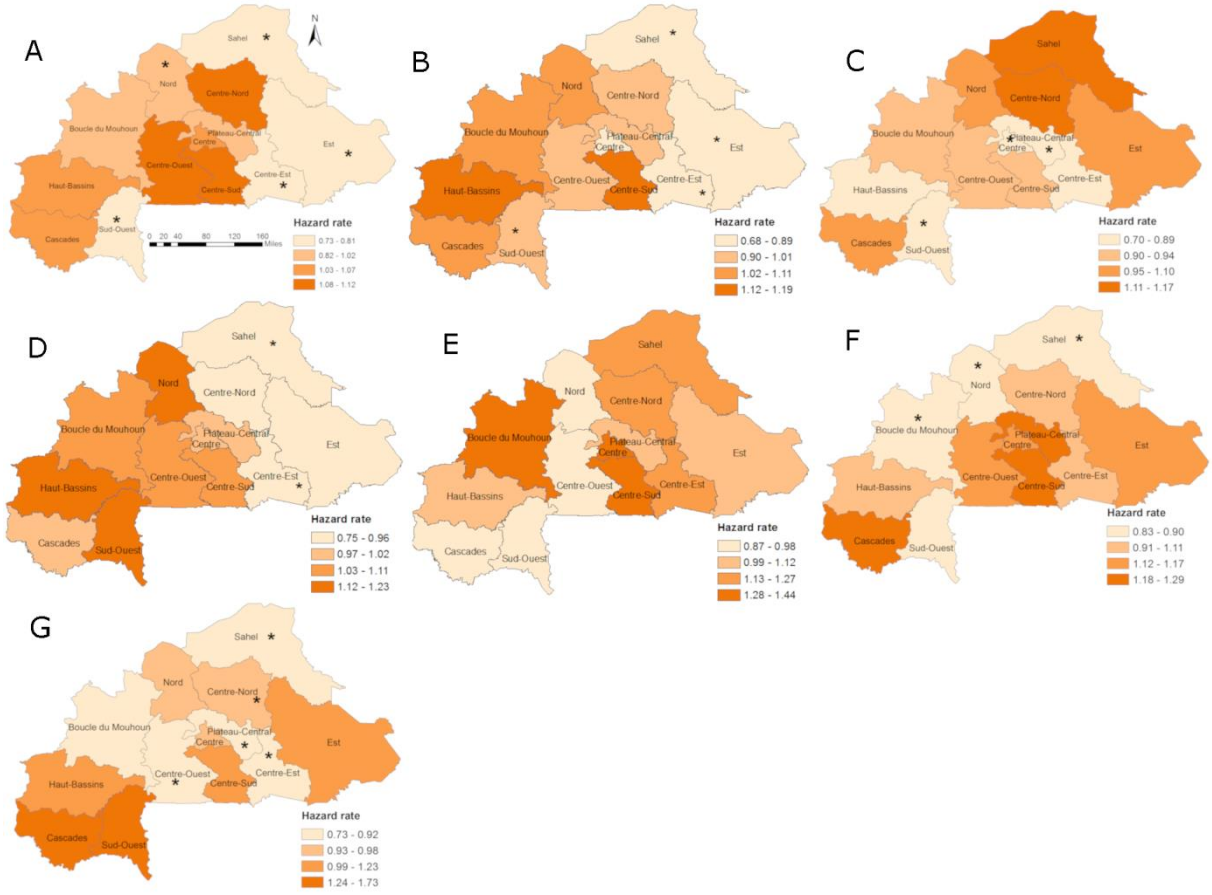

Figure A.2.4: Spatially varying effects of maternal and household health interventions on U5MR. Hazard rates ratio estimates (posterior median) obtained by Bayesian geostatistical Weibull proportional hazards model with spatially varying regression coefficients for the intervention coverage covariates. The distribution of the hazard rates ratio are based on quartile cut-offs: (A) skilled birth attendance, (B) skilled antenatal care, (C) family planning, (D) intermittent preventive treatment of malaria in pregnancy, (E) household ownership of bednets, (F) improved sanitation, (G) improved drinking water.

Chapter 3: Geographical variation in the association between childhood diseases and under-five mortality in Burkina Faso

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Abstract

Background

Preterm birth complications, pneumonia, sepsis, diarrhoea, malaria and intrapartum related events constitute the leading causes of under-5 deaths in sub-Saharan Africa. The prevalence are however heterogeneous within countries. We aimed to assess the association of selected childhood diseases and under-5 mortality adjusting for the coverages of health intervention, climatic and environmental factors at the national and subnational scale in Burkina Faso.

Methods

We calculated the prevalence of malaria parasitemia, acute respiratory conditions, severe anaemia, diarrhoea, malnutrition and low birth weight from the Demographic and Health Survey (DHS) 2010. We carried out Bayesian geostatistical survival analysis, modelling the mortality by cox proportional hazard model with Weibull baseline function. We incorporated spatially varying coefficient to account for the spatial correlation of the mortality. The spatial structure was modelled with conditional autoregressive prior. All the analyses were adjusted for child, mothers, climatic and environmental factors and health interventions coverages. Models were fitted using Markov chain Monte Carlo (MCMC) simulation.

Results

The under-five mortality rate (U5MR) was about 132‰, ranging from 73‰ (region of Centre) to 230‰ (region of Sud Ouest). The average prevalence at country level were 72.21% for malaria positive parasitemia, 21.68% for acute respiratory conditions, 15.86% for diarrhea, 13.8% for low birth weight, 10.06% for severe anemia, and 7.5% for severe acute malnutrition. Each of these diseases was associated with an increase of mortality hazard at the national and regional levels. Malaria positive parasitemia was the predominant factor associated with the under-5 survival over six out of 13 administrative regions. It inflate the mortality hazard by 25% (HRR=1.25, BCI: 1.07-1.47) in the region of Sud-Ouest. Low birth was the second important factor associated with child mortality in four regions and amplifying the mortality hazard by 42% of excess (HRR=1.42, BCI: 1.05-1.77) in in the region of Hauts Bassins. Severe anaemia was associated with child survival in 3 regions. No childhood diseases assessed were associated with child survival in the regions of Centre and Centre-Est.

Conclusion

The pattern of the effects of childhood disease on U5M varies by administrative region. Malaria is the leading cause of under-five deaths. The geographical heterogeneity of the effects of childhood diseases is a disease-specific policy-driven mean for policy-makers for resources and health interventions allocation to reduce U5MR in Burkina Faso.

Keys words: Demographic and health survey, Burkina Faso, Bayesian Weibull survival, spatial varying effect, under-five survival.

3.1 Introduction

Under-5 mortality rate (U5MR) remains a significant public health challenge in sub-Saharan Africa. The main causes of under-five deaths are preterm birth complications, pneumonia, sepsis, diarrhoea, and intrapartum related events. They are almost preventable or treatable with available cost-effective life-saving interventions. Their scaling up of these proven health interventions during the Millennium Developments Goals (MDGs) era contributed to reducing significantly U5MR in sub-Saharan Africa (Liu et al., 2016; Uthman, 2016). However, still out of every 12 children did not reach their fifth birthday (WHO, 2015). The Sustainable Developments Goals (SDGs) related to under-5 is to reduce the U5MR below at least 25‰ by 2030 compared to its baseline rate of 2015 (WHO, 2016). Achieving this goal depends on the pace of the annual reduction rate of U5MR across sub-Saharan Africa. In Burkina Faso, from 1990 to 2015, the U5MR decreased from 202 to 89‰ consisting of a 3.3% of annual reduction rate. To contribute to achieving the U5MR objective by 2030, at least a 4% annual reduction rate is required. Monitoring the progress of reducing U5MR and health interventions coverage is usually limited to national country level averages. Consequently, the subnational heterogeneities are hidden. As well, the subnational distribution of the causes of under-5 deaths is disparate and linked with the individual, family, and local climatic and environmental risk factors (Arku et al., 2016; Gayawan et al., 2016; Noronha et al., 2013). Burke and al. estimated that about 75% of under-five mortality variability could be explained by local factors (Burke et al., 2016). Additionally to the risks factors above, the health system indicators and the coverages of health interventions are other drivers of the spatial variability of under-5 causes of death (Moreno-Serra and Smith, 2012; Muldoon et al., 2011). Another determinant of spatial pattern of childhood co-morbidities is the socio-economic factors reported by associated with U5MR (Kazembe and Namangale, 2007; Kazembe and Nickanor, 2017).

Burkina Faso has three distinct climatic and environmental bands with a relatively large variation of temperatures, rainfall and land cover. Furthermore, 40% of households live under the poverty threshold, with 60% in rural area. About 60% of the poorest households live in 5 of 13 regions of the country (Ministère de l'Economie et des Finances, INSD, 2015). All these factors leverage the incidence and prevalence of diseases responsible for the majority of under-5 deaths. As well, malaria is endemic in the whole country, but the incidence is pronounced in the regions of Boucle du Mouhoun, Centre-Est Hauts Bassins, Centre. Acute malnutrition is dominant in the regions of Est and Boucle du Mouhoun. The regions of Sahel, Nord and Centre are the most affected by acute respiratory infections (Ministère de la santé, 2018). Thus the geographical variation of the burden of the childhood disease shaped the survival of under-fives years old children in Burkina Faso. The U5MR reported by the demographic and health survey (DHS) of 2010 was about 128‰. The regions of Centre-Est (80‰) and Centre (93‰) had the lowest while Sud-Ouest (195‰) and Sahel (235‰) exhibited the highest rates. Therefore, assessing the effects and the contribution of the leading causes of under-5 deaths on the U5MR at the national and subnational level can serve as guidance to areas and diseases-specific allocation. Few studies had focused on the subnational assessment of childhood disease in sub-Saharan Africa. Kazembe and al. in Malawi evaluate the spatial pattern of the different combination of fever, diarrhoea and pneumonia using the Bayesian approach. In Burkina Faso, to our

knowledge, no similar study has been carried out. We aimed to assess the effects of the main childhood diseases on child survival taking into account individual, climatic and environmental factors and the coverages of health interventions at the national and subnational scale. Our findings will bring evidence for policymakers to increase the impact of the scarce resources by targeting areas and disease adequately and accelerate the pace towards the achievement of the under-five related SDGs.

3.2 Methods

3.2.1 Study area

Burkina Faso is a low-income country with 40.1% of the population living below the poverty threshold and 0.402 as Human Development Index (HDI) (PNUD, 2016). Located in West Africa, between 9° 20' and 15° north latitude and between 5° 30' west longitude and 2° 30' east longitude Burkina Faso is characterised by three (3) distinct climatic areas (Ibrahim, 2012):

- the Sahelian zone above the 14° north parallel covers about 25% of the territory. The annual average of rainfall varies between 300 and 600 mm. The rainy season often lasts for less than 2 months per year;
- the Sudano-Sahelian zone situated between 11° 30' and 14° north parallels covering approximately 50% of the territory. The rainfall varies between 600 and 900 mm (3 to 4 months of rain per year) and;
- the Sudanian zone south of north parallel 11° 30' which covers about 25% of the territory and the rainfall varies between 900 and 1200 mm (4 to 6 months of rain per year).

This geographical difference of the climate is associated with individual, economic and health system factors to modulate the annual incidence of under-five related leading causes of death. The climatic factors shape malaria's annual seasonality (rainy period), acute respiratory infections, malnutrition (mostly in the dry period).

3.2.2 Data source and information collected

The demographic and health survey (DHS) is a nationally representative standard survey that compensates for the lack of the civil vital registration system in countries such as Burkina Faso. The sample of Burkina Faso DHS 2010 was about 14 536 households in 574 georeferenced clusters. The sample accounted for 15 375 under-5 years old children.

In the DHS procedure, each woman's full birth history provides adequate information for survival analysis, thanks to the recording of the date of birth and death of each child. We extracted information related to 1):

- severe anaemia; (defined as haemoglobin rate less than 7g/dl,2),
- malaria (defined as the positive smear, 3)
- acute respiratory conditions constituted by the presence of cough, fever and nose running or chest block,
- diarrhoea defined as the presence of diarrhoea in the past two weeks,
- acute severe malnutrition defined as weight for age less than 3 standard deviations and

- low birth weight defined as a baby birth weight less than 2500 kg.

Besides, we include socio-demographic factors such as child sex, the birth order, the place of delivery, and residence. The covariates related to the mothers were the age group, the age at first delivery, the education level and the number of lived births. According to household factor's, we focused on the wealth index categorised into three modalities (low, moderate and high level).

Table A.3.1 in appendices illustrates the definition and the health interventions relative to children, mothers and household computed to adjust our analysis. Finally, remote sensing climatic and environmental information related to the land surface temperature (LST), the vegetation index, the distance to water bodies, and the type of land cover were also gathered for adjustment seek. Table A.3.2 in appendices precise the source, the spatial and the temporal resolution.

3.2.3 Statistical analysis

We fit Bayesian geostatistical model build on Weibull baseline function to assess the association between child survival (U5MR) and the selected childhood diseases. We adjusted the model for individual (children, mother, and household), health interventions and climatic and environmental covariates. Bivariate analysis was firstly carried out to select the associated covariates (diseases).

We extended the Bayesian geostatistical model, including spatially varying coefficient, to estimate the diseases' effect at the subnational (regional) level. The spatial correlation was introduced via a Gaussian process, adopted on cluster-specific random effects with an exponential correlation function of the distance between survey clusters. Spatially varying regression coefficients for the interventions were used to capture the geographical variation of the association's at the subnational level and were modelled by random regional effects with a conditional autoregressive prior distribution. That is, we introduced spatial dependence among the regions via a conditional autoregressive (CAR) prior. Appendix Text B.3 resumes the formulation of the models. The Bayesian model parameters were estimated using Markov Chain Monte Carlo (MCMC) simulation via OpenBUGS version 3.2.3 (Imperial College and Medical Research Council; London, UK). Maps were produced in ArcGIS version 10.2.1 (Esri Inc.; Redlands, CA) and graphs in R (R Core Team; Vienna, Austria). We run two chains algorithm for 300 000 iterations with an initial burn-in of 15,000 iterations. Convergence was assessed by the Gelman and Rubin diagnostic (Gelman and Rubin, 1992). Parameter estimates were summarised using their posterior median and the corresponding 95% Bayesian Credible Interval (BCI). The bivariate analyses were carried out in STATA version 15 (StataCorp.; College Station, TX, USA). Variables with a p-value less than 0.15 were included in the geostatistical model.

3.3 Results

3.3.1 Background characteristics of the sample.

We analyse clusters with complete records. The sample size was large as 483 (85%) clusters and accounting for 11 084 (72%) under-5 years' old children. In total, 1109 (9.19%) children died before their fifth birthday. The U5MR was 132‰ ranging from 73‰ (region of Centre) to 230‰ (region of Sud-Ouest). Figure 3.1 shows the spatial variation of U5MR.

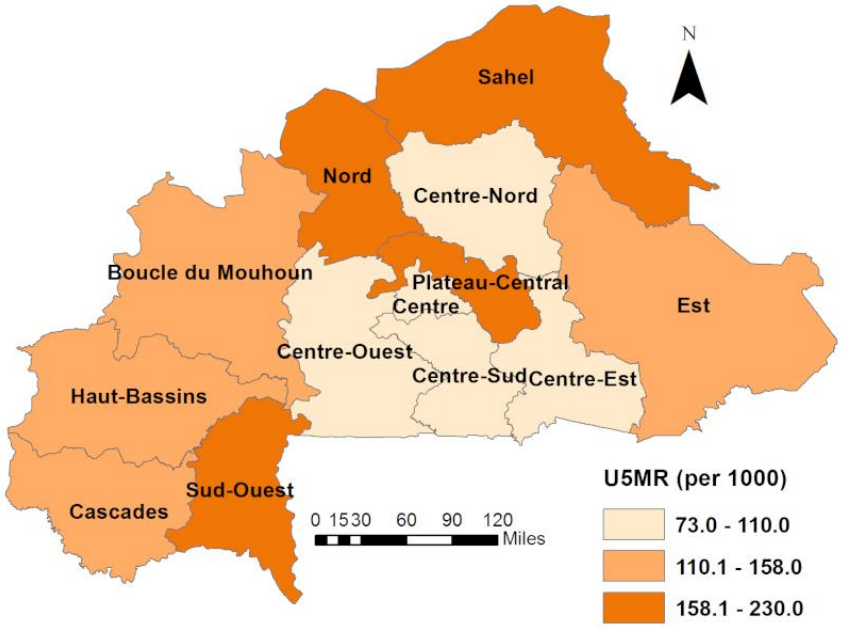

Figure 3.1: Geographical distribution of the U5MR in Burkina Faso, 2010.

Male and female were equally represented; most of the children lived in rural areas (90.41%), 63.29% are born in health facilities and around one-quarter were born after the fifth rank.

About 4.7% of the mothers were younger than 19 years, 67% experienced their first delivery at this age and 10% of mothers had more than five children. Nearly 12% of mothers had primary or above educational level. Relative to the household wealth index, about 46% belong to the low level. Table 3.1 summarises the background characteristics of the sample.

3.3.2 Burden of diseases and the coverage of health interventions

The country average prevalence of positive smear (parasitemia) of malaria was 72.2%. The regions of Boucle du Mouhoun (82.0%) and Sud-Ouest (80.5%) bear the highest prevalence while the region of Centre conveys the lowest (<50%). The prevalence of severe anemia was 10.1%. The regions of Sud-Ouest, Est and Nord were the most affected by severe anaemia with 16.2, 15.8% and 12.7%, respectively. Unlikely, the prevalence of severe anaemia was low in the region of Centre with 1.76%. The prevalence of acute respiratory conditions (cough, fever and nose running or chest block) was particularly high in the regions of Sud-Ouest (32.7%) and Centre-Sud (35.2%) compared to the national average of 21.7%. The countrywide prevalence of diarrhoea was high as 15.9%, with regions Hauts Bassins, Centre Sud and Centre Ouest showing the highest prevalence. Centre-Est, Centre-Nord and Centre-Sud exhibit the highest prevalence of low birth weight. The Detailed results are indicated in table 3.2. The distribution of the diseases is also provided as a map in figure A.3.1 in the appendix.

In terms of co-morbidities, the region of Sahel bears simultaneously high prevalence of malaria, severe anaemia and malnutrition. The most frequent overlap of diseases is the acute respiratory conditions and diarrhoea encountered in Centre-East, Centre-Sud, Hauts Bassins and Sud-Ouest.

The health interventions can be grouped into three groups, relatively to their coverage:

- health interventions with coverage above 70%: immunisation, ownership of nets, antenatal visit, and safe drinking water.
- Health interventions with coverage ranging from 50% to 70% are skilled birth attendance and vitamin A supplementation.
- Those with coverage below 50% are exclusive breastfeeding and family planning.

The regional distribution of the intervention coverage's indicates that Sahel, Sud-Ouest, Centre Ouest, and Est have the lowest health interventions coverage in general.

3.3.3 Bivariate analysis

Table 3.1 resumes the results of the bivariate analysis. Except the sex of the child, the socio-demographic factors are associated with child survival. Concerning the health interventions, only immediate breastfeeding, malaria treatment and intermittent preventive treatment of malaria in pregnant women are not associated with child survival. the childhood diseases significantly associated with child survival are malaria positive parasitemia (hazard rate ratio (HRR) =1.07, 95% CI: 1.01-1.13), acute severe malnutrition (HRR=1.11, 95% CI: 1.05-1.87) and severe anemia (HRR=1.08, 95% CI: 1.01-1.16).

There was no significant association between acute respiratory conditions, low birth weight, diarrhoea and child survival.

Table 3.1: Background characteristics of the sample and crude hazard rate of bivariate analysis

Covariates	N = 11,084	Number of death (%)	HRR (95% CI)	P-Value
Children characteristics				
Sex				
Female	5,605 (50.6)	482 (8.8)	1	
Male	5,479 (49.4)	537 (9.6)	1.11 (0.98-1.25)	0.109
Place of residence				
Urban	1,063 (9.6)	63 (6.0)	1	
Rural	10 021 (90.4)	956 (9.5)	1.63 (1.26-2. 10)*	<0.001
Place of delivery				
health facility	7 015 (63.3)	531 (7.6)	1	
Home	4 069 (36.7)	488 (12.0)	1.46 (1.29-1.65)*	<0.001
Birth order				
1-5	8 287 (74.8)	727 (8.8)	1	
>5	2 797 (25.2)	292 (10.4)	1.23 (1.07-1.41)*	0.003
Mothers characteristics				
Mother age group				
<19	519 (4.7)	68 (13.2)	1	
20-35	7922 (71.5)	681 (8.6)	0.45 (0.35-0.58)*	<0.001
≥35	2 643 (23.89)	269 (10.12)	0.51 (0.39-0.67)*	<0.001
Age at first birth				
≤19	7 475 (67.4)	300 (8.3)	1	
>19	3 610 (32.6)	720 (9.6)	1.67 (1.02-1.34)*	0.025
Number of live birth				
1-5	7 803 (70.4)	631 (8.1)	1	

>5	3 281 (9.6)	388 (11.8)	1.44 (1.27-1.63)*	<0.001
Mother education level				
primary and above	1 315 (11.9)	75 (5.7)	1	
no education	9 769 (88.1)	945 (9.7)	1.69 (1.34-2.14)*	<0.001
Households characteristics				
Household asset index				
richest	3 405 (30.7)	230 (6.8)	1	
Middle	2 612 (23.6)	243 (9.3)	1.41 (1.18-1.69)*	<0.001
Poorer	5 067 (45.7)	546 (10.8)	1.62 (1.39-1.89)*	<0.001
Health interventions				
Related to under-five				
All vaccines immunisation			0.88 (0.83-0.94)*	<0.001
Measles immunization			0.86 (0.81-0.90)*	<0.001
dpt3 immunization			0.86 (0.82-0.92)*	<0.001
Exclusive breastfeeding			0.92 (0.85-0.98)*	0.018
Immediate breastfeeding			1.04 (0.98-1.11)	0.174
Baby post-natal check within 24 hours			0.84 (0.78-0.91)*	<0.001
Malaria treatment			0.99 (0.93-1.07)	0.945
ITN use by under five			0.93 (0.87-0.98)*	0.021
vitamin A supplementation			0.89 (0.83-0.94)*	<0.001
Related to mothers				
Skill birth attendance			0.80 (0.76-0.85)*	<0.001
Antenatal visit			0.87 (0.83-0.91)*	<0.001
Family planning			0.86 (0.79-0.93)*	<0.001
Intermittent preventive treatment			0.98 (0.92-1.05)	0.570
Related to households				
Improved sanitation			0.88 (0.79-0.98)*	<0.015
Safe drinking water			0.89 (0.85-0.94)*	<0.001
Household ownership of nets			1.12 (1. 05-1.19)*	<0.001
Selected diseases/health conditions				
Malaria parasitemia			1.07 (1.01-1.13)*	0.028
Acute severe malnutrition			1.11 (1.05-1.87)*	<0.001
Acute respiratory conditions			0.92 (0.89-1.00)	0.066
Diarrhoea			0.98 (0.92-1.04)	0.538
Severe anaemia			1.08 (1.01-1.16)*	0.029
Low birth weight			1.01 (0.89-1.15)	0.829
Climatic covariates				
Land surface temperature day (LSTd)	35.02 (1.45)**		1.04 (0.97-1.11)	0.252
Land surface temperature night (LSTn)	21.06 (0.7)**		0.99 (0.93-1.06)	0.800
Rainfall	25.50 (4.6)**		0.91 (0.86-0.96)*	<0.001
Type of land cover				
Gras/ savanna	3 972 (35.8)	411 (10.4)	1	
Crops/urban built up	7 112 (64.2)	608 (8.6)	0.82 (0.72-0.93)*	0.002
Normalised difference vegetation index (ndvi)	0.32 (0.1)**		0.99 (0.93-1.05)	0.779
Enhanced vegetation index (evi)	0.21 (0.1)**		0.96 (0.90-1.02)	0.162
Distance to water bodies	104 (57.9)**		1.08 (1.01-1.14)*	0.019

*: significant effect
**: mean and standard deviation
ITN: insecticide-treated nets

Table 3.2: Distribution of the coverage of health interventions and the prevalence of the causes of deaths.

	Administrative regions													National
	Boucle de Mouhoun	**Cascades**	**Centre**	**Centre-Est**	**Centre Nord**	**Centre Ouest**	**Centre Sud**	**Est**	**Hauts Basins**	**Nord**	**Plateau Central**	**Sahel**	**Sud Ouest**	
Interventions (%)														
Under-five related health interventions														
Measles vaccination	89.3	91.2	98.5	94.89	94.3	85.7	96.4	74.3	86.9	90.5	95.7	80.3	85.2	87.5
dpt3 vaccination	96.5	82.7	96.3	98.4	9670	91.5	96.2	82.8	85.6	93.6	96.6	78.6	91.8	90.6
all vaccination	86.7	75.4	93.5	93.2	93.67	82.5	93.7	68.6	78.9	88.7	90.6	74.1	80.7	83.1
Exclusive breastfeeding	6.5	10.4	3.4	9.2	9.2	6.8	7.9	8.9	7.6	6.2	7.7	5.1	5.8	7.3
Baby post-natal check	15.1	17.3	13.3	40.2	16.0	19.3	28.6	31.3	4.9	22.9	18.3	5.4	8.6	18.7
Under-five ITN use	41.2	51.3	29.5	35.3	30.4	46.5	39.3	44.5	35.7	66.1	72.3	36.8	44.5	43.5
Vitamin A supplementation	72.8	49.0	65.7	81.2	87.6	41.3	88.6	46.1	62.3	75.7	68.5	35.3	64.7	62.9
Put on the breast immediately	37.0	44.7	55.1	21.9	35.4	29.0	45.4	56.9	38.3	47.8	67.2	32.4	37.3	40.8
Malaria treatment	22.1	21.4	32.3	50.1	25.7	35.9	45.4	41.2	38.4	40.9	40.02	19.6	30.9	35.1
Mothers relative health interventions														
Skill birth delivery	62.1	75.3	95.3	87.0	64.0	60.2	87.4	55.3	69.1	62.1	81.0	38.4	41.9	64.1
Antenatal visits	93.3	94.5	98.5	99.5	96.1	95.1	99.4	92.1	95.6	94.9	98.6	86.7	92.3	94.6
Family planning	12.1	14.3	35.2	7.2	7.4	8.5	16.4	11.0	25.7	8.6	14.6	8.1	9.8	12.7
Intermittent preventive treatment	33.4	42.7	32.5	54.8	47.1	46.8	50.3	30.8	29.4	41.4	53.2	21.4	57.1	39.0
Household related health interventions														
Household net ownership	71.9	84.5	64.2	60.1	49.6	73.8	63.8	81.2	63.7	97.8	95.0	79.2	70.5	73.7
Improved sanitation	22.3	30.6	70.2	14.3	18.8	15.8	8.7	5.2	20.9	25.6	38.1	8.2	8.1	18.6
Improved drink water	64.9	90.6	96.0	87.7	84.9	64.5	87.1	64.1	74.2	62.8	93.8	57.6	46.6	71.2
Diseases/health conditions														
Malaria	81.9	71.0	46.45	68.3	72.6	78.5	74.0	69.4	71.4	66.4	62.4	75.8	80.5	72.2
Respiratory conditions	20.9	22.0	16.9	24.5	18.2	22.9	35.2	12.3	25.9	23.3	27.3	14.5	32.7	21.7
Diarrhoea	15.3	13.12	17.6	17.4	15.6	19.4	20.7	8.9	19.5	14.6	14.3	15.5	17.2	15.9
Low birth weight	8.7	11.4	16.6	20.3	23.3	12.5	23.8	11.6	14.1	16.4	16.8	7.0	9.5	13.8
Severe anaemia prevalence	6.5	9.8	1.8	10.7	7.9	11.0	6.7	15.8	9.8	12.7	8.7	16.2	7.08	10.1
Acute severe malnutrition	4.2	11.1	7.9	8.0	5.7	6.8	3.1	9.7	4.2	9.9	6.5	14.9	7.6	7.5
Mortalities rates														
Under-five mortality rate (‰)	118	120	73	81	88	101	110	158	112	163	159	192	230	132

3.3.4 Bayesian Weibull survival and spatially varying regression

Figure 3.1 and Table 3.3 summarise the results. The results are also provided as a map in appendices (Figure A.3.2). All the selected diseases/conditions increase the mortality hazard at the national and subnational levels. At the national level, the amount of the effect ranged between 5 and 9% of reducing child survival.

Positive malaria parasitemia is the cause of death most spread, affecting child survival in 6 out of 13 regions. In the region of Sud-Ouest, it increases the mortality hazard by up to 25% (HRR=1.25, BCI: 1.07-1.47). The low birth weight is the second important cause of death distributed in 4 regions. The effect of the low birth weight is highest in the regions of Hauts-Bassins (HRR=1.42, BCI: 1.05-1.77). Diarrhoea and severe anaemia are significantly associated with child survival in three regions. Acute severe malnutrition is associated with child survival in the regions of Est and Hauts Bassins, while acute respiratory conditions present significant association with child survival in the regions of Centre Sud and Sud Ouest regions.

The region of Sud Ouest shows an overlapping significant effect of malaria positive parasitemia (HRR=1.25, BCI: 1.07-1.47), acute respiratory conditions (HRR=1.50, 95% BCI: 1.29-1.68) and diarrhoea (HRR=1.33, BCI: 1.15-1.44). In the same vein, diarrhoea, low birth weight, and malaria reduce the child's survival the Cascades, while diarrhoea, acute respiratory conditions, and severe anaemia influence the child survival in the region of Centre-Sud.

We did not found any important association between child survival and the disease in the regions of Centre and Centre-Est.

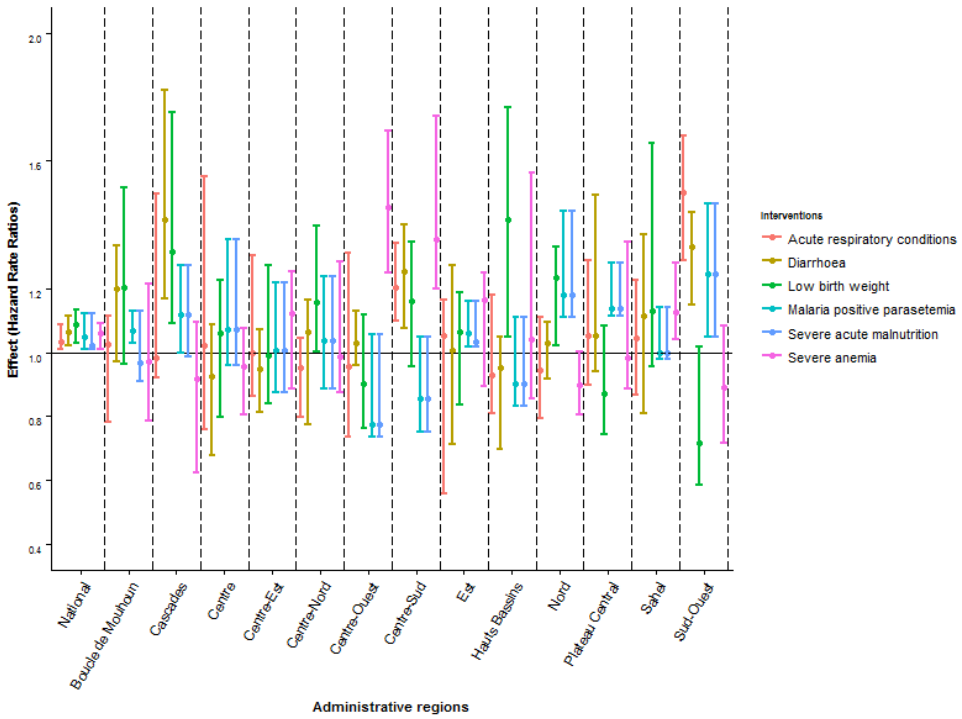

Figure 3.2: Distribution of HRR at national and regional levels

Table 3.3: Posterior estimates of diseases hazard after Bayesian spatial varying

	Malaria	Low birth weight	Severe anaemia	Diarrhoea	Severe acute malnutrition	Respiratory conditions
Geographical scale	**Hazard ratio (95% BCI)**	**Hazard ratio (95% BCI)**	**Hazard ratio (95% BCI)**	**Hazard ratio (95% BCI)**	**Hazard ratio (95% BCI)**	**Hazard ratio (95% BCI)**
National	1.05 (1.01-1.12)*	1.09 (1.03-1.13)*	1.06 (1.01-1.09)*	1.06 (1.02-1.11)*	1.05 (1.03-1.07)*	1.06 (1.01-1.09)*
Regions						
Boucle du Mouhoun	1.07 (1.03-1.13)*	1.20 (0.96-1.52)	0.97 (0.79-1.22)	1.20 (0.97-1.33)	1.18 (0.91-1.28)	1.02 (0.78-1.11)
Cascades	1.12 (1.00-1,27)*	1.32 (1.09-1.75)*	0.92 (0.63-1.10)	1.41 (1.17-1.82)*	1.01 (0.88-1.16)	0.98 (0.92-1.50)
Centre	1.07 (0.96-1.35)	1.06 (0.80-1.23)	0.96 (0.81-1.08)	0.92 (0.68-1.09)	1.01 (0.86-1.16)	1.02 (0.76-1.55)
Centre-Est	1.01 (0.88-1.22)	0.99 (0.84-1.27)	1.12 (0.89-1.25)	0.95 (0.81-1.07)	1.05 (0.91-1.27)	1.00 (0.86-1.30)
Centre-Nord	1.04 (0.89-1-24)	1.16 (1.01-1.39)*	0.99 (0.88-1.28)	1.06 (0.78-1.16)	1.01 (0.95-1.14)	0.95 (0.80-1.04)
Centre-Ouest	0.78 (0.73-1.06)	0.90 (0.76-1.12)	1.45 (1.25-1.69)*	1.03 (0.96-1.13)	1.09 (0.96-1.14)	0.96 (0.73-1.31)
Centre-Sud	0.85 (0.75-1-05)	1.16 (0.96-1.34)	1.35 (1.20-1.74)*	1.25 (1.08-1.40)*	1.10 (0.96-1.20)	1.20 (1.10-1.34)*
Est	1.03 (1.06-1.16)*	1.07 (0.84-1.19)	1.16 (0.90-1.25)	1.01 (0.71-1.27)	1.08 (1.02-1.14)*	1.05 (0.56-1.17)
Hauts-Basins	0.90 (0.83-1-11)	1.42 (1.05-1.77)*	1.04 (0.86-1.56)	0.95 (0.70-1.05)	1.23 (1.03-1.34)*	0.93 (0.81-1.18)
Nord	1.18 (1.11-1.44)*	1.23 (1.02-1.33)*	0.90 (0.80-1.01)	1.03 (0.92-1.10)	1.01 ()0.89-1.16	0.95 (0.79-1.11)
Plateau-Central	1.14 (1.11-1.28)*	0.87 (0.75-1.08)	0.98 (0.89-1.35)	1.05 (0.94-1.49)	1.09 (0.81-1.41)	1.05 (0.90-1.29)
Sahel	1.00 (0.98-1.14)	1.13 (0.96-1.65)	1.13 (1.04-1.28)*	1.11 (0.81-1.37)	1.00 (0.86-1.23)	1.05 (0.87-1.23)
Sud-Ouest	1.25(1.05-1.47)*	0.72 (0.58-1.03)	0.89 (0.72-1.08)	1.33 (1.15-1.44)*	1.03 (0.84-1.23)	1.50 (1.29-1.68)*
Spatial parameters	**Median (95% BCI)**	**Median (95% BCI)**	**Median (95% BCI)**	**Median (95% BCI)**	**Median (95% BCI)**	**Median (95% BCI)**
Range (km)	24.8 (6.5-29.7)	32.5 (20.4-67.0)	41.8 (25.2-62.7)	22.0 (7.9-60.7)	44.8 (16.4-60.0)	49.1 (32.6-60.1)
Spatial Variance	0.16 (0.14-0.20)	0.17 (0.13-0.24)	0.13 (0.10-0.20)	0.14 (0.10-0.23)	0.12 (0.09-0-21)	0.17 (0.11-0.27)
Variance of spatially varying effect	0.20 (0.16-0.25)	0.22 (0.14-0.39)	0.27 (0.17-0.89)	0.23 (0.13-0.30)	0.17 (0.13-0.27)	0.20 (0.15-0,34)

*: important effects.

3.4 Discussion

We aimed primarily to assess the spatial variation in the association between child survival and most important causes of child death and adjusted for socio-demographic, climatic and health interventions coverage. Our results point out that the selected six diseases increase the mortality hazard at the national level. They are consistent with the country's annual statistics reports. Indeed, malaria, acute respiratory infections, and diarrhoea are among the main causes of consultation and death of children under-5 years (Ministère de la Santé, 2016). The amount of the increase at the national level of the mortality hazard is ranged between 5% and 9%.

Our results reflect the endemicity of malaria in Burkina Faso. Indeed, malaria affects the child survival reduction in six out of 13 regions. That is, malaria contributes to increase the mortality hazard by 7, 12, 3, 18, 14 and 25% in the regions of Boucle du Mouhoun, Cascades, Est, Nord, Plateau Central and Sud-Ouest respectively.

The second cause of death affecting child survival negatively is the low birth weight. It increased the mortality hazard in four regions; Cascades, Centre Nord, Hauts-Bassins and Nord. Severe anaemia and diarrhoea increase the mortality hazard in 3 regions, while acute respiratory infections and malnutrition significantly increase the mortality hazard in 2 regions.

The spatial heterogeneity of the contributions of selected to the child mortality matches almost the spatial variability of maternal, child and household health interventions and U5MR. Indeed, the Centre-Sud, Sud-Ouest and Cascades are the regions that bear simultaneously the burden of malaria, acute respiratory infections and diarrhoea. These regions show the highest U5MR with 120 and 110 and 232 per 1000 for Cascades and Centre-Sud, Sud Ouest respectively compared to the national average of 132

per 1000. The regions mentioned above belong to the most watered area. Thus, the combination of high rainfall with inadequate hygiene and sanitation conditions in the regions of Centre Sud (8.7%) and Sud Ouest (8.1%), whilst the national average is 18.6%, may explain the prevalence of diarrheal diseases of 20.65 and 17.24%, respectively (national average prevalence of diarrhoea:15.85%) (Baker et al., 2016; Prüss-Ustün et al., 2014). Thus, focus this focus should be the scope as it is associated with an increase of the mortality hazard by 25 and 35%.

Furthermore, diarrhoea augment by 41% the mortality hazard in the region of Cascades region despite a high coverage in improved drinking water and sanitation and a slightly lower prevalence of diarrheal diseases than the national average (15.28% versus 15.85%). The effect of diarrhoea in this region may be due to an underlying factor such as malnutrition, which prevalence is relatively high in the region, and the co-morbidity diarrhoea-malnutrition is common in under-5 years (Irena et al., 2011; Kumar et al., 2014; Talbert et al., 2012). The regions of Centre Sud, Sud Ouest and Cascades are located in the highest rainfall zone reflecting the high prevalence of malaria parasitemia in the regions of Cascades and Sud Ouest. In consequence, it may explain the impact of malaria on the survival of children under five.

The remaining regions can be divided into two groups: a group where at least one condition or disease increase the mortality hazard (Boucle du Mouhoun, Centre-Nord, Centre-Ouest, Est, Hauts-Bassins, Nord, Plateau-Central, Sahel) and the group where our result did not show any effect of the selected diseases or conditions on child survival (Centre and Centre-Est).

The first group can also be divided into two groups according to the U5MR: the regions of Est, Nord, Plateau-central and Sahel have mortality rates higher than the national rate respectively of 158, 163, 159 and 192‰ while in the regions of Boucle du Mouhoun, Centre-Nord, Centre-Ouest and Hauts-Bassins the rate is relatively lower than the national rate.

The regions of Est, Nord, Plateau-central and Sahel are regions characterised by a high prevalence of malnutrition Est (30.88 versus 26.66% as a national average), respiratory conditions (23.26 versus 21.68% as the national average) in the region of and severe anaemia in the Sahel region (16.24 versus 10.06% as the national average). Despite high coverage of malaria health interventions except for the region of Sahel, Malaria increases the mortality hazard. An extended delays of consultation in these regions, which led to the complications of simple cases of malaria raising the probability of deaths (Gomes et al., 2010). Indeed, these regions are among the most impoverished with high proportions of the two last quintiles of wealth index and this a cause of delayed care-seeking behaviour (Getahun et al., 2010; Chuma et al., 2010; Zoungrana et al., 2014; Chukwuocha et al., 2014). The high prevalence of severe anaemia in these areas can confirm this lengthening of consultation delays because anaemia is one of malaria's major complications. (Carneiro et al., 2006; Oladeinde et al., 2012).

In the second group of regions (Boucle du Mouhoun, Centre-Nord, Centre-Ouest and Hauts-Bassins), the effect of diseases varies according to the prevalence of the disease. Malaria positive parasitemia in the Boucle du Mouhoun region (81% versus 72%) increases the risk of deaths by about 7%, low birth

weight (23% versus 13%) in Centre-Nord, severe anaemia in Centre-Ouest (11.04 versus 10.6). Hauts-Bassins is an exception. The severe malnutrition reduces under-5 survival, whereas its prevalence is lower than the national average. As we mentioned above, malnutrition and diarrhoea are common co-morbidities, and the prevalence of diarrhoea is higher than the national level in this region (19.5 versus 15.9). The geographical heterogeneity of the effects and contribution of the childhood diseases to under-5 survival in Burkina Faso points out the variability of disease pattern in Burkina and must be considered in resources and interventions allocation.

The last group of regions are where none of the selected diseases showed association with child survival. That is, the regions of Centre and Centre-Est regions with the lowest mortality rates 73 and 81‰, respectively. These regions are among the wealthiest regions in terms of household wealth index, and the coverage of health interventions are almost all above the national average. Therefore, the populations of these two regions certainly utilise the under-five health services adequately. Effects may be visible at the lowest level than the regional level as the unit of analysis.

The socio-demographic factors associated with child survival in our study are those generally reported in the literature (Ettarh and Kimani, 2012; Ezeh et al., 2015; Kanmiki et al., 2014; Schell et al., 2007; Yirgu et al., 2017). They are intimately interrelated with the household socio-economic status, which acts as an underlying factor (Kazembe and Nickanor, 2017). Our results are also consistent with the literature. Indeed, rural living area (with substantial deprivation of health and sanitation infrastructure), women with a low level of education, giving birth at home (without skilled assistance), young age at first delivery, the high number of births are risk factors of child death (Ettarh and Kimani, 2012; Nattey et al., 2013; Schell et al., 2007).

3.5 Conclusion

Our study provides a deep spatial understanding of the distribution and the effects of different direct causes of under-5 deaths in Burkina Faso.

The spatial heterogeneity of the effect of the selected diseases on children's survival undermines the regional specificity of Burkina Faso in terms of climatic, socio-economic, individual factors. We provided a comprehensive approach to tracking progress towards under-five relative goals attainment in Burkina Faso. Thus, the allocation of resources and health interventions instead of uniformly implemented should be weighted and integrated according to their weakness and overlapping effect on child survival. Furthermore, our methodology can be applied to other national household surveys (malaria indicators survey, census) to track specific outcome and relevant interventions, disease or health and social conditions.

3.6 Acknowledgements

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3.7 Appendix

Table A.3.1: Description of the health intervention included in the study

Interventions	Definition
Child interventions	
Use of ITN by under-five years	Proportion of children under 5 years in a household who slept under an ITN the previous night of the survey
Malaria treatment	Proportion of children under 5 years in a household who received any antimalarial in the two before the survey
Exclusive breastfeeding	Proportion of infants exclusively breastfed during the first six months after birth
Breastfeeding within 24 hours	Proportion of infants who started breastfeeding within one day after birth
Baby post-natal check within 24 hours	Proportion of infants who have been checked within one day after birth
Measles immunisation	Proportion of children who received vaccination of measles
DPT3 immunisation	Proportion of children who received vaccination of DPT3
All antigen immunisation	Proportion of children who received vaccination of BCG, Polio3 DPT3 and measles
Vitamin A supplementation	Proportion of children receiving vitamin A supplements in the past 6 months
Maternal health interventions	
Skilled birth attendance	Proportion of births that took place with the assistance of a skilled provider
Antenatal care visits	Proportion of pregnant mothers receiving ANC from a skilled provider
Family planning	Proportion of married women using any family planning method
Intermittent preventive treatment (IPT)	Proportion of women who received intermittent preventive treatment for malaria during pregnancy
Household health interventions	
Improved sanitation	Proportion of households using improved sanitation facilities
Improved drinking water	Proportion of households with improved source of drinking water
Household ownership of nets	Proportion of household with at least one net

Tableau A.3.2: Climatic covariates, sources and spatial and temporal resolution. Data were extracted during the year of 2010.

Data Type	Source	Spatial resolution	Temporal resolution
Day/Night Land surface Temperature (LST)	MODIS/Terra[1]	1x1 km^2	8 days
Normalised Difference Vegetation Index (NDVI)	MODIS/Terra[1]	1 x 1 km^2	16 days
Land Cover	MODIS/Combined[1]	0·5 x 0·5 km^2	NA
Rainfall	FEWS NET[2]	8x8 km^2	10 days
Urban rural extent	Global Rural and Urban Mapping project (GRUMP)[3]	1 x 1 km^2	NA

[1]Moderate Resolution Imaging Spectroradiometer (MODIS):
[2]Famine Early Warning System (FEWS) Network: https://earlywarning.usgs.gov/
[3]Socioeconomic Data and Applications Center (SEDAC): http://sedac.ciesin.columbia.edu/data/set/grump-v1-settlement-points

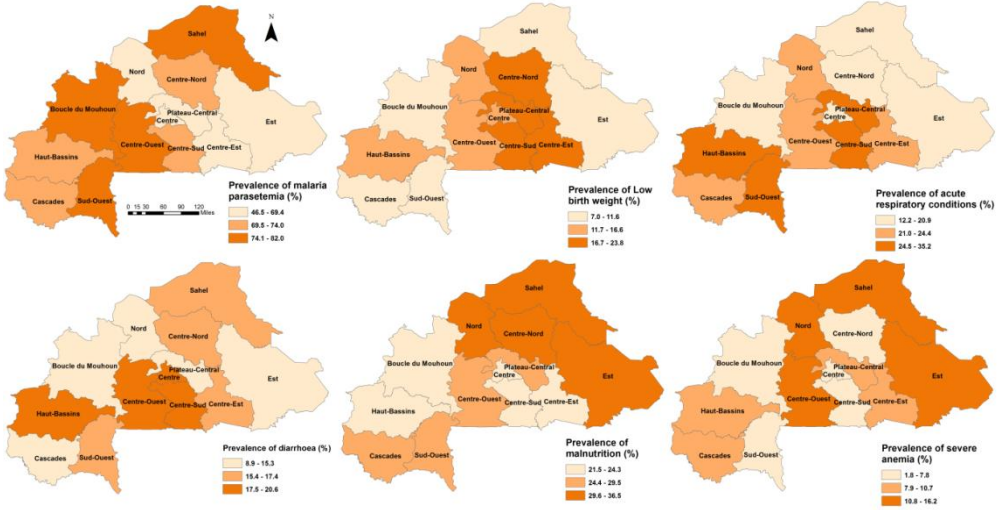

Figure A.3.1: Geographical distribution of the prevalence of childhood selected disease

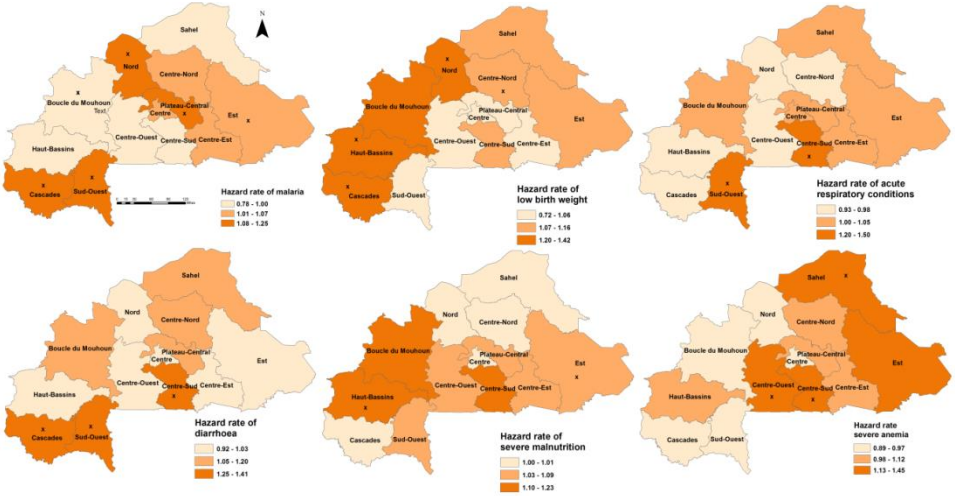

Figure A.3.2: Spatially varying effects of childhood diseases on U5MR. Hazard ratio estimates (posterior median) obtained by Bayesian geostatistical Weibull proportional hazards model with spatially varying regression coefficients for the disease prevalence covariates

Text B.3: Geostatistical proportional hazards model with spatially varying covariates

A Bayesian geostatistical proportional hazards model was fitted to assess the association between under-five mortality and childhood diseases and identify diseases that contribute most to mortality at the subnational level. Let t_{ij} be the age at death or the censoring time (in months) for child j at location i, $\boldsymbol{X_{ij}}$ be the vector of intervention coverage indicator, socio-demographic and climatic factors and $Z_i$be the disease prevalence at location i. We modelled the hazard of death by the equation, $h(t_{ij}) = h_0(t_{ij})\exp(\boldsymbol{\beta}^T\boldsymbol{X_{ij}} + (b + \varepsilon_{k(i)})^T Z_i + W_i)$ and assumed a Weibull baseline hazard i.e. $h_0(t_{ij}) = rt_{ij}^{r-1}$ where r is the shape parameter, $\boldsymbol{\beta}^T = (\beta_1, \dots, \beta_p)$ is the vector of regression coefficients with $\exp(\beta_l), l = 1, \dots p$, corresponding to the hazard rate ratio (HRR). W_i is cluster-specific random frailty which captures spatial correlation in mortality, i.e. clusters in closer proximity are expected to have similar mortality hazard due to common exposures. We modelled $\boldsymbol{W} = (W_1, W_2, \dots, W_n)^T$ by a Gaussian process, i.e. $\boldsymbol{W} \sim N(0, \Sigma)$, with an exponential correlation function of the distance d_{kl} between locations s_k and s_l, that is $\Sigma_{kl} = \sigma^2\exp(-d_{kl}\rho)$. The parameter σ^2 gives the variance of the spatial process, and ρ is a smoothing parameter that controls the rate of correlation decay with distance. For the exponential correlation function, $\frac{-\log(0.05)}{\rho}$ determines the distance at which the correlation drops to 0.05 (i.e. effective range of spatial process). Our model assumed that the relation between childhood diseases and mortality varied across regions by including disease-specific spatially varying coefficients, $b + \varepsilon_k$, where b is the disease effect on child mortality at the global (national) level and $\boldsymbol{\varepsilon} = (\varepsilon_1, \dots, \varepsilon_k)^{\boldsymbol{T}}$ are the varying effects at regional (subnational) levels $k = 1, \dots K$ with $k(i)$ indicating the region k corresponding to the location i. We introduced spatial dependence among the regions via a conditional autoregressive (CAR) prior for $\boldsymbol{\varepsilon}$, that is $\boldsymbol{\varepsilon} \sim N(\mathbf{0}, \Omega)$ with $\Omega = \sigma_1^2(I - \gamma C)^{-1}\Delta$. σ_1^2 is the variance of spatially varying disease effects, Δ is a diagonal matrix with entries $\Delta_{kk} = {g_k}^{-1}$where g_k is the number of neighbours of region k, γ measures overall spatial dependence and C is a proximity matrix with normalised entries that is $C_{kl} = \omega_{kl}/g_k$, ω_{kl} is 1 if region k neighbours l and 0 otherwise. To complete Bayesian model formulation, we assumed inverse gamma priors for all spatial variances with known parameters, i.e. $\sigma^2\sigma_1^2 \sim IG(2.01, 1.01)$, a uniform prior distribution for $\rho \sim U(a, b)$, where a and b chosen such as the effective range is within the maximum and minimum distances of the observed locations and a uniform prior for $\gamma \sim U(\lambda_1^{-1}, \lambda_2^{-1})$ where λ_1, λ_2 are the smallest and largest eigenvalue of $\Delta^{-1/2}C\Delta^{1/2}$. The shape parameter was assigned an exponential prior $r \sim Exp(0.01)$. Non-informative normal priors were adopted for the regression coefficients $\beta_l, b \sim N(0, 10^3)$ for $l = 1, \dots p$.

Model parameters were estimated using Markov Chain Monte Carlo (MCMC) simulation (O'Hara R and Sillanpää M, 2009). We run a two chains algorithm for 200 000 iterations with an initial burn-in of 20,000 iterations. Convergence was assessed by visual inspection of trace and density plots and analytically by the Gelman and Rubin diagnostic (Raftery and Lewis, 1992).

Chapter 4: Constructing a malaria-related health service readiness index and assessing its association with child malaria mortality: an analysis of the Burkina Faso 2014 SARA data

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Abstract.

Background: The Service Availability and Readiness Assessment surveys generate data on the readiness of health facility services. We constructed a readiness index related to malaria services and determined the association between health facility malaria readiness and malaria mortality in children under the age of 5 years in Burkina Faso.

Methods: Data on inpatients visits and malaria-related deaths in under 5-year-old children were extracted from the national Health Management Information System in Burkina Faso. Bayesian geostatistical models with variable selection were fitted to malaria mortality data. The most important facility readiness indicators related to general and malaria-specific services were determined. Multiple correspondence analysis was employed to construct a composite facility readiness score based on multiple factorial axes. The analysis was carried out separately for 112 medical centres and 546 peripheral health centres.

Results: Malaria mortality rate in medical centres was 4.8 times higher than that of peripheral health centres (3.5% vs. 0.7%, $p<0.0001$). Essential medicines was the domain with the lowest readiness (only 0.1% of medical centres and 0% of peripheral health centres had the whole set of tracer items of essential medicines). Basic equipment readiness was the highest. The composite readiness score explained 30% and 53% of the original set of items for medical centres and peripheral health centres, respectively. Mortality rate ratio (MRR) was by 59% (MRR = 0.41, 95% Bayesian credible interval: 0.19-0.91) lower in the high readiness group of peripheral health centres, compared to the low readiness group. Medical centres readiness was not related to malaria mortality. The geographical distribution of malaria mortality rate indicate that regions with health facilities with high readiness show lower mortality rates.

Conclusion: Performant health services in Burkina Faso are associated with lower malaria mortality rates. Health system readiness should be strengthened in the regions of Sahel, Sud-Ouest and Boucle du Mouhoun. Emphasis should be placed on improving the management of essential medicines and to reducing delays of emergency transportation between the different levels of the health system.

Keywords: Bayesian geostatistical models, Burkina Faso, Composite readiness index, Malaria, Service Availability and Readiness Assessment (SARA)

4.1 Introduction

Over the past 20 years, considerable progress has been made in the fight against malaria. Indeed, there was an estimated reduction of 41% of clinical malaria incidence, and an estimated reduction in malaria mortality rate of, 69% (WHO, 2018). This success is mainly explained by the scaling up of cost-effective health interventions, such as insecticide-treated nets (ITNs), indoor residual spraying and artemisinin-based combination therapy (ACT) (Bhatt et al., 2015). Globally, 19 countries eliminated malaria and six of them have been certified malaria-free (WHO, 2018). Notwithstanding, malaria remains a major public health issue in sub-Saharan Africa. Indeed, in 2017, 92% of the 219 million new cases of malaria and 93% of the 435,000 attributable deaths worldwide occurred in this part of the world. The disease burden is particularly high in children under the age of 5 years (WHO, 2018). Burkina Faso accounts for 4% and 6% of the global clinical malaria incidence and malaria-related deaths, respectively. The Malaria Indicator Survey of 2014 estimated that the prevalence of malaria parasitemia determined by rapid diagnostic tests (RDTs) was 61%, compared to 76% in 2010 (Ministère de l'Economie et des Finances, Burkina Faso, 2014).

The importance of health systems strengthening to reach health-related goals and targets is stressed since the early 2000s (Rao et al., 2013; Travis et al., 2004). Human resource shortages and inadequate training, poor supply chain management, inadequate infrastructure and equipment, and weak health information systems prevent the health facilities from responding adequately to populations needs (Chuma et al., 2010; Njogu et al., 2008; WHO, 2007). Consequently, existing tools and strategies need to be improved in order to strengthen health systems (Organization for Economic Cooperation and Development, 2000; PAHO/WHO, 2008; WHO, 2007). In sub-Saharan Africa, only few counties regularly implement health systems assessment. In early 2010, the World Health Organization (WHO) developed the Service Availability and Readiness Assessment (SARA) survey to assess the readiness of health facilities to respond to community needs (WHO, 2015). SARA surveys collect a set of binary tracer items on several domains related to the availability of basic equipment, basic amenities, essential medicines, diagnostic capacity and delivery of health interventions. The data cover readiness of health facilities to provide general services as well as services related to 20 health programmes, including malaria, HIV, tuberculosis, antenatal care, family planning and non-communicable diseases (NCDs).

Several authors have analysed the SARA survey tool or similar methodologies proposing statistical approaches to create a measure of health facility readiness and to relate readiness to health outcomes. Shawon and colleagues (2018), in their study following WHO guidelines, calculated separate readiness scores for each tracer item as the proportion of health facilities possessing the item (Shawon et al., 2018; WHO, 2015). Domain-specific readiness scores for general (e.g. basic amenities, basic equipment, and standard precautions for infection prevention, diagnostic capacity and essential medicines) and for malaria-specific, services (e.g. staff and guidelines, diagnostics, medicines and commodities) were calculated as the mean availability of the tracer items belonging to the domain. A similar approach has been adopted by Kanyangarara et al. (2018) to assess obstetric service readiness in 17 low- and middle-income countries (LMICs) (Kanyangarara et al., 2018). Ali et al. (2018) obtained a general service score as the average of domain-specific scores to compare

family planning service availability and readiness in 10 African countries (Ali et al., 2018). This average composite measure takes into account the different aspects of health facility readiness. However, it assumes an equal contribution of the tracer items to the overall readiness. Boyer and colleagues (2015) applied principal component analysis (PCA) on the tracer items and defined a readiness index based on the first principal component (PC). The index was utilized to assess the association between facility readiness with child survival, low birth weight, maternal and neonatal death in Ghana (Boyer et al., 2015). PCA has been applied to relate general service readiness and health financing factors in 10 countries in Africa and Asia (Leslie et al., 2017), health facility readiness to pregnancy delivery services and service utilization in Haiti (Wang et al., 2017) or to assess facility readiness to maternal health services over time in Nigeria (Gage et al., 2016). Of note, Ssempiira et al. (2019) criticized the use of PCA on binary items and derived a readiness index based on multiple correspondence analysis (MCA) (Ssempiira et al., 2018). To obtain a meaningful readiness score ensuring that the absence of any tracer item from a facility will contribute to a lower score than its presence, the authors proposed a composite measure based on more than one MCA axis.

SARA survey data from Burkina Faso have been used to assess readiness of surgical (Spiegel et al., 2017), obstetric (Kanyangarara et al., 2018) and family planning services (Ali et al., 2018). However, no studies have been carried out to date to investigate the relationship between health service readiness and health outcomes in Burkina Faso. Hence, to fill this gap, we focused our research on malaria-related services and determined the extend at which malaria services readiness is effective and able to prevent malaria deaths in children under the age of 5 years. Our findings will help to optimize resources allocation and improve SARA survey analyses for Burkina Faso and other LMICs.

4.2 Methods

4.2.1 Study area and national health system

Malaria is endemic in Burkina Faso. It is the leading cause of health care consultation, hospitalisation and mortality in under 5-year-old children (Burkina Faso; Ministère de la Santé, 2018). The health system of Burkina Faso is pyramidal and consists of three levels (Burkina Faso; Ministère de la Santé, 2015). The peripheral level is formed by the health district and includes the “Centre de Santé et de Promotion Sociale (CSPS), medical centres, isolate dispensaries, delivery centres and district hospitals. The latter serve as referral centres of the former health facilities. The second level is made of the regional hospitals, which are the reference structures for the district hospitals. The third level comprises the national and teaching hospitals and is the highest level of referral care providing specialized services. In 2016, there were approximately 1,760 CSPS, 47 district hospitals, 8 regional hospitals and 5 national and teaching hospitals.

4.2.2 Data sources

The 2014 SARA survey

We analysed health facility data from the Burkina Faso SARA survey carried out in 2014 that included 786 health facilities grouped in three strata: (i) 19 teaching hospitals, private polyclinics and regional hospitals

(stratum 1); (ii) 90 district hospitals and medical centres (stratum 2); and (iii) 671 CSPS, isolate dispensaries and delivery centres (stratum 3). Strata 1 and 2 correspond to a rather homogeneous group as they are staffed with physicians (in most cases), and hence, we combined them to increase the sample size and created two hierarchical levels of health facilities: medical centres (highest level) consisting of strata 1 and 2 and peripheral health centres (lowest level), including those of stratum 3. Of note, physicians usually staff medical centres, while nurses primarily manage peripheral health centres.

The items in the SARA questionnaire are specific to the services provided by the health facilities and remain the same across health facility levels for a specific service. The facility levels differ in terms of the services and health programmes they offer, the items have different importance or weights depending on the facility level. For example, access to power grid is mostly found in medical centres as they are situated mainly in urban areas, while solar power is the main source of energy in rural areas. Medicines for chronic diseases or surgery, anaesthesia and X-ray equipment are mainly part of the medical centres rather than peripheral health centres.

We defined as tracer items readiness indicator (i) for the general services and (ii) for the malaria-specific services, the proportion of health facilities having the tracer item available. The services were defined as binary variables taking the value "1" if the tracer item was available in the facility and "0" otherwise. Furthermore, we created domain readiness indicators for general (i.e. basic amenities, basic equipment, and standard precautions for infection prevention, diagnostic capacity and essential medicines) and malaria services (i.e. staff and guidelines, diagnostics, medicines and commodities). Domain readiness indicators correspond to the proportion of health facilities having the whole set of tracer items belonging in the domain. We use "1" if all tracer items belonging to the domain where available at the health facility and "0" otherwise.

Health outcome: under-five malaria related mortality

Mortality data were extracted from the Health Management Information System (HMIS) for a full year (January-December 2014). Malaria mortality in children below the age of 5 years was defined as the number of malaria-related deaths among all in-patient visits to a health facility of that age group. The mortality outcome was linked to the SARA database according to the health facility.

4.2.4 Statistical analysis

Bayesian negative binomial models were fitted on the number of malaria-related deaths at the health facility. We assumed that the number of malaria-related deaths at the health facility follows a negative binomial count distribution, and hence, Bayesian negative binomial models were fitted on the malaria deaths data. The total number of children below the age of 5 years visiting the facility (i.e. the denominator of the mortality rate outcome) was considered as an offset term in the model, that is the logarithmic transformation of it was introduced as a covariate with fixed regression coefficient equal to 1. The tracer items were included as covariates in the model. Bayesian variable selection was applied to determine the most important tracers

associated with the malaria mortality rate. A separate analysis was carried out for each facility level, i.e. medical centres and peripheral health centres.

MCA was applied to the most important tracers, adhering to an approach put forth by Ssempiira et al. (2018) (Ssempiira et al., 2018). In short, let K be the set of selected tracers, X^k, $k = 1, \ldots . K$ and $X_{0,i}^k$ and $X_{1,i}^k$ be two binary indicators corresponding to the presence or absence of the X^k from the facility i, respectively, that is, $X_{0,i}^k$ takes value 1 when the tracer k is absent ($X_i^k = 0$) and 0 otherwise. Likewise, $X_{1,i}^k$ takes value 1 when the tracer k is present in health facility i (i.e. $X_i^k = 1$) and 0 otherwise.

The readiness score for health facility i, based on the a^{th} factorial axis is defined by $F_i^a = \frac{1}{K}\sum_{k=1}^{K}\sum_{j_k=0}^{1} W_{j_k}^{a,k} X_{j_k,i}^k$, where j_k indicates the value of X^k and the weights $W_{j_k}^{a,k}$ are the columns standards coordinates on the a^{th} factorial axis corresponding to $X_{j_k,i}^k$. Following the procedure of Asselin (2009), we define a composite readiness score as $F_i^a = \frac{1}{K}\sum_{k=1}^{K}\sum_{j_k\in\{0,1\}}^{1}\sum_{a=1}^{L}\delta(k-a)\ W_{j_k}^{a,k} X_{j_k,i}^k$, where L is the number of factorial axes used in the composite score and $\delta(k-a)$ is the Dirac delta function, which takes the value 1 when the weights related to $X_{j_k,i}^k$ are selected from the factorial axis and 0 otherwise, that is, $\delta(k-a) = 1$ if $k = a$ and $\delta(k-a) = 0$ if $k \neq a$. The factorial axes that will represent the X^k tracer are identified based on a discrimination measure, which is calculated for each tracer and axis and measures the contribution of the tracer to the total variance explained by the axis. To improve interpretation of the score, we translated the weights so that the absence category $j_k = 0$ of the X^k tracer received a zero weight and the presence one $j_k = 1$ received a strictly positive weight indicating the gain in the readiness increase measured by the axis a when a facility i acquires the k^{th}tracer. Hence, the $W_{j_k}^{a,k}$ in F_i is replaced by $W_{j_k}^{+a,k}$, where $W_0^{+a,k} = 0$ and $W_1^{+a,k} = W_1^{+a,k} - W_1^{+a,k}$ (Asselin, 2009). The composite readiness score was converted into a readiness index with three categories by dividing the ordered distribution of the score values into three parts, each containing a third of the values.

Furthermore, we assessed the association between malaria mortality rate and the readiness index described above, using a geostatistical Bayesian negative binomial model. Locational random effects were included in the model to take into account spatial correlation. We assumed a Gaussian process with an exponential correlation function of the distance between health facilities. The analysis was adjusted for the type of health facility location (urban/rural) and of administrative status (public/private). Further details of the statistical methods are provided in Appendix A.

The descriptive analyses were carried out in STATA version 14 (StataCorp.; College Station, TX, USA) and Bayesian models were fitted in OpenBUGS version 3.2.3 (Imperial College and Medical Research Council; London, UK). Maps were produced in ArcGIS version 10.2.1 (Esri Inc.; Redlands, CA, USA).

4.3 Results

4.3.1 Health facility characteristics and malaria mortality

The SARA survey carried out in Burkina Faso in 2014 included 786 health facilities. Among these health facilities, 658 (83.7%) reported complete malaria mortality data, and hence, they were used for subsequent analyses. Seventeen percent of the facilities (n=112) belonged to medical centres. Around 80% of medical centres are located in urban areas, while in peripheral health centres; more than 80% of the facilities are in rural zones (Table 4.1). The government (77% of medical centres and 93% of peripheral health centres) manages most of the facilities. The malaria mortality rate in medical centres is 4.8 times higher than that of peripheral health centres (3.5% vs 0.7%, $p<0.0001$).

Table 4.1: Health facility characteristics and malaria mortality rates according to the SARA survey of 2014 in Burkina Faso

Characteristics	**Medical centres (n=112) n (%)**	**Peripheral health centres (n=546) n (%)**
Location		
Urban	90 (80.4)	83 (15.2)
Rural	22 (19.6)	463 (84.8)
Administrative management		
Public	86 (76.8)	510 (93.4)
Private	26 (23.2)	36 (6.6)
Regions		
Boucle du Mouhoun	9 (8.0)	65 (11.9)
Cascades	4 (3.6)	25 (4.6)
Centre	27 (24.1)	54 (9.9)
Centre-Est	10 (8.9)	38 (7.0)
Centre-Nord	6 (5.4)	41 (7.5)
Centre-Ouest	11 (9.8)	53 (9.7)
Centre-Sud	4 (3.6)	30 (5.45)
Est	9 (8.0)	40 (7.3)
Hauts Bassins	9 (8.0)	55 (10.1)
Nord	8 (7.1)	53 (9.7)
Plateau Central	4 (3.6)	38 (7.0)
Sahel	4 (3.6)	27 (5.0)
Sud-Ouest	7 (6.35)	27 (5.0)
Malaria		
Number of deaths (a)	1,860	347
Number of consultations (b)	53,768	48,524
Mortality rate = a/b	3.5%	0.7%

4.3.2 Domain readiness and tracer indicators

Table 4.2 summarises the domains and tracer items readiness indicators of the general and malaria-specific service. Among the general service domains, basic equipment readiness was the most attainable domain (reached by 64.2% and 48.4% of medical centres and peripheral health centres, respectively). On the other hand, essential medicines was the domain with the lowest readiness (only 0.1% of medical centres and 0% of peripheral health centres had the whole set of essential medicines tracer items). Malaria services consisted of nine tracer items covering three domains. Apart of the diagnostic domain, which had one tracer, readiness of the staff and guidelines domain was higher in peripheral health centres compare to medical centres (57.7 and 45.5, p=0.027). Medicines and the commodities domain readiness was also higher in peripheral health centres but the difference to medical centres was borderline significant (31.5% vs 18.8%, p=0.051).

Bayesian variable selection identified 29 tracers that are related to malaria deaths out of the 49 items across all domains of the general service offered by medical centres (Table 4.2). These are privacy room and emergency transportation (under basic amenities), light source (basic equipment), safe disposal of sharp materials, safe disposal and storage of infectious wastes, latex gloves and precaution guidelines (standard precautions for infection prevention), haemoglobin and glucose in urine (diagnostic), medicines for the management of NCDs (diabetes, cardiovascular and respiratory chronic diseases) and availability of two antibiotics (gentamycin and ceftriaxone) commonly used in medical centres (essential medicines). Five out of nine tracer items were selected in the malaria-specific service of medical centres (i.e. staff trained in malaria diagnostic and treatment, trained in intermittent preventive treatment of malaria, the first line of malaria treatment, paracetamol and ITNs).

For peripheral health centres, 29% (10/34) tracers were selected in the general service. These are similar to those in medical centres with the exception of the essential medicines, as most of them were not available in peripheral health centres. Regarding malaria-specific services offered by peripheral health centres, readiness to the first line of antimalarial drugs (96.3%) and to malaria diagnostics (85.5%) was similar as observed in medical centres.

Table 4.2: Frequency distribution of domains and tracer items readiness indicators as well as posterior inclusion probabilities of general and malaria-specific tracers estimated from the Bayesian variable selection. Tracers with inclusion probabilities higher than 50% were selected for the MCA.

Domain/tracer items	Medical centres (n=112)		Peripheral health centres (n=546)	
	Availability (%)	Posterior inclusion probability[2] (%)	Availability (%)	Posterior inclusion probability (%)
General service				
Basic amenities[1]	***39 (34.8)***		***6 (1.1)***	
Power (electric or solar device)	86 (76.8)	8.5	362 (66.3)	21.4
Improved water source inside or within the ground of the facility	110 (98.2)	-[3]	476 (87.2)	60.9
Room with auditory and visual privacy for patient consultations	81 (72.3)	100	284 (52.0)	39.2
Access to adequate sanitation facilities for clients	109 (97.3)	-	519 (95.1)	-
Communication equipment (phone or SW radio)	111 (99.1)	-	535 (98.0)	-
Facility has access to computer with E-mail/Internet access	56 (50.0)	6.9	10 (1.8)	-
Emergency transportation	106 (94.6)	61.7	515 (94.3)	88.0
Basic equipment	***72 (64.2)***		***264 (48.4)***	
Adult scale	108 (96.4)	-	527 (96.5)	-
Child scale	82 (73.2)	13.2	428 (78.4)	15.1
Thermometer	112 (100)	-	544 (99.6)	-
Stethoscope	112 (100)	-	540 (98.9)	-
Blood pressure apparatus	109 (97.3)	-	533 (97.6)	-
Light source	92 (82.1)	100	349 (63.9)	16.2
Standard precautions for infection prevention	***52 (46.4)***		***223 (40.8)***	
Safe final disposal of sharp materials	85 (75.9)	84.7	422 (77.3)	28.2
Safe final disposal of infectious wastes	82 (73.2)	62.9	336 (61.5)	18.2
Appropriate storage of sharp waste	110 (98.2)	-	535 (98.0)	-
Appropriate storage of infectious waste	103 (92.0)	85.3	494 (90.5)	50.8
Disinfectant	111 (99.1)	-	544 (99.6)	-
Single use (standard disposable or auto-disable syringes)	111 (99.1)	-	543 (99.5)	-
Soap and running water or alcohol-based hand rub	105 (93.8)	33.6	518 (94.9)	99.2
Latex gloves	100 (89.9)	56.1	499 (91.4)	99.3
Guidelines for standard precautions	98 (87.5)	98.3	469 (85.9)	21.2
Diagnostic capacity	***37 (33.0)***		***3 (0.6)***	
Haemoglobin	72 (64.3)	100	9 (1.7)	-
Blood glucose	50 (44.6)	48.2	6 (1.1)	-
Malaria diagnostic capacity	101 (90.2)	17.5	467 (85.5)	21.3
Urine dipstick-protein	103 (92.0)	49.0	501 (91.8)	50.1
Urine dipstick-glucose	104 (92.9)	80.6	491 (89.9)	31.4
HIV diagnostic capacity	106 (94.6)	32.9	512 (93.8)	39.8
Urine test for pregnancy	96 (85.7)	26.0	412 (75.5)	42.3
Essential medicines	***2 (0.1)***		***0 (0)***	
Amoxicillin tablet	101 (90.2)	40.6	523 (95.8)	-
Ampicillin for inject	104 (92.9)	21.7	519 (95.1)	-
Gentamicin injectable	101 (90.2)	77.7	472 (86.5)	30.3
Oxytocin injectable	98 (87.5)	100	502 (91.9)	77.8
Amoxicillin dispersible	94 (83.9)	10.6	475 (87.0)	20.1
Oral rehydration solution (ORS)	95 (84.8)	16.8	476 (87.2)	20.3
Zinc	77 (68.8)	100	418 (76.6)	14.9
Aspirin	94 (83.9)	100	377 (69.1)	19.6
Magnesium sulfate	78 (69.6)	100	121 (22.2)	20.9
Amlodipine	25 (22.3)	100	12 (2.2)	-
Enalapril	20 (17.9)	26.1	6 (1.1)	-
Insulin injectable	8 (7.1)	35.9	5 (0.9)	-
Betablockers	20 (17.9)	100	8 (1.5)	-
Beclomethasone inhaler	14 (12.5)	100	9 (1.7)	-

Ceftriaxone injection	103 (92.0)	93.8	492 (90.1)	58.4
Thiazidic	25 (22.3)	14.2	41 (7.5)	50.6
Glibenclamide tablet	39 (34.8)	100	10 (1.8)	-
Metformin	41 (36.6)	22.9	9 (1.7)	-
Omeprazole	65 (58.0)	10.1	110 (20.2)	20.2
Salbutamol inhaler	86 (76.8)	63.3	288 (52.8)	24.9
Carbamazepine	28 (25.0)	69.9	0 (0.0)	-
Haloperidol	27 (24.1)	96.6	0 (0.0)	-
Simvastatin	4 (3.6)	-		
Fluoxetin	3 (2.7)	-		-
Malaria-specific service				
Staff and guidelines	***41 (45.5)***		***313 (57.7)***	
Guidelines for diagnosis and treatment of malaria	105 (93.8)	22.4	536 (98.2)	-
Guidelines for Intermittent Preventive Treatment	75 (67.0)	13.0	481 (88.1)	31.1
Staff trained in malaria diagnosis and treatment	79 (70.5)	97.5	453 (83.0)	40.9
Staff trained in Intermittent Preventive Treatment	74 (66.1)	100	370 (67.8)	58.9
Diagnostics	***101 (90.2)***		***467 (85.5)***	
Malaria diagnostic capacity (rapid diagnostic test/thin smear)	101 (90.2)	17.5	467 (85.5)	21.3
Medicines and commodities	***21 (18.8)***		***172 (31.5)***	
First-line antimalarial in stock (artemether+lumefantrine, artesunate+amodiaqune)	99 (88.4)	58.8	526 (96.3)	-
Paracetamol cap/tab	104 (92.9)	100	418 (76.2)	34.6
Intermittent preventive treatment of malaria in pregnancy (IPTg) drug (sulfadoxine pyrimethamine)	62 (55.4)	28.4	356 (65.2)	17.1
ITNs	29 (25.9)	73.2	185 (33.9)	26.2

[1]Domain readiness indicators were defined as availability of all tracer items belonging to the domain.
[2]Posterior inclusion probability:gives the probability of the tracer to be included in the final model and it is calculated by the proportion of all possible models in the variable selection procedure that include the specific tracer. For example, the posterior inclusion probability of 21.4 estimated for the power tracer indicates that this tracer was included in 21.4% of all possible models generated from all general services-related tracers.
[3]Item not included in the variable selection procedure due to low relative frequency i.e. <5%

4.3.3 Health facility readiness index

MCA was applied on the tracer items selected from the variable selection procedure to obtain a readiness score. Fourteen and six factorial axes were sufficient to build the composite indices for medical centres and peripheral health centres, respectively. Standard coordinates of the selected tracers are provided in Table 4.3 (medical centres) and Table 4.4 (peripheral health centres).

For medical centres, the factorial axis 1 accounted for 10 tracer items, followed by axis 2 with five tracer items. The most weighted rescaled tracer items were the emergency transportation and appropriate storage of infectious waste picked from factorial axes eight and six, respectively. On the first factorial axis, a subset of four tracers met the Global First Axis Ordering Consistency (FAOC-G) requirement in the positive direction, while a second subset of 25 tracer items met this condition in the negative direction (i.e. the score monotonically increases/decreases for all tracer items) (Asselin, 2009). Hence, there are two subsets of tracer items that are inconsistent and one subset should have been discarded, leading to a loss of information if we had constructed the score using the first factorial axis. With regard to peripheral health centres, four tracer items showed a high discrimination measure on factorial axis 1. The highest weighted tracers are “thiazidic” and “running water source or soap” from axes 4 and 5, respectively. The discrimination measures of the tracers and the rescaled weights are given in Tables B.42 and B.4.2 (in Appendix B) for medical centres and peripheral health centres, respectively.

Figure 4.1 shows the proportion of variation in the tracers explained by the first factorial axis and the composite readiness score based on (i) the whole set of tracers and (ii) the subset of tracers identified by the Bayesian variable selection. The results show that the composite score explains more than twice the variance explained by the first factorial axis (medical centres: 30% vs. 15%; peripheral health centres 53% vs. 18%). Furthermore, the composite score based on the subset of tracers explained more variation than the composite score based on the whole set (medical centres: 30% vs. 26%; peripheral health centres: 53% vs. 30%).

Table 4.3: Standard coordinates of tracer items on the first 14 factorial axes (medical centres) derived from the SARA survey in 2014 in Burkina Faso.

Tracers	Category	Frequency, n (%)	Factorial axes*													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
Privacy room	No	31 (27.7)	**-0.281**[a]	**-1.196**	0.358	**-2.537**	1.257	**-1.370**	**-0.195**	0.746	0.171	***-5.265***	**-3.066**	1.560	0.252	1.213
	Yes	81 (72.3)	**0.107**	**0.458**	-0.137	**0.971**	-0.481	**0.524**	**0.075**	-0.285	-0.065	***2.015***	**1.173**	-0.597	-0.097	-0.464
Emergency transportation	No	6 (5.4)	0.063	**-3.332**	**-2.716**	4.195	0.012	**-7.946**	**4.844**	***-11.193***	**-0.109**	**-1.787**	1.657	3.354	**-2.609**	2.616
	Yes	106 (94.6)	-0.004	**0.189**	**0.154**	-0.237	-0.001	**0.450**	**-0.274**	***0.634***	**0.006**	**0.101**	-0.094	-0.190	**0.148**	-0.148
Light power	No	20 (17.9)	**-0.925**	***-3.350***[b]	0.885	0.805	0.298	2.439	**-4.057**	**-1.751**	**-0.649**	**-3.378**	2.240	**-4.542**	**-0.070**	**-0.001**
	Yes	92 (82.1)	**0.201**	***0.728***	-0.192	-0.175	-0.065	-0.530	**0.882**	**0.381**	**0.141**	**0.734**	-0.487	**0.987**	**0.015**	**0.000**
Safe final disposal of sharps	No	27 (24.1)	1.254	**-0.656**	***-4.856***	**-2.973**	**-0.352**	0.664	**-0.421**	**-0.995**	1.152	**-0.588**	2.051	**-0.445**	**-0.888**	**-0.100**
	Yes	85 (75.9)	-0.398	**0.208**	***1.542***	**0.944**	**0.112**	-0.211	**0.134**	**0.316**	-0.366	**0.187**	-0.652	**0.142**	**0.282**	**0.032**
Safe final disposal of infectious wastes	No	30 (26.8)	0.859	**-0.684**	***-4.958***	**-2.727**	0.017	0.163	**-1.408**	**-0.591**	1.160	0.798	**-0.069**	0.185	**-0.102**	**-0.391**
	Yes	82 (73.2)	-0.314	**0.250**	***1.814***	**0.998**	-0.006	-0.060	**0.515**	**0.216**	-0.424	-0.292	**0.025**	-0.068	**0.037**	**0.143**
Appropriate storage of infectious waste	No	9 (8.0)	1.198	**-2.643**	0.035	1.036	**-1.691**	***-9.057***	**-1.236**	**-0.570**	**-1.376**	2.107	5.636	**-5.990**	3.825	3.190
	Yes	103 (92.0)	-0.105	**0.231**	-0.003	-0.091	**0.148**	***0.791***	**0.108**	**0.050**	**0.120**	-0.184	-0.492	**0.523**	-0.334	-0.279
Latex gloves	No	12 (10.1)	**-0.252**	**-3.347**	0.867	0.983	**-4.095**	**-0.858**	***-6.782***	3.797	**-3.464**	0.525	2.358	0.705	**-3.537**	**-1.541**
	Yes	100 (89.9)	**0.030**	**0.402**	-0.104	-0.118	**0.491**	**0.103**	***0.814***	-0.456	**0.416**	-0.063	-0.283	-0.085	**0.424**	**0.185**
Guidelines for standard precautions	No	14 (22.5)	***-3.610***	0.980	**-1.949**	**-1.532**	**-1.850**	**-1.734**	4.077	1.023	**-2.052**	**-3.909**	**-0.936**	**-3.326**	**-1.546**	1.195
	Yes	98 (87.5)	***0.516***	-0.140	**0.278**	**0.219**	**0.264**	**0.248**	-0.582	-0.146	**0.293**	**0.558**	**0.134**	**0.475**	**0.221**	-0.171
Haemoglobin test	No	40 (35.7)	**-1.086**	**-1.396**	**-0.563**	0.630	**-2.200**	0.331	0.568	**-0.251**	**-2.686**	1.100	**-0.855**	1.830	***-3.237***	0.473
	Yes	72 (64.3)	**0.603**	**0.775**	**0.313**	-0.350	**1.222**	-0.184	-0.316	**0.139**	**1.492**	-0.611	**0.475**	-1.017	***1.798***	-0.263
Glucose dipstick	No	8 (7.1)	**-2.850**	0.482	**-4.354**	0.289	***-6.397***	2.569	3.601	4.457	**-1.015**	**-5.601**	0.354	**-5.051**	**-0.402**	**-0.182**
	Yes	104 (92.9)	**0.219**	-0.037	**0.335**	-0.022	***0.492***	-0.198	-0.277	-0.343	**0.078**	**0.431**	-0.027	**0.389**	**0.031**	**0.014**
Amlopdipin	No	87 (77.7)	**-0.329**	**-0.723**	0.354	**-0.378**	**-0.280**	**-0.416**	**-0.848**	0.125	1.106	0.339	**-0.459**	0.036	0.424	0.184
	Yes	25 (22.3)	**1.144**	**2.515**	-1.231	**1.315**	**0.974**	**1.448**	**2.953**	-0.436	-3.848	-1.180	**1.597**	-0.125	-1.477	-0.640
Aspirin	No	18 (16.1)	***-3.484***	3.093	**-0.109**	**-0.623**	1.267	**-1.229**	0.818	2.121	**-2.599**	1.476	0.217	**-2.705**	1.985	1.667
	Yes	94 (83.9)	***0.667***	-0.592	**0.021**	**0.119**	-0.243	**0.235**	-0.157	-0.406	**0.498**	-0.283	-0.042	**0.518**	-0.380	-0.319
Beclomethasone inhaler	No	98 (87.5)	**-0.205**	**-0.683**	0.214	**-0.707**	**-0.065**	**-0.013**	0.293	**-0.313**	**-0.362**	0.313	0.484	0.025	0.342	**-0.079**
	Yes	14 (12.5)	**1.435**	**4.781**	-1.495	**4.948**	**0.452**	**0.094**	-2.052	**2.190**	**2.536**	-2.189	-3.386	-0.177	-2.394	**0.555**
Beta-blockers	No	92 (82.1)	**-0.433**	**-0.793**	0.614	**-0.473**	**-0.185**	0.294	0.561	**-0.134**	0.132	**-0.074**	0.098	0.032	0.439	0.587
	Yes	20 (17.9)	**1.990**	**3.648**	-2.824	**2.176**	**0.849**	-1.355	-2.581	**0.616**	-0.609	**0.339**	-0.450	-0.145	-2.021	-2.701
Ceftriaxone	No	9 (8.0)	***-6.392***	1.090	0.991	**-0.869**	3.199	**-1.868**	**-2.313**	**-2.918**	2.354	**-0.844**	3.647	1.036	**-6.562**	**-1.918**
	Yes	103 (92.0)	***0.558***	-0.095	-0.087	**0.076**	-0.280	**0.163**	**0.202**	**0.255**	-0.206	**0.074**	-0.319	-0.090	**0.573**	**0.168**
Gentamicin	No	11 (9.8)	***-4.331***	**-1.279**	**-2.234**	4.478	2.838	2.256	**-0.629**	**-0.754**	1.864	1.838	**-1.003**	**-2.284**	**-0.105**	6.498
	Yes	101 (90.2)	***0.472***	**0.139**	**0.243**	-0.488	-0.309	-0.246	**0.069**	**0.082**	-0.203	-0.200	**0.109**	**0.249**	**0.011**	-0.708
Glibenclamide	No	73 (65.2)	**-0.724**	**-0.211**	**-0.581**	0.607	0.655	0.053	**-0.176**	**-0.305**	**-1.378**	**-0.786**	0.346	0.540	1.845	***-1.922***

	Yes	39 (34.8)	**1.356**	**0.395**	**1.088**	-1.137	-1.225	-0.099	**0.329**	**0.571**	**2.580**	**1.471**	-0.648	-1.011	-3.453	***3.598***
Insulin injectable	No	104 (92.9)	**-0.123**	***-0.424***	0.222	**-0.186**	**-0.106**	**-0.147**	**0.493**	0.038	0.378	0.233	**-0.339**	**-0.364**	**-0.207**	**-0.641**
	Yes	8 (7.1)	**1.596**	***5.512***	-2.880	**2.420**	**1.375**	**1.909**	**-6.404**	-0.489	-4.911	-3.035	**4.404**	**4.737**	**2.688**	**8.330**
Magnesium	No	34 (30.4)	***-2.083***	**-2.028**	**-0.340**	1.431	0.424	0.597	**-1.968**	0.063	0.339	**-0.313**	**-2.323**	0.905	0.300	**-0.988**
	Yes	78 (69.6)	***0.908***	**0.884**	**0.148**	-0.624	-0.185	-0.260	**0.858**	-0.028	-0.148	**0.136**	**1.013**	-0.395	-0.131	**0.431**
Oxytocin	No	14 (12.5)	***-3.089***	**-0.951**	**-3.370**	5.102	**-0.779**	2.837	**1.260**	**-2.386**	2.970	1.110	**-1.926**	**-2.982**	0.951	**-0.272**
	Yes	98 (87.5)	***0.441***	**0.136**	**0.481**	-0.729	**0.111**	-0.405	**-0.180**	**0.341**	-0.424	-0.159	**0.275**	**0.426**	-0.136	**0.039**
Salbutamol	No	26 (23.2)	***-3.000***	**-0.517**	**-1.091**	**-1.330**	**-0.915**	**-0.662**	**-0.223**	1.480	**-2.038**	1.850	**-0.362**	1.727	0.879	1.003
	Yes	86 (76.8)	***0.907***	**0.156**	**0.330**	**0.402**	**0.277**	**0.200**	**0.067**	-0.448	**0.616**	-0.559	**0.109**	-0.522	-0.266	-0.303
Zinc	No	35 (31.3)	***-2.157***	0.502	**-0.495**	**-0.975**	0.011	2.273	**0.503**	**-0.816**	1.147	0.610	1.572	2.790	1.487	0.844
	Yes	77 (68.8)	***0.980***	-0.228	**0.225**	**0.443**	-0.005	-1.033	**-0.229**	**0.371**	-0.522	-0.277	-0.715	-1.268	-0.676	-0.383
ITNs	No	83 (74.1)	**-0.220**	0.045	**-0.747**	**-0.247**	0.762	**-1.081**	**-0.434**	**-0.005**	**-0.520**	0.795	***-1.332***	**-0.377**	0.161	**-0.081**
	Yes	29 (25.9)	**0.628**	-0.128	**2.139**	**0.708**	-2.180	**3.093**	**1.242**	**0.015**	**1.487**	-2.276	***3.811***	**1.079**	-0.461	**0.231**
Staff trained in malaria diagnosis and treatment	No	33 (29.5)	***-1.091***	1.604	**-0.341**	**-0.226**	***-3.506***	**-0.728**	**-1.149**	1.928	2.217	**-0.102**	0.246	0.246	1.343	**-0.185**
	Yes	79 (70 5)	***0.456***	-0.670	**0.143**	**0.094**	***1.465***	**0.304**	**0.480**	-0.806	-0.926	**0.043**	-0.103	-0.103	-0.561	**0.077**
Staff trained in intermittent preventive treatment in pregnancy (IPTp)	No	38 (33.9)	**-0.158**	**-0.459**	**-0.829**	2.575	**-1.426**	***-2.856***	**0.619**	0.713	1.757	**-1.492**	1.060	2.415	0.922	0.162
	Yes	74 (66.1)	**0.081**	**0.236**	**0.426**	-1.322	**0.732**	***1.467***	**-0.318**	-0.366	-0.902	**0.766**	-0.544	-1.240	-0.474	-0.083
First line treatment of malaria	No	13 (11.6)	***-4.606***	2.906	0.766	**-1.353**	0.142	**-1.435**	**0.786**	0.550	2.369	1.904	2.504	0.379	**-0.856**	**-4.781**
	Yes	99 (88.4)	***0.605***	-0.382	-0.101	**0.178**	-0.019	**0.188**	**-0.103**	-0.072	-0.311	-0.250	-0.329	-0.050	**0.112**	**0.628**
IPTg drug	No	50 (44.6)	***-5.589***	3.721	1.822	**-2.447**	5.322	**-2.872**	**-2.985**	0.352	1.426	**-2.683**	3.527	**-0.455**	**-4.909**	2.079
	Yes	62 (55.4)	***0.430***	-0.286	-0.140	**0.188**	-0.409	**0.221**	**0.230**	-0.027	-0.110	**0.206**	-0.271	**0.035**	**0.378**	-0.160
Carbamazepine	No	84 (75.0)	**-0.144**	0.764	0.367	**-0.450**	***-1.050***	0.110	**-0.594**	**-1.146**	**-0.364**	0.136	**-0.686**	0.030	0.566	0.637
	Yes	28 (25.0)	**0.432**	-2.292	-1.101	**1.349**	***3.149***	-0.331	**1.782**	**3.438**	**1.093**	-0.408	**2.057**	-0.091	-1.698	-1.911
Haloperidol	No	85 (75.9)	**-0.183**	0.825	0.330	**-0.199**	**-0.894**	**-0.172**	**-0.410**	**-1.475**	**-0.025**	**-0.361**	**-0.402**	**-0.354**	**-0.078**	**-0.660**
	Yes	27 (24.1)	**0.577**	-2.599	-1.039	**0.627**	**2.815**	**0.541**	**1.292**	**4.644**	**0.079**	**1.136**	**1.266**	**1.116**	**0.244**	**2.078**
Inertia explained by the factorial axis (%)			**14.5**	**8.9**	**6.7**	**6.1**	**5.9**	**5.3**	**4.7**	**4.4**	**4.0**	**3.7**	**3.6**	**3.4**	**3.0**	**2.9**

*First 14 factorial axes to build the composite readiness score as there is no information gain beyond axis 14

[a]Four tracers consistent with the FAOC-G in negative direction (not bold) and 25 consistent in positive direction (bold)

[b]Highlighted in bold and italic are the weights of tracers from factorial axes selected to build the composite readiness score

Table 4.4: Standard coordinates of tracer items on the first six factorial axes (peripheral health centres) derived from the SARA survey in 2014 in Burkina Faso.

Tracers	Category	Frequency, n (%)	Factorial axes*					
			1	2	3	4	5	6
Improved water source	No		0.457[a]	0.048	**-5.424**	0.301	***-5.699***	0.095
	Yes	476 (87.2)	-0.067	-0.007	**0.798**	-0.044	***0.838***	-0.014
Emergency transportation	No		***-5.770***[b]	**-0.594**	**-1.284**	**-0.830**	**-1.483**	3.543
	Yes	515 (94.3)	***0.347***	**0.036**	**0.077**	**0.050**	**0.089**	-0.213
Soap or running water	No		**-1.239**	**-0.895**	8.502	**-5.784**	***-7.725***	**-0.620**
	Yes	518 (94.9)	**0.067**	**0.048**	-0.460	**0.313**	***0.418***	**0.034**
Storage infectious waste	No		0.602	***-6.612***	**-0.633**	1.732	**-0.529**	0.274
	Yes	494 (90.5)	-0.063	***0.696***	**0.067**	-0.182	**0.056**	-0.029
Latex gloves	No		0.418	***-7.016***	1.337	1.780	**-0.218**	0.025
	Yes	499 (91.4)	-0.039	***0.661***	-0.126	-0.168	**0.021**	-0.002
Urine dipstick	No		***-4.999***	0.574	**-0.718**	1.596	**-1.019**	2.063
	Yes	501 (91.8)	***0.449***	-0.052	**0.065**	-0.143	**0.092**	-0.185
Ceftriaxone	No		***-3.772***	**-1.310**	**-1.489**	**-1.567**	3.602	1.638
	Yes	492 (90.1)	***0.414***	**0.144**	**0.163**	**0.172**	-0.395	-0.180
Oxytocin	No		***-5.750***	**-0.119**	1.406	0.905	**-0.920**	0.604
	Yes	502 (91.9)	***0.504***	**0.010**	-0.123	-0.079	**0.081**	-0.053
Thiazidic	No		0.048	**-0.190**	**-0.263**	***-0.751***	0.136	0.041
	Yes	41 (7.5)	-0.586	**2.338**	**3.235**	***9.250***	-1.672	-0.510
IPTg training	No		**-1.518**	**-0.266**	**-0.552**	**-0.122**	0.163	***-4.223***
	Yes	370 (67.8)	**0.722**	**0.127**	**0.263**	**0.058**	-0.077	***2.009***
Inertia explained by the factorial axis (%)			**20.0**	**14.2**	**10.5**	**10.3**	**9.9**	**8.8**

*First 6 factorial axes to build the composite readiness score as there is no information gain beyond axis 6
[a]Four tracers consistent with the FAOC-G in negative direction (not bold) and 6 consistent in positive direction (bold)
[b]Highlighted in bold and italic are the weights of tracers from factorial axes selected to build the composite readiness score

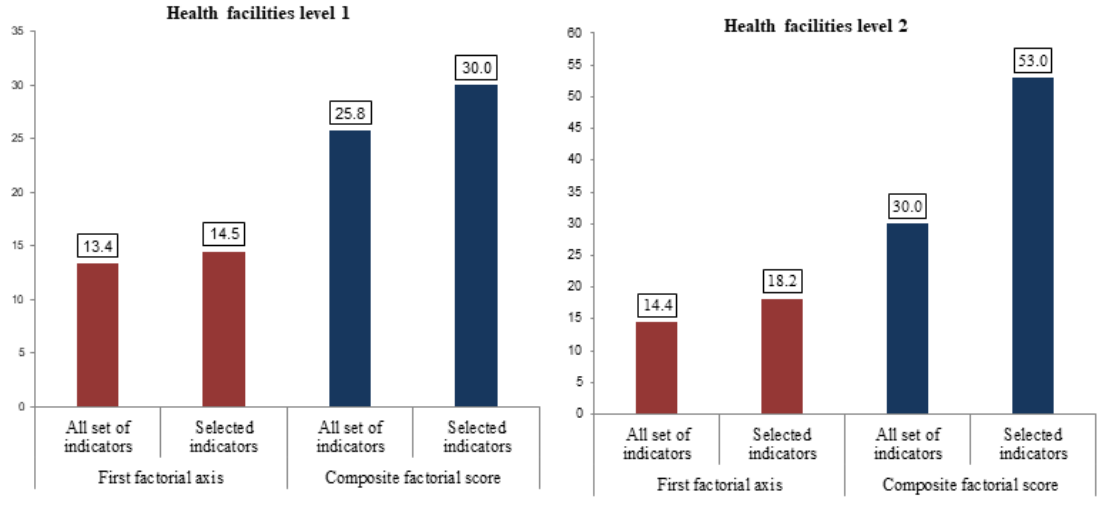

Figure 4.1: Proportion of variance explained by the first factorial axis (red) and the composite readiness score (blue) based on the whole set and the subset of tracers identified by the Bayesian variable selection.

4.3.4 Association between facility readiness and the malaria mortality

The composite readiness score was converted into a categorical index with three categories defined by the tertiles of its distribution. Results of the Bayesian geostatistical negative binomial model fitted on malaria mortality indicated that medical centres with the highest and moderate readiness experienced a lower mortality rate by 19% and 6%, respectively, compared to the facilities with the lowest readiness (Table 4.5). However, this difference lacked statistical significance. The type of management and the location of health facilities do not influence malaria mortality.

Peripheral health centres at the highest readiness category had a mortality rate ratio (MRR) of 0.41 (95% Bayesian credible interval (BCI): 0.19-0.91) compared to those with the lowest readiness. Furthermore, urban health facilities were associated with a statistically important reduction of malaria mortality compared to those in rural areas (MRR: 0.49, 95% BCI: 0.31-0.78). The median spatial range distance (distance over which the spatial correlation is no more important) was higher in medical centres compared to peripheral health centres.

Table 4.5: Posterior estimates (median and 95% BCI) of the association between health facility readiness and malaria mortality obtained from a Bayesian geostatistical negative binomial model.

	Medical centres	**Peripheral health centres**
Readiness index	MRR[a] (95% BCI)	MRR (95% BCI)
Low	1.00	1.00
Middle	0.94 (0.76-1.25)	0.74 (0.54-1.00)
High	0.81 (0.74-2.51)	0.41 (0.19-0.91)*
Location		
Rural	1.00	1.00
Urban	0.97 (0.48-1.77)	0.49 (0.31-0.78)*
Administrative status		
Private	1.00	1.00
Public	1.12 (0.51-2.17)	0.69 (0.46-1.01)
Spatial parameters		
Spatial variance	0.26 (0.14-0.53)	0.46 (0.29-0.67)
Spatial range (km)	43.27 (13.63-89.92)	26.32 (6.39-83.1)

[a]MRR: mortality rate ratio

*: statistically important association

The geographical distribution of malaria mortality rate showed a similar pattern with that of the proportion of health facilities with lowest readiness (Figure 2), indicating that regions with high malaria mortality rate have high proportion of facilities with low readiness and vice versa. In particular, the region of Centre (first region in terms of health infrastructure and population) showed for both health facility

levels low malaria mortality rates, while Sud Ouest, Sahel and Boucle du Mouhoun were those among the highest mortality and highest proportion of low performing facilities.

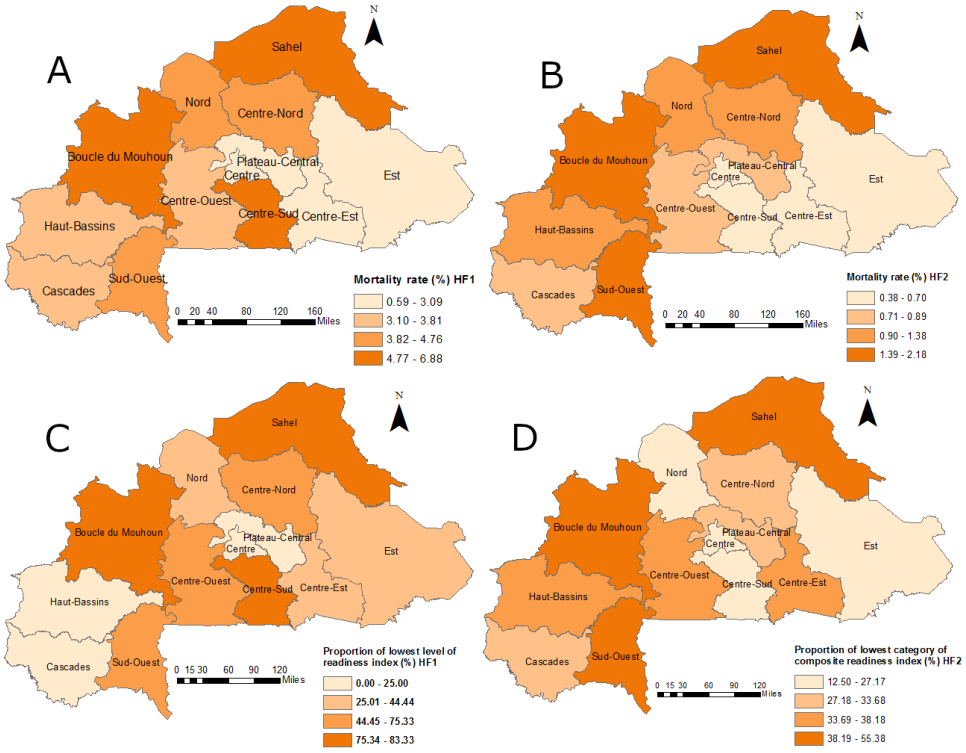

Figure 4.2: Spatial distribution of malaria-related mortality rate among children under the age of 5 years for medical centres (A) and peripheral health centres (B) and the proportion of health facilities HF1 (C) and peripheral health centres (D) in the lowest category of the corresponding composite readiness index.

4.4 Discussion

Malaria services readiness and malaria-related mortality.

The aim of our study was to estimate the extent to which malaria services readiness in Burkina Faso was associated with malaria mortality. Service delivery is an essential building block of the WHO health systems framework (WHO, 2007). Our research indicated that the higher the readiness index, the lower the mortality in peripheral health centres. Hence, the index is sensitive enough to identify some of the barriers in the quality of the management of malaria cases. Information from Malaria Indicator Surveys and of the HMIS can be included as additional components of this index to look into other aspects of case management, such as delays of seeking care, the severity of cases consulting or the quality of care provided. Our results corroborate with previous investigations done in Bangladesh, Ghana, Haiti, Mozambique, Nigeria and Tanzania that also used SARA or similar survey data and revealed a positive effect of readiness on health outcome (Boyer et al., 2015; Fernandes et al., 2014; Gage et al., 2016; Leslie et al., 2017; Wang et al., 2017; Wenjuan W et al., 2014).

The lack of a statistically important association between facility readiness and malaria mortality in medical centres might be explained by the severity of malaria cases seeking treatment in medical centres. Indeed, peripheral health centres refer complicated cases to medical centres. Hence, although the latter are better equipped and staffed, the mortality rate is partially influenced by the seriousness of their cases. On the other hand, the reduced mortality rate in peripheral health centres with highest readiness is certainly related to prompt diagnosis and adequate treatment, since peripheral health centres receive patients at an early stage of the disease. This is consistent with the important association of the emergency transportation tracer with malaria mortality. In medical centres, emergency transportation obtained the highest weight. Reducing the delay of reference from peripheral health centres to medical centres will reduce the probability of deaths due to a severe malaria (Hatherill et al., 2003; Philpot et al., 2008; Burke et al., 2014; Treleaven et al., 2017). In addition, training health workers of peripheral health centres would allow for early reference decisions. At community level, populations must be encouraged to consult very early. In peripheral health centres, we noticed that medicines for NCDs management had low availability, although one drug devoted to chronic diseases had the highest weight. The low availability could be explained by insufficiency in the supply of this type of drug and thus a low quality of the management of chronic diseases. On the contrary, its presence may mean competent health workers in the provision of drugs and thus a better quality of care and therefore to the management of malaria cases as well.

Tracer items and domains readiness

Results of the individual tracers and domain readiness indicators are consistent with the role assigned to each level. Peripheral health centres are the first contact with any health issues and thus they provide the so called “minimum package” of health care and services, while medical centres provide the “complementary package”. Basic equipment was the most available domain for both levels of health care and for general services. The most widely available items within this domain were thermometer, stethoscope, adult scale and blood pressure apparatus, which represent minimum essential equipment to manage patients. However, their availability was almost 50% in peripheral health centres meaning that the quality of health care is not guaranteed in about half of the peripheral health centres, suggesting lack of financial resources and of management of supplies in peripheral health centres.

The weakest domain for both levels for general services was the essential medicine with an availability of less than 1%. Two types of medicines appeared in this domain; medicines for infectious diseases (availability >80%) and medicines for chronic diseases (availability <10%). The situation depicts the epidemiological profile of Burkina Faso, where infectious diseases are still predominant, but also indicates that services towards chronic diseases and NCDs in 2014 were inadequate, particularly in view of NCDs rapidly gaining importance in LMICs (Burkina Faso; Ministère de la Santé, 2018; Unwin et al., 2001; Holmes et al., 2010; Vos et al., 2015). This also indicates the weakness in the drug supply circuit of health facilities from the expression of adequate needs, to the availability of drugs at the point of purchase (Cameron et al., 2009; Wagenaar et al., 2014).

The diagnostic capacity domain was very weak in peripheral health centres (0.6%) compared to medical centres (33%) even though in peripheral health centres, large number of biological diagnostic tests do not need sophisticated equipment. Peripheral health centres generally refer patients who need further biological testing. Nevertheless, the level of availability of malarial diagnosis capacities was >80% appreciable in both levels and reflects the high workload relative to malaria in consultations (Burkina Faso; Ministère de la Santé, 2015).

The basic amenities domain is related to the health infrastructure investment and depends heavily on the financial support of the government. At the time of the SARA survey in 2014, only 1.9% of peripheral health centres had a computer. Hence, computers were the exception rather than the norm in peripheral health centres.

Regarding malaria-specific services, the average availability of "staff and guidelines" and the "medicine and commodity" domains was higher in peripheral health centres than medical centres. More than 80% of them had their staff trained and knew the guidelines for malaria management. In addition, more than 95% in these facilities possessed first-line treatment for malaria. Malaria is the most important cause of morbidity and mortality in under 5-year-old children, which explains that substantial efforts are being made to train peripheral health facility workers, render medicines and other medical supplies available for malaria case management at all levels of the health system. In recent years, there has been a shift from first-line medicines to ACTs, introduction of RDTs, and ITN campaigns (Diabaté et al., 2014; Zongo et al., 2016). However, the availability of ITNs in health facilities had reduced the availability of malaria readiness in general because it is mostly during mass campaign that ITNs are distributed to pregnant women.

Variables selection

The variable selection highlighted facts that are consistent with the health system in Burkina Faso. In both health facility levels and for general service readiness, "emergency transportation" was selected. In general, emergency transportation (ambulances) which reduces the delay to reach a health centre is available in medical centres. Peripheral health centres use mainly motorcycles for transportation. The malaria management policy in Burkina Faso requests that cases are confirmed before treatment; yet, there is still considerable empiric treatment (Burkina Faso; Ministère de la Santé, 2018). Without a diagnostic test, malaria might be confused with other infectious diseases, which has ramifications on disease management, including treatment (Crawley et al., 2010; Gwer et al., 2007). This may explain the heavy prescription not only of antimalarial but also of antibiotics, such as "gentamicin" and "ceftriaxone".

Geographical distribution of readiness and mortality rate

The geographical distribution of the under-5 malaria-related mortality corresponds almost to the HMIS statistics in 2014 suggesting that the regions of the Boucle du Mouhoun, Sahel and Sud-Ouest had the highest mortality rates and that malaria was the leading cause of deaths in this age group at that time. Regions with low mortality rates are concentrated in the central and eastern part of the country for both levels. Apart from the fact that there is a greater concentration of health workers around the central region, there is no evidence to explain this distribution of mortality (Burkina Faso; Ministère de la Santé, 2018). Similarly, to the

mortality rate, the geographical distribution of the readiness index is heterogeneous for both levels. Nevertheless, the regions of Centre and Hauts Bassins are the best equipped and have the highest numbers of health facilities. They gather more than half of health human resources in Burkina Faso and possess most performant medical centres.

Strengths and limitations

Our findings clearly favoured the construction of a composite readiness indicator rather than one derived from the first factorial axis. Indeed, the proportion of variance explained has more than doubled in both health facility levels compared to the first component. The composite index takes also into account the multifactorial and multidimensionality of the readiness allowing capturing tracers items that are represented better by high order axes. The variable selection identifies the subset of the most important tracers that are related to malaria mortality producing a score that explains even more variation in the tracers and it is directly related to a specific health outcome and thus, can led comprehensive policy decisions to strengthen the specific health services and care. The methodology can be applied on SARA or SARA-like survey in other countries.

However, SARA survey assess availability of items the day of the survey and thus do not take into account the variability over time of the items and one day may not be sufficient to get the mean availability of an item in a health facility longitudinally. The SARA proposed methodology weights all tracer items equally in the construction of readiness index; however, our proposed approach addresses this limitation. Unfortunately, mortality data in the HMIS were not available for several health facilities; therefore, we could not include data from those facilities in the analysis. Our results reflect the readiness of malaria services in Burkina Faso in 2014. The country has performed two more surveys in 2016 and 2018. Our methodology can be easily extended to construct a temporally varying readiness index and therefore assess potential improvements in the health facility malaria service provision.

4.5 Conclusion

Our results indicate that investing in health services is an effective means for reducing the burden of malaria in Burkina Faso. The broad implication is that resources and efforts must be maintained and strengthened, particularly at medical centres where mortality rate is high and at weak peripheral health centres. The emergency transportation mechanisms between the different levels of the health system need to be further enhanced. The composite readiness score created by exploiting more than one MCA factorial axis produces a more informative and consistent measure of health facility readiness that captures all aspects of readiness unlike the index based on only the first axis.

Abbreviations

ACT, Artemisinin-based combination therapy; BCI, Bayesian credible interval; CSPS, Centre de Santé et de Promotion Sociale; FAOC-G, Global First Axis Ordering Consistency; HMIS, Health Management and Information System; IPT, intermittent preventive treatment of malaria; IRS, indoor residual spraying; ITN, insecticide-treated net; LMICs, low- and middle-income countries; MCA, multiple correspondence analysis; MRR, mortality rate ratio; NCD, non-communicable disease; ORS, oral rehydration solution; PC, principal

component; PCA, principal component analysis; RDT, rapid diagnostic test; SARA, Service Availability and Readiness Assessment; WHO, World Health Organization.

Declarations

4.6 Acknowledgements

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Authors' contributions

OM participated in the data acquisition, analysis, interpretation and drafted the manuscript; **JEOD** contributed to the data acquisition and interpretation of data; **AS** contributed to the interpretation of the data; **JU** contributed to interpretation of data and revisions of the manuscript; **PV** formulated research goals and objectives, contributed to financial acquisition, statistical methodology, interpretation of results and revisions of the manuscript. All authors reviewed, commented and approved the final version of the manuscript prior to submission.

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Availability of materials and data

The SARA database and the HMIS database are accessible via request to the Department of Statistics of the Ministry of Health of Burkina Faso (zongoaugustin@yahoo.fr)

Ethics approval and consent to participate

We used secondary data of the Service Availability and Readiness Assessment (SARA) survey and the Health Management and Information System (HMIS) that were made available by the "Direction Générale des Études et des Statistiques Sectorielles", Burkina Faso. The research was approved by the National Ethics Committee for Health Research of Burkina Faso under the deliberation N°2014-7-072. All data were anonymized.

Consent for publication

Not applicable

Competing interests

The authors have no competing interest to declare.

4.7 Appendix

Appendix A

Text A.4.1: Model formulation.

A geostatistical negative binomial model [1] was fitted to assess the effect of the facility readiness index on malaria mortality adjusted for facility characteristics (type of health facility location and of administrative status). Let Y_i be the number of malaria related deaths reported by health facility i during January – December 2014. Y_i is assumed to follow a negative binomial distribution, $Y_i \sim NB\,(p_i, r)$ where $p_i = {}^{r}/_{r\ +\mu_i}$ and r is the dispersion parameter of the distribution. We relate the predictors to the mean count μ_i of the malaria mortality outcome reported at facility i via the log-linear regression equation, $log(\mu_i) = \log(N_i) + \boldsymbol{\beta}^T\boldsymbol{X} + \omega_i + \varphi_i$ where N_i is the offset which was considered to be the total number of children hospitalized due to malaria. $\boldsymbol{X}$ are the predictors, that is, the facility readiness index and facility characteristics, and $\boldsymbol{\beta}$ is the vector of regression coefficients. ω_i are facility location random effects added in the model to account for spatial dependence in the malaria mortality. We assumed a Gaussian process on $\boldsymbol{\omega} = (\omega_1, \omega_2, \ldots, \omega_k)^T$, that is, $\boldsymbol{\omega} \sim N(0, \sigma^2 R)$ where R is a correlation matrix, defined by an exponential parametric function of the distance d_{ij} between the locations of facilities i and j i.e. $R_{ij} = \exp(-d_{ij}\rho)$. The parameter σ^2 measures the spatial variation and ρ is a smoothing parameter that controls the rate of correlation decay with increasing distance. The range parameter, $\frac{3}{\rho}$ estimates the minimum distance beyond which spatial correlation is negligible. Non-spatial variation is estimated by the location random effects φ_i, which is assumed to be independent and normally distributed with mean 0 and variance σ_φ^2, that is, $\varphi_i \sim N(0, \sigma_\varphi^2)$. Model fit and parameter estimation was performed using Bayesian formulation and Markov Chain Monte Carlo (MCMC) estimation. Model specification was completed by assigning prior distributions to model parameters. An inverse-gamma hyperprior was assigned for the variance σ_φ^2, a gamma distribution for the spatial smoothing parameter, and non-informative Gaussian distributions for the regression coefficients with mean 0 and variance 100. Model parameters were estimated using MCMC simulation, running a two-chain algorithm with a burn-in of 10,000 iterations followed by 200,000 iterations. Convergence was formally assessed by the Gelman and Rubin diagnostic [2], implemented in CODA.

Text A.4.2: Multiple correspondence analysis

Let K denote the number of binary tracer items, N be the number of health facilities and $\boldsymbol{X}_{Nx(2*K)}$ denote the indicator matrix in which the facilities are displayed as rows and each tracer is represented by the inclusion of two columns $\boldsymbol{I}_{j_k}^k$, one per category of the tracer $k = 1, \ldots, K$, corresponding to its presence ($j_k = 1$) or absence ($j_k = 0$) from the facility. Let $\boldsymbol{P}$ be the matrix $\boldsymbol{P} = \frac{1}{N*K}\boldsymbol{X}$, r and c the vectors of the row and column totals of $\boldsymbol{P}$, respectively, and $\boldsymbol{S}$ the matrix $\boldsymbol{S} = \boldsymbol{D}_r^{-\frac{1}{2}}(\boldsymbol{P} - \boldsymbol{r}\boldsymbol{c}^T)\boldsymbol{D}_r^{-\frac{1}{2}}$ where $\boldsymbol{D}_r = diag\{\boldsymbol{r}\}$ and $\boldsymbol{D}_c = diag\{c\}$. A readiness score F_i^a corresponding to health facility i and based on the a^{th} factorial axis of MCA is defined by $F_i^a = \frac{1}{K}\sum_{k=1}^{K}\sum_{j_k \in \{0,1\}} W_{j_k}^{a,k} X_{j_k,i}^k$ where the weights $W_{j_k}^{a,k}$ are the corresponding column

standard coordinates of the a^{th} factorial axis, that is, they are elements of the a^{th} column of the matrix $\boldsymbol{D}_c^{-\frac{1}{2}}\boldsymbol{V}$ where $\boldsymbol{V}$ is the right singular vector of $\boldsymbol{S}$. The factorial score of the first axis is then defined by $F_i^1 = \frac{1}{K}\sum_{k=1}^{K}\sum_{j_k\in\{0,1\}} W_{j_k}^{1,k} X_{j_k,i}^k$. The variance explained by the a^{th} factorial axis is given by the eigenvalues $\lambda_a = (\boldsymbol{D}_s^2)_{\boldsymbol{a}}$.

Text A.4.3 Construction of a composite readiness index

Following the approach proposed by Asselin (2009), for each indicator k we define a discrimination measure Δ_l^a on each factorial axis a, $\Delta_k^a = \sum_{j_k\in\{0,1\}} \frac{n_{jk}^k}{N}(W_{j_k}^{a,k})^2$ where $n_{j_k}^k$ is the absolute frequency of the j_kth category of indicator k [3] The average of the discrimination measures across the K indicators on the a^{th} axis corresponds to the total variance explained by the axis, that is, $\lambda_a = \frac{1}{K}\sum_{k=1}^{K}\Delta_k^a$.

For each factorial axis, we split the indicators in two groups, each satisfying the Global First Axis Ordering Consistency condition (FAOC-G) in one of the two axis orientations, i.e. positive (G_1) or negative (G_2). We then calculate the total variance explained by each group in the axis, that is, $\Delta_{G_j}^a = \sum_{k\in G_j}\Delta_k^a$ where $j = 1,2$ and retain on the axis the group of indicators explaining more variation that a threshold T_a which is taken to be 50% of the variance explained by the axis, that is, $\mathrm{T}_a = 0.5 * K * \lambda_a$. The groups of indicators retained on the axes, are overlapping and an indicator can be retained on several axes. We remove intersections by selecting the factorial axis with the highest discrimination measure for than indicator among all axes. We define the composite readiness score $F_i = \frac{1}{K}\sum_{k=1}^{K}\sum_{j_k\in\{0,1\}}\sum_{a=1}^{L}\delta(k-a)W_{j_k}^{a,k}X_{j_k,i}^k$ where L is the number of factorial axes used in the composite score and $\delta(k-a)$ is the Dirac delta function which takes the value 1 when the k^{th} indicator is retained on the a^{th} factorial axis and 0 otherwise, that is, $\delta(k-a) = 1$ if $k = a$ and $\delta(k-a) = 0$ if $k \neq a$. To improve interpretation of the score we translate the weights so that the absence category $(j_k = 0)$ of the k indicator to receive a zero weight and the presence one $(j_k = 1)$ to receive a strictly positive representing the gain in the readiness increase measured by the axis a when a facility i acquires the k tracer. Therefore the $W_{j_k}^{a,k}$ in F_i is replaced by $W_{j_k}^{+a,k}$ where $W_0^{+a,k} = 0$ and $W_1^{+a,k}$=$W_1^{+a,k} - W_0^{a,k}$.

Text A.4.4: The Bayesian variable selection formulations

To identify the most important readiness tracer items related to malaria deaths, Bayesian geostatistical variable selection was implemented using stochastic search and adopting a spike and slab prior distributions for the regression coefficients [4]. For every readiness indicator I_k a Bernoulli variable γ_k was introduced with Bernoulli probability π_k corresponding to the inclusion of I_k in the model. For the coefficient β_k, we assume a prior distribution which is mixture of non-informative normal distributions, $\beta_k \sim \delta(\gamma_{k-1})N(0,\tau_k^2) + (1-\delta(\gamma_{k-1}))N(0,\vartheta_0\tau_k^2)$ where $\delta(.)$ is the Dirac delta function. Therefore, in case I_k is included in the model (slab) and an informative normal prior shrinking β_k to zero (spike) if I_k is included in the model, $\beta_k \sim N(0,\tau_k^2)$ (slab) and in case I_k is excluded, $\beta_k \sim N(0,\vartheta_0\tau_k^2)$ where $\vartheta_0 = 10^5$ is a very large number shrinking the variance to zero i.e. spike component of the prior. We have adopted a $Beta(1,1)$ hyperprior for π_k and an inverse gamma prior for the variance τ_k^2 with mean 1 and variance 10.

Appendix B

Table B.4.1: Selection of factorial axes included in the composite score for medical centres.

Tracers	Discrimination measures														Selected factorial axes	Weights[b] $W_1^{+\alpha,k}$
	Factorial axes[a]															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14		
Privacy room	**0.004**	**0.049**	0.003	**0.150**	0.036	**0.038**	**0.001**	0.009	0.000	**0.387**	**0.128**	0.032	0.001	0.017	10	7280
Emergency transportation	0.000	**0.056**	**0.028**	0.061	0.000	**0.188**	0.062	**0.315**	**0.000**	**0.007**	0.006	0.022	**0.012**	0.011	8	11826
Light power	**0.027**	**0.217**	0.011	0.009	0.001	0.068	**0.168**	**0.030**	**0.004**	**0.090**	0.039	**0.152**	**0.000**	**0.000**	2	4078
Safe final disposal of sharps	0.072	**0.012**	**0.502**	**0.171**	**0.002**	0.007	**0.003**	**0.014**	0.017	**0.004**	0.048	**0.002**	**0.008**	**0.000**	3	6399
Safe final disposal of infectious wastes	0.039	**0.015**	**0.602**	**0.166**	0.000	0.001	**0.034**	**0.006**	0.019	0.008	**0.000**	0.000	**0.000**	**0.002**	3	6771
Appropriate storage of infectious waste	0.018	**0.054**	0.000	0.006	**0.015**	**0.377**	**0.006**	**0.001**	**0.007**	0.014	0.099	**0.106**	0.039	0.026	6	9848
Latex gloves	**0.001**	**0.119**	0.006	0.007	**0.118**	**0.005**	**0.259**	0.077	**0.057**	0.001	0.024	0.002	**0.045**	**0.008**	7	7596
Guidelines for standard precautions	**0.269**	0.012	**0.036**	**0.020**	**0.029**	**0.023**	0.111	0.007	**0.024**	**0.080**	**0.004**	**0.054**	**0.010**	0.006	1	4126
Haemoglobin test	**0.095**	0.096	0.012	0.013	**0.158**	0.003	0.008	**0.002**	**0.159**	0.025	**0.014**	0.063	**0.176**	0.004	13	5035
Glucose dipstick	**0.090**	0.002	**0.098**	0.000	**0.185**	0.027	0.047	0.068	**0.003**	0.088	0.000	**0.067**	**0.000**	0.000	5	6889
Amlopdipin	**0.054**	**0.162**	0.029	**0.030**	**0.016**	**0.032**	**0.117**	0.002	0.169	0.015	**0.026**	0.000	0.019	0.003	2	3238
Aspirin	**0.336**	0.163	**0.000**	**0.005**	0.018	**0.015**	0.006	0.038	**0.051**	0.015	0.000	**0.048**	0.023	0.016	1	4151
Beclomethasone inhaler	**0.043**	**0.290**	0.021	**0.213**	**0.002**	**0.000**	0.028	**0.030**	**0.036**	0.025	0.058	0.000	0.025	**0.001**	2	5464
Betablockers	**0.125**	**0.257**	0.116	**0.063**	**0.009**	0.021	0.068	**0.004**	0.003	**0.001**	0.002	0.000	0.027	0.047	2	4441
Ceftriaxone	**0.517**	0.009	0.006	**0.004**	0.053	**0.016**	**0.022**	**0.033**	0.019	**0.002**	0.041	0.003	**0.114**	0.009	1	6950
Gentamicin	**0.296**	**0.016**	**0.036**	0.133	0.052	0.029	**0.002**	**0.003**	0.015	0.013	**0.004**	**0.019**	**0.000**	0.135	1	4803
Glibenclamide	**0.142**	**0.007**	**0.042**	0.042	0.047	0.000	**0.003**	**0.008**	**0.141**	**0.042**	0.008	0.019	0.193	**0.203**	14	5520
Insulin injectable	**0.028**	**0.208**	0.043	**0.027**	**0.009**	**0.015**	0.148	0.001	0.073	0.026	**0.053**	**0.059**	**0.017**	**0.157**	2	5936
Magnesium	**0.274**	**0.159**	**0.003**	0.054	0.005	0.008	**0.079**	0.000	0.002	**0.002**	**0.084**	0.012	0.001	**0.013**	1	2990
Oxytocin	**0.197**	**0.011**	**0.109**	0.227	**0.005**	0.060	0.011	**0.036**	0.050	0.006	**0.019**	**0.043**	0.004	**0.000**	1	3530
Salbutamol	**0.394**	**0.007**	**0.024**	**0.033**	**0.015**	**0.007**	**0.001**	0.029	**0.050**	0.038	**0.001**	0.031	0.007	0.009	1	3908
zinc	**0.306**	0.010	**0.007**	**0.026**	0.000	0.123	0.005	**0.013**	0.024	0.006	0.040	0.120	0.030	0.010	1	3137
ITN	**0.020**	0.001	**0.107**	**0.011**	0.098	**0.176**	**0.025**	**0.000**	**0.031**	0.066	**0.181**	**0.014**	0.002	**0.001**	11	5142
Staff trained in malaria diagnosis and treatment	**0.072**	0.096	**0.003**	**0.001**	**0.302**	**0.012**	**0.026**	0.069	0.081	**0.000**	0.001	0.001	0.023	**0.000**	5	4971
Staff trained in IPTg	**0.002**	**0.010**	**0.024**	0.207	**0.061**	**0.220**	0.009	0.012	0.063	**0.042**	0.021	0.102	0.013	0.000	6	4323
First line treatment of malaria	**0.403**	0.099	0.005	**0.015**	0.000	**0.014**	0.004	0.002	0.029	0.017	0.029	0.001	**0.003**	**0.088**	1	5211
IPTg drug	**0.348**	0.095	0.017	**0.028**	0.128	**0.033**	**0.032**	0.000	0.006	**0.020**	0.034	**0.001**	**0.056**	0.010	1	6019
Carbamazepine	**0.009**	0.156	0.027	**0.037**	**0.194**	**0.002**	**0.050**	0.175	0.016	**0.002**	0.050	**0.000**	**0.029**	0.036	5	4198
Haloperidol	**0.015**	0.191	0.023	**0.008**	**0.148**	**0.005**	**0.025**	**0.304**	**0.000**	**0.015**	**0.018**	**0.013**	**0.001**	0.040	8	6119
Variance Threshold (T_a)	2.099	1.289	0.971	0.883	0.853	0.762	0.680	0.644	0.574	0.529	0.516	0.492	0.438	0.427		
Variation explained (Δ_{G1}^{a})	**4.068**	**1.746**	**1.634**	**1.007**	**1.269**	**1.174**	**0.974**	**0.610**	**0.578**	**0.780**	**0.583**	**0.577**	**0.442**	**0.519**		
Variation explained (Δ_{G2}^{a})	0.130	0.831	0.308	0.759	0.437	0.350	0.315	0.315	0.571	0.278	0.449	0.407	0.435	0.334		
Variation explained after eliminating intersection	3.340	1.133	1.104	0.000	0.682	0.597	0.259	0.620	0.000	0.387	0.181	0.000	0.176	0.203		

[a]Not bold cells: Group 1, negative orientation; Bold: Group 2, positive orientation

[b]Weights were multiplied by 1000

Table B.4.2: Selection of factorial axes included in the composite score for peripheral health centres

Tracers	Discriminant measures[a]						**Selected factorial axes**	Weights[b] $W_1^{+\alpha,k}$
	Factorial axes							
	1	2	3	4	5	6		
Improved water source	0.006	0.000	**0.455**	0.001	**0.471**	0.000	5	6537
Emergency transportation	**0.400**	**0.003**	**0.010**	**0.004**	**0.013**	0.066	1	6117
Soap or running water	**0.017**	**0.006**	0.411	**0.186**	**0.318**	**0.002**	5	8143
Storage infectious waste	0.008	**0.651**	**0.004**	0.033	**0.003**	0.001	2	7308
Latex gloves	0.003	**0.656**	0.018	0.031	**0.000**	0.000	2	7677
Urine dipstick	**0.448**	0.004	**0.005**	0.024	**0.009**	0.034	1	5448
Ceftriaxone	**0.312**	**0.027**	**0.026**	**0.028**	0.141	0.026	1	4186
Oxytocin	**0.579**	**0.000**	0.018	0.007	**0.007**	0.003	1	6254
Thiazidic	0.006	**0.063**	**0.089**	**0.716**	0.022	0.002	4	10001
IPTg training	**0.219**	**0.005**	**0.015**	**0.001**	0.001	**0.745**	6	6232
Variance Threshold (T_a)	0.999	0.708	0.526	0.515	0.494	0.439		
Variation explained (Δ_{G1}^{a})	**1.9752**	**1.411**	**0.606**	**0.935**	**0.823**	**0.747**		
Variation explained (Δ_{G2}^{a})	0.023	0.004	0.447	0.096	0.164	0.131		
Variation explained after eliminating intersection axes	1.740	1.308	0.000	0.716	0.790	0.745		

[a]Not bold cells: Group 1, negative orientation; Bold: Group 2, positive orientation

[b]Weights were multiplied by 1000

Chapter 5: Assessing temporal changes in the association of malaria-related health service readiness and malaria mortality in under-5 years old between 2012 and 2014 in Burkina Faso

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Abstract

The malaria burden has decreased steadily in Burkina Faso over the past decade due to cost-effective interventions and health system reforms. We aimed to quantify the contribution of malaria services readiness on the decline of malaria mortality in the under-5 age group from 2012 to 2014.

Method

We grouped in two levels the health facilities (medical and peripheral health centres) of the Service Availability and Readiness Assessment Surveys (SARA) surveys of 2012 and 2014. We joined tp this data information relative to malaria lethality and consultations form the Health management and information system of the corresponding year. We applied an equally weighted Bayesian geostatistical variable selection to retain the most important items. We fitted multiple correspondence analysis (MCA) on the selected tracer items to derive a composite readiness scores for both types of health facilities level. The composite readiness scores were then split into 3 ordered (low, moderate and high) composite readiness index. Bayesian geostatistical negative binomial model was used to assess the association of the readiness index and the malaria lethality.

Results

The readiness of malaria-related health service increased for both medical centres and peripheral health centres in 2014 compared to 2012. We observed a reduction of malaria mortality rate in medical centres with an incidence rate ratio (IRR) = 0.45 (95% Bayesian credible interval (BCI): 0.59-0.95) and for peripheral health centres with an IRR=0.63 (95%BCI: 0.53-0.77). Medical centres in the highest readiness index was associated with a low mortality rate compared to those in the lowest level: IIR=0.48 (95% BCI: 0.35- 0.65). Related to peripheral health centres, the moderate and highest readiness level was significantly associated with a lower mortality rate compared to the lowest readiness group: IRR= 0.72 (95% BCI: 0.57-0.90) and IRR= 0.62 (95% BCI: 0.49-0.78) respectively.
The spatial distribution of malaria lethality indicated that regions with high lethality rate are where the proportion of health facilities in the low readiness level is high.

Conclusion

Our results provide evidence that improving health services' capacity is valuable for malaria control in an endemic area. The approach is a comprehensive alternative to analyse SARA surveys and other similar surveys linking the health service readiness and a health outcomes to measure progress towards health objectives.

Keywords: *Burkina Faso, Service availability and readiness assessment, multiple correspondence analysis, malaria, composite readiness index.*

5.1 Introduction

Malaria is a major public health issue in Burkina Faso representing the main workload of peripheral health facilities (Ministère de la Santé, 2017). In 2016, 50.1 and 45.0% of under-5 year's old consultations in the complete health services and peripheral health services were malaria cases. Under-5 year's old children bear the heavy burden. Indeed, malaria represents more than 50% of the causes of deaths occurring in this age group (Ministère de la Santé, 2017). Nevertheless, several strategies and interventions contributed to reducing the burden of malaria over the past fifteen years, especially in children under-5 year's old and pregnant women. The country introduced artemisinin-based combination therapies (ACT) as the "first line" malaria drugs in place of chloroquine extended the rapid diagnostic tests (RDTs) to all health facilities and community levels and scaled up the community-based treatment. In terms of malaria preventive intervention, the country carried out a mass distribution of long-lasting insecticides treated nets (LLINs), seasonal chemoprophylaxis in less than 5 years, indoor residual spray (IRS) and routine intermittent preventive treatment in pregnant women. From 2010 to 2014, LLINs ownership increased from 57 to 90%; rapid diagnostic RDTs were performed in 33% of febrile children compare to 5% in 2010; nearly 50% received antimalarial drugs, compared to 35% in 2010. In the same interval, malaria parasitemia decreased from 66% to 46%, but the level of anemia remained stationary (Ministère de la santé, 2014), the under-5 malaria mortality rate (U5MR) decreased roughly from 2.5 to 1.5% (Ministère de la Santé, 2018). The progress made should not obscure the weakness of the health system that hinder the optimal implementation of lifesaving health interventions. Indeed, in Sub-Saharan Africa, shortage of qualified health workers, drugs stock-outs, lack of adequate diagnostic means, low coverage of health infrastructure, weak health information system, financial constraints reduce the optimal implementation of proven health interventions in their real-life (Travis et al., 2004; WHO, 2018, 2007). Several authors have reported that the decline of malaria-attributed or all-cause under-5 mortality rate is related to the increase of the coverage of proven cost-effective health interventions (Druetz, 2018; Eckert et al., 2017; Kipp et al., 2016; Rowe, 2017; Thwing et al., 2017; Victora et al., 2016). In Burkina Faso, the effect of malaria preventive interventions indicated disparate results. Wehner and al. and Louis and al. did not found changes in malaria incidence and child mortality rate, while Beiersmann and al. found a significant decrease in malaria parasitemia between 1999 and 2009 (Beiersmann et al., 2011; Louis et al., 2015; Wehner et al., 2017). Inpatients cases management (including malaria) is compromised by the lack of human resources, lack of adequate equipment (rapid diagnostic test storage), drugs shortages and absence of emergency transportation means (Albertini et al., 2012; Compaoré et al., 2014). Kouldiati and al. reported that the quality of the routine care, management of severe childhood diseases and non-medical care aspects is low in 50% of the peripheral health facilities (Koulidiati et al., 2016). In consequence, the country has initiated a regular monitoring of the capacity of health facilities to provide the needed health care through the Service Availability and Readiness Assessment (SARA). The purpose of the SARA survey is to assess the effectiveness of the health facilities to provide the quantity and the quality of needed health care (WHO, 2015). The survey focused on several components

of the building blocks of the WHO conceptual framework of the health system such as the service delivery, staff, medicines and equipment. As well, WHO recommends that the SARA survey be implemented periodically to ensure that the minimum required providing the necessary care is available in health facilities. Indices concerning basic amenities, equipment, medicines, diagnostic capacities on various health services and programs are calculated and can be compared in time as well as in space. The standard statistical approach to derive the indices is to average individual "tracer items" by domains and then par health service or program. Successive SARA surveys allow spatially and temporally assessing of the progression of readiness of a health service or program. Furthermore, the SARA survey is a distal proxy of the assessment of the performance of the health system. However, the standard approach does not link improved readiness to any health outcome.. Quantifying the contribution of the readiness of malaria related-services on malaria-attributed lethality is a valuable investment because malaria is the leading cause of death in children under 5 years of age. We sought to extend our previous work, using the same methodology to estimate the magnitude of the temporal change in malaria service readiness and its association with the under-5 malaria-attributed lethality rate using the SARA surveys of 2012 and 2014.

5.2 Methods

5.2.1 Study settings

Located between the 9° 200 and the 15° 540 North latitude, the 2° 200 East longitude and the 5° 300 West longitude, Burkina Faso is part of the Sudanian belt with two seasons: a dry season from November to June and a rainy season from July to October. The Rainfall is meagre and unevenly distributed across the country, varying on average between 300 mm in the North and 1200 mm in the South.

The health system consists of three levels that provide primary, secondary and tertiary care from the bottom to top respectively.

The health district is the first level and consists of two grades: 1) the Centre de Santé et de Promotion Sociale (CSPS), which are the most remote health facilities and constitute the gateway of the health system, and 2) the district hospital which serves as a reference for remote health centres. The regional hospital represents the second level, and the third one is made up of the national and teaching hospitals providing the highest level of care. Malaria is endemic and constitutes with acute respiratory infections, diarrheal diseases, HIV/AIDS, tuberculosis, and neglected tropical diseases, the major public health issues.

5.2.2 Data sources

The SARA survey is a facility-based survey assessing the availability (physical presence) and the readiness (capacity to deliver) of health services. It is a standardised survey based on selected "tracer items" related to "general" and "specific" services, care or programs. Tracer items are grouped by domains (staff, training, diagnostics...).

The general service is composed by five domains (i.e. basic amenities, basic equipment, standard precautions for infection prevention, diagnostic capacity and essential medicines) and malaria-related service comprises three domains (i.e. staff and guidelines, diagnostics, medicines and commodities).

For each domain, the readiness is the mean percentage of the availability of the "tracer items" of the domain. The readiness of the "specific" services, care or programs is the average percentage of the readiness of the different domains that constitute it. We used the "general service" items as basic "tracer items" that any health facility should possess and the malaria-specific "tracer items". The "general service" is composed of five domains, and the malaria service comprises three domains. The detailed compositions of both types of services are given in table 1. The 2014 SARA survey had 10 more tracer items related to the "essential drugs" domain than the 2012 survey. However, information on these 10 items was collected in 2012 and we adjusted them for the 2014 survey. We extracted from the health management and information system (HMIS) the under-5 malaria-attributed deaths and consultations.

5.2.3 Statistical analysis

We combined the two surveys of 2012 and 2014 and grouped the health facilities into two hierarchical levels: teaching hospitals, private polyclinics and regional hospitals, district hospitals and medical centers constitutes the medical centers level as their staff include physicians. The "Centre de Santé et de Promotion Sociale", isolate dispensaries and delivery centers formed the level of peripheral health centers. They are almost ruled by nurses.

We describe the samples using frequencies and proportions. The chi-square tests served to compare the availability of the tracer items between the two levels. We computed the individual tracer item indicator as the percentage of availability of the item. The domain indicator corresponds to the average availability of the tracer item of the domain and the service or program indicator is the average availability of the domain composing the service.

We merged the two surveys' data (level by level) and fitted Bayesian geostatistical variable selection using under-5 mortality attributable to malaria as the outcome to select the most relevant tracer items. All items had the same weights because the two samples were different (size and health facilities). That is, is we introduced a Bernoulli variable with Bernoulli probability corresponding to the inclusion of the indicator in the model for each tracer items. The spatial correlation was accounted for by assuming a Gaussian process on health facility locational random effects. The formulation of the variable selection is summarised in the appendix (Text B.5.1). Finally, we applied multiple correspondence analysis (MCA) on the set of selected items. MCA is the multivariate analysis method appropriate for categorical data like the SARA survey (Greenacre and Blasius, 2006). Items are binary, with "1" for the presence of the item and "0" otherwise.

Let K be the set of selected indicators X^k, $k = 1, \ldots . K$ with posterior inclusion probability equal to or more than 50%. We created two binary indicators $X_{0,i}^k$ and $X_{1,i}^k$ corresponding to the presence and absence of the indicator in the health facility i. That is, $X_{0,i}^k$ takes value 1 when the indicator k is absent

in health facility i (i.e. $X^k = 0$ and 0 otherwise. Likewise, $X_{1,i}^k$ takes value 1 when the indicator k is present in health facility i (i.e. $X^k = 1$ and 0 otherwise).

The readiness score for health facility i, based on the factorial axis, is defined by $F_i^a = \frac{1}{K}\sum_{k=1}^{K}\sum_{j_k=0}^{1} W_{j_k}^{a,k} X_{j_k,i}^k$, where j_k indicates the value of X^k and the weights $W_{j_k}^{a,k}$ are the columns standards coordinates on the pa^{th} factorial axis corresponding to $X_{j_k,i}^k$. Following the procedure of Asselin (2009), the composite readiness score is defined as $F_i^a = \frac{1}{K}\sum_{k=1}^{K}\sum_{j_k\in\{0,1\}}^{1}\sum_{a=1}^{L}\delta(k-a)\ W_{j_k}^{a,k} X_{j_k,i}^k$, where L is the number of factorial axes used in the composite score and $\delta(k-a)$ is the Dirac delta function which takes the value 1 when the weights related to $X_{j_k,i}^k$ are selected from the factorial axis and 0 otherwise, that is, $\delta(k-a) = 1$ if $k = a$ and $\delta(k-a) = 0$ if $k \neq a$. Identification of the factorial axis that will represent the X^k indicator depends on a discrimination measure calculated for each indicator and axis, measuring the contribution of the indicator to the total variance explained by the axis. To improve interpretation of the score, we translated the weights so that the absence category $j_k = 0$ of the X^k indicator received a zero weight and the presence one $j_k = 1$ received a strictly positive weight representing the gain in the readiness increase measured by the axis a when a facility i acquires the kth tracer. Therefore, the $W_{j_k}^{a,k}$ in F_i is replaced by $W_{j_k}^{+a,k}$ where $W_0^{+a,k} = 0$ and $W_1^{+a,k} = W_1^{+a,k} - W_1^{+a,k}$.

The full formulation of the MCA and the process to derive the composite readiness is resumed in appendices (B.5.2 and B.5.3).

Following our previous work, we first determined the weight of each item selected and then, established the composite readiness score of each health facility. The composite readiness score was then split into 3 ordered categories named low, moderate and high composite readiness index.

The descriptive analyses were carried out in STATA version 14 (StataCorp.; College Station, TX, USA) and Bayesian models fitted in OpenBUGS version 3.2.3 (Imperial College and Medical Research Council; London, UK). Maps were produced in ArcGIS version 10.2.1 (Esri Inc.; Redlands, CA).

5.3 Results

5.3.1 Baseline characteristics

The samples size were 686 and 780 health facilities in 2012 and 2014 respectively. We used approximately 84% of each sample, with 84.3 (578/686) in 2012 and 84.4 (658/780) in 2014. We excluded health facilities with inconsistent data (missing coordinate, mortality data). Grouping both samples and the health facilities in two levels, results of 194 and 1042 medical centres and peripheral health centres respectively. Overall, as shown in Table 1, the availability of the domains of “general service” for medical centres is significantly higher than that of peripheral health centres.

The domains of basic equipment (60.82%) and standard precautions for infection prevention (41.27%) are the most available for medical centres and peripheral health centres, respectively, while essential medicines (0%) is the lowest domain for both types of health facilities regarding the "general services". Relative to malaria tracer items, the availability of staff and guidelines domain's are significantly higher in peripheral health centres than medical centres. The availability of malaria diagnostic capacity is about 90% in medical centres and 80% in peripheral health centres. The availability of the domain of medicines and commodities is 0% for both levels; however, the availability of individual tracer items is globally higher in peripheral health centres than in medical centres.

The Bayesian geostatistical variable selection was fitted to identify the most important items related to malaria mortality. The selection retained 53.8 (28/52) and 44.7 (17/32) items for medical centres and peripheral health centres, respectively. Likewise, in medical centres, malaria management's essential elements, including malaria first-line medicines and paracetamol, have been selected. However, malaria diagnostic was not included. For peripheral health centres, the availability of the first-line medicine for malaria treatment was almost above 95% and was not included in the model for selection. Unlike in medical centres, the malaria diagnostic was selected as an essential item related to malaria lethality.

For general service indicators, in medical centres, items selected belong to all five domains for both types of health facilities. Antibiotics (ciprofloxacin, ceftriaxone, gentamicin, amoxicillin, and ampicillin) have been selected for essential medicines. The results of the variable selection are shown in table 5.1.

Table 5.1: Baseline characteristics of the sample: tracer indicators and domains availabilities, posterior probabilities inclusion of tracer indicators

Domains	**Medical centres**		**Peripheral health centres**	
	Availability proportion (%)	**Posterior probability inclusion (%)**	**Availability proportion (%)**	**Posterior probability inclusion (%)**
		General service indicators		
Basic amenities	**53 (27.3)**		**8 (0.8)**	P<0.0001
Power	149 (76.8)	100	617 (59.2)	100
Improved water source inside OR within the ground of the facility	186 (95.9)	-	893 (85.7)	28.5
Room with auditory and visual privacy for patient consultations	149 (76.8)	100	653 (62.7)	100
Access to adequate sanitation facilities for clients	191 (98.5)	-	989 (94.9)	22.6
Communication equipment (phone or SW radio)	191 (98.5)	-	1025 (98.34)	-
Facility has access to computer with email/internet access	81 (41.78)	3.64	14 (1.3)	-
Emergency transportation	180 (92.8)	100	933 (89.5)	100
Basic equipment	**118 (60.8)**		**424 (40.7)**	P<0.0001
Adult scale	190 (97.9)	-	993 (95.3)	-
Child scale	143 (73.7)	12.5	831 (79.8)	16.8
Thermometer	194 (100)	-	1.39 (99.7)	-
Stethoscope	194 (100)	-	1028 (98.67)	-

Blood pressure apparatus	195 (98.5)	-	1005 (96.5)	-
Light source	151 (77.8)	100	547 (52.5)	45.78
Standard precautions for infection prevention	**101 (52.1)**		**430 (41.3)**	P=0.006
Safe final disposal of sharps	148 (76.3)	0.62	772 (74.1)	33.11
Safe final disposal of infectious wastes	146 (75.3)	100	674 (64.7)	17.61
Appropriate storage of sharps waste	190 (97.9)	-	992 (95.2)	-
Appropriate storage of infectious waste	177 (91.2)	0.46	876 (84.01)	11.84
Disinfectant	194 (100)	-	1035 (99.3)	-
Single use-standard disposable or auto-disable syringes	194 (100)	-	1032 (99.0)	-
Soap and running water or alcohol-based hand rub	186 (95.9)	-	949 (91.1)	100
Latex gloves	175 (90.2)	100	900 (86.4)	99.55
Guidelines for standard precautions	171 (88.1)	100	917 (88.0)	68.6
Diagnostic capacity	**47 (24.2)**		**4 (0.4)**	P<0.0001
Haemoglobin	119 (61.3)	14.4	13 (1.3)	-
Blood glucose	72 (37.1)	100	16 (1.5)	-
Malaria diagnostic capacity	175 (90.2)	34.2	826 (79.3)	99.55
Urine dipstick- protein	154 (79.4)	58.2	830 (79.7)	23.02
Urine dipstick- glucose	152 (78.5)	100	801 (76.9)	64.17
HIV diagnostic capacity	182 (93.8)	0.48	959 (92.0)	74.03
Urine test for pregnancy	165 (85.1)	100	709 (68.0)	8.56
Syphilis rapid test=d9	62 (32.0)	2.6	7 (0.7)	-
Essential medicines	**0 (0)**		**0 (0)**	
Amitriptyline tablet	39 (20.1)	100	4 (0.4)	-
Ciprofloxacin cap/tab	178 (91.8)	100	952 (91.4)	100
Co-trimoxazole syrup/suspension	174 (89.7)	26.8	942 (90.4)	21.12
Diazepam 5 mg cap/tab	188 (96.9)	-	1011 (97.0)	-
Diclofenac 50/75 mg cap/tab	177 (91.2)	100	962 (92.3)	100
Paracetamol syrup/suspension	178 (91.8)	100	915 (87.8)	14.13
Amoxicillin tablet	179 (92.23)	100	1000 (96.0)	-
Ampicillin for inject	182 (93.8)	100	1004 (96.4)	-
Gentamicin injectable	173 (89.2)	100	864 (82.9)	69.34
Oxytocin injectable	168 (86.6)	100	977 (93.8)	100
Amoxicillin dispersible	167 (86.1)	21.8	941 (90.3)	25.56
ORS	164 (84.5)	100	924 (88.7)	16.04
Zinc	101 (52.1)	13.8	589 (56.5)	16.58
Aspirin	166 (85.6)	13.2	739 (70.9)	7.55
Magnesium sulfate	128 (65.98)	47.6	214 (20.5)	59.19
Amlodipine	37 (19.1)	100	24 (2.3)	-
Enalapril	24 (12.4)	12.0	12 (1.2)	-
Insulin injectable	18 (9.3)	19.4	9 (0.9)	-
Beta-blockers	34 (17.5)	29.0	14 (1.3)	-
Beclomethasone inhaler	24 (12.4)	100	15 (1.4)	-
Ceftriaxone injection	179 (92.3)	100	897 (86.1)	86.9
Thiazidic	26 (13.4)	100	43 (4.1)	-
Glibenclamide tablet	59 (30.41)	2.40	16 (1.5)	-
Metformin	82 (36.61)	3.67	16 (1.5)	-
Omeprazole	82 (42.27)	18.4	130 (12.5)	11.6
Salbutamol inhaler	152 (78.35)	1.68	569 (54.6)	9.62

Simvastatin	6 (3.09)	-		7 (0.7)	-
			Malaria indicators		
Staff and guidelines	**89 (45.88)**			**632 (60.7)**	P=0.0002
Guidelines for diagnosis and treatment of malaria	186 (95.88)	-		1026 (98.45)	-
Guidelines for IPT	132 (68.04)	4.26		947 (90.9)	12.79
Staff trained in malaria diagnosis and treatment	154 (79.38)	6.44		918 (88.1)	100
Staff trained in IPT	119 (61.34)	1.85		706 (67.8)	10.29
Diagnostics	**175 (90.21)**			**826 (79.3)**	**P=0.0005**
Malaria diagnostic capacity	175 (90.21)	34.2		826 (79.27)	99.55
Medicines and commodities	**0 (0)**			**0 (0)**	
First-line antimalarial in stock	173 (89.18)	100		996 (95.6)	-
Paracetamol cap/tab	181 (93.30)		100	1004 (96.4)	-
IPT drug	94 (48.45)		100	621 (59.6)	14.6
ITN	49 (25.26)		15.2	328 (31.5)	87.19

5.3.2 Under-five malaria mortality rate

Between 2012 and 2014, there was a significant decrease in the malaria mortality rate for both health facilities. The distributions of health facilities by regions, type of area and administrative type of management are summarised in table 5.2.

Table 5.2: Distribution of malaria lethality rate between 2012 and 2014

Characteristics	**Medical centres (N=194) n (%)**	**Peripheral health centres (N=1042) n (%)**	**P. value**
Type of area			
Urban	150 (77.32)	104 (9.98)	
Rural	44 (22.68)	938 (90.02)	
Administrative management			
Private	38 (19.59)	83 (7.97)	
Public	156 (80.41)	959 (92.03)	
Regions			
Boucle du Mouhoun	18 (9.28)	109 (10.46)	
Cascades	7 (3.61)	56 (5.37)	
Centre	45 (23.20)	91 (8.73)	
Centre-Est	17 (8.76)	79 (7.58)	
Centre-Nord	10 (5.15)	81 (7.77)	
Centre-Ouest	15 (7.73)	95 (9.12)	
Centre-Sud	8 (4.12)	67 (6.43)	
Est	15 (7.73)	78 (7.49)	
Hauts Bassins	17 (8.76)	93 (8.93)	
Nord	14 (7.22)	95 (9.12)	
Plateau Central	7 (3.61)	76 (7.29)	
Sahel	8 (4.12)	60 (5.76)	
Sud-Ouest	13 (6.70)	62 (5.95)	
Malaria in under-5 (SARA 2012 and 2014)			
Number of deaths (a)	3945	1150	
Number of consultations (b)	93682	94691	
Mortality rate =a/b	4.21	1.21	
Malaria in under-5 (SARA 2012)	n=82	n=496	

Number of deaths (a)	2085	803
Number of consultations (b)	39914	46167
Mortality rate =a/b	5.22	1.74
Malaria in under-5 (SARA 2014)	n=112	n=546
Number of deaths (a)	1860	347
Number of consultations (b)	53768	48524
Mortality rate =a/b	3.46	0.72

5.3.3 Multiple correspondence analysis results

Tables 5.3 and 5.4 showed the coordinates of the selected tracer items on the 12 and 10 factorial axes used to build the composite readiness score for medical centres and peripheral health centres, respectively. Cells in grey are those coordinates that respected the positive increasing Global First Axis Ordering Consistency condition (FAOC-G), and highlighted in black are selected axes corresponding to the relevant item.

Tables A.5.1 and A.5.2 in the appendix summarised the type algorithm of the minimal sequence, the discriminant measures and the rescaled weights for both health facility levels.

The composite readiness score computed explained 34 and 36% of variability for medical centres and peripheral health centres, respectively. Relative to medical centres, factorial axes 1 and 2 account for 9 and 5 items, respectively, while for peripheral health centres, the first tow axis represents 7 and 2 items respectively.

The most weighted items for medical centres are “Latex gloves”, “Emergency transportation” and “Guidelines for standard precautions” and better correlated with factorial axes 12, 9 and 12. For peripheral health centres, the three items highly weighted are “Soap and running water or alcohol-based hand rub”, “Emergency transportation” and “Guidelines for standard precautions” and are captured by axes 2, 10 and 7, respectively. We noticed that the first factorial axis is correlated with almost all the medicines items for both levels.

Table 5.3: MCA results for medical centres readiness indicators.

			Factorial axes*											
Tracer indicators	**Categories**	**Distribution**	**Dimensions**											
			1	3	3	4	5	6	7	8	9	10	11	12
Power	no		0.119	-0.523	-0.798	-0.846	1.320	4.362	0.854	**-5.154**	-0.934	-1.495	1.875	-0.833
	yes	149 (76.80)	-0.036	0.158	0.241	0.255	-0.399	-1.317	-0.258	**1.557**	0.282	0.452	-0.566	0.251
Room with auditory and visual privacy for patient consultations	no		-0.328	-0.279	-2.085	1.205	-3.496	1.709	**-4.093**	-0.908	-3.139	-3.210	-2.042	0.195
	yes	149 (76.80)	0.099	0.084	0.630	-0.364	1.056	-0.516	**1.236**	0.274	0.948	0.970	0.617	-0.059
Emergency transportation	no		-0.688	-0.919	1.298	-2.472	6.564	2.082	-5.229	7.421	**-8.059**	0.359	-3.632	-3.248
	yes	180 (92.78)	0.053	0.072	-0.101	0.192	-0.511	-0.162	0.407	-0.577	**0.627**	-0.028	0.282	0.253
Light source	no		-0.189	**-2.323**	-1.526	-2.802	1.186	1.909	0.002	2.601	0.000	-2.229	0.842	3.972
	yes	151 (77.84)	0.054	**0.661**	0.435	0.798	-0.338	-0.544	-0.001	-0.741	0.000	0.635	-0.240	-1.131
Safe final disposal of infectious wastes	no		-0.096	0.388	0.042	-1.789	**-4.006**	-1.178	1.879	-1.254	-4.317	3.120	-1.784	1.757
	yes	146 (75.26)	0.031	-0.128	-0.014	0.588	**1.317**	0.387	-0.618	0.412	1.419	-1.026	0.587	-0.578
Latex gloves	no		0.199	-1.551	-4.710	-3.213	-1.352	1.436	4.374	0.669	3.743	-2.635	-7.358	**-8.642**

	yes	175 (90.21)	-0.022	0.168	0.511	0.349	0.147	-0.156	-0.475	-0.073	-0.406	0.286	0.799	**0.938**
Guidelines for standard precautions	no		-2.465	-0.997	1.502	-1.029	-4.541	1.214	-1.857	0.474	-2.399	-1.448	5.241	**-7.012**
	yes	171 (88.14)	0.332	0.134	-0.202	0.138	0.611	-0.163	0.250	-0.064	0.323	0.195	-0.705	**0.943**
Blood glucose	no		-0.117	**-1.338**	-0.150	-0.802	-0.378	0.600	0.011	0.373	0.517	1.871	-1.248	-0.255
	yes	72 (37.11)	0.198	**2.267**	0.255	1.359	0.641	-1.016	-0.019	-0.633	-0.875	-3.170	2.114	0.431
Urine dipstick- protein	no		-0.800	**-4.668**	3.085	1.558	-0.989	0.726	1.537	1.306	0.383	-0.794	0.928	0.772
	yes	154 (79.38)	0.208	**1.212**	-0.801	-0.405	0.257	-0.189	-0.399	-0.339	-0.099	0.206	-0.241	-0.201
Urine dipstick-glucose	no		-0.850	**-4.699**	2.774	1.323	-1.189	0.966	1.420	0.713	-0.730	-1.280	0.401	0.393
	yes	152 (78.35)	0.235	**1.298**	-0.767	-0.365	0.329	-0.267	-0.392	-0.197	0.202	0.354	-0.111	-0.109
Urine test for pregnancy	no		0.192	-2.085	1.894	1.800	-3.743	2.088	**-5.149**	-0.362	5.638	1.680	-0.494	0.316
	yes	165 (85.05)	-0.034	0.366	-0.333	-0.316	0.658	-0.367	**0.905**	0.064	-0.991	-0.295	0.087	-0.056
Amlodipine	no		-0.224	-0.539	**-0.775**	-0.149	-0.077	-0.575	-0.164	-0.729	0.423	-0.342	-0.297	0.835
	yes	37 (19.07)	0.953	2.289	**3.288**	0.634	0.327	2.440	0.695	3.095	-1.794	1.452	1.261	-3.541
Amoxicillin tablet	no		**-6.166**	1.964	-1.190	2.605	-0.814	1.501	0.688	2.305	1.291	1.581	-0.348	0.171
	yes	179 (92.27)	**0.517**	-0.165	0.100	-0.218	0.068	-0.126	-0.058	-0.193	-0.108	-0.133	0.029	-0.014
Ampicillin for inject	no		**-6.598**	1.636	2.173	-1.097	0.169	0.050	0.673	-3.843	1.089	0.020	-1.700	-2.102
	yes	182 (93.81)	**0.435**	-0.108	-0.143	0.072	-0.011	-0.003	-0.044	0.253	-0.072	-0.001	0.112	0.139
Beclomethasone inhaler	no		-0.111	-0.375	-0.536	-0.300	-0.053	**-0.815**	-0.332	0.246	-0.048	0.491	0.837	-0.363
	yes	24 (12.37)	0.785	2.657	3.797	2.128	0.373	**5.775**	2.349	-1.740	0.337	-3.475	-5.930	2.573
Ceftriaxone injection	no		**-6.130**	-0.176	-2.350	0.448	0.406	3.038	0.570	1.980	-1.040	2.652	2.084	1.256
	yes	179 (92.27)	**0.514**	0.015	0.197	-0.038	-0.034	-0.255	-0.048	-0.166	0.087	-0.222	-0.175	-0.105
Gentamicin injectable	no		-3.254	-0.266	2.176	**-6.630**	2.060	0.524	-3.305	-2.571	0.106	0.835	-1.121	0.718
	yes	173 (89.18)	0.395	0.032	-0.264	**0.805**	-0.250	-0.064	0.401	0.312	-0.013	-0.101	0.136	-0.087
ORS0	no		**-2.983**	0.941	2.811	-1.286	-1.531	-2.525	0.498	-3.163	0.499	0.287	0.411	-0.547
	yes	164 (84.54)	**0.546**	-0.172	-0.514	0.235	0.280	0.462	-0.091	0.579	-0.091	-0.053	-0.075	0.100
Oxytocin injectable	no		-1.810	0.083	3.744	**-6.185**	1.824	1.410	-0.757	-1.251	0.447	-0.507	0.362	1.067
	yes	173 (89.18)	0.280	-0.013	-0.579	**0.957**	-0.282	-0.218	0.117	0.194	-0.069	0.079	-0.056	-0.165
Thiazidic	no		-0.108	**-0.692**	-0.623	0.001	0.534	-0.402	-0.455	-0.367	0.114	0.010	0.123	-0.252
	yes	26 (13.40)	0.699	**4.473**	4.026	-0.008	-3.451	2.598	2.943	2.371	-0.736	-0.066	-0.797	1.626
IPT drug	no		-0.570	-0.804	**-1.687**	0.567	-0.254	0.534	0.752	-0.409	-1.290	0.219	0.616	0.348
	yes	94 (48.45)	0.607	0.856	**1.794**	-0.603	0.270	-0.568	-0.800	0.435	1.372	-0.233	-0.655	-0.370
Paracetamol syrup/suspension	no		**-6.061**	1.480	-2.852	1.176	-0.197	1.965	2.721	1.585	1.794	1.941	0.428	1.427
	yes	178 (91.75)	**0.545**	-0.133	0.256	-0.106	0.018	-0.177	-0.245	-0.142	-0.161	-0.174	-0.038	-0.128
First-line antimalarial in stock	no		**-4.379**	1.933	0.622	2.408	2.367	-1.257	-0.155	0.528	0.823	-2.984	-0.243	-1.420
	yes	173 (89.18)	**0.532**	-0.235	-0.075	-0.292	-0.287	0.153	0.019	-0.064	-0.100	0.362	0.029	0.172
Paracetamol cap/tab	no		**-6.023**	1.688	-0.764	3.868	1.024	-0.261	-3.483	2.007	-0.252	-0.403	-5.216	2.372
	yes	181 (93.30)	**0.433**	-0.121	0.055	-0.278	-0.074	0.019	0.250	-0.144	0.018	0.029	0.375	-0.170
Diclofenac 50/75 mg cap/tab	no		**-3.955**	-1.780	2.951	2.327	1.247	-5.420	-3.083	-2.632	-1.997	-0.991	-3.368	-0.367
	yes	177 (91.24)	**0.380**	0.171	-0.283	-0.224	-0.120	0.521	0.296	0.253	0.192	0.095	0.323	0.035
Ciprofloxacin cap/tab	no		**-6.091**	1.007	-2.050	0.692	0.353	2.213	3.430	1.114	0.855	0.999	2.003	0.146
	yes	178 (91.75)	**0.548**	-0.091	0.184	-0.062	-0.032	-0.199	-0.308	-0.100	-0.077	-0.090	-0.180	-0.013
Amitriptyline tablet	no		-0.263	0.001	0.003	**-0.781**	-0.662	-0.836	0.506	0.645	0.163	-1.298	-0.018	0.153
	yes	39 (20.10)	1.044	-0.003	-0.011	**3.103**	2.633	3.322	-2.013	-2.562	-0.648	5.160	0.070	-0.610
Syphilis rapid test	no		-0.004	1.050	-0.477	-0.799	**-1.036**	0.628	-1.002	0.592	0.724	-0.005	0.630	0.386
	yes	62 (31.96)	0.010	-2.236	1.016	1.700	**2.205**	-1.336	2.133	-1.260	-1.542	0.011	-1.340	-0.821
Inertia explained by the factorial axis (%)			**18.94**	**9.502**	**6.508**	**6.247**	**4.78**	**4.409**	**4.074**	**4.023**	**3.828**	**3.454**	**3.231**	**3.126**

*: first 14 factorial axes to build the composite readiness score

[a]: tracer indicator consistent with the FAOC-G in the positive direction (grey) and those consistent with negative direction (not shaded)

[b]: in bold are the weights of selected tracer indicators form factorial axes selected to build the composite readiness score

Table 5.4: MCA results for peripheral health centres readiness indicators.

			Factorial axes*									
Tracer indicators	**Categories**	**Distribution**	**Dimensions**									
			1	2	3	4	5	6	7	8	9	10
Power=i1	no		-0.062	-0.402	-0.610	0.441	**-3.894**	-1.333	0.384	0.481	-1.086	1.298
	yes	617 (59.21)	0.042	0.277	0.420	-0.304	**2.682**	0.918	-0.264	-0.332	0.748	-0.894
Room with auditory and visual privacy for patient consultations	no		0.199	0.361	**-2.681**	-2.401	0.698	-0.221	-0.270	1.233	-0.299	-0.104
	yes	653 (62.67)	-0.118	-0.215	**1.597**	1.430	-0.416	0.131	0.161	-0.734	0.178	0.062
Emergency transportation	no		-2.195	0.753	3.726	-4.112	-3.115	3.441	-1.950	1.188	1.021	**-7.281**
	yes	933 (89.54)	0.256	-0.088	-0.435	0.480	0.364	-0.402	0.228	-0.139	-0.119	**0.851**
Soap and running water or alcohol-based hand rub	no		-1.427	**-8.296**	-2.052	-0.273	0.946	-0.091	0.676	-2.572	2.201	-0.943
	yes	949 (91.07)	0.140	**0.813**	0.201	0.027	-0.093	0.009	-0.066	0.252	-0.216	0.092
Latex gloves	no		-1.055	**-6.634**	-1.671	-0.979	-0.783	0.234	-0.510	-0.742	1.617	-0.577
	yes	900 (86.37)	0.167	**1.047**	0.264	0.155	0.124	-0.037	0.081	0.117	-0.255	0.091
Guidelines for standard precautions	no		-1.693	-0.900	1.909	-3.521	0.597	-3.594	**-7.690**	2.260	-1.484	2.485
	yes	917 (88.00)	0.231	0.123	-0.260	0.480	-0.081	0.490	**1.048**	-0.308	0.202	-0.339
Malaria diagnostic capacity	no		-1.391	-1.470	2.018	0.071	1.608	3.018	-0.263	-1.991	**-5.342**	1.743
	yes	826 (79.27)	0.364	0.384	-0.528	-0.019	-0.421	-0.789	0.069	0.521	**1.397**	-0.456
Urine dipstick- glucose	no		**-2.343**	-0.855	2.615	-0.628	-1.803	-0.297	1.287	1.082	0.574	-0.549
	yes	801 (76.87)	**0.705**	0.257	-0.787	0.189	0.543	0.089	-0.387	-0.326	-0.173	0.165
HIV diagnostic capacity	no		**-4.825**	0.839	4.119	-1.415	0.378	-1.926	3.173	-2.399	1.381	3.796
	yes	959 (92.03)	**0.418**	-0.073	-0.357	0.122	-0.033	0.167	-0.275	0.208	-0.120	-0.328
Ceftriaxone injection	no		**-3.213**	0.751	-2.839	2.803	-1.153	1.531	-3.219	1.006	-2.318	-0.947
	yes	897 (86.08)	**0.519**	-0.121	0.459	-0.453	0.186	-0.247	0.520	-0.163	0.375	0.153
Gentamicin injectable	no		**-3.280**	0.148	-0.877	1.015	1.498	-1.875	0.265	0.604	0.909	1.533
	yes	864 (82.92)	**0.676**	-0.030	0.181	-0.209	-0.309	0.386	-0.055	-0.124	-0.187	-0.316
Magnesium sulfate	no		-0.268	-0.314	0.170	0.635	0.591	**-0.887**	0.485	0.937	-0.683	-0.877
	yes	214 (20.54)	1.039	1.217	-0.659	-2.457	-2.287	**3.432**	-1.876	-3.625	2.643	3.395
Oxytocin injectable	no		**-5.941**	2.461	0.395	-2.348	3.212	-1.231	1.347	1.019	5.066	3.163
	yes	977 (93.76)	**0.395**	-0.164	-0.026	0.156	-0.214	0.082	-0.090	-0.068	-0.337	-0.210
ITN	no		-0.525	0.046	-0.649	**-1.038**	-0.122	0.863	1.256	0.914	-0.626	0.377
	yes	328 (31.48)	1.143	-0.100	1.412	**2.261**	0.265	-1.879	-2.734	-1.989	1.364	-0.821
Staff trained in malaria diagnosis and treatment	no		-1.323	2.085	-1.673	-3.333	-0.589	-4.968	1.526	**-6.863**	-3.010	-3.466
	yes	918 (88.10)	0.179	-0.282	0.226	0.450	0.080	0.671	-0.206	**0.927**	0.407	0.468
Diclofenac 50/75 mg cap/tab	no		**-4.908**	2.306	-1.733	4.581	-2.198	2.101	-0.705	-0.825	2.370	-0.764
	yes	962 (92.32)	**0.408**	-0.192	0.144	-0.381	0.183	-0.175	0.059	0.069	-0.197	0.064
Ciprofloxacin cap/tab	no		**-4.735**	1.395	-4.331	1.814	0.625	1.766	-1.972	-2.326	0.130	-1.698
	yes	952 (91.36)	**0.448**	-0.132	0.409	-0.171	-0.059	-0.167	0.186	0.220	-0.012	0.160
Inertia explained by the factorial axis (%)			**0.143**	**0.090**	**0.078**	**0.070**	**0.063**	**0.060**	**0.057**	**0.055**	**0.054**	**0.051**

*: first 14 factorial axes to build the composite readiness score

[a]: tracer indicator consistent with the FAOC-G in the positive direction (grey) and those consistent with negative direction (not shaded)

[b]: in bold are the weights of selected tracer indicators form factorial axes selected to build the composite readiness score

Figure 5.1 compares the inertia explained by using the first factorial axis (based on all indicators and selected indicators) and the composite readiness score. From 2012 to 2014, there was a substantial gain in inertia explained by the first factorial based on all the set and selected indicators and the composite readiness score by both health facilities levels. The composite readiness score rose from 33% to 41% for medical centres, increasing from 27% to 31% for peripheral health centres.

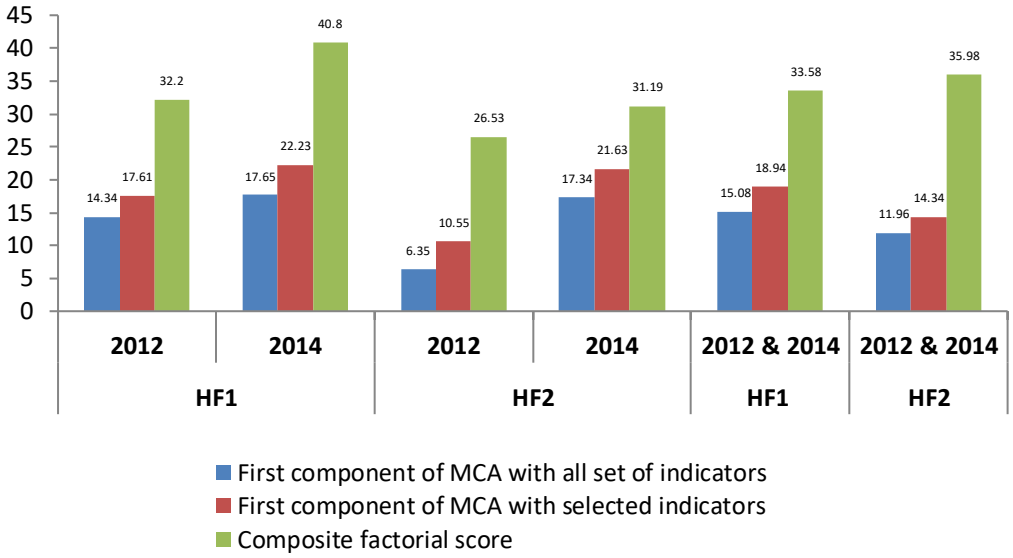

Figure 5.1: evolution of the inertia explained by the first factorial axis based on all indicators (blue), selected indicators (red), and the composite readiness score (green) by the level of health facilities.

5.3.4 Association between the composite readiness index and the malaria lethality

Following our previous work, we grouped into three levels the composite readiness score and named it composite readiness index. After adjusting for health facility location area (urban and rural) and administrative type of management (public and private) the readiness index showed a significant reduction by 55 and 37% in 2014 compared to 2012 for medical centres (IRR=0.45, 95% BCI: 0.59-0.95) and peripheral health centres (IRR=0.63 95, BCI0:53-0.77) respectively. Medical centres with the highest level of the composite index had a lethality rate lower by 52 % (IRR=0.48, 95%BCI: 0.35- 0.65) compare to those in the lowest level of reediness. For peripheral health centres, the middle and the highest readiness level are more performant. Indeed the lethality rate was reduced by 27% (IRR=0.73 (0.57-0.94) and 38% (IRR=0.62 (0.50-0.77) comparing the moderate and high level of readiness to the lowest.

Table 5.5: Estimates (posterior median and 95% Bayesian credible intervals) of the effects readiness index, location of health facilities, administrative status on under-5 malaria mortality.

	Medical centres	**Peripheral health centres**
Readiness index	**IRR (BCI)**	**IRR (BCI)**
Low level	1	1
Moderate level	0.80 (0.59-1.08)	0.73 (0.57-0.94)*
High level	0.48 (0.35- 0.65)*	0.62 (0.50-0.77)*
location of HF		
rural	1	1
urban	0.76 (0.58-1.02)	0.51 (0.40-0.97)*
Administrative status		
Private	1	1
Public	2.02 (1.38-2.09)*	0.48 (0.25-0.92)
Time trend		
2012	1	1
2014	0.45 (0.59-0.95)*	0.47 (0.38-0.57)*
Spatial variance	14.46 (10.25-20.39)	46.08 (37.55-52.9)
Parameter of dispersion	2.03 (1.57-2.63)	0.55 (0.48-0.64)
Range	5.04 (3.25-7.59)	6.48 (4.00-7.60)

*: significant result

5.3.5 Spatial distribution of malaria mortality and the lowest level of composite readiness index.

Based on the selected tracer items, we compute the composite readiness score (continuous) and transform it to a composite index (categorical) by health facility level.

Figures A.5.1, 5.2 and 5.3 in the appendix show the spatial distribution (administrative regions) of lethality rates and the proportion of the lowest composite readiness index based on joined 2012 and 2014, respectively. The geographical patterns of malaria lethality matched the distribution of the lowest readiness index. That is, the lower the proportion of health facilities with low readiness, the lower the malaria lethality.

Figures A.5.3 and A.5.4 in the appendix illustrate the distribution of continuous composite readiness score for both health facility levels. The histograms are skewed toward low readiness.

5.4 Discussion

We assessed the contribution of the temporal change in readiness of the malaria related-services on the under-5 malaria lethality rate between 2012 and 2014 using SARA surveys. The SARA surveys serve to assess whether health facilities can provide needed care. The capability is a prerequisite to the quality of health deliveries and constitutes an essential proxy of the health system performance. Regular monitoring provides a temporal trend of the readiness for policymakers. Our work constitutes a comprehensive analysis linking readiness and a public health issue in Burkina Faso. Our findings indicate that the readiness of the malaria related-health services had increased from 2012 to 2014 for both health facilities levels. This temporal change is associated with a significant reduction in malaria lethality in 2014 compared to 2012.

Both surveys have been carried alongside the National Malaria Control Program's Strategic plan 2011-2015. The strategic plan led to reinforcement and extension of malaria control interventions undertaken a few years earlier (Ministère de la santé, 2011). Among these interventions, we cite the management of malaria cases only after a rapid diagnostic test, training of health professional and community health workers, removal of under-five children user's fee in some health districts of the country, mass distribution of insecticide-treated nets (Druetz et al., 2015; Kiemde et al., 2018; Ministère de la santé, 2014; Ridde et al., 2013; Siribié et al., 2016). Our results are consistent with several scholars concerning the proven effect of health system indicators on under-5 mortality in general in sub-Saharan Africa (Boyer, 2015; Farahani et al., 2009; Quinhas F. Fernandes et al., 2014; Muldoon et al., 2011). They indicate that human health resources, financing, coverage of health interventions reduce the under-5 mortality rate significantly. Few studies have however assessed the effect of health facilities or health system readiness on health outcome. We report that peripheral health centres in the middle and the highest composite readiness index experienced less malaria lethality than those in the lowest readiness index. Unlikely, the effect was observed only for the highest readiness index for medical centres. Our results are compatible with the country's health system's organisation. Indeed, severe cases of malaria are referred from peripheral health centres to medical centres following the reference pathway. Peripheral health centres are the gateway of the health system and received in general patients at the early stage of malaria onset. Thus, the management of these cases is more prone to recovery.

Unlikely, complicated malaria cases are referred to medical centres. Thus, the probability of death is higher. Our results are also coherent with the 2014 SARA survey which reports an improvement in general and malaria services' availability and readiness compared to 2012 (Ministère de la Santé, 2014). However, in space, our results differed slightly in the region of Centre (the largest region in terms of both public and private health infrastructures). In 2014, this region had indices that were generally below the national averages, while our results were in the opposite direction. The large number of private health facilities in this region can explain this. We have been removed most of them from our analyses for lack of consistent malaria mortality data. Thus, both surveys of 2012 and 2014 reported that the private health facilities had significantly lower indices compare to public health facilities.

The overlapping of the spatial distribution of low malaria lethality and high readiness versus high lethality rate and low readiness reinforce our findings. Overall, the regions of Sahel, Sud Ouest, and Boucle du Mouhoun are the most concerned by weak health facilities.

The left skewness of the composite readiness score is an indication of the overall pattern of the readiness health facilities to provide malaria care. Targeting these extreme weak health facilities and regions will accelerate the pace of the reduction of malaria lethality.

The high proportion of availability of individual tracer items and domains in medical centres compare to peripheral health centres can be explained by the structured role of medical centres to primarily deal with patients referred by the peripheral health centres. Thus, they dispose of equipment, medicines supply and human resources of a higher degree. This is especially noticeable for general service indicators and particularly the diagnostic capacity. On the contrary, peripheral health centres are more prone to receive malaria cases, which is confirmed by the higher proportion of availability of malaria staff and guidelines compared to medical centres. In General, the domain of essential medicines is the weakest and may be explained by a lack of competencies in the management of medicines (command, provision and storage) mostly those for non-communicable diseases.

The variable selection that we performed presents a double advantage by 1) retaining the essential items related to the outcome and 2) reducing the number of indicators. The approach could be compared to the conventional selection of indicator by the variance explained, the effect on health outcome.

Despite some limitations of our study relative to the mortality data extracted from the HIMS database, (leading to the removal of private health facilities), we provide a comprehensive approach to measure the progress in health facilities strengthening, measuring the impact of malaria-specific- health services readiness on malaria lethality in Burkina Faso. We derive composite readiness based on selected indicators instead of using only the first component. More variance is captured by the composite readiness score compare to the first component of the MCA. Furthermore, as we stipulate in the methodology, we remove indicators with more than 95% or less than 5 % of availability. In consequence, an important tracer item linked with a health outcome could be removed. Nevertheless, the variable selection will come out with items that can be added to improve the readiness of the health facilities. This is an advantage over the convenience selection of indicators as done by Boyer (Boyer, 2015; Boyer et al., 2015).

The study's main limitation was the quality of the number of deaths and consultations related to malaria gathered from the HMIS. The removal of health facilities with missing data limited the comparison between public and private health facilities.

5.5 Conclusion

Our findings provide evidence that investing in health services has contributed to the decline in under-5 malaria lethality in Burkina Faso. The investments need to be maintained and reinforced, especially in medical centres. A particular focus on the medicines and supply management (command, provision,

storage) at the medical centres as well at peripheral health centres is needed to increase the readiness of health facilities to manage inpatients properly.

5.6. Acknowledgements

We are grateful to the Ministry of Health of Burkina Faso and its Department of Statistics to provide the SARA survey database and allow us access to the health management information system database. This work has been carried out under the support of the Swiss Programme for Research on Global Issues for Development (r4d) project no. IZ01Z0-147286.

5.7 Appendix

Table A.5.1: medical centres type algorithm. Minimal sequence

	Discrimination measures													
Indicators	Factorial axes												**Selected factorial axes**	Weights $W_1^{+\alpha,k}$
	1	3	3	4	5	6	7	8	9	10	11	12		
Power	0.001	0.008	0.013	0.013	0.025	0.253	0.009	0.323	0.010	0.023	0.034	0.007	8	6711
Room with auditory and visual privacy for patient consultations	0.006	0.002	0.085	0.027	0.176	0.039	0.206	0.010	0.114	0.107	0.041	0.000	7	5330
Emergency transportation	0.007	0.006	0.009	0.030	0.160	0.015	0.087	0.172	0.193	0.000	0.033	0.026	9	8686
Light source	0.002	0.146	0.043	0.140	0.019	0.046	0.000	0.078	0.000	0.049	0.007	0.140	2	2984
Safe final disposal of infectious wastes	0.001	0.005	0.000	0.066	0.252	0.020	0.047	0.021	0.235	0.111	0.034	0.032	5	5323
Latex gloves	0.001	0.025	0.157	0.070	0.009	0.010	0.085	0.002	0.058	0.026	0.190	0.253	12	9580
Guidelines for standard precautions	0.155	0.013	0.020	0.009	0.133	0.009	0.019	0.001	0.030	0.010	0.119	0.207	12	7955
Blood glucose	0.004	0.288	0.002	0.068	0.012	0.027	0.000	0.010	0.017	0.205	0.085	0.003	2	3606
Urine dipstick- protein	0.032	0.538	0.161	0.039	0.012	0.006	0.025	0.018	0.001	0.006	0.007	0.005	2	5880
Urine dipstick- glucose	0.038	0.580	0.138	0.030	0.019	0.011	0.023	0.006	0.006	0.016	0.001	0.001	2	5998
Urine test for pregnancy	0.001	0.073	0.041	0.036	0.118	0.034	0.190	0.001	0.214	0.017	0.001	0.001	7	6054
Amlodipine	0.040	0.117	0.166	0.006	0.001	0.062	0.005	0.091	0.029	0.017	0.012	0.092	3	4063
Amoxicillin tablet	0.603	0.031	0.008	0.036	0.003	0.008	0.002	0.018	0.005	0.007	0.000	0.000	1	6682
Ampicillin for inject	0.544	0.017	0.020	0.005	0.000	0.000	0.001	0.039	0.003	0.000	0.006	0.009	1	7033
Beclomethasone inhaler	0.016	0.095	0.132	0.040	0.001	0.208	0.032	0.017	0.001	0.059	0.160	0.029	6	6590
Ceftriaxone injection	0.596	0.000	0.030	0.001	0.001	0.034	0.001	0.013	0.003	0.020	0.012	0.004	1	6644
Gentamicin inj	0.243	0.001	0.037	0.333	0.025	0.001	0.054	0.032	0.000	0.003	0.005	0.002	4	7435
ORS0	0.308	0.015	0.094	0.019	0.020	0.051	0.002	0.074	0.002	0.001	0.001	0.002	1	3529
Oxytocin inj	0.096	0.000	0.141	0.370	0.025	0.014	0.004	0.010	0.001	0.001	0.001	0.006	4	7142
Thiazidic	0.014	0.294	0.163	0.000	0.088	0.046	0.055	0.035	0.003	0.000	0.003	0.013	2	5165
IPT drug	0.066	0.065	0.197	0.021	0.003	0.013	0.025	0.007	0.068	0.002	0.013	0.004	3	3481
Paracetamol syrup/suspension	0.625	0.019	0.048	0.008	0.000	0.015	0.027	0.009	0.011	0.012	0.001	0.006	1	6606
First-line antimalarial in stock	0.441	0.043	0.003	0.044	0.033	0.008	0.000	0.001	0.003	0.037	0.000	0.008	1	4911
Paracetamol cap/tab	0.493	0.019	0.003	0.067	0.004	0.000	0.035	0.012	0.000	0.000	0.063	0.013	1	6456
Diclofenac 50/75 mg cap/tab	0.284	0.029	0.054	0.032	0.007	0.124	0.037	0.027	0.015	0.003	0.035	0.000	1	4335
Ciprofloxacin cap/tab	0.632	0.009	0.025	0.003	0.001	0.019	0.043	0.004	0.003	0.003	0.012	0.000	1	6639
Amitriptyline tablet	0.052	0.000	0.000	0.151	0.083	0.122	0.042	0.066	0.004	0.231	0.000	0.003	4	3883
Syphilis rapid test	0.000	0.223	0.032	0.085	0.109	0.037	0.087	0.030	0.043	0.000	0.027	0.010	5	3241

Variance Threshold (T_a)	2.651	1.330	0.911	0.875	0.669	0.617	0.570	0.563	0.536	0.483	0.452	0.438		
Variation explained (Δ_{G1}^{a})	5.299	2.280	1.103	1.405	0.952	0.643	0.810	0.648	0.674	0.528	0.506	0.557		
Variation explained (Δ_{G2}^{a})	0.003	0.381	0.719	0.345	0.386	0.592	0.331	0.452	0.398	0.439	0.398	0.319		
Variation explained after eliminating intersection axes	4.527	1.846	0.363	0.855	0.361	0.208	0.396	0.193	0.193	0.000	0.000	0.460		

Dark grey: consistent increasing, Light grey: consistent decreasing, Indicator scores highlighted in red outline the dimensions within which they were selected

Table A.5.2: Peripheral health centres types algorithm. Minimal sequence

	Discrimination measures										**Selected factorial axes**	Weights $W_1^{+\alpha,k}$
	Factorial axes											
Indicators	1	3	3	4	5	6	7	8	9	10		
Power=i1	0.000	0.010	0.020	0.009	0.663	0.074	0.006	0.009	0.044	0.059	5	6576
Room with auditory and visual privacy for patient consultations	0.003	0.007	0.335	0.241	0.018	0.002	0.002	0.050	0.003	0.000	3	4277
Emergency transportation	0.081	0.006	0.127	0.139	0.072	0.083	0.025	0.009	0.007	0.313	10	8131
Soap and running water or alcohol-based hand rub	0.029	0.608	0.032	0.001	0.006	0.000	0.003	0.036	0.026	0.004	2	9109
Latex gloves	0.025	0.626	0.034	0.011	0.006	0.001	0.002	0.005	0.022	0.003	2	7681
Guidelines for standard precautions	0.056	0.010	0.039	0.119	0.003	0.106	0.457	0.038	0.016	0.043	7	8738
Malaria diagnostic capacity	0.073	0.051	0.083	0.000	0.043	0.143	0.001	0.057	0.405	0.040	9	6739
Urine dipstick- glucose	0.237	0.020	0.161	0.008	0.062	0.002	0.028	0.019	0.005	0.005	1	3048
HIV diagnostic capacity	0.289	0.005	0.115	0.012	0.001	0.019	0.049	0.028	0.009	0.063	1	5242
Ceftriaxone injection	0.239	0.008	0.102	0.089	0.014	0.023	0.095	0.009	0.047	0.007	1	3732
Gentamicin injectable	0.318	0.000	0.012	0.015	0.029	0.044	0.001	0.004	0.009	0.024	1	3956
Magnesium sulfate	0.040	0.034	0.009	0.109	0.086	0.183	0.052	0.188	0.098	0.151	6	4319
Oxytocin injectable	0.337	0.036	0.001	0.026	0.044	0.006	0.007	0.004	0.093	0.034	1	6336
ITN	0.086	0.000	0.072	0.165	0.002	0.098	0.195	0.100	0.046	0.016	4	3299
Staff trained in malaria diagnosis and treatment	0.034	0.053	0.030	0.105	0.003	0.201	0.018	0.352	0.066	0.082	8	7790
Diclofenac 50/75 mg cap/tab	0.287	0.040	0.020	0.122	0.026	0.022	0.002	0.003	0.025	0.002	1	5316
Ciprofloxacin cap/tab	0.304	0.017	0.139	0.022	0.002	0.018	0.021	0.028	0.000	0.014	1	5183
Variance Threshold (T_a)	1.219	0.766	0.665	0.596	0.539	0.512	0.482	0.470	0.461	0.430		
Variation explained (Δ_{G1}^{a})	2.435	1.359	0.796	0.825	0.847	0.636	0.606	0.509	0.726	0.581		
Variation explained (Δ_{G2}^{a})	0.003	0.173	0.535	0.367	0.232	0.388	0.357	0.431	0.196	0.278		
Variation explained after eliminating intersection axes	2.012	1.234	0.335	0.165	0.663	0.183	0.457	0.352	0.405	0.313		

Dark grey: consistent increasing, Light grey: consistent decreasing, Indicator scores highlighted in red outline the dimensions within which they were selected

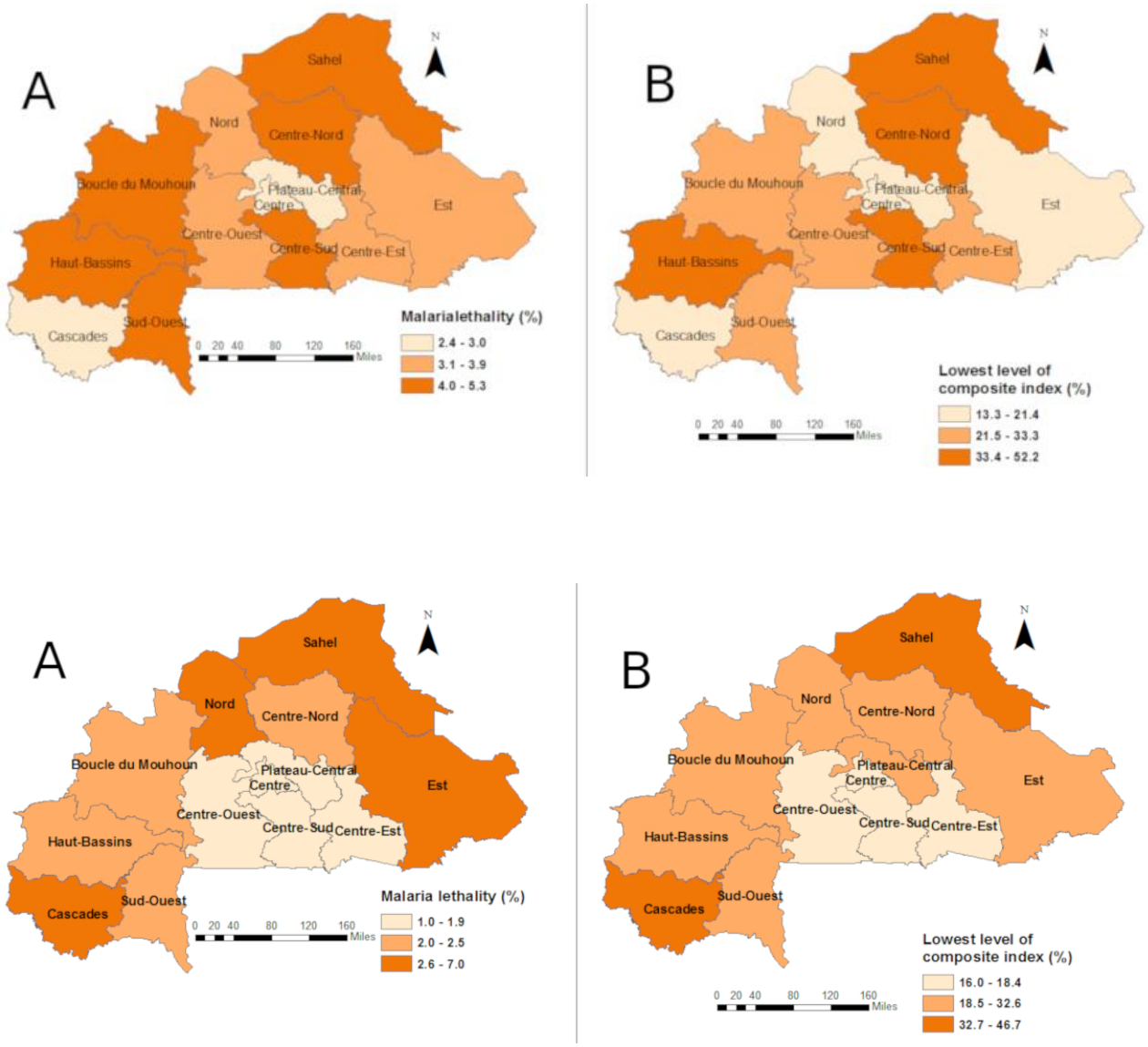

Figure A.5.1: Spatial distribution of under-5 malaria-related mortality rate in medical centres and peripheral health centres (A) and the lowest category of the composite readiness indices medical centres and peripheral health centres (B) based on SARA surveys 2012 and 2014. The cut-off is three quantiles

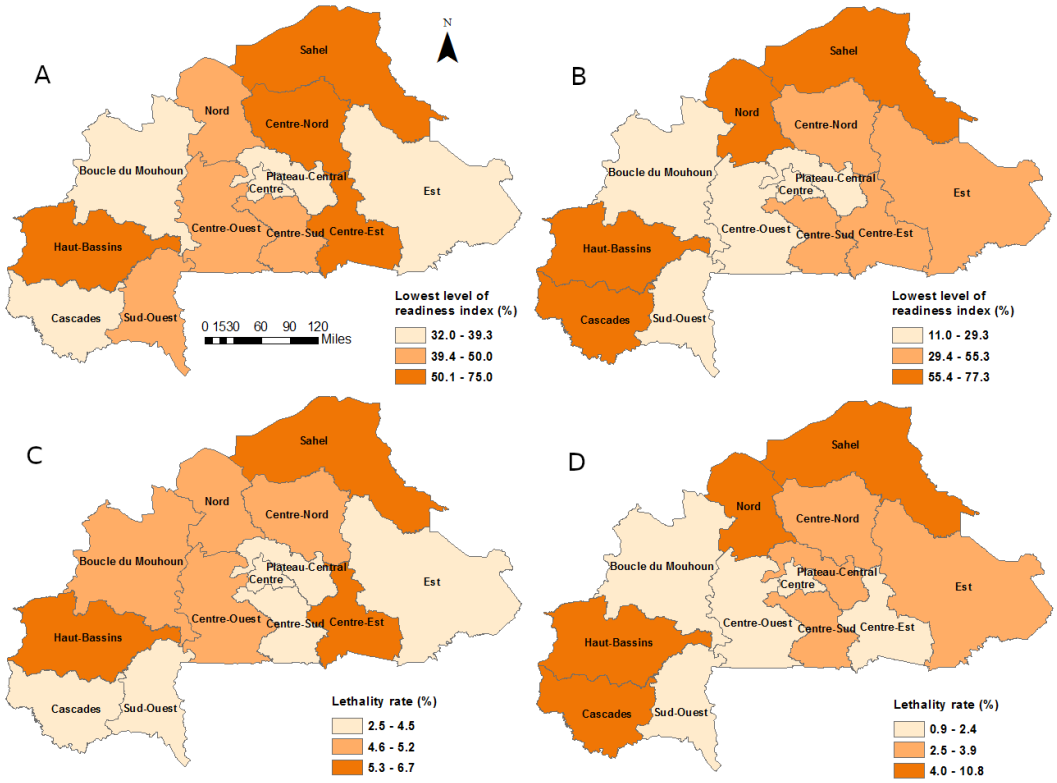

Figure A.5.2: Spatial distribution of under-5 malaria-related mortality rate for medical centres (A) and peripheral health centres (B) and the lowest category of the composite readiness indices medical centres (C) and peripheral health centres (D) based on SARA survey 2012. The cut-off is three quantiles

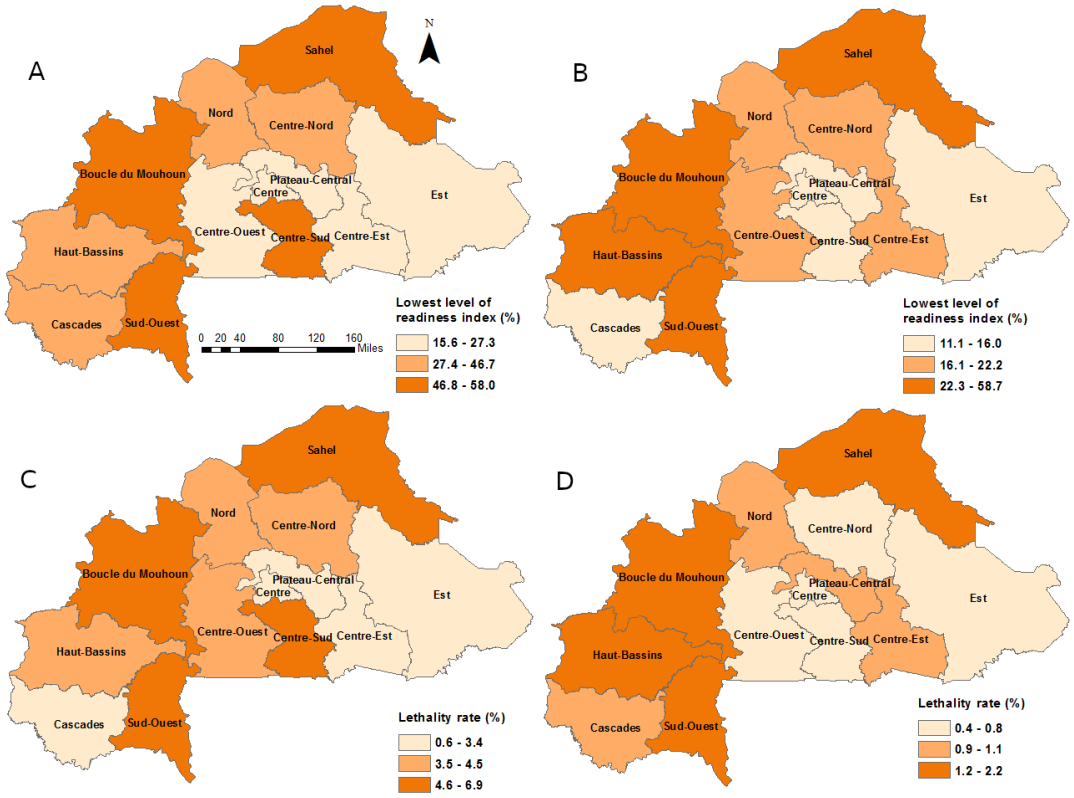

Figure A.5.3: Spatial distribution of under-5 malaria-related mortality rate for medical centres (A) and peripheral health centres (B) and the lowest category of the composite readiness indices medical centres (C) and peripheral health centres (D) based in SARA survey 20914.The cut-off is three quantiles

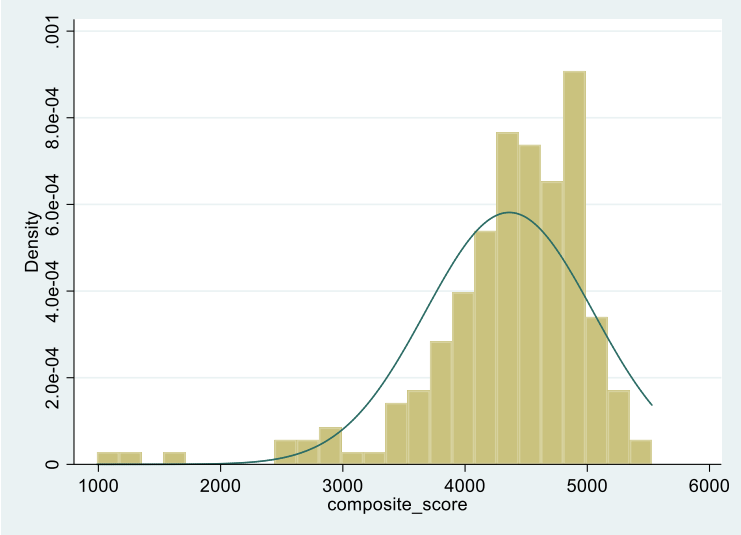

Figure A.5.4: Histogram of composite readiness score of medical centres based on SARA 2012 and 2014

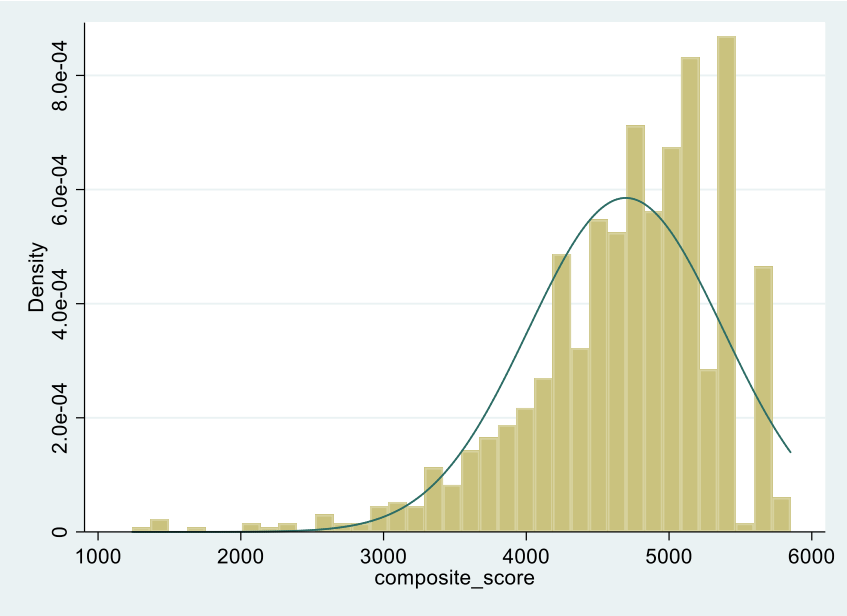

Figure A.5.5: Histogram of composite readiness score of peripheral health centres based on SARA 2012 and 2014

Text B.5.1: The Bayesian variable selection formulations

We use a probabilistic selection of the indicators instead of adequately select them to fit the MCA. We estimated that all indicators could be relevant to improve the health system a priori.

To select the most important tracer indicators associated with the malaria mortality in each health facility level, we fit spike and slab Bayesian geostatistical variable selection models (Chammartin et al., 2013b). For every tracer indicator X_k a Bernoulli variable γ_k was introduced with Bernoulli probability $\pi_k$corresponding to the inclusion of $_{sk}$in the model. For the coefficient β_k, we assume a prior distribution which is a mixture of non-informative normal distributions, $\beta_k \sim \delta(\gamma_{k-1})N\left(0,\tau_k^2\right) + \left(1-\delta(\gamma_{k-1})\right)N(0,\vartheta_0\tau_k^2)$ where (.) is the Dirac delta function. Therefore, in case X_k is included in the model, the prior distribution $\beta_k$has a non-informative prior distribution $\beta_k \sim \delta\left(0,\tau_k^2\right)$ and in case X_k is excluded, $\beta_k \sim \delta\left(0,\vartheta_0\tau_k^2\right)$ where $\vartheta 0 = 10^{-5}$ is a very small number shrinking the variance to zero i.e. spike component of the prior. We have adopted a $Beta(1,1)$ hyperprior for π_k and an inverse gamma prior for the variance τ_k^2 with mean 1 and variance 10.

We selected an $item$ if the probability of selection of this item is superior to 50%.

The statistical evaluation was carried out in OpenBUGS version 3.2.3 (Imperial College and Medical Research Council, London, UK). We discard the first 2000 iterations and run 200000 iterations. We check the convergence through the graphical and retain the last 20 000 iterations (Gelman and Rubin, 1992).

Text: B.5.2. Multiple correspondence analysis

Let K denote binary indicators, each having two levels, that is, $J = 2k$. Let I be the number of health facilities and Let $\boldsymbol{X}_{N\chi(2*K)}$ denote the indicator matrix in which the facilities are displayed as rows, and each indicator/tracer $I_k, k = 1, \dots, K$ is represented by the inclusion of two columns, one per category of the tracer indicator k, corresponding to its presence ($j_k = 1$) or absence ($j_k = 0$) from the facility. N is the number of facilities, K is the number of indicators. $Z = N^{-1}X$. Let r and c be the row and column totals of Z, respectively. We further denote $D_c = diag\{c\}$ and $D_r = diag\{r\}$. The MCA score corresponding to health facility i is defined as follows;

$MCA_i = X_{i1}a_1 + X_{i2}a_2 + \cdots + X_{iJ}a_J,$

where $\boldsymbol{a} = (a_1, a_2, .., a_j)^T$ is the first component of the column standard coordinates v scaled by k, that is, $\boldsymbol{a} = \frac{1}{k}V^{(1)}$, where $V^{(1)}$ is the first column of V obtained from the following singular value decomposition, $\boldsymbol{D_r^{-\frac{1}{2}}}(Z - \ ^{RCT})\boldsymbol{D_c^{-\frac{1}{2}}} = \boldsymbol{V\Delta Q^T}$, where $\boldsymbol{\Delta}$ is the diagonal matrix of the singular values and $\boldsymbol{\Delta^2}$ is the matrix of the eigenvalues. $\boldsymbol{V = D_c^{-\frac{1}{2}}Q}$.

Text: B.5.3. Creation of a composite readiness index

We follow the approach proposed by Asselin (Asselin, 2009).

A composite readiness index was created from MCA results as follows. We let $L \leq \mathrm{J} - \mathrm{K}$ be the number of dimensions determined by the rank of the indicator matrix X and J the total number of categories for the K readiness indicators. The discrimination measure Δ_l^k of the indicator I_k for each dimension I is given by; $\Delta_l^k = \frac{\sum_{j_k=0}^{1} N_{j_k}^k W_{k,jk,l}^2}{\mathrm{N}}$. The eigenvalue λ_l of dimension I and the total inertia I_{tot} are estimated by; $\lambda_l = \frac{\sum_{k=1}^{K} \Delta_l^k}{\mathrm{K}}$, $\mathrm{I}_{tot} = \sum_{l=0}^{L} \lambda_l$

For each axis I, we looked for two subsets of indicators, each satisfying the Axis Ordering Consistency condition (AOC) in one of the two-axis orientations, i.e., positive or negatively. We retained one of its sum of discrimination measures was maximal and the sum of its discrimination measures represented the larger part of the total discriminating power of dimension I (>=50% of $\mathrm{K} * \lambda_1$). Axis I was then adopted as a readiness dimension, and the sum of discrimination measures of this AOC subset was identified as the readiness-relevant inertia of dimension I . We repeated this sequence for subsequent dimensions until no additional information was obtained, thus producing subsets of K indicators describing multidimensional facility readiness at each dimension I.

Since the facility readiness type sets from different dimensions are not disjoint, the potential intersection was removed by selecting the indicator from the dimension possessing the highest discrimination measure.

The final weights($W_{jc}^{+l,k}$) were calculated for each indicator category and re-scaled as follows; $W_{jk}^{+l,k} = (W_{jk}^{\alpha,k} - W_1^{\alpha,k}) * 1000$, where $W_{jc}^{\alpha,k}$ is the standardised score of category j of indicator k on the

factorial scale α, $W_1^{\alpha,k}$ is the score of lowest level category of indicator k. A composite score C_i was developed for facility i as follows; $C_i = \frac{\sum_{k=1}^{K}\sum_{j_k=0}^{1} W_{j_k}^{+\alpha,k} I_{j,k}}{2a}$, where $W_{j_k}^{+\alpha,k}$ are the scaled standard column coordinates on the $path$ selected factorial axis, for the j_k category of the I_k indicator, where $W_{j_k}^{+\alpha,k} = \begin{cases} 0, \ j_k = 0 \\ W_{j_k}^{-\alpha,k} - W_0^{\alpha,k} \ j_k = 1 \end{cases}$, $I_{j,k}$is the column of $\boldsymbol{X}$ corresponding to the j_k category of I_k.

Chapter 6: Assessing the effect of maternal, socio-economic, education and health system factors on maternal mortality across sub-Saharan Africa

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Abstract

Introduction

Coverage of maternal health interventions has increased significantly in low- and middle-income countries over the past 15 years. However, the maternal mortality ratio (MMR) has steadily declined and even increased in some countries. The objective of this study was to estimate the magnitude of the effect of changes in coverage of key maternal health interventions in the last two Demographic and Health Surveys (DHS) on the decline of the maternal mortality ratio (MMR) in sub-Saharan Africa.

Methods

We have compiled the annual rates of change (ARC) of the following maternal health interventions: skilled birth attendance, skilled antenatal care, family planning, post-natal visits using the latest two DHS of 24 sub-Saharan African countries. We fitted Bayesian negative binomial model linking the number of maternal deaths as the outcome with the ARC of health interventions adjusted for health human resources, health financing, macro-economic, female education, water and sanitation indicators of each country extracted from the World Bank Database.

Results

The median MMR decreased from 619.5 to 516.5 per 100 000 live births in between the two latest rounds of DHS. The annual largest reduction rate was observed in Rwanda (20%) and Congo (10%). Between the two surveys time point, 63% of countries included have reduced their MMR. Unlikely, the MMR increased in the Democratic Republic of Congo (DRC) and Sierra Leone by respectively 7 and 6%. The health intervention associated with the MMR decline were the skilled birth attendance (adjusted incidence rate ratio (aIRR=0.68, 95%BCI: 0.59-0.79), family planning (aIRR=0.51, 95%BCI: 0.41-0.65), at least 4 antenatal care visit (aIRR=0.82, 95%BCI: 0.72-0.94), female education (aIRR=0.61, 95%BCI: 0.51-0.76), and Out-of-pocket expenditure in health (aIRR=0.45, 95%BCI:0.24-0.77).

Conclusion

Our results suggest that besides the health sector, education is an important sector contributing to reducing the MMR. Indeed, multi-sectoral commitment is desired to improve maternal health in sub-Saharan Africa.

Keywords: maternal mortality, sub-Saharan Africa, Bayesian modelling, annual rate of change

6.1 Introduction

Since the late 1980s, maternal health has been a major public health concern of the international community. From the Nairobi (Kenya) Safe Motherhood Conference, the Cairo (Egypt) and Rio (Brazil) summits, to the Millennium Development Goals (MDGs) in 2000, donors, local government, United Nations (UN) agencies, individuals and other stakeholders have committed themselves through several initiatives calling for the amelioration of women's health (Smith and Rodriguez, 2016; Zureick-Brown et al., 2013). MDG 5 (reduce the maternal mortality ratio by 75 per cent by the end of 2015 compared to its 1990 level) comes as a unified response and commitment to reducing the high burden of maternal mortality, particularly in limited resources setting. Maternal death is defined as the death of a woman while pregnant or within 42 days of termination of pregnancy, irrespective of the duration and site of the pregnancy, from any cause related to or aggravated by the pregnancy or its management, but not from accidental or incidental causes (WHO et al., 2015). Haemorrhage, hypertension disorder and sepsis are the main direct causes of maternal deaths in sub-Saharan Africa (SSA) (Alkema et al., 2016; Khan et al., 2006; Say et al., 2014). Indirect causes account for around one quarter and are related to the health system, educational, economic and political factors such as conflicts (Alvarez et al., 2009; Muldoon et al., 2011; Parkhurst et al., 2005). They are almost preventable, and cost-effective interventions do exist. A set of evidence-based health interventions covering the critical periods of a woman's reproductive life were identified to be scaled up to reduce MMR in a group of high burden countries, mostly in sub-Saharan Africa during the MDGs era (Kerber et al., 2007; Victora et al., 2016). Substantial results were achieved and globally, MMR dropped by 44% from 385 in 1990 to 216 maternal death per 100 000 live births in 2015 (WHO., 2015). In SSA, the MMR decreased from 947 to 546 per 100 000 live births in the same period. Despite the hopeful achievement, an important number of women continued to die in SSA. Indeed, 66% of the 303 000 total maternal deaths in 2015 occurred in SSA. Furthermore, there is a large heterogeneity between countries with MMR ranging from 42 to 1360 deaths per 100 000 live births for Cabo Verde and Sierra Leone respectively. Maternal mortality is an important indicator reflecting the socio-economic development, performance of the health system, social inequalities, quality of governance (Benova et al., 2014; Cheng et al., 2012; Karlsen et al., 2011; Muldoon et al., 2011). The complexity encapsulates the challenge for African countries to contribute to the global Sustainable Development Goal (SDGs) of reducing maternal mortality to fewer than 70 per 100 000 lives birth in 2030 (Kumar et al., 2016; WHO, 2015). An annual reduction of 7.5% is needed to reach this goal, and each country (high burden countries) should reduce by at least two-thirds of its MMR of 2010. Sub-Saharan countries need to address inequities in access to reproductive health services, scale-up and increase the coverages of cost-effective interventions and strengthen the health system to be able to achieve the related SDG. Assessing the progress in the increase of the coverage of maternal health interventions and the MMR rate are essential for resources allocation. The "countdown initiative" is extended for the SDGs period. WHO and partners regularly update the trend of MMR (Countdown to 2030 Collaboration, 2018; WHO et al., 2015). MMR is a complex indicator, and the regular updates of

the trend and impact of health interventions are based on statistical modelling. there is a clear closed link between MMR and the health system performance, socioeconomic and governance indicators. Due to the lack of civil registration system in most of the SSA countries, MMR measurement is based on the sisterhood method used by the Demographic and health surveys (DHS) carried out every 3-5 years. Few studies have evaluated the effect of changes in the coverages of maternal health interventions within rounds of DHS. Alvarez and al. assessed the correlation between MMR and skilled birth and antenatal attendance, educational and economic indicators based on data collected from 1997 and 2006. In Nepal, Sanu and al. have concluded that the improvement of maternal health interventions alongside four DHS rounds led to MMR decline. As the coverage of maternal health interventions and MMR fluctuate according to factors quoted above, it is important at the regional level how the variation influences the MMR decline. The objective of the study was to quantify the effect of the annual rate of change of essential maternal health interventions on the MMR, adjusted for educational, economic, and health financing indicators. To this end, we used the latest DHS from the MDG period..

6.2 Methods

6.2.1 Data sources, sample size and study variables

We gathered the number of maternal deaths, the years of exposure, the maternal mortality ratio and the coverages of maternal health interventions from the two latest Demographics and health surveys (DHS) of 24 SSA countries carried out between 2009 and 2015. The countries included are Cameroon, Chad, Congo, DRC, Ethiopia, Gabon, Guinea, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Tanzania, Uganda, Zambia and Zimbabwe (The DHS Program, 2017). The maternal health interventions were the skilled birth attendance (SBA), skilled antenatal care visit, at least four antenatal care visit, family planning (FP), unmet need of FP and skilled post-natal care visit for mothers (within 42 days after delivery). These health interventions are part of the "continuum of care" that is still promoted to scale up for the SDGs achievement (Victora et al., 2016). We collect socio-economic (Gross domestic product (GDP), the Gross national income (GNI) per capita, the government expenditure in health, the out-of-pocket expenditure in heath, improved sanitation and safe drinking water), education (the adult and female literacy rate) and health human resources (the physician and midwives and nurses densities (per 1000 persons)) indicators from the World Bank Database (The World Bank, 2017). We replaced missing values of health human resources densities, adult and female literacy rate by the estimates of the nearest year. Preferences were given to the estimates before the year of the survey. The range of such replacement estimates is more or less 4 years. The rationale is that the indicators vary a little within 5 years and the estimates of the MMR in the DHS cover 7 years before the surveys.

6.2.2 Statistical analysis

The outcome variable was the maternal mortality rate modelled through the number of maternal deaths and the number of years the women were exposure to the fatal event.

For each covariate, we calculated the annual rate of change and multiplied it by 100. As such, the rate is positive if a country increased the indicator level between the two surveys. The formulation is as followed.

$$ARC = \left(\frac{\ln(y_{t+n}/y_t}{n}\right) * 100$$

Where y_{t+n} is the coverage of the covariate at the last survey and y_t the coverage of the covariate at the previous one. n (in years) represents the interval between the two surveys.

The two rates are expressed as percentage. We fitted Bayesian negative binomial with fix effect. That is, let $\boldsymbol{Y}_{jt}$ be the number of maternal deaths in country j at survey t. We assume that $\boldsymbol{Y}_{jt}$ are distributed according to the negative binomial distribution.

$$\mathbf{Y}_{jt} \sim \text{dnegbin}(\mathbf{P}_{jt}, \boldsymbol{r})$$

Where P_{jt}, is the proportion of deaths occurring in-country j at survey t and r is the dispersion parameter with,

$$\mu_j = r\frac{1-p}{p} \text{ and } \sigma_i^2 = r(1-p)p^{-2}.$$

We modelled the association above between covariates (X) and mortality rate by country on the logit link, as

$$log(\mu_{jt}) = log(N_{jt}) + \beta_0 + \sum_1^k \beta_u X_u, \; u=1,2,\ldots\ldots k,$$

where μ_{jt} is the number of deaths in country j at survey t, N_{jt} the total person-years of exposure contributed by each woman aged from 15-49 years in each country, β_i the regression coefficients and ε_t the survey period effects.

The model was fitted using Markov Chain Monte Carlo (MCMC) simulation algorithm in OpenBugs version 3.1.2 (Imperial College and Medical Council, London, UK) to estimate model parameters (Gelfand and Smith, 1990). We ran a single chain sampler discarding the first 10,000 iterations. Convergence was assessed graphically, and we retain the last 20 000 iterations.

6.3 Results

6.3.1 Background descriptive statistics

The average duration between the last two surveys in this group of countries was 6 years, with the most extended delays of 12 and 10 years for Gabon and Chad, respectively.

The median MMR decreased by approximately 100 per 100 000 lives birth, from 619.5 to 516.5 per 100000 lives birth over the period. The largest ARR was observed in Rwanda (20%) followed by Congo (10%). The MMR increased in DRC and Sierra Leone by respectively 7 and 6%. Between the two surveys time point, 63% (15/24) of the countries reduced the MMR. Figure 6.1 shows the MMR per country, and the corresponding table is in the appendix (Table: 6.A).

The coverages of the majority of the indicators considered (health interventions, socio-economic indicators, health human resources) improved in the interval between the two DHS rounds. However, the GDP growth and the government expenditure in health showed a negative annual rate evolution. The

coverages of prenatal visits, assisted deliveries, family planning and maternal post-natal visits less than the overall mean in Chad, Ethiopia, Liberia and Sierra Leone. The Out-of-pocket expenditure in health rate varied between 30% and 40% and augmented in Cameroon, Guinea, Niger, Nigeria and Sierra Leone. On average, the government expenditure on health is as high as 10%. The GDP growth did not exceed 6% overall. The access to improved water and sanitation has increased but showed large variation between countries. The female education rate went from 52 to 63% in the overall interval.

Midwives and nurses density varied from 0.438 to 0.510 per 1000 persons for both rounds. Gabon has the highest density of midwives and nurses with 5 per 1000 persons.

Table 6.1 resumes the results, and table 6.A as well as figure 6.A in appendix indicates the information per country.

Table 6.1: Summary of MMR, maternal health interventions, economic, educational and health human resources for both rounds of DHS and the ARC.

	Survey 1 Median (IIQ)	**Survey 2 Median (IIQ)**	**ARR/C Median (IIQ)**
Maternal Mortality Ratio	619.5 [472.5-819]	516.5 [391.5-753]	
Maternal Health interventions (%)			
Skilled Birth Attendance	49.8 [42.3-67.6]	62.7 [49.1-79.1]	3.08 [3.02]
Skilled Antenatal Care	87.2 [79.6-93.6]	93.3 [85.0-95.6]	1.42 [2.06]
At least 4 ANC	50.3 [40.0-67.6]	53.1 [47.8-75.1]	2.96 [4.01]
Skilled Post-natal Care	41.3 [25.4-52.3]	46.4 [40.1-68.6]	6.07 [8.41]
Family Planning (Modern and any)	20.9 [11.9-33.7]	23.8 [14.3-41.3]	3.51 [4.71]
Unmet need for family planning	20.75 [17.3-25.25]	21.00 [17.25-24-35]	1.00(5.25)
Health Financing covariates			
Health expenditure, public (% of government expenditure)	11.1 [7.5-14.0]	9.9 [8.1-12.6]	-0.26 [6.67]
Out-of-pocket health expenditure (% of total expenditure on health)	40.5 [31.3-51.6]	33.6 [24.7-44.0]	-2.37 [4.58]
Socio-economic development indicators			
GDP growth (annual %)	6.4 [5.0-8.9]	5.5 [4.0-8.1]	-0.92 [18.04]
GNI per capita, Atlas method (current US$)	510.0 [310-860]	820.0 [420-1315]	8.02 [4.66]
Improved water source (% of population with access)	63.6 [52.5-72.4]	72.0 [55.9-75.2]	1.29 [1.07]
Improved sanitation facilities (% of population with access)	23.1 [14.1-38.3]	25.6 [16.039.0]	1.54 [1.61]
Adult literacy rate (population 15+ years, both sexes (%))	61.4 [38.4-71.8]	66.4 [41.0-79.0]	0.75 [3.18]
Female literacy rate (population 15+ years, both sexes (%))	51.5 [25.6-66.1]	62.3 [29.0-73.5]	1.41 [3.61]
Health Human resources (per 1000 people)			
Physicians density	0.061 [0.028-0.162]	0.0785 [0.037-0.140]	1.87 (7.40)
Nurses and midwives	0.438 [0.262-1.148]	0.510 [0.328-0.915]	1.58 [6.58]

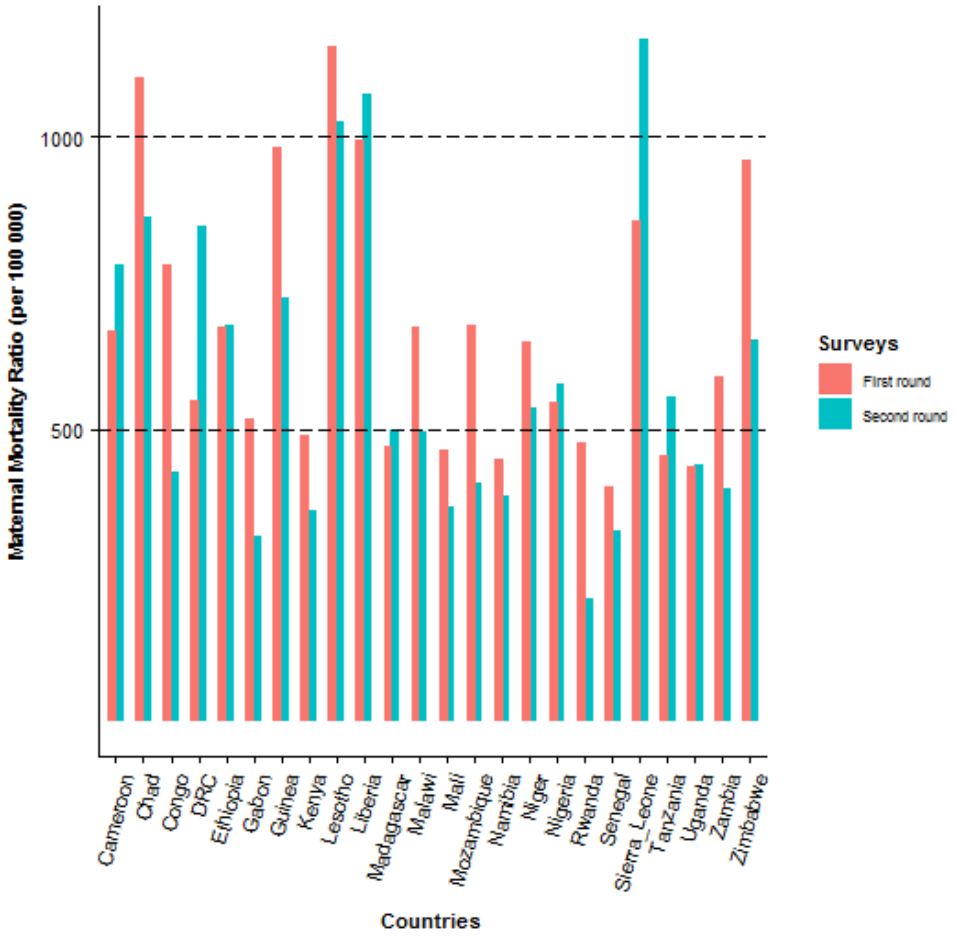

Figure 6.1: MMR trend per country of the two times point of HDS.

6.3.2 Association between MMR and the selected covariates

The results are provided in table 2. The health interventions significantly associated with MMR reduction are the skilled birth attendance reduces the MMR (aIRR=0.62, 95%BCI: 0.47-0.71), at least four antenatal visits (aIRR=0.82, 95%BCI: 0.72-0.94) and family planning (aIRR=0.49, 95%BCI: 0.29-0.63). Additional indicators that have contributed to the reduction of the MMR are female literacy and out-of-pocket expenditure in health.

Table 6.2: Crude and Bayesian negative binomial incidence rate ratios

Covariates	Adjusted IRR (95% BCI)
Maternal health interventions	
Skilled birth attendance	0.62 [0.47-0.71]*
Skilled antenatal care	1.08 [0.79-1.34]
At least 4 ANC	0.82 [0.72-0.94]*
Family planning	0.49 [0.29-0.63]*
Unmet need of family planning	0.83 [0.63-1.25]
Skilled post-natal care	1.07 [0.92-1.33]
Socio-economics indicators	
GDP growth	1.02 [0.91-1.16]
GNI per capita	1.03 [0.76-1.09]
Improved drinking water	0.68 [0.31-1.74]
Improved sanitation	0.55 [0.25-1.08]
Female literacy	0.62 [0.37-0.79]*
Adult literacy	0.98 [0.37-2.48]
Health financing	
Government expenditure in health	1.00 [0.86-1.11]
Out-of-pocket expenditure in health	0.45 [0.24-0.77]*
Health human resources	
Midwifes/nurses density	2.10 [0.25-3.35]
Physicians	0.98 [0.37-2.49]
Dispersion parameter	1.58 [0.68-2.19]

6.4. Discussion

Sub-Saharan countries had failed to meet the MDG 5 that called for a three-quarter reduction of maternal mortality rate by the end of 2015 (WHO et al., 2015). This may reflect inadequate efforts as well as the interrelationship and complexity of the social, economic, political and health determinants of maternal health, particularly in Africa.. The international community endorsed ambitious goals related to maternal health within the Sustainable Development Goals (SDGs) in 2015. Sub-Saharan Africa is most concerned with increasing the annual rate of MMR reduction to achieve the sustainable development goal of reducing MMR to less than 70 per 100,000 live births by 2030. We considered the sectors that influence maternal health in a group of 24 SSA countries. Skilled delivery, at least four antenatal care visits, and family planning were the most important health interventions in predicting MMR reduction. The results are consistent with other studies highlighting the importance of these covariates as critical to overcoming the high burden of maternal mortality in Africa (Ahmed et al., 2012; Alvarez et al., 2009; Nyamtema et al., 2011; Ronsmans and Graham, 2006; Shrestha et al., 2014). The aforementioned health interventions are strongly linked to critical stages for women of reproductive age: preconception (before pregnancy), prenatal (during pregnancy), and inter-conception (between pregnancies) (Kerber et al., 2007). Delivery in a health facility, assisted by a trained professional with adequate equipment, drugs, and supplies, is essential to prevent maternal death by treating and managing all life-threatening situations, such as haemorrhage, eclampsia and sepsis (Alkema et al., 2016; Bosu et al., 2007; Ronsmans

et al., 2003). Antenatal care and family planning are also essential to detect preventable early outcomes, space births, and reduce the risk of mortality (Ahmed et al., 2012; Berhan and Berhan, 2014; Stover and Ross, 2010). In addition to these health interventions, out-of-pocket and female education have shown a protective effect. The financial barrier is an important determinant of the first delay, namely the delay in the decision to go to health services (Thaddeus and Maine, 1994). Several countries have reconsidered the impact of user fees on access to health care and services. They have implemented health-financing reforms such as subsidies, removal of user fees, health insurance, and performance-based payment, as in Burkina Faso, Cameroon, Ghana, Nigeria, Rwanda, and Tanzania (Ataguba and McIntyre, 2012; Lagomarsino et al., 2012; McPake et al., 2013; Ridde and Morestin, 2011). These reforms are essential and must be strengthened to accelerate progress toward the goals. Indeed, Rwanda, which has undertaken a profound reform of its health system, has achieved MDG 5 (Alkema et al., 2016; Bucagu et al., 2012; Thomson et al., 2018). Overall, our results highlight the wide range of social, economic, access to health care and services, educational factors that shape mothers behaviours and their health (Braveman et al., 2011). In contrast to our study, some authors have found that water and sanitation and health human resources are significant predictors of maternal mortality (Cheng et al., 2012).

Beyond the general downward trend, there was a huge variation between countries' MMRs. Indeed, MMR varied from 400 to 1155 per 100,000 live births and 210 to 1165 per 100,000 live births for round 1 and round 2 of DHS, respectively. Chad, DRC, Lesotho, Liberia, Malawi, Niger and Sierra Leone recorded very high MMRs in the two rounds of DHS. On the other hand, Rwanda achieved about a 20% annual reduction rate between 2010 and 2014.

Countries with high maternal mortality rates have mostly faced or continue to face armed conflict resulting in population displacement. (Oyerinde et al., 2011; Urdal and Che, 2013; Varpilah et al., 2011). HIV/AIDS epidemic might have contributed to high maternal mortality in Malawi, Lesotho, Tanzania… (Bicego et al., 2002; Zaba et al., 2005). These factors weaken the health system and expose the most vulnerable segments of society, namely children and pregnant women (Chi et al., 2015; O'hare and Southall, 2007; Urdal and Che, 2013). In general, armed conflict destroys health infrastructure, reduces financial capacity and access to health facilities, and increases the risk of death from pregnancy and childbirth-related complications.

The trend in maternal health interventions coverages follows the same trends as the maternal mortality rate, with large variation between countries and often within countries between the two surveys rounds. However, antenatal care coverage is relatively high, followed by skilled birth attendance. Almost one in two women observed post-natal visit (up to 42 days after delivery), while family planning was adopted by around one in five women. In general, health intervention coverage is globally fewer than the level recommended of 80% (Kerber et al., 2007).

Indicators relative to the health system, economy and education reflect, in general, the maternal health, social development and political stability of the country in SSA. In this sense, the most fluctuating variable is government expenditure on health.

No macro-economic indicators (GDP and GNI government) and expenditure in health have shown a significant effect on maternal mortality. Nevertheless, they are part of the factors that affect the health of the mother (Alvarez et al., 2009). Indeed, they influence the quantity, quality and distribution of health infrastructure, health equipment at the population level. Unfortunately, none of the 24 countries has devoted the 15% budget to health as planned by the Abuja summit in 2001 (Lu et al., 2010). Furthermore, the mean growth of the GDP within the period was negative.

Human resources for health in SSA are another important challenge toward universal coverage, a key target of the SDGs (Campbell et al., 2013; Reich et al., 2016; ten Hope-Bender et al., 2014). The shortage is significant in remote areas where furthermore poverty, lack of education are important. Developing resources in terms of quantity and quality (doctors and midwives) whose density is still far from the required standards is a prerequisite for achieving the Sustainable Development Goals in 2030 for most SSA countries.

Our study has some limitations. The data are not from the same source and may not use the same estimation methods. In addition, estimates for some variables in the same survey year are missing for some countries, and we substitute with closer estimates. Because of the sample size, we did not stratify countries by factors such as level of stability, economic growth, or development to avoid potential confounding in our estimates. Nevertheless, our results are consistent and in line with the literature.

6.5 Conclusion

Maternal health interventions are effective in reducing maternal mortality. However, their effect remains closely linked to social and economic factors, the health system, and overall national contexts. Our results showed the critical role of skilled attendance at delivery, antenatal care, family planning, and education of women in reducing maternal mortality. Increasing their coverage and adopting health financing alternatives to reduce out-of-pocket expenditures and empower women will increase the annual reduction rate of maternal mortality rate in SSA.

6.6. Acknowledgements

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6.7 Appendix

Table A.6.: Evolution of MMR, the coverage of maternal health interventions, socio-economic indicators and health system-related indicators

Country	Survey	# maternal deaths	MMR	SBA	ANC	Skilled Post-natal care	FP	fp unmet	4 ANC	GDP	GNI	Improved sanitation	Improved drinking water	OOP	Government expenditure on health	Physicians density (/1000)	Midwives density (/1000)	Adult literacy	female literacy
Cameroon	2004	215	669	61.8	83.0	6.0	26.1	20.9	0.6	3.7	840	43.2	65.9	71.9	7.1	0.18	1.47	68.4	58.7
	2011	252	782	63.6	84.7	39.9	24.0	17.0	0.7	4.1	1240	44.9	73.1	48.7	6.4	0.08	0.52	71.3	64.8
Chad	2004	1761	1099	20.7	42.6	10.7	2.5	18.3	0.2	33.6	340	10.5	46.7	55.5	15.9	0.04	0.26	28.4	18.0
	2014	455	861	24.3	63.7	19.8	5.4	22.9	0.3	6.9	980	12	50.8	39.2	9.0	0.04	0.31	39.0	29.0
Congo	2005	114	781	86.1	88.2	29.8	44.3	10.2	0.7	7.8	930	13.4	71.7	40.3	6.2	0.22	1.08	90.5	79.0
	2011	90	426	94.0	92.6	76.8	44.3	12.6	0.8	3.4	2060	14.4	74.8	28.0	7.6	0.10	0.82	79.3	72.9
DRC	2007	93	549	74.0	85.3	83.0	20.1	24.4	0.5	6.3	250	25.6	49.7	50.1	9.9	0.09	0.96	61.2	46.1
	2013	420	846	80.1	88.4	47.1	19.3	42.8	0.5	8.5	370	27.9	51.8	39.4	9.3	0.09	0.96	75.0	62.9
Ethiopia	2005	197	673	5.7	27.6	5.1	14.7	33.8	0.1	11.8	160	15.2	38.3	30.6	11.2	0.03	0.25	29.8	17.9
	2011	217	676	10.0	33.8	9.2	19.6	29.6	0.2	11.2	390	23	49.7	31.8	19.0	0.03	0.25	39.0	28.9
Gabon	2000	60	519	87.3	95.1	88.0	35.6	18.7	0.6	-1.9	3090	38.8	83.8	50.1	5.3	0.29	5.03	75.0	67.0
	2012	43	316	90.2	94.7	29.0	33.6	20.5	0.8	5.3	9040	41.4	92.2	21.0	8.2	0.29	5.00	82.3	79.9
Guinea	2005	193	980	38.0	82.1	29.8	10.5	21.2	0.5	3.0	340	15.3	67.8	70.6	3.3	0.10	0.51	29.7	18.2
	2012	114	724	42.5	85.2	43.0	8.5	23.7	0.6	3.9	440	18.9	74.8	53.7	8.0	0.10	0.50	25.3	12.2
Kenya	2008	127	488	43.8	91.5	47.0	32.0	16.3	0.5	0.2	840	28.7	58.5	49.9	6.1	0.18	0.37	72.2	66.9
	2014	106	362	61.8	95.5	57.0	42.6	17.5	0.6	5.4	1260	30.1	63.1	26.1	12.8	0.20	0.87	78.7	74.0
Lesotho	2009	136	1155	61.5	91.8	52.6	35.9	23.2	0.7	2.2	1270	28	80.7	19.7	11.0	0.05	0.59	75.8	85.0
	2014	67	1024	77.9	95.2	71.0	48.9	20.7	0.7	2.3	1370	30.2	81.6	16.5	13.1	0.05	0.59	76.6	84.9
Liberia	2007	127	994	46.3	79.3	70.2	13.3	20.6	0.8	9.5	160	14.8	68.5	38.0	17.3	0.01	0.27	42.9	27.0
	2013	188	1072	61.1	95.9	72.0	20.2	31.1	0.8	8.7	370	16.4	73.8	31.1	9.9	0.01	0.27	42.9	27.0
Madagascar	2003	61	469	51.3	79.9	42.7	21.6	23.6		9.8	280	11.4	46.9	40.7	11.7	0.15	0.30	70.7	65.3
	2008	190	498	43.9	86.3	43.5	39.9	14.6	0.5	7.1	400	11.1	45	36.8	13.5	0.19	0.28	64.5	61.6
Malawi	2010	331	675	71.4	94.7	52.0	35.4	26.1	0.5	6.9	430	38.8	81	10.2	20.1	0.02	0.34	61.3	51.3
	2015	225	497	89.8	94.8	0.0	59.2	20.9	0.5	2.8	340	41	90.2			0.02	0.34	62.1	55.2
Mali	2006	167	464	49.0	70.4	28.0	7.5	31.2	0.4	4.7	490	20.6	58.7	51.5	13.0	0.08	0.21	26.2	18.2
	2012	76	368	58.6	74.2	45.2	10.0	23.3	0.4	-0.8	730	23.3	70.9	49.5	12.4	0.09	0.44	33.6	24.6
Mozambique	2003	144	678	47.7	84.6	38.9	18.3	18.4	0.5	6.5	280	15.5	43.3	11.7	15.0	0.03	0.30	48.2	33.2
	2011	103	408	54.3	90.6	53.2	12.3	28.5	0.5	7.1	480	19.3	49.3	6.6	7.7	0.05	0.38	50.6	36.5
Namibia	2006	86	449	81.4	94.6	74.6	46.6	9.3	0.9	7.1	3870	30.3	83.9	3.2	11.8	0.37	2.76	76.5	78.4
	2013	65	385	88.2	96.6	77.3	50.2	11.7	0.6	5.7	5800	33.6	89.6	7.4	13.9	0.37	2.78	88.3	88.0
Niger	2006	224	648	32.9	46.4	18.2	10.0	14.0	0.1	5.8	260	8.2	49.8	51.7	16.1	0.02	0.22	28.7	15.1
	2012	194	535	29.3	82.8	40.2	12.5	16.0	0.3	11.8	390	10.1	56.2	60.5	7.6	0.02	0.14	15.5	8.9
Nigeria	2008	398	545	38.9	57.7	41.5	15.4	20.2	1.0	6.3	1160	31.2	61.2	60.5	7.6	0.37	1.49	51.1	41.4
	2013	480	576	38.1	60.6	40.6	16.0	21.8	1.2	5.4	2700	29.6	66.6	72.9	6.5	0.40	1.61	51.1	41.4
Rwanda	2010	91	476	69.0	98.0	17.5	28.6	10.2	0.4	7.3	560	57.2	73.1	28.1	11.3	0.06	0.66	65.9	61.6
	2014	34	210	90.7	99.0	45.7	30.9	18.9	0.4	7.6	700	60.8	75.5	28.1	9.9	0.06	0.68	68.3	64.7
Senegal	2005	121	401	51.9	87.4	41.1	8.7	21.5	0.4	5.6	770	42.6	71.1	34.3	12.4	0.05	0.30	41.9	33.0
	2010	326	326	65.0	93.2	62.8	9.6	19.9	0.5	4.2	1050	45.1	74.8	37.7	8.8	0.06	0.43	52.1	40.4
Sierra Leone	2008	97	857	42.4	86.9	63.0	10.2	27.6	0.8	5.4	420	12.3	55.4	79.7	11.1	0.02	0.18	34.8	24.2

	2013	306	1165	59.7	97.1	76.0	22.1	25.0	1.5	20.7	650	13	60.6	62.7	10.8	0.02	0.32	32.4	24.9
Tanzania	2010	142	454	50.6	95.9	25.3	28.8	18.3	0.4	6.4	690	13.1	55.2	31.9	10.9	0.01	0.20	67.8	60.8
	2015	200	556	64.0	98.0	36.4	32.4	22.1	0.5	7.0	910	15.6	55.6	23.2	12.3	0.03	0.40	80.4	73.0
Uganda	2006	151	435	42.1	93.5	25.5	19.6	40.6	0.5	10.8	340	17	66.1	41.4	15.1	0.12	1.34	71.4	62.1
	2011	241	438	58.0	94.9	35.1	23.6	34.3	0.5	9.4	630	18.3	74.2	35.5	16.2	0.12	1.31	73.2	64.6
Zambia	2007	106	591	46.5	93.7	48.0	29.9	26.5	0.6	8.4	880	42.2	59	38.6	9.5	0.05	0.70	61.4	51.8
	2013	151	398	64.2	95.7	68.2	35.1	21.1	0.6	5.1	1730	43.5	63.8	30.0	11.0	0.16	0.71	83.0	77.8
Zimbabwe	2010	136	960	66.2	89.8	41.4	41.3	8.6	0.6	15.4	530	37.7	77.9	39.4	7.5	0.07	1.22	83.6	80.1
	2015	99	651	78.1	93.3	68.9	48.6	10.4	0.8	1.4	960	36.8	76.9	35.9	8.5	0.07	1.19	86.9	88.3

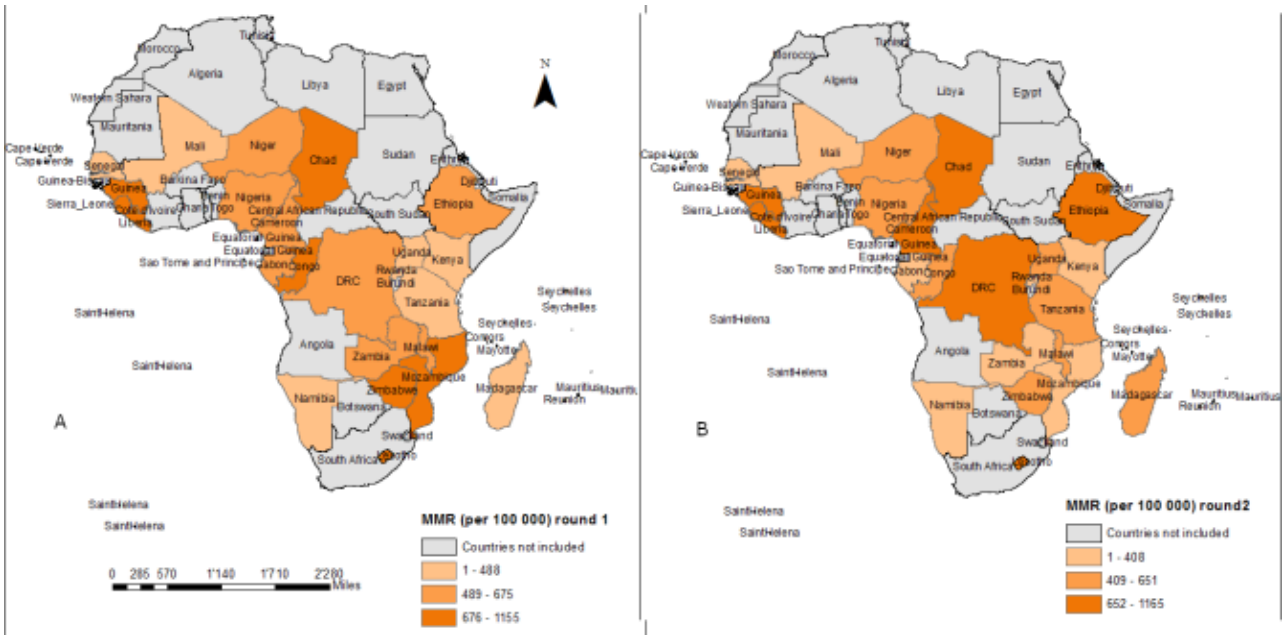

Figure: A.6: Geographical evolution of MMR per country in first (A) and second round of surveys (B)

Chapter 7: General discussion

The thesis contributes to the field of epidemiology and public health with advanced methods and knowledge. We presented Bayesian statistical methods to estimate the contribution and effects of health interventions at the local scale on under-5 mortality, to assess the contribution and the effects of most common childhood diseases on under-5 mortality, to assess the influence of the readiness of health on a malaria lethality and to assess the contribution of health system, socioeconomic and educational indicator on the decline of MMR in SSA. he thesis generated ways to target the granular administrative area to optimize health intervention outcomes in Burkina Faso. Besides, we developed a comprehensive statistical alternative to exploit routine surveys in health facilities to strengthen malaria-related health services. Finally, we reported that investment in human resources for health (trained professionals), women's empowerment (education), and health financing accelerate the path to maternal health goals.

Five manuscripts have been authored and embedded in the thesis as stand-alone chapters, where the methodologies, results and discussion are presented. This section highlights the main contributions of this research, the significance of the findings, and discusses the limitations of the thesis and future extensions.

Table 7.1 synthesizes the contribution of each chapter to the three pillars of Swiss TPH research, namely innovation, validation, and application.

Tableau 7.1: Overview of the major findings and contribution of the respective chapters in the current Ph.D. thesis according to the 3 main research pillars at the Swiss TPH, namely innovation, validation and application

Chapter	Title	Innovation	Validation	Application
2	Geographical variation in the association of child, maternal and household health interventions with under-five mortality in Burkina Faso			
		Explanation: we assessed for the first time in Burkina Faso the subnational variation in the associations of cost-effective health interventions and under-5 mortality with spatially varying regression coefficients		
3	Geographical variation in the association between childhood diseases and under-five mortality in Burkina Faso			
		Explanation: we assessed for the first time in Burkina Faso the subnational variation in the effects of childhood diseases on under-5 mortality with spatially varying regression coefficients		
4	Constructing a malaria-related health service readiness index and assessing its association with child malaria mortality: an analysis of the Burkina Faso 2014 SARA data			
		Explanation: we have derived a composite readiness score from routine health facility survey data specific to malaria-related health services. The score was created by combining several multiple correspondence analysis factorial axes. This was also developed for the first time in Burkina Faso.		
5	Assessing temporal changes in the association of malaria-related health service readiness and malaria mortality in under-5 years old between 2012 and 2014 in Burkina Faso			
		Explanation: we extended the methodology of Chapter 4 into a spatio-temporal framework combining two health facility surveys and assessed the association between malaria-related mortality in under-5 years old with health facility readiness over time.		
6	Assessing the effect of maternal, socio-economic, education and health system factors on maternal mortality across sub-Saharan Africa			
		Explanation: We assessed the effects of the temporal changes in several maternal health interventions, health financing, socio-economic indicators and maternal mortality across sub-Saharan Africa. This is an ecological study using country as a statistical unit.		

7.1 Significance

7.1.1 Epidemiological methods

In Chapters 2 and 3, we run Bayesian geostatistical models with spatially varying coefficients to capture geographic variation in the effects of health interventions and childhood common disease on child survival in Burkina Faso. In recent years, routine household surveys that have collected geo-referenced health data have been conducted in sub-Saharan Africa. However, analyses of these data most often do not consider geographic variation in health interventions and health outcomes. Typically, information derived from these surveys is summarized as national averages. Our research addresses the geographical disparities and generates subnational estimates of the effects of health interventions as well as the principal diseases on child mortality. To our knowledge, no study has provided such estimates for Burkina Faso.

Our modelling approach assumes that the effects are spatially structured at the regional level using conditional autoregressive prior (CAR) distributions on the regression coefficients. In particular, we consider that the effects of health interventions and diseases on child survival are more similar in nearby regions than in remote regions. This is a good approach for assessing the effects of health interventions or diseases on child survival in a country with high child mortality rates. The models also adjust for climatic and environmental confounders. These are identified via Bayesian variable selection, which accounts for the spatial correlation of the data.

As under-five mortality rates are declining in most sub-Saharan African countries, local-level assessment becomes very valuable for policymakers to target interventions in the space.

Altogether, our results in Chapters 2 and 3 showed that there are indeed large geographic variations in the effects of interventions. We observed similar variations with the effects of childhood diseases on infant mortality. Estimates of spatial variation patterns provide a useful decision-making tool for policymakers, allowing them to target weak areas and increase the impact of health interventions by implementing geographically targeted interventions on specific diseases.

Our statistical approaches in Chapters 4 and 5 derive a composite readiness score by extending the previous work by Ssempiira et al., (2018). Conventional methodological approaches to multidimensional data reduction use the first component of PCA or MCA depending on the type of data, i.e., continuous or categorical respectively. This is the approach used by several researchers (Ayele et al., 2014; Boyer et al., 2015; Gage et al., 2016; Jackson et al., 2015; Oyekale, 2017). Unlikely, our approach provides several advantages such as 1) selects the most important items that are related to a specific health outcome, 2) adhering to the principle of monotonic increase or decrease of the PCA/MCA score and 3) capturing greater variability in the data compared to the first component. In addition, we linked the readiness score to a health outcome, i.e., malaria mortality, in contrast to the common approach of summarizing the average availability of tracer items by domain and service Indeed, we have

shown that high levels of readiness are associated with reduced malaria mortality. Our methodology can be used to identify weak health services by disease at the local level.

The methods of Chapters 2, 3, 4, and 5 can also be used to monitor the under-five MDG targets at the local level. For Burkina Faso, the results show that the country should focus on malaria, scaling up related interventions, and strengthening health service factors such as RDT use and antimalarial drug availability.

The sisterhood method used to estimate maternal mortality by DHS precludes analysis at the subnational level because of the small number of maternal deaths that the survey can capture. Nevertheless, we used Bayesian negative binomial models to assess the effects of different covariates on MMR. Maternal mortality is related to various factors such as health, social, economic, and political factors. Our analysis provides clear evidence of the contribution of health system factors such as coverage of health interventions, health financing, education and economic covariates included in our analysis.

7.1.2 Implications for disease control

In most sub-Saharan African countries, health is a cross-sectional issue, and hence, decision making is not always based on evidence because of the opinion of various actors'.

Disease control strategies require reliable data, rigorous analysis, and sound decision making. To this end, we determined the magnitude and geographic distribution of U5MR, prevalence of childhood illnesses, coverage of health interventions, and disease prevalence. Using Bayesian risk profiling, we identified the most effective interventions, highlighted regions with high mortality rates, and the diseases that have the greatest impact on child survival in Burkina Faso. Finally, we need to combine and plan the implementation of effective health interventions to target specific regions and diseases. Because the goal is to optimize the effect of scarce resources, local-level analyses are of paramount importance. Indeed, in Chapter 1, our results suggest that, even though all of the health interventions evaluated are evidence-based, their real-world effect varies, and this geographic variation should determine resource allocation. Furthermore, our results imply that different combinations of health interventions are needed to increase their effectiveness in reducing U5MR in Burkina Faso.

In Chapter 2, it emerged that malaria is the most important cause of death among children under 5 years of age. This is the case as reported by the HMIS data. However, the regional variation suggests that the delivery of a health intervention should correspond to this geographic variation.

Overall, the findings in Chapters 1 and 2 demonstrate the need for a paradigm shift from uniform, national resource allocation to locally targeted delivery. Thus, periodic DHS data or similar surveys are needed to capture spatial and temporal variations in the effects of interventions on health outcomes. Unfortunately, this is not always the case, and since 2010, Burkina Faso has not conducted a DHS.

Relevant advances in statistical analysis resources are needed to help the Ministry of Health support this paradigm shift.

7.1.3 Implications for health system strengthening

The health system is a known determinant of the burden of disease in sub-Saharan Africa. However, insufficient attention has been directed to monitoring its performance in most SSA countries. In Chapters 5 and 6, we established a direct link between health service readiness and under-five malaria mortality. The readiness index is a useful policy tool for strengthening the health system in terms of drugs, health infrastructure, human resources, and service delivery. The most important implication is that the index could rank health facilities according to their performance. Poorly performing health facilities were associated with higher malaria mortality. Furthermore, we translated these results into maps and grouped regions according to the level of preparedness of malaria services. Subsequently, these regions can be prioritized for strengthening malaria-related health services.

7.2 Limitations

Spatially varying effect modelling

In Chapters 3 and 4, we assume spatially structured effects (of interventions or disease risk on U5M). However, this assumption can be clearly understood in the case of diseases rather than health interventions. This is because we consider the effects of diseases in nearby regions to be more similar due to the similarity of climatic and environmental factors that influence disease incidence. This may not be true for the effects of health interventions, which may vary geographically. However, they may not be spatially structured (i.e., the implementation of a health intervention in nearby areas may be similar to that in distant areas). Spatial range parameters for interventions and disease risk effects did not indicate a clear pattern of strong spatial correlation in either case. Thus, exchangeable or unstructured geographic effects for the corresponding regression coefficients may provide a better model fit than spatially structured effects.

Another limitation of both Chapters 3 and 4 is the sample size of regions at which level we estimate the spatially varying coefficient. The number of 13 regions is small and can reduce the consistency of the estimates

Lag-time between health intervention coverage, diseases prevalence and U5MR estimations in DHS

We assessed the effects of known health interventions and diseases that impact under-five survival in Chapters 1 and 2. However, early breastfeeding and household ownership of insecticide-treated nets did not show an association with under-five mortality at the subnational level, contrary to findings in the literature (Fegan et al., 2007; Larsen et al., 2014; Khan et al., 2015; Sankar et al., 2015). In the DHS, an estimate of MMR5 is based on the 5 years before the survey, whereas for most health interventions, the period used to calculate coverage is much shorter. Thus, if the intervention is not implemented during the 5 years corresponding to the mortality estimate, the effect will not appear. In Burkina Faso, it was in 2010 (the same year as the DHS) that the mass distribution of ITNs took place. Thus, the ownership

of ITN increased afterwards (Zöllner et al., 2015; Samadoulougou et al., 2017). Previously the possession of ITNs by households was low. This could explain the lack of effect of the ownership of ITNs on U5M (Samadoulougou et al., 2017).

Maternal mortality and epidemiological contextual factors

Maternal mortality is a sensitive indicator of population health because it highlights the quality and access to health services. It is therefore difficult to assess the association between MMR and the coverage of health interventions in different countries and settings, given potential confounding factors. Maternal mortality is a rare event, so it is difficult to assess its association with health interventions. DHS estimates MMR based on the 7 years before the survey, and the coverage of health intervention is estimated every year. Also, the period for estimating MMR and maternal health interventions are not contemporaneous, which may reduce the effect of MMR interventions. In addition, several indicators we used are not calculated in the same year as the survey.

Quality of HMIS data

The health facility composite readiness index derived in Chapters 3 and 4 is based on the selected indicators using malaria-related mortality data extracted from the HMIS database. These data have several weaknesses such as lack of completeness, underreporting, and inconsistency between data sources. Indeed, we removed the majority of private-sector health facilities because of the absence of death reports. As a result, the composite index is primarily based on public health facilities that reduce the scope of the index. Since 2014, HMIS data have been centralized in the district health information software (DHIS2). The objective is to improve the quality of HMIS data. Nevertheless, regular monitoring of this database is necessary to ensure its quality, namely its completeness.

7.3 Future research and extension

The spatially varying effect at the district level

Spatially varying regression coefficients corresponding to the intervention and health effects could be estimated at the district level. This would allow effects to be estimated at higher geographic scales (i.e., 70 zones instead of 13). However, the models would need to be validated on simulated data, as increasing the number of zones reduces the data points per zone. Another area that requires further study is the performance of Bayesian variable selection for variables with spatially varying effects.

Extension of the methodology to derive composite readiness index to other surveys/health programme.

The SARA survey collected information on about 20 health services or programs. Indeed, the methodology can be applied to health programs using, for example, the U5MR as a health outcome for children's programs such as Integrated Management of Childhood Illness (IMCI), HIV, and acute respiratory infections. In addition, a single readiness index can be derived for all tracer items.

7.4 Final conclusion and recommendations

Our research has provided comprehensive methods and results to explore fully geo-referenced household survey data in sub-Saharan Africa. The attainment of SDGs requires innovative approaches to monitor and optimise the impact of health interventions.

The first substantive implication of our results is to shift from the whole country to specific regional policy and decision-making. Our results show for the first time in Burkina Faso geographical variation of the association between U5MR with health intervention and childhood diseases. We identified regions where strengthening specific health interventions can reduce the burden of under-5 years old deaths.

This region-specific allocation of resources guides the development of the future strategic plan and health policy in Burkina Faso.

The second key finding is the importance of a well-functioning health system to address the most important public health problem, malaria. We demonstrated the strong association between health services readiness and malaria-related mortality in under-5 years old. Thus, national health spending and donor funding should contain health systems strengthening as a primary intervention. Regular monitoring of health system performance is also recommended to guide disease control efforts.

The third finding is that health systems, in conjunction with social and economic factors, play an important role in reducing MMR in Africa. Nevertheless, we noted that some countries have experienced an increase in MMR, suggesting that other factors, such as political instability or cultural factors need to be addressed to accelerate the pace of MMR reduction.

Finally, there is an urgent need to build capacity in advanced statistical methods so that those responsible for managing and analysing health data can effectively support policymakers with information on local disparities in disease burden and the impact of health interventions.

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Curriculum Vitae

1. Personal Details

2.	
Name	**Millogo**, Ourohiré
Date/ Place of birth	31th December 1973, Lahirasso, Burkina Faso
Nationality	Burkinabè
Permanent Home Address (Burkina Faso)	P.O. BOX: O2, Nouna, Burkina Faso Cell: (+226) 70110424 E-mail: ourohire2001@yahoo.fr
Profession	MD, Epidemiologist/biostatistician
Interests	Child and maternal health, Disease surveillance and mapping, Health system, Evaluation

2. Education Background

College/University	Year Attended	Diploma/ Degree
University of Basel, Switzerland	2015-2018	PhD, epidemiology
Institut Régional de Santé Public (IRSP), Ouidah, Benin	2009-2011	Master en Epidémiologie
Université de Ouagadougou, Ouagadougou, Burkina Faso	2009	IUD HIV/AIDS
Ministry of Health	2005	Certificate Health Districts Management
Université de Ouagadougou, Ouagadougou, Burkina Faso	1994-2004	Doctorat d'Etat en Médecine
Lycée Ouezzin Coulibaly, Bobo Dioulasso, Burkina Faso	1987-1994	Baccalauréat série C

3. Language skill: French and English

4. Computing skills and Software experience: STATA, EpiInfo/Data, R, OpenBUGS

5. Professional/Work Experience

1. Since 2019: head of scientific and technical unit of Nouna Resaerch Center

2. 2016-2019: Head of Department of Research, Training and Communication of Nouna Research Center

3. November 2011-March 2018: Member of the Department of Research, Training and Communication of Nouna Research centre,
- Field Coordinator of INDEPTH project on safety platform of Burkina Faso site.
- Field Coordinator of EU project on "Improving the quality of care for maternal and child health (QUALMAT)" of Burkina Faso.
- District coordinator of the implementation of the research project an experimental strategy to improve immunization coverage of children aged 0 to 11 months in the Nouna Health District" with the Centre for Research in Nouna Health, 2004-2008

4. October 2006-December 2009: Nouna Health District Officer

5. September 2004-october 2006: General practitioner in Nouna Health District Hospital, Head of Chirurgical Unit, responsible of supervision, training and monitoring of Nouna Health District Management Team.

6.2. Journal Publications

1. **Millogo O**, Doamba JEO, Sié A, Utzinger J, Vounatsou P. Constructing a malaria-related health service readiness index and assessing its association with child malaria mortality: an analysis of the Burkina Faso 2014 SARA data. **BMC Public Health. 2021 Jan 5;21(1):20**.

2. Wang X, Li Y, O'Brien KL, Madhi SA, Widdowson M-A, Byass P, et al. Global burden of respiratory infections associated with seasonal influenza in children under 5 years in 2018: a systematic review and modelling study. **The Lancet Global Health. 2020 Apr 1;8(4):e497–510.**

3. Millogo O, Doamba JEO, Sié A, Utzinger J, Vounatsou P. Geographical variation in the association of child, maternal and household health interventions with under-five mortality in Burkina Faso. **PLOS ONE. 2019 Jul 1;14(7):e0218163.**

4. Sié A, Diarra A, **Millogo O**, Zongo A, Lebas E, Bärnighausen T, et al. Seasonal and Temporal Trends in Childhood Conjunctivitis in Burkina Faso. **The American Journal of Tropical Medicine and Hygiene. 2018 Jul 5;99(1):229–32.**

5. Yé M, Tapsoba C, Zabré P, Diboulo E, Sanou A, Kagoné M, et al. Déterminants du choix des postes en zone rurale par les professionnels de santé au Burkina Faso. **Sante Publique. 2018 Jul 30;HS(HS):113–25.**

6. Yé M, Kagoné M, Sié A, Bagagnan C, Sanou H, **Millogo O,** et al. Promoting access equity and improving health care for women, children and people living with HIV/AIDS in Burkina Faso through mHealth. **Journal of Public Health. 2018 Dec 1;40(suppl_2):ii42–51.**

7. Yé M. Use of Mobile Phone to Promote Governance and Equity within the Health System: Experience of Rural Health District in Burkina Faso. Journal of Healthcare Communications [Internet]. 2016 May 17 [cited 2021 Jan 17];1(3). Available from: https://healthcare-communications.imedpub.com/abstract/use-of-mobile-phone-to-promote-governance-and-equity-within-the-health-system-experience-of-rural-health-district-in-burkina-faso-9554.html

8. Sanou H, Yé M, Duclos V, Brice B, Tinto I, **Millogo O**, et al. Notes sur le processus de mise en place d'une plateforme de santé mobile: design, défis et perspectives à venir. 2016;35.

9. Streatfield PK, Khan WA, Bhuiya A, Hanifi SMA, Alam N, **Millogo O,** et al. HIV/AIDS-related mortality in Africa and Asia: evidence from INDEPTH health and demographic surveillance system sites. **Global Health Action. 2014 Dec 1;7(1):25370.**

10. Moussilou M-N, Agueha V, Glele Y, **Millogo O**, Oke M, Michel M. Évaluation du projet « Renforcement de la surveillance du paludisme », Bénin. **Revue d'Épidémiologie et de Santé Publique. 2012 Sep 1;60:S121.**