THE GLOBAL ASSOCIATION BETWEEN MATERNAL MORTALITY AND SKILLED HEALTH WORKERS

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ABSTRACT OF THE THESIS

The Global Association between Maternal Mortality and Skilled Health Workers
by
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Hypothesis: The primary null hypothesis is that there is no significant negative global relationship between maternal mortality and percent births overseen by skilled health workers. The secondary null hypothesis is that there is no spatial clustering of countries that exhibit high or low rates of maternal mortality and variables significantly associated with maternal mortality.

Methods: In addition to the independent variable of interest, percent births overseen by skilled health workers, the analyses will assess maternal mortality’s relationships with the following variables: mothers receiving prenatal care, female contraceptive prevalence, adolescent births, physicians per capita, and per capita health expenditure. First, bivariate relationships with maternal mortality will be tested through simple linear regression. Second, a multiple linear regression model will be constructed from statistically significant bivariate associations with maternal mortality. Last, geospatial analyses will be conducted to determine the geographic locations associated with high and low levels of all variables included in statistical analyses.

Results: In simple linear regression tests, all independent variables were significantly related to maternal mortality. Furthermore, bivariate modeling revealed that many countries were concentrated among low levels of maternal mortality. Multiple linear regression revealed that percent births overseen by skilled health workers, contraceptive prevalence, and adolescent birth rate remained significant even when controlling for other variables. Geospatial analysis showed that maternal mortality was high in Africa and southern Asia.

Summary: Maternal mortality is significantly associated with percent births overseen by skilled health workers, even when controlling for several covariates.
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CHAPTER 1

INTRODUCTION

The World Health Organization (WHO) defines “maternal mortality” as “the death of a woman while pregnant 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” (AbouZahr, 2003). In 2000, global maternal mortality was over 529,000 total deaths, although there is likely underreporting (Mathai, 2005). Concordantly, reducing the 1990 rate of maternal mortality (546,000 deaths) by three-quarters is the WHO’s Millennium Development Goal (MDG) #5. This designation calls international attention to this significant problem. A disproportionately high proportion of maternal deaths is concentrated in developing regions, although maternal mortality incidence can be found in other regions as well. Therefore, an accurate and thorough understanding of maternal mortality as a public health issue must take into account its global dispersion.

There are several medical causes of maternal mortality. Hemorrhage and excessive bleeding account for 25% of maternal deaths (World Health Organization [WHO], 2005). The most common pathological cause of late pregnancy bleeding is placental hemorrhage, in which the placental lining is separated from the uterus, partially or completely. Obstetrical hemorrhage can occur during labor, delivery, or postpartum. Ectopic pregnancies, in which the fetus is outside the uterus, may lead to bleeding. Postpartum hemorrhage has been defined as the loss of over 500 mL of blood following delivery or the loss of over 1000 mL of blood following cesarean section (Anderson and Etches, 2007).

Infections account for 13% of maternal deaths (WHO, 2005). Puerperal infections, which are infections contracted during childbirth, account for 77,000 yearly deaths worldwide (AbouZahr, 2003). The most common causes of puerperal infections are Streptococcus spp and Staphylococcus aureus. Other known causes of puerperal infection are Bacteroidesfragilis, Clostridium pelfringens, and Escherichia coli. Puerperal infection is usually diagnosed by the presence of fever at an oral temperature above 100.4° F.
Unsafe abortions account for another 13% of maternal deaths (WHO, 2005). It is defined as an abortion in an environment below medical standards, an abortion performed by insufficiently trained personnel, or both. On a per capita basis, Latin America and the Caribbean have the greatest number of unsafe abortions compared to other continents. Unsafe abortions are most prevalent in countries where abortion is illegal (Sedgh, Henshaw, Singh, Ahman, & Shah, 2007).

Other contributing causes to maternal mortality may be young maternal age (Friede et al., 1987) and certain pre-existing conditions, as they may predispose the body to the medical complications that lead to maternal death. These pre-existing conditions could be hypertension, anemia, malaria, hepatitis, heart disease, and/or AIDS (Rogo, Oucho, & Mwalali, 2006).

Since health workers are trained to manage complications that arise during delivery, the availability of skilled health workers is a pivotal variable of interest in the study of maternal mortality. A skilled health worker is defined to be “an accredited health professional—such as a midwife, doctor, or nurse—who has been educated and trained to proficiency in the skills needed to manage normal (uncomplicated) pregnancies, childbirth and the immediate postnatal period, and in the identification, management and referral of complications in women and newborns” (WHO, 2008).

Skilled health workers are important to the study of maternal mortality, because their experience and training allow them to minimize complications associated with childbearing. It is necessary to analyze the proportion of births overseen by skilled health workers in order to quantify the contribution of skilled health workers to the reduction in maternal mortality.

The primary research question that will be addressed in this thesis is, “After adjusting for possible confounders, is maternal mortality significantly negatively associated with births attended by skilled health workers (as a percentage)?” Research findings will estimate the contribution of skilled health workers to the reduction of maternal mortality, and can guide policies and maternal health and childbirth programs. The null hypothesis is that maternal mortality is not significantly associated with births overseen by skilled health workers, while the alternative hypothesis is that there is a significant association between maternal mortality and births overseen by skilled health workers.
The secondary research question that will be addressed in this thesis is, “Is there spatial clustering of countries that exhibit high or low rates of maternal mortality and variables that are significantly associated with maternal mortality?” Mapping country-specific rates visually will allow for the geographic description of trends and patterns in maternal mortality. These findings will inform how global organizations, such as the World Bank of the Global Fund, should invest in the specific maternal mortality intervention strategies where they will be most needed and should be of highest priority.
CHAPTER 2

LITERATURE REVIEW

In order to adequately cover the breadth of public health literature associated with maternal mortality, this literature review is divided into four sections: prenatal behavior and education, health care system context, political context, and economic context. “Prenatal Behavior and Education” focuses on the literature surrounding actions that may have been taken before the birth episode or actions that may be taken before pregnancy to prevent maternal mortality. “Health Care System Context” discusses actions that may be taken by health systems in order to reduce the incidence of maternal mortality. “Political Context” presents political pressures on actions pertaining to maternal mortality. “Economic Context” discusses the literature about investments that may lead to the prevention of maternal mortality.

Prenatal Behavior and Education

The percent of mothers that receive prenatal care may be related to the global prevalence of maternal mortality (Carroli, Rooney, & Villar, 2001). Those that receive prenatal care may be less likely to suffer the complications that most frequently lead to death, such as bleeding or infection during delivery. Therefore, higher rates of prenatal care may be inversely related to maternal mortality.

The amount of per capita adolescent births could be associated with higher risk of maternal mortality (Conde-Agudelo, Belizan, & Lammers, 2004; Patton et al., 2009). The female body may be less prone to complications at certain ages than others. For example, pregnant teenagers are more prone, compared to pregnant non-teenagers, to cephalopelvic disproportion, toxemia, or hypertension (Davis, 1989). Furthermore, adolescents may lack the resources required to seek professional care, as adolescents may have lower wages than their older counterparts. Such care may be related to availability of healthcare professionals overseeing the delivery or those administering prenatal care. Furthermore, a lack in the quantity of healthcare professionals may increase the price, given a stable demand. This may
exacerbate the inability of adolescents to pay for adequate healthcare. For similar reasons, the percent of a country’s population below the poverty level may be related to the rate of maternal mortality (Devitt, 1977).

In Korea and Thailand, improvement in access to education for girls and women has been a key driver of improved maternal health outcomes. Such education need not be health-specific. Increased education for girls and women has been shown to delay childbearing age, thereby reducing the adolescent birth rate (Ware, 1984).

The proportion of inhabitants using contraceptives may be correlated to maternal mortality (Winikoff, & Sullivan, 1987). A Nigerian study of over 1,500 surveyed adult, premenopausal women concluded that a relatively high rate of unwanted pregnancy may develop due to lower access to contraceptives (Okonofua, Odimegwu, Ajabor, Daru, & Johnson, 1999). Illegal abortion from unwanted pregnancies accounts for 25-50% of maternal deaths worldwide (Mahler, 1987).

Figure 1 shows the relationships between maternal mortality rate and associated social determinants, using aggregated, country-level data. Data were obtained from the World Bank databank. Data were collected by the World Bank, WHO, United Nations Children’s Fund (UNICEF), United Nations Population Division, Global Poverty Working Group, and Macro International. All plots were made using IBM SPSS Statistics 20 (Armonk, New York).

**Health Care System Context**

Higher risk of maternal mortality is found to be associated with differences in health care context between counties. The percent of births overseen by skilled health staff is an important correlate to maternal mortality (Cook, 2002). Death is more likely when birth is overseen by unqualified, lay people who are not able to adequately respond to some situations, such as complications, arising during delivery. Cook (2002) argued that increased skilled health staff is needed to address higher maternal mortality in these countries. Furthermore, it has been suggested that lower numbers of skilled health staff per capita may contribute to maternal mortality because more time is necessary for transport to healthcare facilities (Thaddeus & Maine, 1994).
Figure 1. Bivariate relationships between maternal mortality rate and associated social determinants from aggregated, country-level data.
Much evidence has been reported to suggest that greater access to health care may reduce maternal mortality. In China, Sri Lanka, and Malaysia, the establishment of national networks of health centers have resulted in increased quality and coverage of maternal health services. These efforts have been facilitated by greater community outreach of goods and personnel. As a result, maternal mortality has been greatly reduced in a relatively short amount of time (Goodburn & Campbell, 2001).

In Cuba, maternal mortality rates have improved via investments in roads, telephones lines, referral systems, and provider partnerships; these infrastructure improvements contribute to faster access to care, reducing the delays between onset of obstetric complications and outcome (Thaddeus & Maine, 1994). Therefore, by ensuring quicker responses to medical complications, the likelihood of maternal mortality decreases.

In India and much of sub-Saharan Africa, incentive programs to expand the availability of emergency obstetric care services for the poor have resulted in better rates of maternal mortality. This expansion in availability allows for an increase in births overseen by skilled health workers, thereby greatly reducing the likelihood of maternal mortality (Cook, 2002).

In Jamaica, better health information dissemination has resulted in a reduction in unwanted pregnancies, thereby reducing maternal mortality by delaying childbearing age. Therefore, access to health information may be indirectly related to maternal mortality outcomes through its effect on childbearing age. Concordantly, a retrospective cohort study found that age is closely associated with maternal mortality (Walker, McCaw, Ashley, & Bernard, 1986).

In Honduras, implementation of maternal mortality surveillance has allowed for better identification of tools that are best suited to aid at-risk subgroups, like adolescents and the impoverished. Such surveillance has been in accordance with guidelines set forth by the Pan American Health Organization (PAHO) (Berg, Danel, & Mora, 1995).

**Political Context**

Contraception interventions in Thailand, Indonesia, Cambodia, and Bangladesh have shown great improvements to maternal health. However, the efficacy of these interventions may be an underutilized phenomenon, as political impediments prevent foreign aid from
going to contraception funding. This is the result of a fear that the governments of developing countries will interpret birth control funding as an attempt to reduce or eliminate their population (Harvey, 1996).

Political priority for maternal mortality interventions does not exist in several developing countries, including Angola and the Central African Republic. It has been argued that the generation of political priority will require the greater presence of maternal mortality in the public consciousness and the establishment of new institutions to guide global efforts in implementing maternal health interventions (Shiffman & Smith, 2007).

**ECONOMIC CONTEXT**

In Buor and Bream, 2004 quantitative analyses on the determinants of maternal mortality in Sub-Saharan Africa, it was shown that a negative correlation \( r = -0.742; \) two-tailed \( p < 0.01 \) exists between maternal mortality and per capita health expenditures (Buor & Bream, 2004). A greater per capita investment in health may be related to a greater availability of medical resources and medical professionals. Since higher access to medical services should allow greater numbers of women to see skilled health staff for prenatal care and/or deliveries, per capita health expenditures would indirectly decrease the rate of maternal death.

Some countries, notably Bolivia and Mexico, have directly given insurance coverage and monetary aid for poor women, which has enhanced their decision-making power and overall social status. This may be the result of perceiving increased value for those with more money. For example, a daughter or wife that is directly given money from the government is likely to have more decision-making power in her family unit. This direct increase in monetary aid and insurance coverage has resulted in a reduced rate of adolescent birth rate, increased rate of prenatal care, and lower maternal mortality (Borghi, Ensor, Somanathan, Lissner & Mills, 2006).

In 2009, a Technical Working Group of the World Bank’s High Level Taskforce on International Innovative Financing for Health Systems calculated the total cost of the health systems strengthening necessary to eliminate maternal mortality in 49 low income countries by 2015. This work was based on their argument that health systems strengthening would be essential to meeting each of the MDGs, including MDG #5. What followed were two costs,
using both a normative approach and a marginal approach, that averted 322,000 maternal
deaths while simultaneously a providing 56 million women access to skilled health personnel
at birth, prenatal care, and contraceptives (Mills, Chowdhury, Miranda, Seshadri, & Axemi, 2009).

The normative approach is based on scaling up existing interventions. Using this
approach, it was estimated that meeting MDG #5 for these 49 low income countries would
cost $251 billion, using US 2009 dollars. The marginal approach, technically termed
“marginal budgeting for bottlenecks,” is an approach, jointly developed by the World Bank,
UNICEF, and WHO, that takes into account intervention efficacies, foreseeable
impediments, equity, and financial allocation. This approach estimated that meeting MDG
#5 for these 49 low-income countries would cost $112 billion (based on US 2009 dollars)
(Mills et al., 2009).

Table 1 shows the cost of each DALY averted for various contraceptive programs,
organized by level. Prenatal care interventions are some of the most cost effective, while
health systems strengthening interventions are, on average, the most cost prohibitive (Mills et
al., 2009). However, it should be noted that the benefits of strengthening a health system
include the prevention of a wide spectrum of both communicable and non-communicable
diseases, extending far beyond the prevention of maternal deaths (Travis et al., 2004).

Economics plays a pivotal role in the incidence of maternal mortality. 99% of
maternal mortality occurs in developing countries (Mills et al., 2009). Furthermore, maternal
mortality exhibits negative association with per capita health expenditure (Figure 1f). In
countries with greater per capita health expenditures, it is more likely that health systems
would be strong enough to provide more comprehensive and more accessible maternal care.
Furthermore, survey studies of family members to maternal mortality victims have strongly
linked maternal mortality to poverty in individuals (Graham, Fitzmaurice, Bell, & Cairns,
2004).

It is clear that maternal mortality’s association with percent skilled health staff is
confounded by several other determinants, because the relationship between percent skilled
health staff and maternal mortality is not likely to often exist in a vacuum. Fluctuations in
several other social variables, such as those in the realm of behavior and education, may
independently explain wide degrees of variation in maternal mortality for some communities.
Table 1. Cost Comparison of Maternal Mortality Intervention Packages. All Measures are Reported in US 2006 Dollars

<table>
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<tr>
<th>Intervention</th>
<th>Level</th>
<th>Cost per DALY Averted</th>
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<tr>
<td>Contraception</td>
<td>Individual</td>
<td>$6 (intrauterine device) to $20 (condoms or injections)</td>
</tr>
<tr>
<td></td>
<td>Household</td>
<td>$44</td>
</tr>
<tr>
<td></td>
<td>Community-based services</td>
<td>$42</td>
</tr>
<tr>
<td>Post-Abortion Care</td>
<td></td>
<td>$4.40 to $17.19</td>
</tr>
<tr>
<td>Prenatal Care</td>
<td>Through public system</td>
<td>$2.26 per pregnant woman per year</td>
</tr>
<tr>
<td></td>
<td>Through religious missions</td>
<td>$6.43 per pregnant woman per year</td>
</tr>
<tr>
<td>Iron and Folic Acid Supplementation</td>
<td></td>
<td>$13</td>
</tr>
<tr>
<td>Health Systems Strengthening</td>
<td>Public Hospitals</td>
<td>$73 per emergency episode</td>
</tr>
<tr>
<td></td>
<td>Mission Hospitals</td>
<td>$86 per emergency episode</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$56 to $104 per caesarian section</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$11 to $16 per normal delivery</td>
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Examples of these behavior and education variables include prenatal care and contraceptive prevalence. Furthermore, they can be directly related to an economic context, as in the case of per capita health expenditure or percent below poverty level. They may be in the context of health care systems, such as in the availability of physicians. Other confounders, like those that characterize a country’s political context, may be less quantifiable. Therefore, though the focus of this study is on analyzing the relationship between skilled health staff with maternal mortality using the most recent international data, it is important to explore and adjust for the possibility of several confounders.
SUMMARY

While maternal mortality is correlated with several determinants, whether they exist in the context of health care systems, economics, maternal education, or otherwise, investing in any one of these determinants has its own respective payoff. It is important to acknowledge the cost-efficacy of such investments in order to gain an accurate understanding of the options currently available for alleviating the extensive burden of maternal mortality.

METHODS

This cross-sectional study used secondary data, derived from several sources, with country as the unit of analysis. Bivariate and multivariate statistical analyses were conducted. Descriptive geospatial analysis was also conducted.

DATA SOURCES

A data set was created for maternal mortality, births overseen by skilled health staff, mothers receiving prenatal care, female contraceptive prevalence, adolescent births, physicians per capita, and per capita health expenditure. All data were retrieved from World Bank Databank, a tool that allows for the compilation of datasets with variables aggregated at the country level. All available countries were used in this analysis (n = 211). Data was excluded for groups of aggregated countries, such as “North America” or “World,” were removed from the dataset. In statistical tests where at least one country was missing data, that country was omitted from the analysis. Therefore, the bivariate (including geospatial) analyses between maternal mortality and births overseen by skilled health staff included 162 countries, that with mothers receiving prenatal care included 149 countries, that with female contraceptive prevalence included 132 countries, that with births from adolescents included 172 countries, that with physician prevalence included 164 countries, and that with per capita health expenditure included 175 countries. Multiple linear regression analysis included 107 countries.

MEASUREMENT

Maternal mortality ratio was jointly developed by the World Health Organization (WHO), United Nations Children’s Fund (UNICEF), United Nations Population Fund (UNFPA), and the World Bank. The number of births attended by skilled health staff and
mothers receiving prenatal care were collected by UNICEF. Health expenditure per capita (in US dollars) was developed by the WHO, adolescent birth rate was collected by the United Nations Population Division, and contraceptive prevalence was determined through household surveys conducted by Macro International and UNICEF. These variables were obtained by the World Bank for compilation into the World Bank Databank’s database.

**Main Variables**

Maternal mortality: Data on maternal mortality were obtained through the World Bank databank feature and were collected using household surveys, registration systems, mortality studies, disease surveillance, and national censuses. A maternal mortality rate (per 100,000) was obtained for each country. Maternal mortality will serve as the dependent variable in the multiple regression model, which will be explained in more detail in the analysis section below. Estimates for maternal mortality are produced every two to five years.

Births Overseen by Skilled Health Staff: Information on births overseen by skilled health staff was collected through household surveys conducted at the national level for each country. Several surveys were used to collect data on births overseen by skilled health staff. These surveys are conducted every 3-5 years. Routine registration data was also used when available. Based on these sample data, a percent of births overseen by skilled health staff was obtained for every country possible. This variable serves as the primary independent variable of interest for the multiple regression analysis. Estimates for births overseen by skilled health staff are published annually.

**Confounding Variables**

It is necessary to control for variables that may confound the relationship between births overseen by skilled health workers and maternal mortality. In a global analysis, it is important to account for geographic variation, because a statistically significant association between two variables may only be practically useful in certain areas of the world. For this reason, it is necessary to use geospatial analysis in order to understand the areas that are driving statistically significant associations.
Information on mothers receiving prenatal care, as a percentage of women aged 15 to 49 years that had given birth, were mostly collected through household surveys conducted at the national level. Estimates for prenatal care are published annually.

Female contraceptive prevalence was collected through nationally representative surveys. Many different types of surveys were used to obtain this data, including family planning surveys, general health surveys, and socioeconomic surveys. These surveys provided the percent of women aged 15 to 49 who are currently using at least one method of contraception. Data on female contraceptive prevalence is updated annually.

Adolescent birth rate (per 1,000 women aged 15 to 19 years) were collected through civil registration, surveys, and censuses. For civil registration, data were obtained from country reports. For surveys, data were obtained from many different nationally-sponsored surveys. For censuses, data were directly obtained from the respective national offices. Estimates of adolescent birth rate are produced every year.

Number of physicians (per 1,000) was computed through several sources, including health facility assessments, routine information collection, surveys, and population censuses. In order to improve comparability of national estimates, common definitions, common classifications, and cross-nationally comparable data were used when available.

Data on health expenditures per capita were collected by combining national expenditures on preventative and curative health services, including family planning, nutrition, and emergency healthcare.

**ANALYSIS**

This study is a cross-sectional analysis of the most recent international data, which consists of 211 countries from which maternal mortality rates were available. The primary research question of this study is, “After adjusting for possible confounders, is maternal mortality significantly associated with births attended by skilled health workers (as a percentage)?” Concordantly, the null hypothesis for the primary research question is that maternal mortality is not significantly associated with births overseen by skilled health workers, while the alternative hypothesis is that there is a significant association between maternal mortality and births overseen by skilled health workers. These hypotheses were
evaluated by using statistical methodologies involving bivariate and multivariate regression analysis and geospatial analysis.

**BIVARIATE ANALYSIS**

Bivariate analysis was conducted to check the simple association between dependent variable (maternal mortality) and the independent variable of interest. Descriptive statistics were used to present distributions of the maternal mortality rate and independent variables. Simple linear regression was used to analyze the relationship of maternal mortality to each of the following variables: births overseen by skilled health staff, mothers receiving prenatal care, female contraceptive prevalence, adolescent births, physicians per capita, and per capita health expenditure. Simple linear regression was chosen as a precursor to multiple linear regression in order to explore maternal mortality’s relationships, independent of confounders.

**LINEAR REGRESSION**

Linear regression works by calculating a trend line that fits best between the variables in the analysis. In calculating this trend line, parameter estimates are computed. This parameter estimate can be interpreted thusly: “For every one level increase in [independent variable], a [parameter estimate] increase/decrease in [dependent variable] can be expected.”

It is also important to ascertain a standard error when conducting linear regression. This is typically done so that one can understand how well the trend line fits the plotted data. This standard error can be interpreted as a measure of possible variation in the parameter estimate.

*t values and corresponding p-values are also useful statistics to obtain when running linear regression tests. With these numbers, this study will determine whether or not a statistically significant amount of variation in the dependent variable is explained the independent variables(s). In multiple linear regression, these statistics are typically reported both the overall model and each variable. For the individual independent variable, this study interprets a test statistic as conveying that the independent variable explains statistically significant (or non-significant) amount of variation in the dependent variable, controlling for the other independent variables in the model.
Finally, the $R^2$ value allows for the quantification of exactly how much variation in the dependent variable is explained by the independent variable(s). It is expressed in percentage terms, where the maximum possible value is 1 and the minimum possible value is 0. When multiple independent variables are in a model, the $R^2$ value is typically reported for the entire model.

**Multiple Linear Regression Analysis**

Multiple regression was chosen to statistically test the research hypothesis. Data from 107 countries were analyzed. Using a multiple regression model, the variable of interest, births overseen by skilled health staff, will be examined for statistical significance and the magnitude of an association with the dependent variable, maternal mortality. In order to further describe these associations, geospatial analyses were performed.

Multiple linear regression models were then constructed to analyze the relationship between maternal mortality, births attended by skilled health staff, and other confounding variables. Multiple regression analyses were performed using SAS Version 9.3 (Cary NC: SAS Institute).

In this study, multiple regression analysis was used in order to test the relationship between maternal mortality and births overseen by skilled health workers, controlling for covariates. Therefore, multiple regression analysis allows one to quantify the relationship between two variables while controlling for a third (or more) variables.

**Geographic Information System (GIS)**

GIS is a tool designed to portray spatial information. An analysis of this portrayal should allow one to visually ascertain associations, if there exist any. Furthermore, geospatial analyses are useful for a thorough explorations of variable associations. Given the expansive geography covered by this analysis, it is critical to explore the geographic areas that are subject to high and low levels of the variables of interest. The results of this study are expected to be used for the formulation of maternal mortality intervention programs that focus on health system strengthening in the context of the specific country for which they are being developed.
ArcGIS (Redlands, CA: Esri) software was specifically used to conduct the geospatial analyses in this study. In ArcGIS, one can acquire a basemap that is tied to spatial information, which allows the program to draw the basemap onto a coordinate system, such as a Mercator projection of a Peters projection. In ArcGIS, spreadsheets can be imported with data that is relevant to the study. ArcGIS has a feature that allows for these spreadsheets to be matched with data in basemap files. By doing this, one can associate spatial data with health data. Finally, ArcGIS has features that allow for the representation of data in the basemap. For instance, one can create a choropleth (color gradient) map in ArcGIS. One can also display data by using proportional symbols. These two data presentation methods were employed in the geospatial analyses for this study. A myriad of other methodologies are also available using ArcGIS software.

**GEOSPATIAL ANALYSIS**

Geospatial analyses are useful because it visualizes spatial relationships between variables. Therefore, maps can help visually uncover several associations. For example, geospatial analyses may help to physical areas that are more plagued by disease and disability than other areas. Furthermore, it may be possible to identify whether or not multiple variables are simultaneously prevalent.

ArcGIS software was used for all geospatial analysis. A geodatabase was created with a layer for a political world map, using a 1984 World Geodetic System projection, and a table containing maternal mortality and births overseen by skilled health staff. Tabular data were then geocoded onto the world map layer. Symbology features in ArcMap were employed to create a color choropleth gradient for maternal mortality and graduated symbols representing births overseen by skilled health staff.
CHAPTER 3

RESULTS AND DISCUSSION

SAMPLE CHARACTERISTICS

Mean maternal mortality was 169.76 with a range between 2 and 1,100. Therefore, maternal mortality was skewed downwards, with relatively few countries exhibiting extremely high values (Table 2, Figure 1). Mean births overseen by skilled health staff was 81.42% with a range between 6% and 100%. It was evident that countries are skewed toward greater percentages of births overseen by skilled health staff, with relatively few countries exhibiting extremely low values (Table 2, Figure 1).

Per capita health expenditure exhibited the greatest range, between $12 and $8,362. Given this wide range, it should be expected that the parameter estimate will be very low, as the parameter estimate would convey the change in maternal mortality per one dollar of health expenditure. Conversely, physicians per 1,000 had the lowest range, between 0 and 7. Given this narrow range, it should be expected that the parameter estimate will be very high. The standard deviation exceeded the means for maternal mortality and per capita health expenditure. This suggests wide fluctuations between countries (Table 2).

For every variable except contraceptive prevalence, the mean was greatly skewed beyond the midpoint. This is concordant with Figure 1, which shows that majority of countries were skewed toward lower maternal mortality, higher births overseen by skilled health workers, higher prenatal care, higher percent using contraception, lower births from adolescents, lower physician prevalence, and lower per capita health expenditures (Table 2).

BIVARIATE ANALYSIS

Maternal mortality was found to be significantly associated with births overseen by skilled health staff in simple linear regression. All confounding variables were found to be separately, significantly related to maternal mortality in simple linear regression tests (Table 3). The $R^2$ statistic was highest for the bivariate association between maternal mortality and births overseen by skilled health staff ($R^2 = 0.583$). This suggests that births overseen by
Table 2. Descriptive Statistics of All Variables in the Analysis

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maternal Mortality per 100,000&lt;sup&gt;a&lt;/sup&gt;</td>
<td>180</td>
<td>2</td>
<td>1100</td>
<td>169.76</td>
<td>224.535</td>
</tr>
<tr>
<td>Percent births overseen by skilled health staff&lt;sup&gt;b&lt;/sup&gt;</td>
<td>176</td>
<td>6</td>
<td>100</td>
<td>81.43</td>
<td>24.287</td>
</tr>
<tr>
<td>Percent of mothers receiving prenatal care&lt;sup&gt;b&lt;/sup&gt;</td>
<td>160</td>
<td>26</td>
<td>100</td>
<td>89.39</td>
<td>14.990</td>
</tr>
<tr>
<td>Female contraceptive prevalence per 1,000&lt;sup&gt;b&lt;/sup&gt;</td>
<td>140</td>
<td>5</td>
<td>88</td>
<td>47.66</td>
<td>22.275</td>
</tr>
<tr>
<td>Births from adolescents per 1,000&lt;sup&gt;c&lt;/sup&gt;</td>
<td>188</td>
<td>1</td>
<td>199</td>
<td>49.30</td>
<td>41.262</td>
</tr>
<tr>
<td>Physicians per 1,000&lt;sup&gt;c&lt;/sup&gt;</td>
<td>171</td>
<td>0</td>
<td>7</td>
<td>1.55</td>
<td>1.580</td>
</tr>
<tr>
<td>Per capita health expenditure&lt;sup&gt;e&lt;/sup&gt;</td>
<td>187</td>
<td>12</td>
<td>8362</td>
<td>1009.75</td>
<td>1716.142</td>
</tr>
</tbody>
</table>

<sup>a</sup>WHO, UNICEF, UNFPA and the World Bank  
<sup>b</sup>UNICEF  
<sup>c</sup>United Nations  
<sup>d</sup>World Bank  
<sup>e</sup>World Health Organization

skilled health staff independently explains the greatest amount of variation in maternal mortality. This statistic was lowest for the association between maternal mortality and per capita health expenditure ($R^2 = 0.135$), which suggests that per capita health expenditures explains the lowest amount of variation in maternal mortality.

The bivariate analyses conducted in this study (Table 3) indicate that for every percent increase in births overseen by skilled health staff, 7.269 less instances of maternal mortality (per 100,000) occurred. For every percent increase in mothers receiving prenatal care, 8.714 less instances of maternal mortality (per 100,000) occurred. For every one unit increase in female contraceptive prevalence (per 1,000), 7.266 less instances of maternal
Table 3. Results From Simple Linear Regression Tests with Maternal Mortality\(^a\) per 100,000 as the Dependent Variable

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>(\beta)</th>
<th>Standard Error</th>
<th>(t)</th>
<th>(p)</th>
<th>(R^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent births overseen by skilled health staff(^b)</td>
<td>162</td>
<td>-7.269</td>
<td>0.482</td>
<td>-15.07</td>
<td>&lt;0.0001</td>
<td>0.583</td>
</tr>
<tr>
<td>Percent of mothers receiving prenatal care(^b)</td>
<td>149</td>
<td>-8.714</td>
<td>1.099</td>
<td>-7.92</td>
<td>&lt;0.0001</td>
<td>0.293</td>
</tr>
<tr>
<td>Female contraceptive prevalence per 1,000(^b)</td>
<td>132</td>
<td>-7.266</td>
<td>0.698</td>
<td>-10.41</td>
<td>&lt;0.0001</td>
<td>0.453</td>
</tr>
<tr>
<td>Births from adolescents per 1,000(^c)</td>
<td>179</td>
<td>3.685</td>
<td>0.293</td>
<td>12.56</td>
<td>&lt;0.0001</td>
<td>0.467</td>
</tr>
<tr>
<td>Physicians per 1,000(^c)</td>
<td>164</td>
<td>-89.426</td>
<td>9.093</td>
<td>-9.83</td>
<td>&lt;0.0001</td>
<td>0.372</td>
</tr>
<tr>
<td>Per capita health expenditure(^c)</td>
<td>175</td>
<td>-0.046</td>
<td>0.008</td>
<td>-5.21</td>
<td>&lt;0.0001</td>
<td>0.135</td>
</tr>
</tbody>
</table>

\(^a\)WHO, UNICEF, UNFPA and the World Bank  
\(^b\)UNICEF  
\(^c\)United Nations  
\(^d\)World Bank  
\(^e\)World Health Organization

Mortality (per 100,000) occurred. For every one unit increase in births from adolescents (per 1,000), 3.685 more instances of maternal mortality (per 100,000) occurred. For every one unit increase in physician prevalence (per 1,000), 89.426 less instances of maternal mortality (per 100,000) occurred. For every one dollar increase in per capita health expenditures, 0.046 less instances of maternal mortality (per 100,000) occurred.

**Multiple Linear Regression**

Multiple linear regression models revealed that the relationship between births overseen by skilled health workers and maternal mortality remained significant despite controlling for all confounding variables. The \(R^2\) statistic for the overall model is 0.6742, which shows that the entire multiple regression model explains a great deal of variation in
maternal mortality. Prenatal care, physician prevalence, and health expenditure per capita were not found to be significantly associated with maternal mortality when controlling for covariates (Table 4).

Table 4. Results From Multiple Linear Regression Tests with Maternal Mortality\(^a\) per 100,000 as the Dependent Variable (\(n = 107; R^2 = 0.6742; p < 0.0001\))

<table>
<thead>
<tr>
<th>Variable</th>
<th>(\beta)</th>
<th>Standard Error</th>
<th>(t)</th>
<th>(p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>384.50055</td>
<td>98.48149</td>
<td>3.90</td>
<td>0.0002</td>
</tr>
<tr>
<td>Percent births overseen by skilled health staff(^b)</td>
<td>-4.19294</td>
<td>1.20986</td>
<td>-3.47</td>
<td>0.0008</td>
</tr>
<tr>
<td>Percent of mothers receiving prenatal care(^b)</td>
<td>2.43666</td>
<td>1.48648</td>
<td>1.64</td>
<td>0.1043</td>
</tr>
<tr>
<td>Female contraceptive prevalence per 1,000(^b)</td>
<td>-3.34656</td>
<td>0.80968</td>
<td>-4.13</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Births from adolescents per 1,000(^c)</td>
<td>1.68132</td>
<td>0.42339</td>
<td>3.97</td>
<td>0.0001</td>
</tr>
<tr>
<td>Physicians per 1,000(^e)</td>
<td>-7.92930</td>
<td>12.73550</td>
<td>-0.62</td>
<td>0.5349</td>
</tr>
<tr>
<td>Per capita health expenditure(^e)</td>
<td>-0.00282</td>
<td>0.03413</td>
<td>-0.08</td>
<td>0.9344</td>
</tr>
</tbody>
</table>

\(^a\)WHO, UNICEF, UNFPA and the World Bank  
\(^b\)UNICEF  
\(^c\)United Nations  
\(^d\)World Bank  
\(^e\)World Health Organization

The multivariate analyses conducted in this study (Table 4) indicated that for every percent increase in births overseen by skilled health staff, controlling for covariates, 4.192 less instances of maternal mortality (per 100,000) occurred. For every one unit increase in female contraceptive prevalence (per 1,000), controlling for covariates, 3.347 less instances of maternal mortality (per 100,000) occurred. For every one unit increase in births from
adolescents (per 1,000), controlling for covariates, 1.681 more instances of maternal mortality (per 100,000) occurred.

**GEOSPATIAL MODELING**

Geospatial modeling of bivariate relationships revealed that most countries exhibited low levels of maternal mortality. Many of these countries are concentrated in North America and Europe. Sub-Saharan Africa and southern Asia are boxed in Figures 2 through 7, as they exhibited very high rates of maternal mortality.

Geospatial analysis showed that maternal mortality was high in sub-Saharan Africa and southern Asia, which were also regions where births overseen by skilled health workers were low (Figure 2). This association was also evident in Bolivia in South America, where maternal mortality is high and births overseen by skilled health workers is low. Notable exceptions to this trend are South Africa and Botswana, where maternal mortality is high but births overseen by skilled health workers was also high. Colombia, Venezuela, and Algeria exhibited relatively high levels of maternal mortality (80 – 120 per 100,000), but had over 90% of its births overseen by skilled health workers.

The visual association between maternal mortality and mothers receiving prenatal care was not as strong as the visual association between maternal mortality and births overseen by skilled health workers (Figure 3).

Countries with both high and low levels of maternal mortality exhibited high levels of prenatal care. The only countries with high levels of maternal mortality but low levels of prenatal care are Afghanistan, Sudan, Chad, Nepal, Niger, and Nigeria. However, there were no countries with low levels of maternal mortality and low levels of prenatal care.

The visual association between maternal mortality and per contraception use seemed quite strong (Figure 4).

Only countries with high levels of maternal mortality exhibited low levels of women using contraception. Colombia and Paraguay exhibited both relatively high levels (80 – 120 per 100,000) of maternal mortality and high contraception use. Many countries in southern Africa had high levels of maternal mortality and did not have extremely low levels of
Figure 2. Maternal mortality percent births overseen by skilled health staff.
Figure 3. Maternal mortality versus percent receiving prenatal care.
Figure 4. Maternal mortality versus contraception use.
Figure 5. Maternal mortality versus adolescent birth rate.
Figure 6. Maternal mortality versus physician prevalence.
Figure 7. Maternal mortality versus per capita health expenditure.
contraception use. These countries are South Africa, Lesotho, Swaziland, Namibia, Botswana, Zimbabwe, Zambia, Malawi, Burundi, and Kenya. The visual association between maternal mortality and adolescent births was strong, but exhibited several exceptions (Figure 5).

Although South America exhibits wide variations in maternal mortality, all the countries in South America seem to exhibit a homogenous expression of adolescent birth rate. Nevertheless, much of North America and all of Europe exhibited both low levels of maternal mortality and low levels of adolescent births. Also, much of sub-Saharan Africa and south Asia exhibited high levels of maternal mortality and high levels of adolescent births. Notable exceptions to this, which exhibited high levels of maternal mortality but low adolescent birth rates, are Botswana, Rwanda, Burundi, Pakistan, Bhutan, Myanmar, Laos, and Cambodia.

The association between maternal mortality and physician prevalence was clearly evident, but not very strong (Figure 6). A large amount of data was missing for physician prevalence, especially for countries in sub-Saharan Africa. In prior maps, sub-Saharan Africa has been critical to the establishment of a clear visual association. Among countries with physician data available, those with high levels of maternal mortality also exhibited low levels of physician prevalence. However, several countries that exhibited low physician prevalence also exhibit low maternal mortality, like the United States, China, Iran, Saudi Arabia, Poland, Romania, and Turkey. The visual association between maternal mortality and per capita health expenditure was weak (Figure 7).

While it was true that all countries with high per capita health expenditure exhibited low rates of maternal mortality, several other countries with low rates of maternal mortality exhibited relatively low per capita health expenditure. The former group, with both low levels of maternal mortality and high per capita health expenditures consisted of the United States, Canada, and countries in Western Europe. All countries in Africa and South America exhibited low per capita health expenditure. Many of these countries had high rates of maternal mortality. However, much of Asia exhibited low rates of maternal mortality and low per capita health expenditure. Therefore, the visual association between maternal mortality and per capita health expenditure was not very clear.
SUMMARY

Multiple regression analysis supports the hypothesis that, after adjusting for possible confounders, maternal mortality is significantly negatively associated with births attended by skilled health staff. While the strength and significance of the association was weakened in multivariate analysis, compared to bivariate analysis, births attended by skilled health staff was still significant at the $\alpha = 0.05$ level.

Geospatial analyses support the hypothesis that spatial clustering exists for countries that exhibit high rates of maternal mortality and low rates of maternal mortality. Furthermore, geospatial analyses show that variables significantly associated with maternal mortality in multivariate analyses (births overseen by skilled health staff, female contraceptive prevalence, and adolescent birth rate) also exhibited spatial clustering.
CHAPTER 4

CONCLUSION

Maternal mortality was responsible for over 500,000 deaths worldwide in 2000. Reducing the 1990 rate of maternal mortality by three-quarters has been designated a Millennium Development Goal, which all United Nations member states have agreed to achieve by 2015.

Much literature exists to describe the many efforts that have already been made to reduce the incidence of maternal mortality. A great deal of progress has been made in reducing maternal mortality through several types of interventions. These interventions include the better dissemination of information, improvement of communication infrastructure, investment in female education, or increased availability of obstetric care. It is evident that developing countries have found several innovative ways to reduce their burden of maternal mortality.

A breadth of literature also points toward several potential significant associations with maternal mortality. Therefore, in order to adequately analyze maternal mortality’s relationship with births overseen by skilled health staff, it becomes necessary to control for several confounders. The following variables were considered confounders in these analyses: percent of mothers receiving prenatal care, female contraceptive prevalence, adolescent birth rate, physicians per 1000, and per capita health expenditure.

A simple linear regression model revealed a significant association between births overseen by skilled health staff, the independent variable of interest, and maternal mortality, the dependent variable of interest. Further simple linear regression models reveal significant associations between maternal mortality and all confounding variables. When controlling for these confounding variables in a multiple linear regression model, the relationship between birth overseen by skilled health staff and maternal mortality remained significant. These findings are consistent with current scientific literature, which strongly suggests a significant causative relationship between a birth not overseen by skilled health staff and a maternal death outcome.
Geospatial modeling reveals that a great deal of maternal mortality is concentrated in sub-Saharan Africa and southern Asia. These regions also have notably high concentrations of countries that exhibit low percentages of births overseen by skilled health staff.

There occasionally existed some unexpected aberrations in several associations with maternal mortality, even those that remained significant in multivariate analyses. These abnormalities may be the result of external investment, such as the availability of loans from the World Bank or the United States Agency for International Development, or internal initiatives, such as cultural movements or policy agendas.

In summary, a literature review was first conducted to uncover potentially significant predictive variables of maternal mortality. These variables were then tested for to determine significant bivariate associations with maternal mortality. A multiple regression model was subsequently constructed using variable found to be significant in bivariate analyses. By doing this, it was possible to determine that the relationship between maternal mortality and births overseen by skilled health staff was significant, despite controlling for all other variables. Finally geospatial analyses made it possible to determine the specific countries and regions where an independent variable was most likely to cause a high maternal mortality rate.

**Strengths**

This is the first study, to my knowledge, to make use of both linear regression and geospatial modeling to analyze associations with maternal mortality rate. These techniques allow one to thoroughly ascertain patterns and trends in maternal mortality.

The multiple regression model accounts for 67.42% of maternal mortality worldwide. The statistically significant relationship between maternal mortality and births overseen by skilled health workers persisted, despite accounting for other variables that were shown in simple linear regression analyses to potentially affect maternal mortality. These findings are consistent with findings from previous literature, which report that maternal death is more likely when births are overseen by unqualified, lay people than when overseen by skilled health staff (Cook, 2002; Thaddeus & Maine, 1994).

**Limitations**

Ecological fallacy is a key limitation of these analyses. Therefore, it is noteworthy to point out that associations derived from group data may not apply to individuals. Moreover,
although the analyses adjusted for a wide range of confounders, it was not possible to account for all variations in human activity that may have contributed to differential incidences of maternal mortality.

Another limitation in this analysis is the inclusiveness of variable definitions. For instance, skilled health workers is defined as “an accredited health professional—such as a midwife, doctor, or nurse—who has been educated and trained to proficiency in the skills needed to manage normal (uncomplicated) pregnancies, childbirth and the immediate postnatal period, and in the identification, management and referral of complications in women and newborns” (WHO, 2008). This does not take into account highly skilled individuals that routinely oversee deliveries yet lack formal accreditation.

While the oversight of international agencies, such as the World Health Organization or the United Nations, was evident for the collection of data, the possibility for invalid data still exists. The variations in data sources (e.g. household survey versus national census) used to obtain data across countries is of some concern. Furthermore, countries with unavailable data, particularly in the case of physician prevalence, may have confounded the strength or significance of statistical associations.

**FURTHER STUDY AND RECOMMENDATIONS**

Much action can be taken to decrease the global incidence of maternal mortality. For example, by using clever investment techniques, it may be possible to identify the most ideal time and place for each intervention, thereby allowing for the greatest overall benefit. Moreover, the most plentiful benefit will derive from multi-faceted strategies that take into account several variables, including differential intervention efficacies, financial impediment circumventions, equitable resource allocation, and more. Furthermore, it is critical that the interventions themselves are developed to address the specific social determinants that are most likely to correspond to the most incident biological cause of death.

Although all variables were significantly associated with maternal mortality in bivariate analyses, only three variables remained significantly associated in a multivariate model: births overseen by skilled health workers, mothers receiving prenatal care, and adolescent birth rate. While an intervention aimed at reducing the adolescent birth rate would likely be focused on health education, both increasing births overseen by skilled health workers and increasing
mothers receiving prenatal care can be achieved through health systems strengthening. Therefore, while it may be more expensive to conduct health systems strengthening, it is evident that such intervention would be highly effective in controlling maternal mortality. Such an intervention should be focused on sub-Saharan Africa and southern Asia, which are regions that simultaneously have high rates of maternal mortality and low rates of births overseen by skilled health workers. Several countries in these regions also exhibit low rates of prenatal care.

Global health policies set forth by international agencies and developed countries should take into account the specific regions where each statistically associated variables may be most explanatory of maternal mortality. Planning and development of maternal mortality interventions should take into account regional sensitivities of maternal mortality to fluctuations in economic and sociopolitical forces.

New observational research characterizing the relationships between maternal mortality and births overseen by skilled health staff would be especially informative. Economic analyses suggesting innovative and creative methods for the inclusion of birth oversight in health systems strengthening interventions would also be useful.

Although metrics have been developed to quantify the burden of illness and disease, it is ultimately not possible to evaluate the abundant pain and suffering that is caused by maternal death. Such a great adversary must be answered with an even greater response. Eliminating maternal mortality can be accomplished, but the world must band together and achieve new levels of international cooperation, shrewd innovation, and immense aptitude.
REFERENCES


