Maternal Mortality
Then, Now, and Tomorrow
The Experience of Tigray Region, Northern Ethiopia
Hagos Godefay Debeb
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I dedicate this dissertation work to my sister, Mrs. Abeba Godefay Debeb, and all mothers who have lost their lives while giving life.
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ABSTRACT

**Background:** Maternal mortality is one of the most sensitive indicators of the health disparities between poorer and richer nations. It is also one of the most difficult health outcomes to measure reliably. In many settings, major challenges remain in terms of both measuring and reducing maternal mortality effectively. This thesis aims to quantify overall levels, identify specific causes, and evaluate local interventions in relation to efforts to reduce maternal mortality in Tigray Region, Northern Ethiopia, thereby providing a strong empirical basis for decision making by the Tigray Regional Health Bureau using methods that can be scaled at national level.

**Methods:** This study employed a combination of community-based study designs to investigate the level and determinants of maternal mortality in six randomly selected rural districts of Tigray Region. A census of all households in the six districts was conducted to identify all live births and all deaths to women of reproductive age occurring between May 2012 and September 2013. Pregnancy-related deaths were screened through verbal autopsy with the data processed using the InterVA-4 model, which was used to estimate Maternal Mortality Ratio. To identify independent determinants of maternal mortality, a case-control study using multiple logistic regression analysis was done, taking all pregnancy-related deaths as cases and a random sample of geographical and age matched mothers as controls. Uptake of ambulance services in the six districts was determined retrospectively from ambulance logbooks, and the trends in pregnancy-related death were analyzed against ambulance utilization, distance from nearest health center, and mobile network coverage at local area level. Lastly, implementation of the Family Folder paper health register, and its potential for accurately capturing demographic and health events, were evaluated using a capture-recapture assessment.
Results: A total of 181 deaths to women of reproductive age and 19,179 live births were documented from May 2012 to April 2013. Of the deaths, 51 were pregnancy-related. The maternal mortality ratio for Tigray region was calculated at 266 deaths per 100,000 live births (95% CI 198-350), which is consistently lower than previous “top down” MMR estimates. District–level MMRs showed strong inverse correlation with population density ($r^2 = 0.86$). Direct obstetric causes accounted for 61% of all pregnancy–related deaths, with hemorrhage accounting for 34%. Non-membership in the voluntary Women’s Development Army (AOR 2.07, 95% CI 1.04-4.11), low husband or partner involvement during pregnancy (AOR 2.19, 95% CI 1.14-4.18), pre-existing history of other illness (AOR 5.58, 95% CI 2.17-14.30), and never having used contraceptives (AOR 2.58, 95% CI 1.37-4.85) were associated with increased risk of maternal death in a multivariable regression model. In addition, utilization of free ambulance transportation service was strongly associated with reduced MMR at district level. Districts with above-average ambulance utilization had an MMR of 149 per 100,000 LB (95% CI: 77-260) compared with 350 per 100,000 (95% CI: 249-479) in districts with below average utilization. The Family Folder implementation assessment revealed some inconsistencies in the way Health Extension Workers utilize the Family Folders to record demographic and health events.

Conclusion: This work contributes to understanding the status of and factors affecting maternal mortality in Tigray Region. It introduces a locally feasible approach to MMR estimation and gives important insights into the effectiveness of various interventions that have been targeted at reducing maternal mortality in recent years.

Key Words: Maternal mortality, intervention, ambulance, family folder, case-control, cross-sectional survey, verbal autopsy, Tigray, Ethiopia
This thesis is based on the following original papers, which will be referred to in the text by their roman numerals (I, II, III and IV):


The original papers are reproduced here with permission from the respective publishers.
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# ABBREVIATIONS

<table>
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<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ANC</td>
<td>Antenatal Care</td>
</tr>
<tr>
<td>BEmONC</td>
<td>Basic Emergency Obstetrics and Newborn Care</td>
</tr>
<tr>
<td>CHIS</td>
<td>Community Health Information System</td>
</tr>
<tr>
<td>CI</td>
<td>Confidence Interval</td>
</tr>
<tr>
<td>CSA</td>
<td>Central Statistics Agency</td>
</tr>
<tr>
<td>DHS</td>
<td>Demographic and Health Survey</td>
</tr>
<tr>
<td>EDHS</td>
<td>Ethiopia Demographic and Health Survey</td>
</tr>
<tr>
<td>ERCS</td>
<td>Ethiopian Red Cross Society</td>
</tr>
<tr>
<td>FF</td>
<td>Family Folder</td>
</tr>
<tr>
<td>FP</td>
<td>Family Planning</td>
</tr>
<tr>
<td>FMoH</td>
<td>Federal Ministry of Health</td>
</tr>
<tr>
<td>GTP</td>
<td>Growth and Transformation Plan</td>
</tr>
<tr>
<td>HDA</td>
<td>Health Development Army</td>
</tr>
<tr>
<td>HEP</td>
<td>Health Extension Program</td>
</tr>
<tr>
<td>HEW</td>
<td>Health Extension Worker</td>
</tr>
<tr>
<td>HSDP</td>
<td>Health Sector Development Program</td>
</tr>
<tr>
<td>HSTP</td>
<td>Health Sector Transformation Plan</td>
</tr>
<tr>
<td>LB</td>
<td>Live Birth</td>
</tr>
<tr>
<td>MDG</td>
<td>Millennium Development Goal</td>
</tr>
<tr>
<td>MDSR</td>
<td>Maternal Death Surveillance and Response</td>
</tr>
<tr>
<td>MMR</td>
<td>Maternal Mortality Ratio</td>
</tr>
<tr>
<td>PHCU</td>
<td>Primary Health Care Unit</td>
</tr>
<tr>
<td>PNC</td>
<td>Postnatal Care</td>
</tr>
<tr>
<td>SDG</td>
<td>Sustainable Development Goal</td>
</tr>
<tr>
<td>TRHB</td>
<td>Tigray Regional Health Bureau</td>
</tr>
<tr>
<td>UN</td>
<td>United Nations</td>
</tr>
<tr>
<td>VA</td>
<td>Verbal Autopsy</td>
</tr>
<tr>
<td>WDG</td>
<td>Women Development Group</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organization</td>
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<tr>
<td>WRA</td>
<td>Women of Reproductive Age</td>
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</tbody>
</table>
ABOUT THE AUTHOR

After graduating with a BSc in Public Health from the University of Gondar, Ethiopia 16 years ago in 2000 GC, I was assigned as District Health Manager in Central Zone of Tigray, Northern Ethiopia. I worked there for about 7 years, an experience which provided an excellent opportunity for me to develop a deep understanding of the Ethiopian health system. I was responsible for managing and overseeing the preventive and curative health components of the district. The preventive component encompassed community health mobilization, as well as supporting and strengthening the Health Extension Program, whereas the curative component included ensuring the provision of medicines and other supplies to the health centers and health posts, and regular supervision and training of the health cadres. All the above activities add to my understanding of the Ethiopian health system and the national, regional and local health priorities.

While I was a District Health Manager, I joined the University of Gondar for my second degree (MPH) in Public Health from 2005 to 2007 G.C. My master’s thesis which emanates from my experience and observation was entitled “Importance of ANC risk scoring in predicting delivery outcomes in Tigray region: a cohort study”. This exercise gave me valuable insight to further develop an interest in maternal health. Later, I became chief executive officer (CEO) of Axum Saint Mary General hospital which is one of the largest hospitals in Tigray region. As CEO, my responsibility was to lead, manage, and administer both the overall activities of the hospital and health needs in the surrounding catchment area. In addition, I was responsible for supervising and advising BSc Public Health students from Mekelle University assigned to the hospital for practical attachments and student research projects.

Currently, I am the Head of the Tigray Regional Health Bureau, mandated to coordinate, oversee and implement regional health issues and policies throughout the region. With this post, I am involved in political leadership, governance, regulation, policy development. I have been able to see the regional health priorities and improving maternal health has been at top of the agenda. Several new maternal health interventions aimed at improving maternal wellbeing have been introduced to those already in place since I assumed the post. Despite the different interventions to reduce maternal mortality and improve maternal health, little has changed over 10-15 years according to national surveys like the EDHS. Regrettably, my only sister has lost her life due to maternal complications 19 years back. All these
experiences made me develop an interest in, and inspiration to quantify maternal mortality using improved techniques, and to evaluate the impact of different maternal health interventions on maternal mortality.

When I assess and examine maternal mortality and maternal health interventions in Tigray region, it is from an insider’s point of view as Head of the Tigray Regional Health Bureau and it has led me to question the existing methods of measuring maternal mortality. I have been inspired to assess the role of different maternal health interventions to improve maternal health in general and avert maternal mortality in particular. My position as the bureau head facilitated my data collection because I was able to use pre-established communication channels. It also fostered my deep understanding of the Ethiopian health system, specifically the Health Development Army (HDA) with its three pillars (explained further in the thesis): Community action, commitment of political leadership, and the health sector. My involvement in the integration, coordination and mobilization of the HDA and general health status of the community with emphasis on maternal and child health has facilitated my overall understanding of the health system, maternal health issues, and the data collection process.

Photo 1: Professor Peter Byass (left), Ms. Tsgemaryam Teklu, Dr. Gebreab Barnabas, and the author during discussions prior to starting the PhD program, November 2010.
FOREWORD

This dissertation work, entitled “Maternal Mortality – Then, Now, and Tomorrow: The Experience of Tigray region, Northern Ethiopia” tries to reveal the condition of maternal health in rural Ethiopia by addressing the magnitude of maternal mortality, the associated risk factors, innovative approaches to reducing mortality such as ambulance transport service, as well as the institutionalization of routine monitoring for maternal health outcomes in the community. This work is based on the four inter-related articles listed in the “Original Papers” section of this dissertation.

During the early stages of the health sector policy reform, Ethiopia’s health systems and services were few and poorly equipped. In 1994, over 70% of the nation’s health facilities were in urban settings and inaccessible to the 85% of the population who lived in rural areas. Tigray region at that time had a population of 3,136,267, and there were only 4 hospitals, 10 health centers and 102 health stations, which were poorly equipped and staffed by a total of 496 health workers. Out of these, only 5 were physicians (2, 3). Maternal mortality in the Pre Millennium Development Goals (MDG) period, prior to 2000, was one of the highest amounting to 1,400 maternal deaths per 100,000 live births in Ethiopia (4).

Today, most of the health-related MDGs have been achieved as a result of the comprehensive and inclusive policies and strategies that Ethiopia has adopted; for example reduction of child mortality (MDG4) by two-thirds was achieved. Infant mortality has fallen to 48 per 1,000 live births and overall under five mortality has fallen to 67 deaths per 1,000 live births (5). HIV prevalence decreased from 4.5% in 2000 to 1.1% in 2014, and access to ART drugs for those in need increased from 1% in 2004 to 54% in 2014. Ensuring universal access to treatment for malaria and other communicable diseases was also achieved in line with MDG6 by 2015 (6, 7, 8).

However, MDG5 – that aimed at reducing maternal mortality ratio (MMR) by three-quarters to 267 deaths per 100,000 live births – showed only a slight reduction according to national and international estimates in Ethiopia. Recent MMR estimates from international agencies such as the United Nations (UN), World Health Organization (WHO), Global Burden of Disease (GBD), and Demographic and Health Survey (DHS) have ranged between 350 and 676 deaths per 100,000 live births (4, 9, 10, 11, 12, 13). The significant variation in maternal mortality estimates as reported by different agencies calls for more robust and locally generated information, but across all the various estimates it is nonetheless clear that
there have been great reductions in maternal mortality since 1990, when the MMR was 1,400 deaths per 100,000 live births (14).

Ethiopia has now concluded the twenty year Health Sector Development Program (HSDP I - IV) and is starting a new five-year strategy (2015-2020), called the Health Sector Transformation Plan (HSTP), which fits into the second national Growth and Transformation Plan (GTP-II) (14). The HSTP stems from another twenty-year strategic document named as “Envisioning Ethiopia’s path towards universal health coverage through strengthening primary health care”. Such visionary strategies must follow the transformation of population dynamics, industrialization, urbanization, globalization, technology, climate change, and the triple burden of communicable disease, non-communicable disease, and injuries (15). Hence, current strategies focus on the optimization of the primary health care concept with due emphasis on equity and quality at all levels of health care delivery as a core of the entire health system, and as a means to reach to the most needy segments of the population (16). Through the robust community engagement enabled by the Health Development Army (HDA), there is more promising hope for Ethiopian mothers over the next twenty years. The HDA was initiated in Tigray in 2011, building on the foundations of the Health Extension Programme (HEP), which started in 2003. The HDA aims to integrate the community at large as represented by women, the health work force found in the health system, and the political leadership found at all levels.

The HSTP has three key features to guide the development of the health sector going forward: quality and equity, universal health coverage, and woreda (District) transformation. The document also sets out four pillars of excellence to help the sector achieve its mission and vision. These are: 1) Excellence in health service delivery, 2) Excellence in quality improvement and assurance, 3) Excellence in leadership and governance, and 4) Excellence in health system capacity. Some of the maternal health impact-level targets of HSTP by 2020 are to reduce MMR to 199 per 100,000 live births; reduce under five-year, infant and neonatal mortality rates to 30, 20 and 10 per 1,000 live births respectively; and reduce stunting, wasting and under-weight in under-5 year to 26%, 4.9% and 13%, respectively (15). The targets have been set based on the 2015 GC performance report and in consideration of the Sustainable Development Goals (SDGs), which succeeded the MDGs after 2015 (15).
Additional efforts are needed to reduce maternal mortality and achieve the maternal health targets, with interventions guided by context-specific and reliable evidence (17, 18). Locally generated evidence plays a critical role in informing local and regional policy makers, and it will help to assess and evaluate the different maternal health interventions to achieve the SDGs that target to bring maternal mortality below 70 maternal deaths per 100,000 live births.
INTRODUCTION

Motherhood is something that many women aspire to at some point in their lives. Yet the normal, life-affirming process of pregnancy and delivery carries with it serious risks of death and disability. Each year, an estimated 303,000 maternal deaths occur globally, resulting in a maternal mortality ratio (MMR) of 216 per 100,000 Live Births (LB) (80% CI: 207-249), based on the most recent WHO report, from 2015 (14). A more complex indicator is lifetime risk, which accumulates the chances of dying from the complications of pregnancy and childbirth during a woman’s reproductive life, and so accounts for fertility rate as well as obstetric risk. Globally, the lifetime risk of dying from maternal causes is one in 180. In other words, for every 180 women, one will die of maternal causes (14).

The burden of maternal death is not uniformly distributed throughout the world. Obstetric risk is by far the highest in sub-Saharan Africa. In 2015, the MMR for sub-Saharan Africa was estimated to be nearly 546 per 100,000 LB (80% CI: 511-652), three times higher than that of South Asia (182 per 100,000 LB), eight times higher than in Latin America and the Caribbean (68 per 100,000 LB), and more than 30 times higher than in industrialized countries (16 per 100,000 LB) (14). This differential in maternal mortality has long been cited as the “largest discrepancy between the developing and developed world of all public-health statistics” (19).

Global maternal mortality rates have shown significant reduction in recent times, from 380 in 1990 to 210 in 2013, and a reduction of 45%. However, this reduction is below the planned MDG goal of reducing maternal mortality by 75% by 2015 (14). In addition, many investigators believe there is little evidence to suggest any progress in reducing maternal death, especially in sub-Saharan Africa (20, 21). There is wide variation among countries ranging from 1000 maternal deaths per 1000 live births in some developing countries to less than 10 per 100, 000 live births in others (22). Despite this, there are some success stories among countries with initially high MMRs that have been able to document significant reductions over time. For example, in Rwanda, the MMR fell from 1,400 to 320 deaths per 100,000 LB, and in Nepal, the MMR fell from 790 to 190 between 1990 and 2013 (9, 23).

Such country case studies tell an important and encouraging story. They show that substantial decreases in maternal mortality are feasible, and they give hope of reaching the SDG target of reducing maternal mortality ratio to less than 70 per 100,000 live births by the year 2030. Finally, they show the considerable diversity in the mechanisms that contribute to the decline in maternal mortality, including policies such as liberalization of abortion laws,
control of infectious diseases, ensuring access to hospital care, and provision of professional midwifery care (23, 24).

**Maternal Mortality**

Maternal mortality is one of the most revealing indicators of health system status. The level of maternal mortality tells us about the risk attributable to pregnancy and childbirth as well as the performance of health systems in terms of access to health care and the quality of care provided. Reduction of maternal mortality is a globally prioritized agenda. Consequently, there have been substantial maternal mortality reductions globally (14), but with huge variations between countries.

The rate of reduction in maternal mortality is related to the amount and efficiency of government and societal efforts to implement public policies that promote social development and health improvement. Such broad efforts result in a shift from maternal death predominantly due to direct obstetric causes to deaths due to indirect causes, from death due to communicable diseases to deaths caused by non-communicable diseases; from a younger maternal population to an older one; and a decrease in MMR along with an increase in institutionalized maternity care and finally over-medicalization. This gradual shift in causes of maternal mortality is called obstetric transition (22).

Even though there is a reduction in maternal mortality globally (14), the wide variation between countries could be explained by the position of a country in the obstetric transition. In stage I, MMR >1000 maternal deaths per 100,000 live births and characterized by very high maternal mortality, high fertility and predominance of direct causes of maternal deaths. Most countries in sub Saharan Africa are in stage II of the obstetric transition, which is characterized by high maternal mortality, ranging from 300-999 maternal deaths/100,000 live births due to direct maternal causes. However, in stage II a greater proportion of mothers may start to seek and receive care in health facilities. In stage III maternal mortality is still high ranging 50-299 maternal deaths per 100,000 live births. In this stage, access remains an issue for much of the population but greater proportion of pregnant women start reaching health facilities (22, 25).

Due to the complexity of their determinants, maternal mortality indicators expose the health disparities between poorer and richer nations. In particular, unacceptably high levels of mortality continue to persist in low-resource regions such as sub-Saharan Africa, a fact that has been described as “one of the shameful failures of development” (26). Many estimation
exercises and much debate have occurred around the persistently unacceptable levels of maternal mortality in the world’s poorer countries (7).

Maternal mortality is determined by a wide range of factors including, among others, individual women’s circumstances and characteristics, logistical support in the event of emergencies such as transport and communication, and health service availability and quality. For example, in the UK, maternal death has been linked to individual factors such as the presence of pre-existing medical conditions and previous pregnancy complications, as well as health service level factors such as inadequate uptake of services such as antenatal care (27). In Brazil, maternal death was associated with social factors and Maternal and Newborn Care (MNC) services such as lower maternal education and having had a previous Caesarean section, as well as lack of antenatal care (28). While they vary greatly, determinants of maternal health tend to be inter-related, and careful investigation is needed to tease out which factors are major, and potentially modifiable. The different types of barriers preventing women from experiencing healthy pregnancies and childbirths have been conceptualized in various ways, the best known being the Three Delays model (29).

This model classifies the reasons why mothers may experience poor health outcomes into three categories: Delay 1, delay in decision to seek care; Delay 2, delay in reaching care; and Delay 3, delay in receiving adequate quality of care in health facilities. In higher income countries, where a large proportion of deliveries take place in hospitals, Delay 3 is predominant, and delays in recognition and treatment of life-threatening complications as well as substandard practices contribute directly to maternal deaths (30). Confidential enquiries into maternal deaths in a diverse range of countries, together with findings from clinical audits, suggest the proportion for which substandard medical care played a substantial role is often more than a third (31). By contrast, factors related to Delay 1 and Delay 2 remain major barriers in many parts of sub-Saharan Africa, due to the low status of women, poor understanding of maternal risks, poor socioeconomic status, lack of transportation or communication resources, and other sub-optimal infrastructure (14).

**Measurement of Maternal Mortality**

Unfortunately, the countries with the highest levels of maternal mortality often have difficulties obtaining reliable data for estimating the magnitude of the problem, and for exploring its causes. This is due to inadequate and lack of well-established information systems (32). Accurate maternal mortality data is needed from global to local levels, and in
order to obtain such data, efforts are needed by a wide range of actors. Global authorities need to set overarching health sector goals and agendas. National leaders need to piece together their national health picture, allocate budgets, and design approaches. Researchers and epidemiologists must assess the impact of specific health interventions, perform trend analysis, and evaluate programs. Health managers need to effectively plan health services using local resources. In spite of these clear needs, local assessments of the magnitude of maternal mortality are rarely made, so the best available information for health planning may come from global estimates, even if these may not reflect local circumstances. The lack of sound, comprehensive, and locally relevant evidences on maternal mortality often hampers the implementation of appropriate interventions and health policies to counter women’s deaths. In order to develop, implement and evaluate policies for reducing maternal mortality, it is essential to understand the magnitude of the problem as well as the associated risk factors (32).

Current experience reveals that while routine registration of all births and deaths would be ideal for capturing accurate data, the civil registration systems in Sub-Saharan Africa and south Asia are not fully operational. In this case, estimation must replace direct measurement, for example through periodic national surveys like the Demographic and Health Surveys. However, the retrospective nature of the birth history approach and the relatively small sample size limits the scope of these surveys (33, 34). They cannot give regional or locality-specific results, yet country level aggregate figures can often be irrelevant or misleading at regional or local level (12). In addition, many of the current estimation methods from sources such as the Global Burden of Disease Project and different UN agencies do not address indirect causes of maternal death and thus cannot readily assess the interactions between pregnancy and other co-morbid conditions such as HIV/AIDS (33, 34).

Global population health estimates exhibit huge variability and may be calculated over extended time periods, including the use of data that is over 20 years old (33). Global estimates from the WHO and UN agencies (14) and the Global Burden of Disease (10, 18) have to apply very sophisticated modeling methods to these very scanty data in order to generate outputs that hopefully reflect realities of maternal mortality patterns, but they do so with varying degrees of success (33-35). We characterize these types of estimates here as “top–down” measurement processes. The alternative approach, for a country or a region, is to undertake direct measurement of maternal mortality, in order to inform health service management and planning, and to provide strategic insights in terms of necessary interventions. Using this approach, the EDHS reported maternal mortality rate of 673 per
100,000 live births in 2005 (12) and 676 per 100,000 live births in 2011 (12), indicating little to no change between the two surveys. We characterize this as a “bottom–up” approach, which is one of the methods we have employed in this thesis to measure MMR in Tigray Region.
BACKGROUND

Socio-demographic and economic conditions

Next to Nigeria, Ethiopia is the second most populous country in Africa. The total population was projected at 91,008,650 individuals up to July 2016 based on the 2007 population census with an annual growth rate of 2.6% (36). Nearly a quarter of the population (23.4%) are in the reproductive age group (15-49) years of age. The average fertility rate declined from 4.8 births per woman in 2005 to 4.6 births per woman in 2016 (5). Nearly 84% of the population lives in rural areas. Agriculture is the mainstay of the Ethiopian economy, constituting about 43% of the gross domestic product and 80% of exports (37).

Map 1: Map of Tigray, Ethiopia.

Historical and geographic context of Tigray region

Tigray Regional State is the northernmost of the nine regional states of the Federal Democratic Republic of Ethiopia (37). Tigray region is bordered by Eritrea to the north, Sudan to the west, Afar Region to the east, and Amhara Region to the south (Map 1). The total area is about 54,570 km² with a mean population density of 102 persons/km², and an elevation ranging from 600-2,700 meters above sea level. Tigray is one area of the origins of
human civilization in the horn of Africa. There are different archeological attractions such as the ancient temple of Yeha (around 100 BC), the Aksum Obelisks (400 BC to 600 AD), Ge’ez inscriptions and various religious antiquities. The climate of the region is characterized as 39% kola (semi-arid), 49% woyna dega (warm temperate), and 12% dega (temperate), with an annual rainfall ranging from 450 to 980mm.

Sociodemographic and economic characteristics of Tigray Region

The total population of Tigray region according to the most recent, 2014, population projection is 5,055,999 (49.2% male and 50.8% female). The average population growth rate is estimated at 2.4% per annum (36). In terms of settlement distribution, 80.5% of the population is living in the rural areas of the region. As with Ethiopia as a whole, agriculture is the mainstay of the economy in the region. There are approximately 1,300,000 hectares of cultivable land in Tigray, of which 1,023,246 hectares are cultivated. The road network of the region includes 4,949 km dry weather roads, 2,522 km all weather roads, and 497 km paved road. The national grid provides 100% of urban and 15% of rural areas with electricity coverage (38).

The health system of Tigray

The health system in Ethiopia is decentralized, meaning that districts have the responsibility and mandate to monitor the health services and the health status of their populations. In line with this, the Tigray Health System structure has a three-tiered structure, with Primary Health Care Units at the bottom level. Primary Health Care Units are comprised of health posts that serve 5,000 people, health centers for 25,000 people and primary hospitals for 100,000 people. The primary health care system feeds into the secondary level of healthcare, general hospitals serving 1 million people. The tertiary care level consists of specialized teaching and referral hospitals serving a population of around 5 million (39).

The 2015 Tigray Health Profile shows that there are 240 government health facilities- 16 general hospitals, 20 primary hospitals and 204 health centers. There are also 712 health posts staffed by 2 Health Extension Workers (HEWs) each (described in more detail below), which work in close collaboration with their respective catchment health centers. Currently there are 13,000 health professionals and support staff working in the Tigray Region’s health sector (40).
<table>
<thead>
<tr>
<th>Level of Care</th>
<th>Type of Health Facility (Number of people to be served on average)</th>
<th># of HFs in 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tertiary Care</td>
<td>Specialized Referral Hospital (3.5 to 5.0 Million)</td>
<td>1</td>
</tr>
<tr>
<td>Secondary Care</td>
<td>General Hospital (1.0 to 1.5 Million)</td>
<td>15</td>
</tr>
<tr>
<td>Primary Care Unit</td>
<td>Health Center (40,000)</td>
<td>20</td>
</tr>
<tr>
<td>(Primary Health Care Unit - PHCU)</td>
<td>Primary Hospital (60,000 to 100,000)</td>
<td>204</td>
</tr>
<tr>
<td></td>
<td>Health Center (15,000 to 25,000)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Health Post (3,000 to 5,000)</td>
<td>712</td>
</tr>
</tbody>
</table>

Figure 1: The health tier system and the number of health facilities with target population in Tigray region, Ethiopia, 2015

**Health Extension Program**

The Health Extension Program (HEP) is an innovative community-based strategy to deliver disease prevention packages, health promotion services, and related curative interventions at community level, with a particular emphasis on improving uptake of critical maternal and new born health services. It enhances community participation through creation of awareness, behavioral change and community organization and mobilization in four main areas: Disease Prevention and Control, Family Health, Hygiene and Environmental Sanitation, and Health Education and Communication (41). There are 16 health extension packages organized according to these four areas. In each sub-district or tabiya, two female HEWs are responsible for ensuring household implementation of the 16 packages and providing health services in the Health Post (Photo 2). HEWs are graduates of a one-year certificate program that is taken after they have completed their 10th grade education. Some of their contributions to maternal health services include educating mothers to use family planning services, mobilizing pregnant mothers to attend antenatal care, following up pregnant mothers to promote skilled delivery, and working together with the local Women’s Development Groups (41, 42, 43).
Maternal health and maternal mortality in Tigray

The commonest health problems in Tigray region are similar to those at national level, including HIV/AIDS, tuberculosis and malaria, maternal and child health issues, and nutritional problems (37). Similar to other regions in Ethiopia, maternal mortality is a pressing health concern in Tigray region. For this reason, maternal health issue remains among the top health priorities in the region.

Maternal health services such as ANC, delivery and post natal care are rendered at all levels of health facilities ranging from health centers to tertiary levels of care. In addition, health posts which are the lowest levels of care and run by HEWs usually offer services such as ANC and post natal care. Deliveries are usually assisted by skilled nurses and midwives in a hospital and health center. Antenatal care from a skilled health provider has increased from 34% in 2011 (44) to 62% in 2016 (5).

Institutional delivery assisted by skilled provider in a clean and safe environment improves maternal and neonatal health outcome. So, due to tremendous efforts of the health system, institutional delivery by a skilled provider has improved from 11.6% in 2011 to 59.3% in 2016. The fact that many of the maternal and newborn deaths happen in the first 48 hours of delivery points to the importance of postnatal care. Unfortunately only 45% of mothers had
Post Natal Care (PNC) checkup in the first two days after delivery (5). According to the 2016 EDHS, the maternal mortality ratio for the country was 412 (95% CI: 273-551) deaths per 100,000 live births (5).

![Figure 2: Trend of maternal mortality with 95% CI in Ethiopia according to 2000, 2005, 2011 and 2016 EDHS.](image)

**Recent Maternal Health Interventions in Tigray**

The government of Ethiopia has been intensifying its all-round efforts to achieve the MDGs by 2015 (45), which are now updated to the SDGs targets for 2030. To meet the MDG goals and create a fertile ground for the success of SDGs related to maternal health and others, community owned interventions were introduced in Ethiopia in general and Tigray region in particular. In Tigray region, promising results are being recorded in the areas of reproductive health, maternal, newborn, and child health as a result of various recent interventions and initiatives (46). The most important of these are described below.

**Health Development Army**

Building the Health Development Army (HDA) system has been one of the top priorities of the Tigray Regional Health Bureau in the five years since its national implementation started in 2011 (15). The HDA is based on strengthening linkages between the three pillars of community action, commitment of political leadership, and the health sector in order to improve sustainability of health programs and community empowerment. Women’s
Development Group (WDG) 1-to-5 networks (further described below) comprise the community and social mobilization pillar, and the networking principle is also applied among health workers in the health sector pillar. The political leadership pillar emphasizes community representation and governance principles.

**Women Development Group (WDG)**

The community pillar of the HDA is based on the Women Development Group (WDG), which includes women in neighboring households who volunteer to organize in “1-to-5 networks” under the one larger group. The Women Development Groups are a part of the Women’s Association, a civic society structured from the region to the tabiya (sub-district) level. Up to the present date, the Women’s Association takes the leading role in organizing and involving women into WDGs (15, 46). Such kinds of grassroots associations arose historically in Tigray among women, farmers, and youth during the Tigray People’s Liberation Front (TPLF) rebels’ armed struggle against the Derg regime (1973-1990) as a method for communication and supporting the military. The TPLF was eventually victorious which is why ripples of their successful methods can be seen throughout today’s Ethiopia.

Every woman of reproductive age is eligible to engage voluntarily with a local WDG with other neighboring women living in close proximity for ease of gathering for coffee ceremonies (Photo 3). Each WDG is composed of 25-30 women over the age of 18, and within each WDG there are five sub-groups called “one-to-five networks” which includes around 5 members with one democratically elected network leader. The network meets daily and the network leaders have an additional meeting with the WDG team leader every three days. The leaders of the 1-to-5 networks receive initial training by the Health Extension Workers (HEWs) with the technical support of the catchment health center. The 60-hour training is on the 16 health extension packages in four main areas (Disease Prevention and Control, Family Health, Hygiene and Environmental Sanitation, and Health Education and Communication) (47). The WDGs are conceptualized as a way to create demand for health care, wellness, and improved access to health care services. The system enables efficient communication and mobilization and is considered critical to the successful implementation of the HEP (15).

The WDG initiative is achieving unprecedented results in many rural settings of the Tigray region. To date, more than 917,072 women (99.3% of the region’s eligible women) are organized under 29,920 WDGs and 136,997 one-to-five networks (40). The close integration
of the WDGs with the HEWs and primary healthcare units (PHCUs) has proven to be a powerful mechanism through which to achieve development targets and improve service uptake. For example, delivery by skilled birth attendant, an indicator that has been lagging behind for many decades, was reported as 69.2% in Tigray Region in 2015 up from 18.2% in 2011. This figure was three to four times higher than the figure reported in 2011, before the introduction of the HAD initiative (46). Though it needs further investigation, this increase is believed to be attributable to the community mobilization made possible by the active WDG networks (15). However, some women still have not joined or organized into WDGs for various reasons, including uncooperative husbands who do not permit their wives to participate in the network meetings, gatherings, and training sessions, as well as geographical barriers for women living in sparsely populated and hard to reach areas.

Photo 3: Women’s development group discussing different health issues.

The institutionalized WDG approach encourages mothers to take the initiative in implementing various locally feasible innovative interventions. Some of the solutions devised by the WDGs include tackling behavioral barriers to health service uptake and potentially unhealthy traditional practices through community dialogue, encouraging facility-based delivery by preparing cultural porridges and Ethiopian coffee for postnatal mothers at health facilities, and reinforcing positive behavior by celebrating women’s achievements. Following the momentum of the WDG, the health facilities themselves have taken action to address the low rates of facility-based delivery by preparing maternal waiting rooms for the mothers.
coming from distant areas, where they can prepare their own local dishes, rest there for free, and feel at home until they deliver (46).

**Health Infrastructure and Human Resources**

Health facilities in Tigray are gradually being staffed according to the minimum standards set by the Federal Ministry of Health (FMOH) of Ethiopia, with increased deployment of health professionals observed especially within the last five years. Each Health Post in Tigray, covering a population of 3,000 to 5,000, is staffed with at least two HEWs to provide the prescribed package of primary healthcare interventions according to the Health Extension Program. Each Health Center, with an intended catchment of 25,000 population, is staffed with an average of two midwives or nurses trained on Basic Emergency Management of Neonatal Care (BEMoNC) in order to avail basic emergency obstetric services in all primary care units. Primary Hospitals for each district of about 100,000 people are also being established, which are staffed with integrated emergency surgery and obstetrics officers who can perform Caesarian sections in addition to one anesthetist, two OR nurses, four midwives and other staff such as laboratory and pharmacy professionals. The region has also deployed a minimum of one general surgeon and one gynecologist in general and referral hospitals, among other professionals (Figure 3) (46). In addition, there has been a substantial expansion of Health facilities in Tigray region since 2006.

![Figure 3: The change in the absolute number of health providers in Tigray region from 2006-2015](image-url)
Ambulance Transportation

In order to address the situation of transportation shortages and improve accessibility of health services, Ethiopia has become the first sub-Saharan African country to implement a national program of on-demand ambulance transportation; it has been freely available to all women needing obstetric services since 2012 (12). To improve access and overcome the problem of second delay, free ambulance services have been in operation to provide the needed service at woreda/district level. In Tigray Region, a total of 153 ambulances have been distributed, of which 35 were procured through the contributions of the community. Each district has a minimum of two ambulances and nearly 50% of the larger districts have three. The ambulance service in Tigray is managed on a tri-partite basis, between the Tigray RHB, the district health offices, and the Ethiopian Red Cross Society. The three parties have clearly defined roles and responsibilities such that the district health office manages the running cost of the ambulances service. Running costs include maintenance, fuel, driver per diem, and other costs. Red Cross Society manages the day-to-day operation of the ambulances. The TRHB coordinates the intersection between district health office and Red Cross Society such as signing of memorandum of understanding. Furthermore, maternal transportation service is enhanced by locally made stretchers, called ‘traditional ambulances’ that are used to carry a mother in labour to the health post or centre, or to a rendezvous point on the road where they can meet the motorised ambulance. The ambulance service is for all segments of society in need, with a small service fee ($0.50 USD). However, the ambulance service for labouring mothers is free and mothers are given top priority among any other cases to be transported to a health facility.

Registration and Reporting

The Ethiopian Federal Ministry of Health (FMOH) has introduced a Community Health Information System (CHIS) to capture basic health and health related information by the health extension Workers (HEW) at household and individual levels. The CHIS collects data on basic demographic, characteristics, health service delivery and utilization based on the health extension packages. This is done by using a system called the ‘family folder’ which is a family-centered tool designed for HEWs to manage and monitor their work in educating households and delivering an integrated package of promotive, preventive and basic curative health services (48). Over the last 2 years, CHIS implementation has covered 82.5% of the expected rural population in Tigray Region, but the quality of the data collected has not been
verified (46). As a means of organising family based services in Ethiopia, the health extension program has called for the reorganization of information systems to collect and use information for action at local level using the family folder (49).

The base for CHIS is a non-traditional paper health register called the “Family Folder”. The family folder was developed as a data collection tool to be used at the health post level to collect and monitor household health data. It was designed as a comprehensive data collection and documentation tool to be used by HEWs to meet the necessary information needs to provide family centered health service at the community level (49). During the initial roll-out of Family Folders, each household in a Health Post’s catchment area was numbered sequentially with a 5-digit unique identifier (Household Number) and one Family Folder (a paper, A4 size pouch) was generated per household, complete with demographic data on each family obtained through house-to-house visits. Following the initial enumeration, the Family Folders were shelved numerically at the Health Posts, and the Health Extension Workers were expected to bring them along during subsequent household visits, and use them to complete a tally sheet for creating monthly aggregated HMIS reports.

Photo 4: The family folder and the different health cards (Photo: TRHB).

The front cover of the folder contains data on household identification, the household members, and household characteristics such as latrine type and use of long-lasting insecticide treated nets. The backside of the pouch contains information on the HEP packages
training and implementation status of the household. Individual health cards are generated for each household member above 5 years of age based on their gender, while records for children under 5 are recorded on their mother’s health card. The Health Card provides data on individual health status and services like immunization status, family planning uptake, and illness and treatment history. In addition the Integrated Maternal and Child Health Card is issued to every woman when she becomes pregnant as a longitudinal record to document the progression of the pregnancy and delivery. All of the cards are stored in their respective Family Folder, which when taken as a unit provides a quick yet comprehensive overview of the health services a family is receiving, as well as the household’s characteristics (50) (Photo 4).

Family Folders were designed to simplify the workflow of the HEWs and provide them with the necessary information to manage and monitor their work in educating households and delivering the HEP integrated package of health services. They also have potential to provide data for community level health service reports and perhaps even to capture vital events in the future. The scale-up of the Family Folder system means that important programmatic data is becoming available to the managers for monitoring and management decision-making (51). Data available through the Family Folders of CHIS, together with the strong mobilization work of the HDA in creating health awareness in the community may lead to better information, better decisions, and better action.
RATIONALE FOR THE STUDY

The significant variation in maternal mortality reported by different UN and other agencies calls for more robust and locally generated information. No current accurate estimate of MMR or the underlying causes of avoidable maternal mortality is available on a population basis for the Tigray Region, where this research was conducted. This is partly due to the difficulties of finding and correctly identifying maternal deaths and ascertaining levels of maternal mortality at the community level. Hence, local numbers for maternal deaths tend to be derived from health facility based data (52, 53, 54) which do not reliably reflect the population level situation, especially considering that most deliveries occur at home. EDHS 2011 showed that 89.4% of deliveries in Tigray Region occur at home, with only 10.6% of births occurring at a health facility cumulatively during the previous five years. More than half (52.4%) of mothers delivering at home in Tigray Region mentioned lack of transport to a facility as a major barrier (12).

Locally relevant evidence on the magnitude and underlying causes of maternal deaths is clearly essential for planning preventive measures to reduce maternal mortality as well as to track the progress of feasible health interventions, take timely actions, and increase the intensity of accountability at all levels – government, civil society organizations, health care providers, and donors (7). Therefore, a “bottom-up” approach of data processing is an appropriate method to generate timely and locally relevant MMR estimates in Tigray region, which is essential for planning preventative measures and appropriate decision making by the Region’s health leadership (PAPER I).

There is also lack of population-representative, community-based, and locally relevant studies on risk factors for maternal mortality. While there have been some other facility-based and community-based specific studies of risk factors for maternal mortality in Ethiopia, individual determinants of maternal mortality are often unclear and subject to variation by locality, urban-rural status, and other factors. Therefore, this study aimed to characterize individual risk factors for maternal mortality focusing on the rural population of Tigray, Ethiopia (PAPER II).

There are several recently implemented interventions and programs that need to be assessed for effectiveness, including the ambulance service in rural communities that was rolled out in 2012. The ambulance transportation service in the six study districts was evaluated systematically so as to understand the potential impact it may have had in averting maternal deaths since its implementation in Tigray Region (PAPER III).
The Family Folder component of CHIS is another relatively recent innovation that has great potential to improve the data availability, quality, and utilization. When implemented properly, paper health registers can play an important role in supporting delivery of patient care as well as providing an institutionalized method for capturing important population level demographics and vital statistics data. However, if the Family Folder is not being used properly, it will fail to accurately capture health events and may provide a misleading picture to decision makers. Therefore, this study attempted to compare the data recorded on Family Folders against a household survey and HMIS reports (PAPER IV).
OBJECTIVES

General Objective
The main objective of this thesis was to quantify overall levels, identify specific causes, and determine the role of local interventions in relation to efforts to reduce maternal mortality in Tigray Region, Northern Ethiopia, thereby providing a strong empirical basis for decision making by the Tigray Regional Health Bureau using methods that can be scaled at national level.

Specific Objectives

- To quantify the maternal mortality using a bottom-up approach, and compare the results with various top-down estimates of maternal mortality that are available for Ethiopia (PAPER I).
- To determine the population-level individual determinants of maternal mortality in Tigray Region (PAPER II).
- To assess the role of the recently implemented ambulance service in averting maternal deaths in Tigray region (PAPER III).
- To assess the role of the family folder in improving measurement of maternal health related events (PAPER IV).
CONCEPTUAL FRAMEWORK

The proposed conceptual framework presented in Figure 4 shows the collective and individual determinants of maternal health, the outcomes potentially leading up to maternal death, and the fundamental role of monitoring and evaluation. The three items shown under “collective determinants” represent the three inter-related pillars of the health development army:

1. The community, with subcomponents of physical and social environment
2. The health sector, focusing on service delivery
3. The political leadership, including the components of good governance

Each of the three pillars can be thought of as a general concept that encompasses many smaller elements, some of which are listed in the diagram (46). The “individual determinants” (55) shown to the right of the collective determinants include social, biological, and behavioral factors that may be unique to any particular woman. The possible maternal health outcomes shown at the far right side are pregnancy and/or childbirth, complication, maternal death, and a healthy mother. This sequence of potential outcomes is most proximally influenced by the woman’s individual characteristics as well as unexpected factors such as epidemics, natural disasters, or abortion, but it is understood from the directional flow of the framework that the collective determinants play an important role in influencing the individual determinants. Lastly, the diagram shows registration and reporting beneath the collective determinants emphasizing that data for decision making, planning, and action reinforces the integrity of the relationship between the three pillars, the individual, and the maternal health outcomes (Figure 4).

Based on their intended use and on their target audience, some other frameworks on determinants of maternal health emphasize certain aspects or functions of the socio-cultural, economic, and political environment as “distal” determinants. Meanwhile, factors such as health status, health seeking behavior, and access to health services are typically conceptualized as “intermediate” determinants (55). Labeling some factors as “distal” while others are labeled “intermediate” could be justified by the relative difficulty of influencing some determinants of health that may lie outside the direct reach of the health sector (55).

In the framework proposed here, however, the factors commonly thought of as “distal” and “intermediate” are integrated together as collective determinants of maternal health and conceptualized among the three pillars of the HDA. The HDA concept, and specifically the channels opened by the organized WDG provides a powerful linkage mechanism between the
community, the health sector, and the political leadership allowing efficient communication, feedback, and response to occur between the three components.

Figure 4: Conceptual framework for the collective and individual determinants of maternal health outcomes, adapted from McCarthy.
METHODS AND ANALYSIS

This section describes the study location, population, and setting, as well as the data sources and methods for the objectives stated in each paper. Lastly, the different analysis approaches for each paper are presented.

Study Location and Setting

There are 6 administrative zones in Tigray plus one special zone, Mekelle Zone, which is the regional capital and major urban center from where health services are coordinated by the Tigray Regional Health Bureau (TRHB). Within the six Zones, there are 52 districts or Woredas (34 rural and 18 urban), which are further divided into 814 sub-districts or tabiyas (753 rural and 61 urban). The Region contains a total 1,165,575 households. Each woreda contains about 25,000-30,000 households, with an average household size of 4.4 persons (3.4 persons per household in urban areas and 4.6 persons per household in rural areas) (36).

Map 2: Location of study districts in Tigray Region, Northern Ethiopia.

This study was conducted in six randomly selected districts of Tigray Region, Welkayat, Laelay-Adiyabo, Tahtay-Maychew, Saesi-Tsaedaemba, Hintalo-Wajirat and Alamata. The study districts exhibit great variation in topography and population density, especially
Welkayat district, which is the farthest from Mekelle and has a large migrating population due to seasonal farming and its shared border with Eritrea and Sudan.

Research design

This PhD dissertation employs quantitative approach to answer each of the study objectives. The use of different source of data enhanced the credibility, generalizability and applicability of the findings. A cross-sectional study design was applied for Paper I and a case control study was used for Paper II. Paper III employs retrospective record review of ambulance and maternal mortality data. Finally, Paper IV involves retrospective record review and survey data to address the fourth specific objective (Table 1).

<table>
<thead>
<tr>
<th>Study objectives</th>
<th>Research design</th>
<th>Study population</th>
<th>Data collection techniques</th>
<th>Method of analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective 1: Quantify maternal mortality using bottom-up approach</td>
<td>Quantitative Cross sectional survey</td>
<td>All women death 15-49 years of age in the selected districts</td>
<td>House to house face to face questionnaire interview</td>
<td>Descriptive statistics to calculate maternal mortality ratio and poisson regression to calculate the 95% CI</td>
</tr>
<tr>
<td>Objective 2: Characterize the individual determinants of maternal mortality</td>
<td>Quantitative case control study</td>
<td>Cases: All women who died due to pregnancy related causes Controls: All women who gave birth at the same time and survived</td>
<td>Primary data was collected using face to face questionnaire interview from cases and controls</td>
<td>Descriptive statistics and multivariate logistic regression</td>
</tr>
<tr>
<td>Objective 3: Extent of ambulance use and its role on reducing maternal mortality</td>
<td>Retrospective record review of ambulance use and maternal death</td>
<td>Ambulance use in the selected districts and all women death 15-49 years.</td>
<td>Secondary data from ambulance log book and maternal mortality as identified in objective 1</td>
<td>Descriptive statistics and multivariate poisson regression</td>
</tr>
<tr>
<td>Objective 4: Role of family folder in improving measurement of maternal health related events</td>
<td>Retrospective record review and primary data collection using face to face interview with the same checklist</td>
<td>All family folders in the selected districts and household in the same district</td>
<td>Secondary data collection from family folder and from household survey</td>
<td>Descriptive statistics were applied to assess the ability of family folder to capture maternal health related events</td>
</tr>
</tbody>
</table>

Table 1: Study objectives, methodological approaches, data collection and analytical methods used.
Sample size determination and selection

The sample size needed to accurately estimate MMR was calculated based on a MMR assumption of 400/100,000 LB with a 95% confidence interval (9). Using the region’s census projections this was extrapolated to 54 maternal deaths and 13,500 annual live births. Assuming a crude birth rate of 30 per 1000 (36), it would require a base population of 450,000 to reach 13,500 annual births. A design effect of 2 resulted in the desired sample size of 900,000, in order to control the clustering effect of the sampling technique employed in this study. The sampling technique considered a full representation of Tigray region. Therefore, one district from each of the six rural zones in the Region was selected using random number allocation: Welkayat, Laelay-Adiyabo, Tahtay-Maychew, Saesi-Tsaedaemba, Hintalo-Wajirat and Alamata districts (Map 2 and Figure 5). The sampled districts include a total of 131 sub-districts or tabiyas, 183,286 households, and a total population of 843,115, or 93.7% of the total desired sample size. The six study districts cover around 20% of the total population of rural Tigray including 166,515 women of reproductive age (15-49 years), or 19% of the WRA in rural Tigray.

Cross-sectional Household Survey

A two-stage cross sectional survey was used to estimate the magnitude of maternal mortality during the one-year study period (9 May 2012 to 8 May 2013) (see Figure 5). In this cross sectional survey, all deaths of women aged 15-49 years, and under five mortality were recorded parallel to a regional field operation to capture household socio-demographics by HEWs using the family folder. The two stages involved in this cross sectional survey study were: (1) census of all WRA and (2) verbal autopsy to determine the cause of death of WRA.
Stage One of the survey entailed a census of all households in the six districts to identify all deaths to WRA that occurred during the study period irrespective of the cause or pregnancy status. In the same process all live births were identified. The census was conducted during the scale-up of the family folder intervention in the entire region. The Health extension workers were numbering house holds and filling demographic data throughout Tigray at the time of the census. At that time a separate questionnaire was developed and distributed to all the data collectors (HEWs) to collect data on the deaths of any women aged 15-49 years in the selected study districts.

In Stage Two, the HEW responsible for that geographical sub-district visited the household of each deceased woman of 15-49 years identified in Stage One to carry out a verbal autopsy interview. Verbal autopsy was used to identify the cause of death of all the women 15-49 who died during the study period using InterVA (which determines cause of deaths using a probabilistic model rather than physician review, and which produces up to three probable causes of death (56, 57)). The VA format was adapted from the 2012 WHO
VA instrument for the death of a person aged 15 years and above (58) and translated into the local language (Tigrigna). HEWs received three days training on the details of the VA tool, interviewing techniques, indigenous terminologies, concepts of illness, and their manifestations. VA respondents included adult relatives or other adults who were caregivers at the time of death. Two trained public health professionals supervised the data collection process and finally the data was processed using the InterVA-4 (version 4.02) model. Since the study was done in one-year period recall bias was not a threat (59).

All deaths that occurred between May 2012 and April 2013 to a WRA, who was pregnant at the time of death, or within 6 weeks of termination of pregnancy, were considered as pregnancy-related. All pregnancy-related deaths, regardless of cause, were considered to be maternal deaths under the conservative assumption for calculating MMR. This avoids the difficulty of how to assign pregnancy-related deaths of indeterminate cause and it also helps mitigate confusion over how to attribute indirect causes of maternal mortality. All pregnancy-related deaths identified through the VA process described above were used in calculating the MMR:

- Total number of pregnancy-related deaths as identified through VA and the total number of live births (28) as identified through the household census were used to calculate MMR, expressed per 100,000 live births.
- To calculate 95% CI around MMR estimates, the Poisson distribution was assumed using the Stata12 cii command.

**Case-control Study**

A community-based case-control study with age and geographical matching was carried out to identify individual level risks for maternal death while controlling for wider geographic variations. A case of maternal death was defined as a WRA who died during pregnancy, childbirth or puerperium due to maternity-related causes. Controls were defined as WRA who delivered a live baby during the reference period and who were alive up to six weeks post-partum.

Sample size was calculated using Epi Info Version 3.5.1 assuming 95% confidence, 80% power, 20% proportion of exposure among controls to key parameters (52), odds ratio of 2.5, 1:4 case to control ratio, and 10% non-response rate, giving a desired sample size of 62 cases and 248 controls.
The study included all of the pregnancy-related deaths identified through the census and verbal autopsy process described above as cases, and extended the aforementioned one-year study period by three months (September 2013 from June 2013) in order to reach the desired sample size. For each case, a sampling frame was drawn up consisting of all women meeting the control criteria who lived in the same geographical administrative level (tabiya) as the deceased woman. Four controls were selected for each case using simple random sampling (Figure 6).

Figure 6: A diagram showing the sampling procedure for cases and controls.

A structured questionnaire was used to collect data of interest for the case-control study. The questionnaire was administered to adult caregivers of the deceased woman (for cases) or to the woman herself (for controls) by trained data collectors who are district maternal and child health experts using health extension workers as community guides. The questionnaire was developed in English following a review of similar studies and relevant guidelines and
protocols, and then translated into the local language (Tigrigna). The contents of the data collection tool include socio-demographic and economic, level of husband involvement and obstetric characteristics.

Training on the objectives of the study, methods of data collection and ethical issues was given to the supervisors for one day by the principal investigator. Later, training with the same content was given to the data collectors for three days by the supervisors. Pretest was done to examine the time taken to complete a single questionnaire, content of the data collection tool, and clarity of the questions. To avoid variation on the response due to the interviewers’ way of asking, intensive training was given to build consensus among the interviewers. The husband involvement section of the questionnaire was adapted from different studies that examined male partner involvement in maternal and child health services (60-63).

Bivariate logistic regression was used to analyze the relationship between maternal death and various independent variables with Crude Odds Ratios and 95% CI estimated for each parameter. A score for husband’s involvement in the wife’s reproductive health was developed based on 9 inter-correlated variables that addressed different types of support such as financial, moral/psychological, and physical accompaniment (Example: Did your husband encourage you to get ANC/delivery services?). Since there was no reason to suppose that the score had a linear relationship with the risk of maternal death, it was quantified as the number of positive responses out of 9, dichotomized as above or below the median number of positive responses, and analyzed as a single variable in further analyses. Correlation was assessed between husband involvement score and women’s participation in volunteer WDGs. The husband involvement index measures husband involvement during ANC, delivery and postnatal care, while participation in the WDG is voluntary as a means of strengthening their health. In addition, correlation was examined between the dependent (pregnancy related deaths) and independent variables (Husband involvement, WDG, ANC, family planning utilization).

A multivariate logistic regression model was built using all the factors which were significantly associated with maternal death in the bivariate analysis, giving Adjusted Odds Ratios and 95% CI.
Ambulance Service Operational Assessment

The vehicle logbooks for the ambulances in the six districts underwent data capture for the same one-year study period as that described above (9 May 2012 to 8 May 2013). Data elements for each ambulance run included whether the trip was related to a delivery, from which community the call originated, the patient’s name, distance travelled by the ambulance, the destination health facility, and the date of service. Completeness of vehicle logs was assessed by the odometer readings in kilometers. Descriptive statistics were used to characterize the patterns of ambulance transportation at district level and proportion of deliveries that used an ambulance (calculated per month per district) using the delivery data collected during the household census and VA process. We then calculated the distance travelled by ambulances for delivery-related trips, the mean distance travelled per delivery and per live births, and trends in the destination of delivery-related ambulance trips.

Trends in MMR among different groups, districts and tabiyas who used ambulances versus those who did not, and districts and tabiyas who have mobile phone coverage versus those who did not were compared, and finally Multivariable Poisson regression modeling was used to assess the contributions of various factors to tabiya-level maternal mortality, number of maternal deaths at tabiya level as dependent variable and Independent variables (tabiya level). Distance to nearest district health center, presence or absence of mobile telephone coverage, whether ambulances were used to transport deliveries were also checked, and Impact analysis (deaths averted) of the ambulance program in the six districts were computed.

Family Folder Implementation Audit

Quantitative methodology was used to examine the implementation of Family Folder in the six study districts. In order to select study households for inclusion in the quantitative analysis, each Health Post prepared a list of all households in their catchment area as a sampling frame and selected a 25% sample using systematic random sampling. Based on an estimated catchment size of 1000 households per Health Post, the projected sample size was a total of 250 households (25%) per Health Post and was 28,000 households.

A capture-recapture assessment was undertaken aiming to compare three different data sources to better understand the performance of Family Folders for collecting community health information. Certain demographic, maternal health, and child health data elements were selected for comparison between the three data sources and defined in terms of a 1-year
study period from November 10, 2014 to November 10, 2015. Patterns of completeness and accuracy of the selected data elements were compared between three data sources: (1) Data abstracted from the Family Folders of sampled households using a specifically designed data abstraction form; (2) Data from a two-part household survey of the sampled households on demographic information, reproductive and child health, using a specifically designed questionnaire; and (3) Non-sampled data from the routine aggregated HMIS reports made from the 32 Health Centers included in the study.

Two diploma level health professionals were assigned at each health post to abstract data from the Family Folders as well as conduct the Household Survey. The data collectors received a 2-day training led by the principal investigator on the objectives of the study, familiarization with the Family Folder and the data collection tools, interviewing techniques, and data quality.

Photo 5: HEW checking the family folders in the health post (TRHB 10 Years Health Bulletin).
Definitions of Key Terms

The definitions given below are the current standard definitions of key terms as obtained from different sources.

Maternal Death

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 (65).

Pregnancy-related deaths

Deaths of women while pregnant or within 42 days of the termination of pregnancy, irrespective of the cause of death (66).

Direct obstetric death

Direct obstetric deaths are deaths resulted from obstetric complications of the pregnant state (pregnancy, labor, and puerperium) from interventions, omissions, incorrect treatment, or from a chain of events resulting from any of the above. (66).

Indirect obstetric deaths

Indirect obstetric deaths are deaths resulted from a previously existing disease or from a disease that developed during pregnancy and which was not due to direct obstetric causes, but which was aggravated by the physiologic effects of pregnancy (66).

Maternal Mortality Ratio (MMR)

MMR is calculated as the ratio of the number of maternal deaths during given time period per 100,000 live births during same time period (32).

Top-down Approach of Measuring MMR

“Top-down” measurement processes for MMR are defined as global estimates from international agencies such as the UN or WHO which are reached through application of sophisticated modeling methods to whichever data may be available in order to generate outputs that aim to reflect the realities of maternal mortality patterns.

Bottom-up Approach of Measuring MMR

“Bottom-up” measurement processes for MMR refer to direct measurement of maternal mortality at a regional or national level.
Ethical Considerations

This study was approved by the Institutional Review Board (IRB) of the College of Health Sciences of Mekelle University, Ethiopia, and additional permission was obtained from the Tigray Regional Health Bureau. The study was conducted in cooperation with local authorities, and individuals provided informed verbal consent before participating in the study. Individual identifying information was accessible only to the research team and was kept confidential.

The main ethical issues considered when conducting this study included maintaining autonomy of the study participants, minimizing risk, ensuring justice, and avoiding undue influence.

- **Autonomy of study participants:** All participants in each study were informed about the voluntary nature of responding to the study questions. Study participants were fully informed about the risks and benefits of participation in the studies, after which data collectors sought informed consent from each individual who agreed to participate in the study. Finally, all study participants were assured that the information they gave us will remain anonymous and confidential, and will not be shared with any party without their knowledge and consent.

- **Minimizing risk to participants:** The main anticipated risks that study participants may experience concerned the time they took to participate in the interview, and, in some cases, the fact that they were reminded about a deceased family member. To minimize any anxiety this may have caused, data collectors were trained to provide reassurance for the participants during the interviews, and to conduct the interviews in a sensitive manner.

- **Justice:** Inclusion and exclusion criteria were based on scientific merit rather than affiliation to any group, community, population or institution.

- **Undue influence:** The study participants had no knowledge that the PI was a Bureau head in order to ensure that they were able to freely exercise their independent will without concern for any perceived consequences.
RESULTS

A total of 181 deaths among WRA occurring within the first 12-months study period (from 9 May 2012 to 8 May 2013) were identified through the household census, with 51 (28%) determined to be pregnancy-related through the subsequent verbal autopsy process. In addition, 19,179 live births were identified through the same household census with 82.1% being delivered at home and 17.9% in a health facility.

Maternal Mortality Ratio

Over the 1-year study period from May 2012 to April 2013, 51 maternal deaths and 19,179 live births were identified, giving an overall MMR estimate of 266 deaths per 100,000 LB (95% CI: 198-350/100,000). Table 2 shows the characteristics of the 51 women who died of pregnancy-related causes, as determined using Verbal Autopsy. Statistically significant variation in MMR was observed between the six districts, as shown in Table 3; see also Map 3. Welkayat district had the highest burden of maternal mortality, with 24 deaths (47.1% of all deaths) and a MMR of 482 /100,000 LB (95% CI: 309-718/100,000), while Tahtay Maychew only had 1 death (2.0% of all deaths) and an MMR of 37/100,000 LB (95% CI:1-207/100,000). MMR was inversely correlated with population density at district level ($r^2 = 0.86$, $P=0.005$), with lower population density districts, such as Welkayat, having higher MMRs (Table 4). The MMR calculated in this study was much lower than “top-down” estimates from EDHS and GBD project, but it overlaps with estimates from UN, WHO.
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Number of deaths</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age group</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 - 24</td>
<td>10</td>
<td>19.6</td>
</tr>
<tr>
<td>25 - 34</td>
<td>23</td>
<td>45.1</td>
</tr>
<tr>
<td>35 – 49</td>
<td>18</td>
<td>35.3</td>
</tr>
<tr>
<td><strong>Marital status (at death)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never married</td>
<td>2</td>
<td>3.9</td>
</tr>
<tr>
<td>Married or living with a partner</td>
<td>49</td>
<td>96.1</td>
</tr>
<tr>
<td><strong>Education level</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No formal education</td>
<td>41</td>
<td>80.4</td>
</tr>
<tr>
<td>Started formal education</td>
<td>10</td>
<td>19.6</td>
</tr>
<tr>
<td><strong>Occupation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Housewife</td>
<td>36</td>
<td>70.6</td>
</tr>
<tr>
<td>Farmer</td>
<td>9</td>
<td>17.6</td>
</tr>
<tr>
<td>Private employee</td>
<td>4</td>
<td>7.8</td>
</tr>
<tr>
<td>Others</td>
<td>2</td>
<td>3.9</td>
</tr>
<tr>
<td><strong>Place of Death</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Health Facility</td>
<td>15</td>
<td>29.4</td>
</tr>
<tr>
<td>Home</td>
<td>36</td>
<td>70.6</td>
</tr>
<tr>
<td><strong>Timing of Death</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Death took place within 6 weeks of delivery or pregnancy termination</td>
<td>28</td>
<td>54.9</td>
</tr>
<tr>
<td>Pregnant at time of death</td>
<td>23</td>
<td>45.1</td>
</tr>
<tr>
<td><strong>Place of Delivery (n=28)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Health facility</td>
<td>5</td>
<td>17.9</td>
</tr>
<tr>
<td>Home</td>
<td>23</td>
<td>82.1</td>
</tr>
</tbody>
</table>

Table 2: Characteristics of 51 women who died during pregnancy or within 42 days of pregnancy ending from March 2012 to April 2013 in six sampled districts, Tigray Region, Ethiopia
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Number of pregnancy-related deaths</th>
<th>Number of live births</th>
<th>MMR per 100,000 live births (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>District</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Welkayat</td>
<td>24</td>
<td>4,975</td>
<td>482 (309-718)</td>
</tr>
<tr>
<td>Laelay Adiyabo</td>
<td>7</td>
<td>2,637</td>
<td>265 (107-547)</td>
</tr>
<tr>
<td>Tahtay Maychew</td>
<td>1</td>
<td>2,697</td>
<td>37 (1-207)</td>
</tr>
<tr>
<td>Saesi Tsaedaemba</td>
<td>3</td>
<td>2,990</td>
<td>100 (21-293)</td>
</tr>
<tr>
<td>Hintalo Wajirat</td>
<td>8</td>
<td>3,516</td>
<td>228 (98-448)</td>
</tr>
<tr>
<td>Alamata</td>
<td>8</td>
<td>2,364</td>
<td>338 (146-667)</td>
</tr>
<tr>
<td>Age group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 – 24</td>
<td>10</td>
<td>3,076</td>
<td>325 (156-598)</td>
</tr>
<tr>
<td>25 - 34</td>
<td>23</td>
<td>9,432</td>
<td>244 (155-366)</td>
</tr>
<tr>
<td>35 - 49</td>
<td>18</td>
<td>6,668</td>
<td>278 (165-440)</td>
</tr>
<tr>
<td>Marital status</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never married</td>
<td>2</td>
<td>247</td>
<td>810 (98-2925)</td>
</tr>
<tr>
<td>Married or living with a partner</td>
<td>49</td>
<td>18,300</td>
<td>268 (198-354)</td>
</tr>
<tr>
<td>Education level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No formal education</td>
<td>41</td>
<td>14,979</td>
<td>274 (196-371)</td>
</tr>
<tr>
<td>Started formal education</td>
<td>10</td>
<td>4,110</td>
<td>243 (117-447)</td>
</tr>
<tr>
<td>Overall</td>
<td>51</td>
<td>19,179</td>
<td>266 (198-350)</td>
</tr>
</tbody>
</table>

Table 3: Maternal Mortality Ratios (MMR) per 100,000 live births among rural women aged 15-49 years from March 2012 - April 2013 in Tigray Region, Ethiopia

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Number of deaths</th>
<th>Total population</th>
<th>Total Area (sq. Km)</th>
<th>Population Density per sq. km</th>
<th>Health facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>District</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Welkayat</td>
<td>24</td>
<td>162,356</td>
<td>3811.18 sqk</td>
<td>42.6</td>
<td>7</td>
</tr>
<tr>
<td>Laelay Adiyabo</td>
<td>7</td>
<td>130,133</td>
<td>1764.16 sqk</td>
<td>73.8</td>
<td>5</td>
</tr>
<tr>
<td>Tahtay Maychew</td>
<td>1</td>
<td>115,023</td>
<td>498.85 sqk</td>
<td>230.6</td>
<td>5</td>
</tr>
<tr>
<td>Saesi Tsaedaemba</td>
<td>3</td>
<td>116,088</td>
<td>1119 sqk</td>
<td>103.7</td>
<td>7</td>
</tr>
<tr>
<td>Hintalo Wajirat</td>
<td>8</td>
<td>176,527</td>
<td>1933 sqk</td>
<td>91.3</td>
<td>7</td>
</tr>
<tr>
<td>Alamata</td>
<td>8</td>
<td>98,990</td>
<td>753.19 sqk</td>
<td>131.4</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 4: Pregnancy related death, total population and population density by study district, from March 2012 to April 2013 in six sampled districts, Tigray Region, Ethiopia
Maternal deaths:

Districts:
1: Welkayat
2: Laelay Adiyabo
3: Tahtay Maychew
4: Saesi Tsaedaemba
5: Hintalo Wajirat
6: Alamata

MMR:
1: MMR 482 (309-718)
2: MMR 265 (107-547)
3: MMR 37 (1-207)
4: MMR 100 (21-293)
5: MMR 228 (98-448)
6: MMR 338 (146-667)

Map 3: Map of Tigray Region showing the six study districts and MMR for each (Paper-I)
Shading indicates the number of maternal deaths in each local area-tabiya- within each district
Causes of Maternal Death

Among the 51 maternal deaths, 61.3% were due to direct obstetric causes including obstetric hemorrhage (34.4%), pregnancy-related anemia (9.3), pregnancy-induced hypertension (8.1%), and post-abortion deaths (5.9%). Thirty eight point seven percent were from indirect obstetric causes such as anemia (12%), pulmonary tuberculosis (10%), HIV/AIDS (2%), and malaria (2%) (Figure 7).

Figure 7: Cause of death distribution among 51 pregnancy-related deaths by district, Tigray, Ethiopia

Risk Factors for Maternal Death

Case-control study methods were used to investigate the risk factors associated with maternal death in the six study districts. The original one-year study period was extended by three months in order to meet sample size requirements resulting in a 15-month study period from May 2012-August 2013 for the case-control study with 310 female participants (62 cases, 248 controls).

Previous pregnancy complications, a below-median number of antenatal care visits, and a woman’s lack of involvement in her own health care decision-making were significant risk
factors that were not significantly related to maternal death in the multivariable model. Four statistically significant risk factors emerged in the multivariable model. A pre-existing history of other illness, such as anemia, tuberculosis, malaria, and HIV (AOR 5.58, 95% CI 2.17-14.30), was the strongest predictor of maternal death in the multivariable model. In addition, women who had never used contraceptives (AOR 2.58, 95% CI 1.37-4.85), women whose husbands or partners had below-median scores for involvement during pregnancy (AOR 2.19, 95% CI 1.14-4.18) and women who were not members of the Women Development Army (AOR 2.07, 95% CI 1.04-4.11) were at increased risk of death (Table 5).

<table>
<thead>
<tr>
<th>Factor</th>
<th>Value</th>
<th>Crude Odds Ratio (95% CI)</th>
<th>Adjusted Odds Ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical history:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Previous pregnancy-related complications</td>
<td>No</td>
<td>Ref</td>
<td>Ref</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>2.97 (1.27-6.99)</td>
<td>1.63 (0.57-4.61)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Any previous medical illnesses*</td>
<td>No</td>
<td>Ref</td>
<td>Ref</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>6.88 (2.97-15.9)</td>
<td>5.58 (2.17-14.30)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ever used contraceptives before the last pregnancy*</td>
<td>Yes</td>
<td>Ref</td>
<td>Ref</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>3.31 (1.84-5.95)</td>
<td>2.58 (1.37-4.85)</td>
</tr>
<tr>
<td>The last pregnancy:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of antenatal care visits</td>
<td>Above median (3+)</td>
<td>Ref</td>
<td>Ref</td>
</tr>
<tr>
<td></td>
<td>Below median (0-2)</td>
<td>1.92 (1.09-3.40)</td>
<td>1.67 (0.88-3.15)</td>
</tr>
<tr>
<td>Involved in health care decision making</td>
<td>Yes</td>
<td>Ref</td>
<td>Ref</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>2.29 (1.12-4.68)</td>
<td>2.12 (0.94-4.78)</td>
</tr>
<tr>
<td>Personal factors:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Member of Women’s Development Army*</td>
<td>Yes</td>
<td>Ref</td>
<td>Ref</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>2.12 (1.16-3.89)</td>
<td>2.07 (1.04-4.11)</td>
</tr>
<tr>
<td>Husband’s involvement score*</td>
<td>Above median (7-9)</td>
<td>Ref</td>
<td>Ref</td>
</tr>
<tr>
<td></td>
<td>Below median (0-6)</td>
<td>2.37 (1.32-4.24)</td>
<td>2.19 (1.14-4.18)</td>
</tr>
</tbody>
</table>

*Variables significantly associated with maternal death (p < 0.05) in bivariable and multivariable analyses.

Table 5: Bivariable and multivariable analysis of factors associated with maternal mortality in six districts of Tigray Region
Ambulance Service

Descriptive statistics based on review of ambulance logbooks were used to characterize the patterns of ambulance transportation at district level during the one-year study period from May 2012-April 2013. Alamata and Hintalo Wajirat districts did not have ambulances available for the first two months of the one-year study period, so the number of ambulance trips and the distance travelled were extrapolated to cover one year, to allow for analysis against the one-year maternal death data. There was no difference when including versus excluding the extrapolated months’ data suggesting that seasonal or other variations were not present.

A total of 4,779 trips related to deliveries covering a total distance of 178,736 km were made in the six study districts. Across the six woredas, an average of 24.9% of all deliveries (from 19,179 live births) used an ambulance with the percent of deliveries using ambulance transport ranging from 6% in Welkayat to 53% in Saesi Tsaedaemba. The mean distance travelled per delivery was 27.4 km, ranging from 23 km in Welkayat to 45 Km in Hintalo Wajirat. In Alamata district, which contains Alamata General Hospital, 27.8% of trips involved going to a hospital rather than a health center, and in Tahtay Maychew, which is near to Axum Hospital, 47% of trips involved going to a hospital.

Welkayat, Hintalo Wajirat, and Laelay Adiyabo fell into the low ambulance utilization group (below the average of 24.9%, with 39 maternal deaths total), while Tahtay Maychew, Alamata, and Saesi Tsaedaemba fell into the high utilization group (above average of 24.9% with 12 maternal deaths). We compared trends in MMR among these two groups, and found that pregnancy-related mortality was significantly lower in the high utilization group (P=0.01). The MMR for the low utilization group was 350 per 100,000 LB (95% CI: 249-479) compared with the MMR of 149 per 100,000 LB (95% CI: 77-260) for the high utilization group.

Comparisons were also made at tabiya level between the 104 tabiyas that used ambulances for any delivery transports and the 27 that did not use ambulances. The MMR for ambulance utilizing tabiya was 202 per 100,000 LB (95% CI: 135-291), which was significantly lower than MMR of 468 per 100,000 LB in non-ambulance utilizing tabiyas (95% CI: 293-709) (p=0.006). In addition to ambulance utilization status, pregnancy-related mortality was significantly lower in the 103 tabiyas that had mobile network coverage compared with the 28 that did not; network-covered tabiyas had an MMR of 209 (141 to 299) versus MMR 447 (277 to 683) in those without network coverage (p=0.014).
Multivariable Poisson regression modeling was used to assess the contributions of various factors to tabiya-level maternal mortality with the number of maternal deaths at tabiya level as the dependent variable. In the bivariate analysis, all variables were significantly associated with an increased risk of maternal death. In the multivariate analysis, ambulance utilization emerged as the primary significant factor associated with pregnancy-related deaths, while distance to the district health center and mobile network coverage lost their effects (Table 6).

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>Number of local areas</th>
<th>Number of pregnancy-related deaths</th>
<th>Bivariable maternal death rate ratio (95% CI)</th>
<th>Multivariable maternal death rate ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance to district health centre</td>
<td>&lt; 15 km</td>
<td>32</td>
<td>8</td>
<td>Ref</td>
<td>Ref</td>
</tr>
<tr>
<td></td>
<td>15 – 30 km</td>
<td>69</td>
<td>23</td>
<td>1.45 (0.65 to 3.24)</td>
<td>1.23 (0.54 to 2.79)</td>
</tr>
<tr>
<td></td>
<td>&gt; 30 km</td>
<td>30</td>
<td>20</td>
<td>2.33 (1.03 to 5.28)*</td>
<td>1.15 (0.43 to 3.11)</td>
</tr>
<tr>
<td>Mobile telephone network</td>
<td>Not available</td>
<td>28</td>
<td>21</td>
<td>Ref</td>
<td>Ref</td>
</tr>
<tr>
<td></td>
<td>Available</td>
<td>103</td>
<td>30</td>
<td>0.47 (0.27 to 0.82)*</td>
<td>0.57 (0.29 to 1.10)</td>
</tr>
<tr>
<td>Ambulance transport for deliveries</td>
<td>Not utilized</td>
<td>27</td>
<td>22</td>
<td>Ref</td>
<td>Ref</td>
</tr>
<tr>
<td></td>
<td>Utilized</td>
<td>104</td>
<td>29</td>
<td>0.43 (0.25 to 0.75)*</td>
<td>0.51 (0.27 to 0.95)*</td>
</tr>
</tbody>
</table>

*95% confidence interval excludes unity, p < 0.05.

Table 6: Associations between maternal deaths and various tabiya level factors in 131 tabiyas of Tigray Region using Poisson regression

An impact analysis of the ambulance program in the six districts was undertaken to determine deaths that would have been averted if the 3 districts with low ambulance utilization had used ambulances at the same rate as the high utilization group. The low utilization group had a utilization rate of 9.6% (1,070 ambulance utilized /11,128 total deliveries) while the high utilization group had a utilization rate of 46% (3,707 ambulance utilized /8,051 total deliveries). Thus the low utilization group would require an additional 4048 ambulance utilizing deliveries (1070+4048 ambulance utilized /11,128 total deliveries) to achieve the same utilization rate as the high-utilization group (46%). If the low utilization group had 4048 ambulance utilization rate, a MMR reduction from 350 to 149 would be expected. Such a reduction in MMR would have averted 17 of the 39 deaths from the low utilization group.
If each additional ambulance trip involved the mean observed distance of 37.4 km, usage per death averted would be approximately 7,000 km. Conversely, the 178,736 kilometers during the study might have averted around 26 pregnancy-related deaths. If that were the case, then the internally adjusted overall MMR for Tigray Region in the absence of the new ambulance service would have been 401 per 100,000 live births.

**Family Folder**

Of a total of 134 health posts within the six study districts, 112 health posts (under 32 Health Centers) that had started Family Folder implementation prior to November 2014 were included in the study but the remaining 22 were not included because of incomplete records. From the 112 Health Posts that had started Family Folder implementation before November 2014, 99 health posts completed the survey process for a response rate of 88.4%. A total of 24,700 family folders were selected using simple random sampling from 99 health posts, covered by 32 health centers in six Districts. This was 88.3% of the projected sample size of 28,000 (Table 7).

<table>
<thead>
<tr>
<th>District</th>
<th>Welkayat</th>
<th>Laelay</th>
<th>Tahtay</th>
<th>Saesi</th>
<th>Hintalo</th>
<th>Alamata</th>
<th>Total</th>
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</thead>
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<tr>
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<td>7</td>
<td>4</td>
<td>4</td>
<td>7</td>
<td>7</td>
<td>3</td>
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<tr>
<td>Health posts</td>
<td>15</td>
<td>16</td>
<td>15</td>
<td>20</td>
<td>21</td>
<td>12</td>
<td>99</td>
</tr>
<tr>
<td>Family folders</td>
<td>3,676</td>
<td>3,890</td>
<td>3,988</td>
<td>4,776</td>
<td>5,155</td>
<td>3,215</td>
<td>24,700</td>
</tr>
</tbody>
</table>

Table 7: Districts, health centers, health posts, and households assessed during the study, 2014-2015.

The family folders were reviewed and the corresponding households were surveyed over the 1 year study period from November 2014 to November 2015, as summarised in Table 7. Health Center level data were also available for the same 32 health centres, based on the aggregation of their monthly Health Management Information System (HMIS) reports for the same 12-month period, on a non-sampled basis.

**Population**

The total population covered according to the family folders was 120,356, and the corresponding number in the household survey was 114,056. Figure 8 shows total population
detailed in family folders and the household survey at health post, health centre and district levels. Apart from a small number of health posts showing discrepancies, agreement on overall population between the family folders and household survey was good. The concordance correlation at health post level was 0.81 (95% CI 0.74 – 0.88, p < 0.001), and at health centre level 0.97 (95% CI 0.94 - 0.99, p < 0.001). However, more women of reproductive age (15-49 years) were recorded in the family folders (27,211) than in the household survey (21,252), possibly as a result of uncertainty around the 15-49 year age limits. Fewer children aged under 5 years were recorded in the family folders (11,053) than in the household survey (12,776).

Figure 8: Population analyzed as detailed in family folders and the household survey at health posts (open circles), health centres (full circles) and districts (diamonds) levels, against the line of equivalence

**Births**

Births during the one-year period were less consistently recorded in the family folders (1,101 live births, amounting to 4.0% of women of reproductive age as recorded in the family folders) than in the household survey (1,919 live births, or 9.8% of women in the household survey).
Crude birth rate (births per 1,000 population) according to the family folders ranged from zero to 28 across health centres, with a median of 8, compared with the household census ranging from 2 to 30 with a median of 18.

**Deaths**

In terms of outcomes related to life events, stillbirths totalled 21 in the family folders (19 per 1,000 live births) and 42 in the household survey (21 per 1,000 live births). Only three early neonatal deaths (0 to 6 days of life) were recorded in the family folders (3 per 1,000 live births) while 30 were recorded in the household survey (16 per 1,000 live births). Family folders recorded 10 later neonatal deaths (7 to 27 days) (9 per 1,000 live births) while the household survey only recorded five (3 per 1,000 live births). Total under-5 deaths in the family folders were 41 (37 per 1,000 live births) and in the household survey 93 (48 per 1,000 live births). However, 14/99 health posts (14.1%) failed to record any live births or neonatal deaths in the family folders and others recorded very low numbers. Full details of these mortality rates at health centre level are shown in Table 8.
<table>
<thead>
<tr>
<th>District</th>
<th>Health Centre</th>
<th>Stillbirths per 1,000 births</th>
<th>Neonatal deaths in first week per 1,000 live births</th>
<th>Neonatal deaths after first week per 1,000 live births</th>
<th>Under-5 deaths per 1,000 live births</th>
<th>Four or more ANC visits, per 1,000 births</th>
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<tr>
<td></td>
<td></td>
<td>family folder</td>
<td>survey</td>
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<td>20</td>
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<tr>
<td>TOTAL</td>
<td></td>
<td>19</td>
<td>21</td>
<td>3</td>
<td>16</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 8: Childhood mortality rates by health centre from family folders and household survey
Service Utilization

At least one ante-natal care visit was recorded in the family folders for 453 women (396 per 1,000 of all births) compared with 1,796 in the household survey (916 per 1,000). Corresponding figures for at least four ante-natal care visits were 312 per 1,000 in family folders and 372 per thousand in the household survey. Skilled attendance at birth was recorded for 385 women in the family folders (343 per 1,000 of all births) and for 1,061 in the household survey (541 per 1,000). According to the family folders, at least one post-natal care visit was recorded for 400 women (363 per 1,000 live births) and for 1,016 women in the household survey (529 per 1,000). Corresponding figures for at least three post-natal visits were 344 and 149 per 1,000 respectively.

According to the family folders, 1,080 (981 per 1,000) of live births received their first dose of pentavalent vaccine, compared with 1,457 (759 per 1,000) in the household survey. In the family folders, 151 episodes of pneumonia were recorded among 11,053 under-5 children (14 per 1,000) compared with 293 (23 per 1,000) in the household survey. Severe acute malnutrition was recorded among 67 under-5 children (6 per 1,000) in the family folders and 89 (7 per 1,000) in the household survey.

Health Management Information System

Similar variables from the HMIS monthly reports (for the same 32 health centre areas in the same 12-month period, but not sampled within the areas) are shown in Table 8. The total of 14,070 live births is substantially lower than in a previous household survey undertaken throughout the same six districts (19,179 live births in a 12-month period from May 2012 (Paper IV) and the low rates of stillbirths and neonatal deaths may also reflect a lack of HMIS capture of births occurring in the community. This possibility is reinforced by the almost universal reporting of skilled attendance at birth for the births in the HMIS data, but low reporting of post-natal care (which would usually happen after discharge from facilities).
DISCUSSION

This first part of this section is organized according to the three HDA pillars: community actions, health sector actions, and political leadership actions. Under the community pillar, WDG membership and promotion of husbands’ involvement in reproductive health are discussed in relation to the existing literature. Under the health system pillar, MNCH service delivery including the ambulance service are addressed. In the socioecological and political context, governance of the health system and the role of multi-sectoral collaborations are discussed. The final part of the Discussion focuses on registration and reporting in light of its fundamental role underscoring evidence-based practice.

Pillar 1: Community Actions

Promote women’s involvement in Women Development Army

The findings from PAPER II showed that women who were not involved in the WDGs were at greater risk for maternal death. This clearly implies the role of community engagement in promoting healthy maternal outcomes, although the causal pathway of the association cannot be determined.

The mechanisms by which WDG involvement may exert protective maternal health effects are manifold. Similar to the Health Extension Programme model (68, 69), the WDGs promote sharing experiences and best practices among their members as well as creating demand for health services. In this way, behaviors are spread from innovative community members to others, demonstrating Roger’s diffusion of innovations theory pathway from innovators to early adopters to the late majority (70).

The HDA evolved differently in Tigray region compared to other parts of Ethiopia due to the political leadership and commitment by all levels of health professionals and the community, and the evidence clearly shows that in areas with advanced HDA networks, the coverage of key health interventions like skilled delivery have improved significantly (46). Increased HDA participation may also have implications for improved routine reporting of births and deaths to feed into a civil registration and vital statistics system. However, some women still have not mobilized into WDGs for various reasons such as husband opposition or living in hard to reach areas. HDA implementation is an ongoing process that must constantly be refined based on evidence, recognition of excellent practices and operational barriers, and
keeping the momentum with the required support and involvement from the political leadership (15).

**Husbands’ Involvement in Reproductive Health**

As mentioned above, husbands can affect women’s ability to participate in HDA activities and through the cultural and financial power they exert, they can also influence their wives’ reproductive health. In Paper II, husband’s involvement in a wife’s reproductive health decision making was shown to be significantly associated with lower risks of maternal mortality and other studies conducted in Ethiopia have similarly shown a relationship between male involvement and increased utilization of maternal health service (71).

“Husbands’ involvement” is a multifaceted and subjective term. It was conceptualized into three broad categories in a 2015 systematic review and meta-analysis on male involvement and maternal health outcomes (63).

1. Active participation in maternal health services and care (husband’s attendance at ANC together with his wife, husband’s presence at delivery room, and husband’s support/help to wife during post-partum period);
2. Financial support given for pregnancy-related and childbirth-related expenses;
3. Shared decision-making process in relation to wife’s maternal health.

Additionally, the maternal health outcomes potentially affected by husbands’ involvement can range from complications during pregnancy and childbirth, duration of post-partum stay in health facility, maternal depression, service utilization, and mortality.

Prior studies conducted in Ethiopia have focused primarily on the third category of husbands’ involvement (shared decision making) and its effects on service utilization. For example, a study conducted in Holeta Town, Central Ethiopia, measured husbands’ involvement by asking the women if their husbands approved of ANC utilization, and who was responsible for the decision to utilize skilled delivery care. Husbands’ approval was found to increase ANC utilization by almost nine times (71). Another study in Southern Ethiopia interviewed both the women and men separately, framing male involvement based on the man’s statements about his perceptions and preferences on skilled care and studying skilled delivery utilization as the outcome of interest which increased skilled delivery utilization by over two times (62).

In this study, husbands’ involvement was measured using a series of nine parameters, and a score for husbands’ involvement was developed based on the number of positive responses out of the nine items. Four of the nine items fell into category 1 (active participation) and five
fell into category 3 (shared decision making), giving greater depth to the concept of husbands’ involvement. Notably, with regard to category 2 (financial support), all maternal health services are provided free of charge in Tigray Region’s health facilities, thereby reducing the overall cost for mothers to a minimum. However, there may be costs incurred at times of drug stock outs, ambulances being out of service, and the fare for returning back home after delivery.

The issue of husbands’ involvement is complex and arguments have been made about the downsides of certain types of male involvement such as increased male dominance in decision-making, and the potential for escalating labor difficulties when husbands become anxious in delivery rooms (63), even if this latter practice is not often seen in Ethiopia. In the Ethiopian set-up, husbands are frequently the mediator determining women’s access to health services because of family power dynamics and the financial control they exert (72, 73) yet men have typically been excluded from the HEP paradigm of house-to-house visits conducted by the HEWs. Similarly in Mozambique husbands’ involvement remains an important inducement to improve access to maternal health care (74).

Initially, this approach was taken deliberately on the assumption that the cadre of exclusively female HEWs would be most effective by focusing their efforts on the women in the households (68, 69). In fact, one of the reasons why HEWs conduct their house-to-house visits during the daytime is because the men are most likely to be out of the house at that time. Thus they can create a trustful environment for women in the area of reproductive health. Feelings of safety and privacy are indeed important for women when using reproductive health services (75). However, the results of the current study reveal the dangerous effects of neglecting the role of men in family health. Including husbands in the HEWs house-to-house visits and counseling sessions given to mothers during pregnancy, delivery, and after delivery may improve maternal health status. However, when visiting the household of a pregnant mother, the HEWs may need to identify a specific time when the husband is available to emphasize the husband’s important role and ensure that the entire family receives the health education. In addition, husbands should be sensitized to the benefit of women’s involvement in the WDA both for the women’s personal health, family wellbeing, as well as for community cohesion. This may be done through HEW house visits or through male development groups which are structurally similar to the WDG but with a primary focus on agriculture.
**Pillar 2: Health Sector Actions**

**MNCH Services Delivery**

One of the important roles of the health sector leadership is to respond to the demand created in the community, and to identify and scale up solutions at grass roots level from the WDGs as well as the front line health workers.

Service delivery is the primary role of the Health Sector, including the assurance of service availability, accessibility, affordability, awareness, and quality. Since MNCH services are delivered within the health system, the coverage and quality of MNCH services such as ANC, skilled delivery, PNC, and Family Planning depend greatly upon the capacity of health system at large (76). Generally maternal health is highly dependent on effective and efficient health system as witnessed by a study done in sub Saharan Africa (77).

In Tigray Region, health service infrastructure and human resources are provided to districts on a per-population basis rather than by population density. This makes health services more difficult to access in sparsely populated areas, and the correlation between low population density and increased maternal mortality seen in Paper I further suggests that logistical constraints remain as a key determinant of maternal mortality. In addition, remote areas face challenges in retaining health workers, influenced by the general lack of amenities, lack of partner organization presence (Civil societies and NGOs), and lack of other incentives to stay in rural working conditions. For example, Welkayat district, which had the highest maternal mortality rate from the study districts, has several remote sub-districts with poor road networks, inconsistent mobile network coverage, and understaffed health facilities. This is in agreement with efforts made to reduce maternal mortality and improve maternal health in different countries. These efforts clearly demonstrate the challenges countries face in retaining health workforce in remote and hard to reach areas (78, 79, 80).

The results from Paper II also illustrate the link between maternal health and the wider health system in a two-fold manner. First, Paper II showed that history of contraceptive use was associated with decreased risk for maternal death. Utilization of maternal care services such as family planning may be understood as a proxy indicator of health seeking behavior (81). Similarly, maternal mortality has been declining steadily in countries that have better utilization of maternal health services such as ANC, delivery services, and family planning (82). In addition, women who use contraceptives may be empowered to decide when they
want to be pregnant and to control the number of children they bear, thus reducing risks of high parity pregnancy complications (83).

Secondly, Paper II showed that a history of any pre-existing (non-pregnancy related) illness was found to be associated with increased risk of maternal mortality. This suggests that there could be a gap between maternal health services and other components of the health system such as curative processes or disease specific programs. This finding is in concordance with a study done in Uganda, which found that previous medical history such as cardiovascular illness, hypertension, elevated serum lactate and social factors such as educational level are the determinants of maternal near-misses (84)

The proliferation of disease-specific programs, projects, and grants (often referred to as “vertical interventions”), can cause fragmentation in the health system and a multitude of concurrent cycles of training, outreach, financing, reporting, and others (32, 85). In the Ethiopian setup, the “vertical” disease-specific programs play an important and indispensable role in the health system. However, it would be prudent to create more effective links between the disease specific prevention and control programs and maternal health services to streamline the necessary care to pregnant women with co-morbid conditions. A more transformational, “horizontal”, health systems strengthening change is necessary to better utilize scarce resources and effectively integrate maternal health programs, disease specific programs, primary healthcare provided through the government health facilities, and preventative outreach conducted by HEWs.

The WHO has defined “health systems strengthening” as building capacity in critical components of health systems to achieve more equitable and sustained improvements across health services and health outcomes (76). In light of the findings from this study, such health systems changes could include encouraging contraceptive use during any kind of health examination, screening for pre-existing conditions during ANC visits and HEW house-to-house visits to pregnant mothers, and subsequently promoting the appropriate referral systems between different levels of health facilities to avert indirect causes of maternal deaths. This supports the call for sustained efforts in investments in the development of the health workforce, health facilities and other health systems, as well as in the roads and transport to access health services, to bring down maternal mortality in to the lowest level possible (78)

Integration of maternal health services with other disease prevention and control programs is not a new concept. In 1989, the United States Centers for Disease Control (CDC) merged its Division of Reproductive Health with its chronic disease center. Leaders inside and
outside CDC initially puzzled over why reproductive health work was being combined with topics such as tobacco control, diabetes, cancer, and nutrition (86). Today, the logic behind this organizational decision is clear, and issues of maternal and child health are recognized as being inextricably linked to the prevention and control of other diseases. At the most basic level, health care providers have the opportunity to screen and treat mothers for chronic diseases and counsel them on associated risk factors during their ANC and PNC visits. In addition, the experts from diverse fields such as tobacco control, nutrition, and diabetes can contribute greatly in addressing maternal and child health issues (86).

Within the health system of Tigray, a similar merger between the TRHB’s MNCH program and its curative health service programs would be revolutionary and would require intensive revision of business processes, but it could provide synergistic benefits in the areas of both maternal health services delivery and disease prevention and control. For the present time, the TRHB leadership can focus on merging the services at health facility level. In fact, the second-generation HEP is designed to address both non-communicable and communicable disease control as well as maternal health at health post level, but the referral practices must be strengthened to ensure that pregnant mothers with co-morbid illnesses are identified and referred to higher levels of care.

**Strengthening the Ambulance Program**

The Ethiopian health sector has shown pioneering innovation in its implementation of free ambulances services in every rural district of Ethiopia, and the strong buy-in supporting the program from both regional government as well as the communities where the ambulances are distributed is recognized as a key for success. The findings from Paper III demonstrated that the areas where women used the free ambulance transport for their deliveries showed substantially lower pregnancy-related mortality, although an operational assessment could not demonstrate causality. The high correlation observed between ambulance utilization and reductions in mortality confirms the general consensus that effective transport for obstetric health is essential. Unfortunately, this consensus has not translated into action or logistical innovations across most of sub-Saharan Africa where the physical obstacles and lack of private transport options are very extreme. Only a few other sub-Saharan countries have considered and evaluated the provision of transport to facilitate access to emergency obstetric care, for example in Gambia (87), Burundi (88) Uganda (89) and South Africa (90). The findings presented in Paper III are the first of their kind to address non-emergency obstetric transport in Sub-Saharan Africa. But there are studies showing on the effectiveness of
emergency obstetric ambulance transportation in reducing maternal mortality (91, 92).

The extrapolation of potential deaths averted per dollar demonstrates the relative cost effectiveness of the program. But it is important to consider how adequate resource allocation can practically translate into a committed and effective transport service. Collaboration between the health, transport and communication sectors is paramount for a functional system. To this effect, the Tigray Regional Health Bureau works closely with the district health offices and the Ethiopian Red Cross Society to manage the vehicles, the Rural Road Access Program to improve the road infrastructure, and the regional cabinet to enact laws to ensure and safeguard the proper utilization of the ambulances. Appropriate use of the ambulances remains as a challenge, as some HEWs report calling the ambulance for laboring women but being told that the ambulance has gone somewhere else on an apparently non-work related service call (73). In addition, the health sector can collaborate with the regional telecommunication sector to increase network coverage to all areas of the region, and work to create a centralized dispatching system and short-code emergency number to facilitate easy and universal access to the ambulances.

**Pillar 3: Political Leadership Actions**

**Multi-sectoral collaboration**

The conceptual framework presented in this dissertation aims to emphasize the collective interrelation of the political leadership commonly portrayed as a distal determinant – with other determinants of maternal health. The separation or distancing of political actions from health outcomes is dangerous and may discourage researchers and innovators from focusing on interventions targeted at this level. The roles of political leadership are fundamental (93) and can create an enabling environment for smoothing logistical issues and encouraging trust and exchange between the three HDA pillars (the political leadership, the health work force, and the WDG).

Multi-sectoral collaboration is one of the most important roles of the political leadership that can affect health outcomes, as mentioned in Paper III. For example, mobile telephone service is one of the important components of overall ambulance transport policy with an undeniable influence on public health, yet it falls outside the direct jurisdiction of the health sector. In Paper III, mobile network availability at tabiya level was significantly associated with pregnancy-related mortality on a bivariate basis. In Ethiopia, Ethio-Telecom is the sole
network provider, with widespread coverage extending to most areas of the country, other than in particularly hard-to-reach areas. In general, it may be appropriate for the health sector to put pressure on mobile communications operators at national level to extend coverage into all inhabited areas.

Registration and Reporting

Bottom-up MMR estimation

As the proposed conceptual framework shows (Figure 4), registration and reporting is the foundation that supports a functional relationship between the three HDA pillars, each of which plays its own role in generating and utilizing health data. Population health statistics should ideally be measured from reliable individual registration rather than relying on estimates of any kind. Hence, as Ethiopia is the first country in sub-Saharan Africa to implement a national health information system at the household level, it has an exciting and promising opportunity to develop the necessary systems to measure population health accurately. This thesis evaluated the potential of the Family Folders for collecting individual demographic and health event information, but it was clear that some logistic and practical issues needed to be resolved to improve the functionality of the system. Additionally there were some discrepancies in how aggregated HMIS data reflect community-based events.

Thus, until such barriers to individual registration can be overcome, estimates remain relevant as an indispensable resource for planning and policymaking (33, 94). This dissertation work has presented a comparison of two different estimation approaches termed as “top-down” and “bottom-up”, and the results from Paper I exposed the significant variations in the magnitude of MMR results generated by the two approaches. The “bottom-up” estimate was noticeably lower than available “top-down” estimates and revealed important inter-district variations in MMR as well as variation by population density that were otherwise masked by the aggregated country estimates. The contemporary nature of the results mean that they can also be used more widely to monitor, supplement, and strengthen the region’s maternal death surveillance and response system.

In general, the global health community accepts that “top-down” estimation methods are flawed, but recognizes that they are still necessary because of the lack of adequate vital events registration in many countries to generate quality data (33). In fact, it has been estimated that more than 30% of the world’s population lives in areas where less than 5% of
deaths are registered, a serious disparity that casts uncertainty on global health estimates (95). In light of this, it seems paradoxical that more attention is given to creating “top-down” estimates that apply complex modeling methods to scanty data rather than to strengthening health systems’ capacity for “bottom-up” estimation and ultimately for capturing reliable individual level data (33).

The “bottom-up” methodology on which this dissertation work is based could serve as a powerful tool for generating contemporary and locally relevant population health estimates using a household survey approach that is practical, straightforward, and replicable. Several basic steps would be needed in order to apply this survey methodology in regions of larger sub-Saharan African countries or at national level in smaller countries through (1) Identification of births and deaths in the population using whatever cadre of community health workers may be available to carry out the survey; (2) Verbal autopsy done by the community health workers using the free InterVA analysis tool to determine cause of death, and thereby building management capacity and technical expertise.

In the Tigray Region, the overall cost of the survey was estimated to be $60,000 USD to estimate the mortality pattern in a population of over 5 million, or $0.012 per capita, a process that relied on the local HEWs for data collection. Such a survey could play an important transitional role in data generation as well as building the capacity of health workers until compulsory vital event registration can be implemented. Bottom-up estimation is an important stepping-stone to vital registration since vital registration also relies on the same basic steps outlined above. The challenge in progressing to vital registration lies in ensuring the institutionalization of such processes so that they are carried out in an efficient, routine, and timely manner (67).

The experience of this study confirmed the significant logistical challenges related to identifying all deaths in the population, as well as the challenges HEWs face in recording vital and health events on the Family Folder. This study attempted to utilize the potential of HEWs as data collectors because they knew and understood the communities involved, and while the HEWs were able to conduct the household survey effectively, serious differences were observed between the data from the one-time survey and that abstracted from the routinely used Family Folders. The discrepant routine recording practices highlight the existence of a significant barrier to HEWs participation in the future of civil registration, and the underlying reasons must be investigated further. If civil registration were to be implemented in Tigray region through the HEP, strong community ties, well-established
communication channels, and effective human resource motivation strategies would be required.

For cause of death determination, this study used verbal autopsy interviews analyzed using Inter-VA, and found that the verbal autopsy process was relatively easy compared to the antecedent step of identifying deaths (67). It is widely recognized that in largely unregistered populations with a considerable proportion of deaths occurring outside of health facilities, vital event registration would need to rely on Verbal Autopsy for cause of death determination, since physician-issued death certificates are uncommon. Thus, familiarizing communities, health workers, and key informants with the Verbal Autopsy process through conducting “bottom-up” mortality estimation would also strengthen the foundation for a civil registration system to flourish. With the development of smart phone technology and increasing opportunities to automate both the interview and analysis, the verbal autopsy process is only expected to get smoother. Therefore, due attention should be given to the more challenging and antecedent issue of tracing and identifying deaths.

As the conceptual framework shows, registration and reporting underlies the collective determinants of maternal health, and hence its function is not only to generate data but also to strengthen the Health Development Army system. It is clear that the generation of contemporary and locally relevant evidence can benefit political decision makers, health sector leaders, and the community. In addition, the multi-level cooperation between leaders, health researchers, health workers, and the community required to undertake “bottom-up” cause-specific mortality estimation could strengthen a developing health system’s capacity to implement civil registration and vital statistics in the future. Therefore, there may be a double benefit to undertaking bottom-up MMR estimation, namely to generate evidence for action as well as to strengthen the capacity of the health system through involvement in the research process.
Limitations of the Study

This study has some limitations that we acknowledge.

Paper I

- Possible limitations of our study include potential recall bias in identifying pregnancy-related deaths up to a year after they occurred, which would not be necessary if real-time death registration were in place. Nevertheless the recall demands over a one-year period are substantially less than those required in the EDHS methodology which is typically conducted every five years. In addition, a recall up to one year between death and interview did not have any significant effects in the identified cause of death patterns (59).

- Pregnancy-related deaths are generally considered to be important and therefore memorable events within households, and it has been demonstrated that VAs can be administered reliably even after relatively long recall periods (56). However, there is a potential problem arising from the possibility of a household dissolving after the death of the mother as a key member, and consequently not being included in a retrospective survey. This probably occurs relatively rarely in the typical extended family structures in rural Ethiopia. Unlike some surveys of maternal mortality, we avoided the bias that can arise by identifying maternal deaths before determining cause of death, since we followed up all identified deaths among women of reproductive age.

Paper II

- The study was limited to some extent by the relatively small number of maternal deaths that occurred in the six randomly selected districts, with the result that only relatively large effects could be identified. A number of important factors nevertheless emerged. Since no sampling other than the random selection of the districts was involved, it is reasonable to suppose that the cases and controls were representative of the Region. Controls were selected from the same local areas as cases to ensure that observed differences did not relate to variations in local geographic factors; similarly age group was matched to ensure that findings were controlled for age. Consequently no conclusions about the effects of geography or age group could be drawn here. The sample
size was also small as expressed by a wide confidence interval in some of the variables because maternal mortality is a rare event.

**Paper III**
- The uptake of freely available transport in connection with women’s obstetric needs correlated with substantially reduced pregnancy-related mortality in this operational assessment, though cause and effect could not be demonstrated.

**Paper IV**
- In a capture-recapture study, there is no “Gold Standard” to which the various data sources can be compared. It is impossible to assume that the household survey is more accurate than the Family Folder or the HMIS data. Thus the study findings are merely a comparison between the different data sources.
CONCLUSIONS

This dissertation work contributes to understanding the status of and factors affecting maternal mortality in Tigray Region. It introduces a locally feasible approach to MMR estimation, and gives important insights into the effectiveness of various interventions that have been targeted at reducing maternal mortality in recent years, which is invaluable for planning and decision-making.

The Regional Health Bureau (RHB) was able to implement several immediate actions in response to the findings of this study, especially to address the logistical challenges in Welkayat district, where MMR was substantially higher than in the other districts. Following the study conclusion, five additional Health posts were constructed and new health extension workers were trained for the underserved areas in Welkayat, while two extra ambulances were allocated. In addition, RHB conducts regular supportive supervision to health posts and health centers in the entire region, and is planning to allocate one ambulance for every health center by next year. The region is also establishing a health research institute (Tigray Health Research Institute) to research and further follow up and support the health system with evidence-based practices.

The majority of pregnancy–related deaths arose from potentially preventable causes, highlighting the need to increase the accessibility and quality of preventive and emergency obstetric care from the health sector perspective. Additional interventions should focus on encouraging membership of the Women’s Development Groups and devising mechanisms to enhance husbands’ involvement in maternal health. The linkages between maternity care, family planning services, and disease-specific programs must be strengthened so that at-risk mothers can be identified and followed up throughout their pregnancy in a comprehensive and cohesive manner.

The findings presented provide an empirical foundation on which the Tigray Regional Health Bureau can base the programmatic and strategic decisions that will bring about the Region’s vision, in which healthy families and mothers are found in every household.
IMPLICATIONS OF THE THESIS FOR FURTHER RESEARCH

- The sub-studies in this PhD dissertation have assessed the magnitude of maternal mortality and evaluated the impact of different interventions in reducing maternal mortality. They have quantified the magnitude of maternal mortality in Tigray region using a bottom up approach, including at district level. Comparisons were also made between the study districts in order to help tailor and optimise the possible maternal health interventions. Different interventions such as free ambulance transport and the family folder were also evaluated. However, further assessment and evaluation of the quality of the health system’s maternal health services was beyond the scope of this thesis. The provision of quality services is an important base of the Ethiopian health policy framework, and therefore further study on the quality of maternal health services is necessary. Further, examination of the social determinants of maternal health may generate evidence that can strengthen inter- and intra-sectoral collaboration to address maternal health problems.

- The Health Development Army is an innovative approach to address developmental issues at grassroots level. This study highlights the impact of HDA in improving maternal health by framing the HDA pillars as collective determinants of maternal health. A more focused, comprehensive evaluation of the HDA and its impact on maternal health and other health programs may generate additional and valuable evidence that may be used to further enhance its effectiveness.
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