**ORIGINAL RESEARCH ARTICLE**

# Community Level Risk Factors for Maternal Mortality in Madagascar

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## Abstract

This paper explores the effect of risk and socioeconomic factors on maternal mortality at the community level in Madagascar using a unique, nationwide panel of communes (i.e., counties). Previous work in this area uses individual or cross-country data to study maternal mortality, however, studying maternal mortality at the community level is imperative because this is the level at which most policy is implemented. The results show that longer travel time from the community to the hospital leads to a high level of maternal mortality. The findings suggest that improvement to transportation systems and access to hospitals with surgery rooms are needed to deal with obstetric complications and reduce maternal mortality. *(Afr J Reprod Health 2013; 17[4]: 118-129).*

**Keywords**: Maternal Mortality, Health Risks, Health Inputs.

## Résumé

Ce document examine l'effet du risque et les facteurs socio-économiques sur la mortalité maternelle au niveau de la communauté à Madagascar en utilisant un panel national unique de communes (c.-à- d des comtés). Des travaux antérieurs dans ce domaine utilisent les données individuelles ou tirée à travers le pays pour étudier la mortalité maternelle; cependant, l'étude de la mortalité maternelle au niveau communautaire est indispensable, car c'est à ce niveau que la plupart des politiques sont mises en œuvre. Les résultats montrent que plus le temps de déplacement depuis la communauté jusqu'à l'hôpital conduit à un taux élevé de mortalité maternelle. Les résultats suggèrent que l'amélioration des systèmes de transport et l'accès aux hôpitaux qui disposent des salles de chirurgie sont nécessaires pour faire face aux complications obstétricales et pour réduire la mortalité maternelle. *(Afr J Reprod Health 2013; 17[4]: 118-129).*

**Mots-clés:** mortalité maternelle, risques sanitaires, entrées de la santé.

## Introduction

Maternal death can mean the loss of a productive member of the household, the dissolution of the family, and economic and social difficulty for the children[1-2]. In 2010, about 287,000 women around the world died of birth-related conditions, making maternal death one of the leading causes of death among women of childbearing age in the world[3]. The World Health Organization (WHO) groups the causes of maternal death in two broad categories: direct and indirect[4]. The direct causes can come from both pregnancy complications and malpractice[4], while common indirect causes of maternal death are HIV, malaria and tuberculosis[5,6]. The Millennium Development Goals have recognized that the improvement in maternal health one of most important objectives for improving health in developing countries[8]. Maternal mortality, as one of the most important indicators of maternal health, is one of the main public health issues in Sub-Saharan countries because it is not only concerns the health of the woman, but also the health of the newborn[9]. This paper tries to shed light on the socio-economic factors responsible for high, within-country maternal mortality rates using a community-level panel data set from Madagascar.

Madagascar is one of the poorest countries in the Sub-Saharan African region with a GDP per capita of US$990; approximately 90% of the population lives below US$2 per day[11]. However,

maternal mortality rate are below average for the Sub-Saharan region. In 2010 the estimated maternal mortality ratio (maternal deaths per 100,000 live births) in Madagascar was 240, compared to the Sub-Saharan Africa average of 500[3]. This can partly be explained by lower levels of HIV[3] and relatively better public health in Madagascar. For example, prenatal care and contraceptive use, two of the most important indicators of maternal health[12-13], are higher in Madagascar than the Sub-Saharan region. The contraceptive prevalence of women in unions (that is married or unmarried living with partner) aged 15 to 49 in 2008-2009 was 39.9%, 18% higher than the Sub-Sahara countries[14]. In 2009, women of child-bearing age who received prenatal care by skilled health personnel at least once during pregnancy was 86.3% in Madagascar compared to 74% for Sub-Saharan countries[15].

There is little published research on the specific causes of maternal mortality at the country level in Madagascar. However, a study conducted from 1988 to 1997 in Befelatanana Women's Hospital in Antananarivo, the capital city of Madagascar, found that the main direct causes of maternal death were infectious complications, renal and vascular complications, and anesthesia accidents. Other illnesses like malaria, heart disease, and asthma were cited as the leading indirect causes of maternal death[16].

To study how socioeconomic conditions in the community affect maternal mortality, we use a unique, nation-wide panel of communes (i.e., counties) from Madagascar. Previous efforts have focused on factors at the individual or cross-country level. From a policy perspective, understanding the factors that affect maternal mortality at the community level is crucial because this is the level at which most policy is implemented. This paper explores the effect of factors at the community level including the local health environment and access to healthcare resources on the level of maternal mortality. We find that factors like female wages and literacy are associated with lower maternal mortality. Other factors like time to the hospital, local malaria and tuberculosis incidence can represent a burden to women's health. The paper is organized as follows. The next section describes the data sources and methods, section 3 presents the results. Section 4 discusses the implications of our findings and section 5 concludes.

## Methods

The sources of data used in this paper are the 2001 and 2007 Madagascar Commune Censuses and the 1993 population census. A commune is similar to a county in the U.S. The commune census collected information on nearly all of the nearly1400 communes in Madagascar, gathering data on issues like public health, the availability of public goods and services, transportation, and environmental events that affected the community. Variables such as the number of maternal deaths, doctors, and clinics are provided by the 2001 and 2007 Madagascar Commune Censuses. Income, poverty measures, and literacy are based on 1993 population census, which is the most recent population census in the country. Table 1 provides the data source and the descriptive statistics for all the variables. Note that the national statistics for Madagascar are not comparable with the commune statistics on Table 1 since they are not population weighted.

In the commune data, maternal mortality is defined as the number of women dying during childbirth and within 24 hours after the delivery. Kane et al.[17] and Horron[18] found in developing and developed scenarios, respectively, that about 30% of maternal deaths occur within 24 hours after delivery. This definition contrasts with the standard definition: "maternal mortality is 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[4]". One limitation of this data set is that the commune census measure does not consider death from abortion, early onset pre-eclampsia/eclampsia, ectopic, molar pregnancy, among others, are not considered in this paper. The maternal mortality measure could be overestimated if there are significant numbers of reported births at the commune level.

During the period 2001 to 2007 the average maternal mortality ratio (that is maternal death per

**Table 1:** Descriptive Statistics

| Variable | Source | 2001 | | | 2007 | | |
|---|---|---|---|---|---|---|---|
| | | Mean | Std. Dev. | Median | Mean | Std. Dev. | Median |
| Maternal Death (number) | Commune | 1.31 | 2.82 | 0.00 | 1.40 | 5.63 | 0.00 |
| Maternal mortality ratio (maternal deaths per 100,000 birth) | Commune | 1212.54 | 5014.44 | 0.00 | 857.64 | 4546.79 | 0.00 |
| Doctors (number) | Commune | 1.26 | 2.61 | 1.00 | 1.53 | 4.58 | 1.00 |
| Doctors (per 100,000 birth) | Commune | 10.10 | 10.18 | 8.47 | 8.56 | 11.49 | 6.02 |
| Clinics (number) | Commune | 1.45 | 2.34 | 1.00 | 1.72 | 1.17 | 1.00 |
| Clinics (number per 100,000 population) | Commune | 14.67 | 17.19 | 12.36 | 13.51 | 10.84 | 11.04 |
| Time to the Hospital (hours) | Commune | 4.77 | 9.11 | 2.25 | 4.51 | 6.88 | 2.20 |
| Commune with No Vehicles (dummy) | Commune | 0.22 | 0.41 | 0.00 | 0.20 | 0.40 | 0.00 |
| Population (number) | Commune | 12476 | 10704 | 9920 | 17192 | 15813 | 13552 |
| Births (number) | Commune | 385.90 | 893.52 | 185.00 | 294.42 | 391.32 | 197.00 |
| Fertility rate (Births number per 1,000 population) | Commune | 40.73 | 147.33 | 20.39 | 19.10 | 19.85 | 15.73 |
| Female Literacy (number per women population) | Pop. Census | 55.61 | 23.76 | 55.35 | 53.17 | 24.03 | 52.11 |
| Female Wages | Commune | 1399 | 1027 | 1100 | 2223 | 929 | 2000 |
| Mean Income Franc Malagasy) | Pop. Census | 305508 | 94115 | 289377 | 307406 | 97181 | 289522 |
| Poverty Gap | Pop. Census | 0.20 | 0.09 | 0.18 | 0.20 | 0.09 | 0.18 |
| Malaria (dummy) | Commune | 0.90 | 0.30 | 1.00 | 0.88 | 0.33 | 1.00 |
| Tuberculosis (dummy) | Commune | 0.53 | 0.50 | 1.00 | 0.55 | 0.50 | 1.00 |
| Agriculture Workers (number per labor force) | Commune | 0.91 | 0.15 | 0.97 | 0.88 | 0.15 | 0.94 |
| Without Toilet (number per households) | Pop. Census | 0.73 | 0.29 | 0.87 | 0.75 | 0.28 | 0.90 |
| High Crime (dummy) | Commune | 0.28 | 0.45 | 0.00 | 0.30 | 0.46 | 0.00 |
| Cyclone (dummy) | Commune | 0.09 | 0.28 | 0.00 | 0.27 | 0.44 | 0.00 |
| N | | 1039 | | | 1275 | | |

100,000 births) decreased about 29%. The mean maternal mortality ratio for the communes was 1,212 in 2001 and decreased to 857 in 2007. The number of doctors and primary clinics are important determinants of maternal morbidity and mortality. Because the different categories of health professional (that is doctors, nurses, midwives, and nurses aides) are highly correlated, we focus on doctors as highly trained health professionals. Primary clinics are basic facilities with a small number of beds and where at least one health professional (for example nurse, midwife, nurse aide) offers basic health services. During this period, the number of clinics increased from 1.42 in 2001 to 1.72 in 2007 and the number of doctors increased from 1.26 in 2001 to 1.53 in 2007. Due to heavy investments in the transportation sector, variables related to travel to a health provider fell over the period; the average travel time (hours) to the nearest hospital decreased from 4.77 in 2001 to 4.51 in 2007 and the percentage of communes without vehicles also decreased from 22% in 2001 to 20% in 2007.

The population numbers are current year estimates based on the 1993 population census, the most recent local census numbers available at the time of the surveys, and voter registration numbers. Commune population increased from 12,476 in 2001 to 17,192 in 2007. During this period also the median number of births increases from 185 in 2001 to 197 in 2007.

Other variables related to poverty and human capital are also considered as determinants of maternal death. The variables mean commune income, poverty gap, and literacy rate of women comes from the 1993 population census. The mean income was about 307,406 FMG (that is former national currency of Madagascar), about US$136 in 2007. The poverty gap measures how far the average poor person was from the population poverty line in monetary terms. In the periods of 2001 and 2007 the poverty gap indicated that the average person is 20% below the poverty line. Female wages were included as a proxy of opportunity cost of both getting pregnant and sick. The weekly female wage increased 59% in the period of 2001-2007, from 1,399 FMG in 2001 to 2,223 FMG in 2007. The average literacy rate of women in communes in Madagascar was about 53% in 1993.

As discussed above, malaria and tuberculosis are two of the main causes of indirect maternal mortality in Sub-Saharan countries. The commune censuses have data only on the presence of these diseases in the previous three years in the commune, not the number of cases or rates of infection. About 90% of the communes in 2001 and 88% in 2007 reported cases of malaria. The prevalence of tuberculosis was lower than malaria; for example, in 2007, about 55% communes registered tuberculosis cases. Usually the interaction of tuberculosis and HIV in pregnant women is associated with high maternal mortality[19]. In Madagascar, however, the prevalence of HIV is significantly lower than other sub-Saharan countries[3]. The lack of hygiene also may affect women's health, increasing the probability of infections. On average, 75% of the households in the communes in Madagascar did not have toilets in 2007. As mentioned previously, physical labor, such as agriculture work, can be associated with maternal health. During the period 2001-2007, the estimated percent of the population working in agriculture decreased from 91% to 88%.

Other risk factors like climatic events, such as cyclones, and crime can be associated with maternal mortality. It is plausible that crime and climatic events cause vulnerability and reduce the access to health facilities. Furthermore, women who face crime or climatic events can be more likely to suffer injuries. The dummy variable for high crime comes from an official government designation of high crime areas. About 30% of the communes during this period were identified as high crime areas. As a proxy of climatic events, we use a dummy for cyclones that caused damage in the commune in the current year. The proportion of communes that suffered damages from a cyclone increase from 9% in 2001 to 27% in 2007.

***Statistical analysis***

The commune census provides the maternal mortality count by commune. To avoid the effect of birth fluctuation or under-reporting of births on the maternal mortality ratio, we use the number of maternal mortality cases as a dependent variable. Birth fluctuations may be driven by other factors. We estimate a pooled negative binomial model as well as an OLS model as a robustness check. According to the likelihood-ratio test of alpha, a negative binomial estimation is preferred to a Poisson. The negative binomial regression provides unbiased coefficients on estimations based on count dependent variables.

Problems measuring maternal mortality frequently arise in the literature. In Sub-Saharan countries about 50% of maternal deaths are not reported[10,20]. Two of the main reasons for miscounting maternal death are the misclassification of deaths in early pregnancy and abortions[21]. In both developing and developed countries the proportion of deaths in early pregnancy has been estimated at about one quarter of the total number of maternal deaths[18,19]. Maternal death related to amniotic fluid embolism[22], ectopic pregnancy[23], gestational trophoblastic disease[24], and maternal tetanus[25] can occur before the delivery and are associated with

the underreporting of the maternal death[26]. Similar misclassification can result from a death that occurs several days after the delivery. In Sub-Saharan countries also most women receive delivery assistance from traditional birth attendants, traditional healers or family[27-28], which makes it difficult for health professionals and authorities to record the occurrence and the causes of the death. Maternal deaths where health professionals are absent can result in underreporting[21]. The accuracy of the measurement of maternal mortality cases depends on the available healthcare specialists and the accessibility to healthcare facilities. For example, certain causes of maternal death require high technical skills to identify them[18]. Communities with no health professionals, with no health facilities, and located in remote areas are more likely to underreport maternal mortality.

If there is an idiosyncratic measurement error in reported cases of maternal death at the community level and this error is associated with some of the explanatory variables, the coefficients can be biased[29]. In order to deal with this issue we also estimate a negative binomial with commune fixed effect estimation and an OLS fixed effect. A commune fixed effect estimation controls for idiosyncratic constant factors at the commune level. If the measurement error is constant and a direct function of the number of health care professionals in the commune, and the health care in the commune is constant during the periods we expect that a fixed effect model at the commune level can get rid of the measurement error.

One of the limitations of the fixed effect model at the commune level is that half of the observations fall out of the model due to zeros in the dependent variable for both periods. In order to correct this issue, we add a pooled zero inflated negative binomial estimation. A zero inflated negative binomial estimation provides unbiased coefficients for this type of distribution. The Vuong test suggests that zero inflated negative binomials is preferred to the standard pooled negative binomial model. The Vuong z test is significant at the 0.01 level of significance. However, the Akaike and Schwarz criterions suggest that the fixed effect model is a better specification than the zero inflated negative binomial. The pooled zero inflated negative binomial estimation corrects the presence of many zeros in a count dependent variable.

Another methodological issue that we evaluate is the presence of endogeneity. Since maternal mortality is an important indicator of public health, it is possible that planners provide more doctors and clinics to a particular commune based on the level of maternal mortality. If resources are allocated to communities where maternal mortality is higher, this can violate the assumptions of unidirectional causal effect necessary for the orthogonality condition. However, the robust Durbin-Wu-Hauman test suggests that both doctors and clinics are exogenous. We perform an instrumental variable regression as a robustness check. The results of this estimation are not reported since the instruments are weak. Next sections will present the results of the different negative binomial estimations.

## Results

The objective of this paper is to explore the effect of risk factors and socioeconomic determinants on maternal mortality. Table 2 presents the results of the maternal death pooled negative binomial estimations and an OLS estimation. The results for the estimation of the negative binomial with commune fixed effect estimation and an OLS fixed effect are presented in Table 3. The negative binomial estimates (Table 2) suggest that travel time to the hospital, population, births, and incidents of tuberculosis in the community increase maternal mortality. Conversely, variables such as female literacy, female wage, and mean income reduce maternal death. However, this negative binomial estimation show counterintuitive findings, having clinics in the commune is positively related to maternal mortality and poverty gap and number of households without toilet are negatively related to maternal mortality-likely results of the underreporting issue discussed earlier. However, in the commune fixed effect estimations (Table 3) the method that may correct the underreporting issue-clinics have negative and significant effect. This suggests that the fixed effects estimation is able to, at least partially, control for measurement problem at the commune level.

**Table 2:** OLS and Negative Binomial Pooled Estimations of Maternal Mortality Deaths as Dependent Variable

| | **OLS Pool** | | **Negative Binomial Pool** | |
|---|---|---|---|---|
| **Variables** | **Coeff.** | **t** | **Coeff.** | **Z** |
| Doctors (per 1,000 population) | -0.356 | -0.47 | -0.27 | -0.56 |
| Primary Clinics(1,000 rooms divided by population) | 0.018** | 1.51 | 0.015* | 2.23 |
| Time to the Hospital (hours) | 0.055* | 2.67 | 0.032* | 3.52 |
| Commune With no Vehicles (dummy) | 0.265 | 1.05 | 0.162 | 1.14 |
| Population (number divided by 1,000) | 0.036* | 4.06 | 0.017* | 3.69 |
| Births (number divided by 1,000) | 0.414* | 2.52 | 0.338* | 2.28 |
| Female Literacy (number per women population) | -0.013** | -2.01 | -0.010* | -3.00 |
| Female Wages (weekly, national currency divided by 1,000) | -0.129 | -1.92 | -0.097** | -1.94 |
| Mean Income (Ariary[+]) | -0.004 | -1.82 | -0.002** | -1.97 |
| Poverty Gap | -3.407*** | -2.14 | -2.375* | -2.38 |
| Malaria (dummy) | 0.09 | 0.31 | 0.221 | 1.12 |
| Tuberculosis (dummy) | 0.668* | 3.64 | 0.523* | 4.99 |
| Agriculture Workers (number per labor force) | -0.004 | -0.65 | -0.005 | -1.55 |
| Without Toilet (number per households) | -0.009*** | -1.8 | -0.005** | -1.91 |
| High Crime (dummy) | -0.224 | -1.13 | 0.028 | 0.25 |
| Cyclone (dummy) | 0.004 | 0.02 | 0.134 | 0.84 |
| Constant | 4.025** | 2.49 | 2.050** | 2.33 |
| $R^2$ (overall) | 0.0401 | | | |
| Akaike Criterion | 13,550.04 | | 6,426.18 | |
| Bayesian Criterion | 13,647.74 | | 6,529.62 | |
| LR test ($\chi^2$) | | | | |
| Poisson vs. NB | | | 5306.30 (0.000) | |
| N | 2,314 | | 2,314 | |

*** indicates that the coefficient is significant at 10 percent level; ** (*) indicates significance at 5(1) percent level.
+ Ariary is the currency of Madagascar. In 2005 the exchange rate was 2003.026 Ariary per dollar.

The negative binomial commune fixed effect estimations also suggest time to the hospital increase maternal mortality. Furthermore, in this estimation a higher female wage is associated with fewer maternal deaths.

About 37% of the communes have non-zero maternal mortality. Based on this, we performed a zero inflated negative binomial (Table 4). The negative binomial component of the zero inflated estimation offer similar results as the basic negative binomial presented in Table 2. The main difference in this equation is that the number of doctors has a negative effect on maternal mortality in the negative binomial equation.

In the logit component of the zero inflated negative binomial estimation, the dependent variable equals one if maternal mortality is zero. This estimation shows that variables such as malaria and cyclones increase maternal mortality.

**Table 3:** Fixed Effect Estimation of Maternal Mortality Deaths as Dependent Variable

| | **Negative Binomial Commune Fixed** | | **OLS Commune Fixed** | |
|---|---|---|---|---|
| **Variables** | **Coeff.** | **z** | **Coeff.** | **t** |
| Doctors (per 1,000 population) | -0.002 | -0.03 | -0.751 | -0.48 |
| Primary Clinics(1,000 rooms divided by population) | -0.010** | -1.98 | -0.035* | -3.29 |
| Time to the Hospital (hours) | 0.019* | 2.35 | 0.062* | 2.87 |
| Commune With no Vehicles (dummy) | 0.235 | 1.45 | 0.340 | 0.81 |
| Population (number divided by 1,000) | 0.008 | 1.51 | -0.003 | -0.11 |
| Births (number divided by 1,000) | -0.016 | -0.20 | 0.361*** | 1.80 |
| Female Literacy (number per women population) | | | | |
| Female Wages (weekly, national currency divided by 1,000) | -0.014* | -2.52 | 0.035 | 0.24 |
| Mean Income (Ariary, national currency divided by 1,000) | | | | |
| Poverty Gap | | | | |
| Malaria (dummy) | 0.216 | 1.21 | 0.405 | 0.99 |
| Tuberculosis (dummy) | 0.063 | 0.59 | 0.332 | 1.22 |
| Agriculture Workers (number per labor force) | -0.003 | -0.77 | -0.007 | -0.50 |
| Without Toilet (number per households) | | | | |
| High Crime (dummy) | 0.164 | 1.28 | 0.109 | 0.31 |
| Cyclone (dummy) | 0.085 | 0.68 | 0.269 | 0.81 |
| Constant | -0.923*** | -1.94 | 1.396 | 1.03 |
| $R^2$ (overall) | | | 0.0098 | |
| Akaike Criterion | 1,542.08 | | 10,915.68 | |
| Bayesian Criterion | 1,608.06 | | 10,990.39 | |
| Hausman Test ($\chi^2$) Random vs. Fixed | 24.46(0.0176) | | 34.35(0.0003) | |
| N | 1,182 | | 2,314 | |

*** indicates that the coefficient is significant at 10% level; ** (*) indicates significance at 5(1) % level. The robust standard errors are not available for the fixed effect negative binomial. The results of the robust standard error of the OLS fixed effect are similar to the one that we informed.

Consistent with previous findings at the village level, health facilities play an important role in the reduction of maternal death.

Consistent with previous findings at the village level, health facilities play an important role in the reduction of maternal death. Reducing travel time to a hospital is an important strategy to reduce maternal mortality. Furthermore, the estimations suggest that the number of doctors and clinics in the commune are an important factor to reduce maternal mortality. Factors like female wage and literacy also are relevant.

## Discussion

This section puts our empirical findings into a broader context and compares them to other findings in the literature. Unlike most studies in this area, we are able to study the issue at the level at which policy is implemented-the community-using two rounds of a nation-wide panel of communes in Madagascar.

Many studies at the cross-country level have found that maternal health services decrease maternal mortality[30-33]. Factors like the percentage of women receiving trained assistance at childbirth[31], percentage of women receiving prenatal care[33] and access to treatment for pregnancy complications reduce maternal mortality[30]. Robinson and Wharrad[59] found that the number of physicians decreases maternal mortality rates. We find mixed results for the effect of the number of doctors in the community on maternal mortality (Table 4). However, Loudon[34] suggested that doctors may cause the increase in maternal mortality. Similarly, in 1933 the Public Health Relations Committee of the New York Academy of Medicine published a report that showed that 66% of the maternal deaths were due to malpractice and was preventable[35].

**Table 4:** Zero Inflated Negative Binomial Estimation of Maternal Mortality Deaths as Dependent Variable

| Variables | Negative Binomial Equation | | Inflation model –Logit (The observed count is zero) | |
|---|---|---|---|---|
| | Coeff. | Robust z | Coeff. | Robust z |
| Doctors (per 1,000 population) | -0.937*** | -1.91 | -8.842** | -2.13 |
| Primary Clinics(1,000 rooms divided by population) | 0.018* | 3.15 | 45.576* | 2.99 |
| Time to the Hospital (hours) | 0.030* | 3.64 | -0.275*** | -1.73 |
| Commune With no Vehicles (dummy) | 0.055 | 0.4 | -1.23 | -1.51 |
| Population (number divided by 1,000) | 0.009** | 2.39 | -0.036 | -1.35 |
| Births (number divided by 1,000) | 0.876* | 3.27 | 1.139* | 2.82 |
| Female Literacy (number per women population) | -0.007** | -2.01 | 0.04 | 1.39 |
| Female Wages (weekly, national currency divided by 1,000) | -0.057 | -1.19 | 0.690* | 3.03 |
| Mean Income (Ariary, national currency divided by 1,000) | -0.002*** | -1.88 | -0.007 | -1.00 |
| Poverty Gap | -1.988** | -2.08 | -2.313 | -0.45 |
| Malaria (dummy) | -0.016 | -0.07 | -1.942** | -2.72 |
| Tuberculosis (dummy) | 0.433* | 3.72 | -0.645 | -0.89 |
| Agriculture Workers (number per labor force) | -0.001 | -0.27 | 0.201 | 1.54 |
| Without Toilet (number per households) | -0.005 | -1.74 | -0.007 | -0.55 |
| High Crime (dummy) | -0.01 | -0.08 | -0.289 | -0.33 |
| Cyclone (dummy) | 0.048 | 0.28 | -1.763*** | -1.68 |
| Constant | 1.562 | 1.89 | -18.379 | -1.31 |
| Ln Alpha | 1.09 (0.0000) | | | |
| Akaike Criterion | 6381.034 | | | |
| Bayesian Criterion | 6582.17 | | | |
| Number of obs | 2314 | | | |
| Nonzero obs | 861 | | | |
| Zero obs | 1453 | | | |
| Vuong z test<br>Zero inflated Negative Binomial vs. Pool Negative Binomial | 3.84 (0.0001) | | | |

*** indicates that the coefficient is significant at 10% level; ** (*) indicates significance at 5(1) % level.

The incorrect use of doctors' instruments in deliveries and anesthetics were two of the main causes of maternal death in the U.S., explaining 61% of the preventable maternal deaths.

Factors at the village level-like clinics, transportation availability, and infrastructure-can contribute to maternal death. Many of the obstetric causes of maternal mortality (for example eclampsia, hemorrhage, and ruptured uterus) can be prevented with maternal care and adequate obstetrical services[36]. For example, we found that primary clinics reduce maternal death (Table 3). However, distance to the hospital may also be important. Since most surgery rooms and other obstetrical services often are available only in hospitals, distance to the hospital or to the health

provider has been considered an important factor of maternal mortality[30,37]. Another relevant factor related to the distance to the hospital is transport and transportation infrastructure to help women reach specialized health services. In the case of an obstetric emergency, minimizing the time to the health provider is considered one of the more important strategies to reduce maternal mortality[38]. Consistently in our estimations, shorter travel times to hospital are associated with lower maternal death. These findings confirm that the services that are provided by the hospitals (for example surgery rooms, medicines and doctors) and the time to reach these specialized services are crucial for reducing maternal mortality.

The results suggest that female literacy is associated with lower maternal mortality (Tables 2 and 4). Education may be related to higher levels of maternal health through several channels. For example, women with higher levels of education may have some awareness about the effects of illness and treatment; and they may have a higher demand for contraceptives and prenatal care, and a higher likelihood of having a partner with higher levels of education[39]. Both Okonofua et al.[40] and Chowdhury et al.[41] found that increases in education reduce maternal mortality. Female wages also decreases maternal mortality (Tables 2, 3, and 4). Higher female wages can enable women to purchase healthcare. Educated women and women with higher wages may have higher bargaining power in their communities and can be aware of health issues related to maternal mortality.

Higher mean incomes in a community are also associated with fewer maternal deaths (Tables 2 and 4). Poor communes may have a lower use of contraceptives and prenatal care, and fewer individuals that afford the costs related to treatment. The previous evidence of the effects of class or income appears to be mixed. It is documented with individual data that in the early 1900s in Britain, and more recently in Bangladesh, that maternal mortality was higher in higher social classes than in lower classes[26,34]. Conversely, Chowdhury et al.[41] found that increases in the level of household assets decrease maternal death. We expected that poverty has been linked to maternal mortality through malnutrition[34,42]. Malnutrition has been associated with anemia which is one of the main causes of maternal death[43]. Malnutrition may lead to chronic iron deficiency and anemia, which can make women prone to hemorrhage and infections[42,44-45]. Furthermore, women who have faced malnutrition early in life are usually smaller, which increases the likelihood of obstructed labor[42]. Most of the papers that study the determinants of maternal mortality at the individual level evaluate indirect causes. These causes include HIV, malaria and tuberculosis[5,46-47]. Because pregnancy depresses a woman's immune system[48] pregnant women are more susceptible to diseases[49]. Consistent with the literature, our results (Tables 2 and 4) suggest that the presence of tuberculosis is associated with higher maternal mortality. Communes that are affected by tuberculosis can have a hazardous health environment and also poorer public hygiene. Results also suggest (Table 4) that the presence of malaria cases in the communities increases maternal deaths.

Strong physical effort also can also increase health risks to both the pregnant woman and the fetus[50-51]. Contractions and reduction of blood flow to the placenta, which can lead to preterm and spontaneous abortion, have been linked to hard work[50,52]. Agricultural work, specifically, has been linked with preterm delivery[52,53-54]. Carrera[55] suggested that labor overburden can lead to complications that cause maternal death. Furthermore, Cerón-Mireles et al[56] found that the number of hours a pregnant woman spent standing at work is related to preeclampsia and eclampsia, two of the leading causes of obstetric complications. We found that the percentage of individuals working in agriculture is not related to maternal death. However it is possible that a higher proportion of women working in agriculture may face higher levels of miscarriage and death in early pregnancy[52,55].

Commune level factors like health environment and services are crucial to explain maternal mortality levels[40]. This paper expands the works of Lamb et al[57] and Fauveau et al[58] who studied the effect of health workers on maternal mortality at the village level. However, they used a limited number of communes. By using a unique, nationwide panel of communes (that is

counties) in Madagascar we control for many methodological issues and explore the determinants of maternal mortality. This paper found that factors such as access to health services and risk factors are related to maternal mortality in Madagascar.

## Conclusions

The results in this paper have several health policy implications that may help Madagascar reach its millennium development goals related to maternal health and support findings elsewhere related to the causes of maternal mortality. Access to clinics and hospitals and shorter travel times to these facilities can help reduce maternal mortality, implying that continued investments in infrastructure are important. Investments that increase educational and employment opportunities for women will also reduce maternal mortality over time. However, for a more immediate impact on maternal mortality rates, the government and aid organizations should focus on reducing exposure to diseases such as malaria and tuberculosis and increasing emergency aid to areas affected by cyclones or other disasters, with the needs of pregnant women in mind.

## Contribution of Authors

Both, Dr Julio C. Hernandez and Dr Christine M. Moser conceived, designed and analyzed the data for the study. These authors approved the manuscript.

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