Perinatal Mortality in Mexico

Levels and Trends by State and Municipality, 1990 to 2013

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Introduction

The perinatal mortality rate is an important indicator of infant health levels and trends at the national and sub-national level. The perinatal mortality rate not only indicates conditions that effect the health of infants in the first week of life, but also captures the factors that affect prenatal and intrapartum health care (1). This study intends to capture recent levels and trends in perinatal mortality in Mexico at a sub-national level. Since health care is administered in local settings, it is imperative that estimates highlight exactly where the highest burden local administrative areas are. This research project aims to produce estimates of perinatal mortality at the state and municipality level for the period 1990 to 2013.

Perinatal mortality is particularly important because the measure accounts for a population often forgotten in the measurement of disease and death, stillbirths. Although the burden of disease in the first week of life, the early neonatal period, is often discussed, stillbirths are less often accounted for when measuring and tracking maternal and child health. Stillbirths account for over half of all perinatal deaths globally, with one third of stillbirths occurring during the intrapartum period, during delivery (1,2).

Deaths during the perinatal period are associated with poor maternal health, inadequate delivery care, mismanagement of delivery complications, and poor hygiene during and after delivery. Infant characteristics can also play a role, congenital anomalies, cretinism, and neural tube defects all reduce survival probabilities (2). Further, maternal nutrition is related with the birth weight of infants which is associated with perinatal death. Obstructed labor and birth asphyxia are common intrapartum causes of death. Infection risk and death is associated with membrane ruptures and long deliveries.

Perinatal mortality as a health indicator captures elements of maternal health, quality of delivery care, and pediatric care. This indicator can be used to not only track progress and describe health levels or disparities, it can further be used to target interventions at the state and municipality level to provide quality care from pregnancy, to delivery, and finally to neonatal care. There is a need to both identify the municipalities with the largest burden of perinatal mortality and to further identify areas where stillbirths are regarded as a natural loss and thus not reported to the vital registration system. We hope to strengthen our understanding of both the perinatal mortality burden in Mexico as well as the underreporting of stillbirths and early neonatal deaths in this study.

Definition

The perinatal mortality rate depends on the definition of each of the calculation components. The definition of a stillbirths and the perinatal period are particularly important. Equation 1 below is the defined perinatal mortality rate. The definitions below explain each of elements in further detail.

$$Perinatal\ Mortality\ Rate = \frac{\sum(stillbirths + early\ neonatal\ deaths)}{total\ live\ births} \qquad \textbf{1}$$

Stillbirth

A stillbirth, otherwise known as a fetal death, is a death prior to delivery by the mother irrespective of the duration of the pregnancy which shows no evidence of life after the separation. Stillbirths within the perinatal period occur at 22 gestation weeks (154 days) or when the fetus weights 500g or more. This is the definition included in the WHO 2000 report and through MEASURE Evaluation (2,3).

In ICD10 (code P95) stillbirths include fetal deaths after the 20^{th} gestational weeks (3).

Still others use the definition that stillbirths are fetal deaths in the third trimester, 28 or more gestational weeks or a birth weight of 1000g (4).

Given the variations in the initiation of the perinatal period and the definition of a stillbirth, this project will make explicit the working definition used by each data source and when possible restrict deaths to a particular period, 22 gestational weeks or 500g.

Early neonatal death

An early neonatal death occurs in the first 7 days of live, day 0 through 6. Early neonatal deaths are a subdivision of the overall neonatal period which is birth to 28 complete days.

Live birth

Live births are the denominator for the perinatal mortality rate. They include all deliveries (regardless of pregnancy duration) where after separation from the mother the infant shows signs of life. Evidence of life includes breathing, a beating heart, pulsation of the umbilical cord, and movement of voluntary muscles (2).

Perinatal period

This is the period that captures both stillbirths and early neonatal deaths, 22 gestational weeks to 7 days of life.

Challenges

The variations in the definition of stillbirths and the recall bias in gestational age typical in self-reporting from women are both challenges for this research project. The under-reporting of stillbirth and early neonatal deaths in vital registration systems is also an important bias to account for in our study. We address these challenges in the methods section of this report.

Relevance of the Research

As we approach 2015 and the end of the Millennium Development Goals it is critical that there is strong, quantitative, research supporting and tracking progress in Mexico. This research primarily applies to Millennium Development Goal 4 (MDG4), the reduction from 1990 to 2015 of under-5 mortality by two thirds, but is also closely related with MDG5, the reduction of Maternal Mortality by three fourths (5,6). This project also goes beyond the scope of the MGDs, by accounting explicitly for stillbirths. This research also has strong policy implications, especially because of the time-series design on the project. This will allow us to highlight both success stories and poor performers based on rates of change over time, not just absolute numbers of deaths.

Studies to Date

There is a large body of literature related to the measurement of perinatal mortality and the causes of death and disease during this period.

Perinatal mortality

The combination of stillbirths and early neonatal deaths into a single metric, the perinatal mortality rate, has been a common health metric since the mid-20th century. This metric was first justified based on the similar causes of death that occur in stillbirths and within the first week of life, namely asphyxia (7). There are both global and country specific assessments of perinatal mortality. The first comprehensive sets of estimates for stillbirths were published in 2006 by two sources, the World Health Organization (WHO) and another analysis by Saving Newborn Lives/Initiative for Maternal Mortality Programme Assessment (IMMPACT) (8,2). The WHO analysis was updated in 2011 to include trends since 1995 and point estimates for 2009 (9). Stillbirth estimates were featured in a special issue of the Lancet 2011 with articles discussing the continued burden of stillbirths, the causes of death in this age group, and the challenges of accurately measuring deaths with under-reporting in registration systems and variable definitions / societal perceptions (4,10,11).

The measurement of early neonatal deaths in a time-series, national-level analysis is currently published by both the UN Inter-agency group for Child Mortality Estimation (IGME) and the Institute for Health Metrics (IHME) (12,13). Both groups regularly update their estimates with revised databanks and methodological improvements.

The estimation of perinatal mortality rates as an explicit outcome has been included in several of the stillbirth and neonatal health reports released by the WHO, including the 2006 publication (7). There are also rate estimates available through several survey series including the Demographic and Health Surveys when complete birth histories and pregnancy history modules are included.

Perinatal mortality in Mexico

Perinatal and overall under-5 mortality have also been researched specifically in Mexico (14). In 2001 the Mexican Ministry of Health launched the *Arranque Parejo en la vida* program with an explicit goal to reduce maternal and perinatal mortality rates in Mexico. The program included neonatal screening and folic acid supplementation (14,15). De Los Santos-Garate et al have investigated perinatal outcomes after 40 gestational weeks in a retrospective cohort study in Mexico using the NEOSANO perinatal network database (16). The NEOSANO's Perinatal Network includes five hospitals in Mexico City, three hospitals in Tlaxcala City, and one hospital in Oaxaca City. There have been several regional and national studies of perinatal mortality related topics in Mexico (14,16–18). However, to our knowledge, there is no comprehensive set of estimates of perinatal mortality rates and deaths available for all states and municipalities in Mexico. This information gap will be directly addressed in this research project and is the fundamental motivation of our work.

Methods

Data

For this study we need both live birth and death records data. We relied on census data and vital registration records. **Table 1** below accounts for all of the data sources we currently have and at what level we have data

Table 1: Source of Births, Deaths (Stillbirths and ENN), and Small-Area Covariates

Source Name	State or Municipality Level	Information Available
Census 1990	Both	Urban-rural status, indigenous status not available, years of education, employment status
CONTEO 1995	Both	Urban-rural status, indigenous status not available, years of education, employment status
Census 2000	Both	Urban-rural status, indigenous status, years of education, employment status
CONTEO 2005	Both	Urban-rural status, indigenous status not available, years of education, employment status not available
Census 2010	Both	Urban-rural status not available, indigenous status, years of education, employment status
Fetal Deaths Registry (1990-2011)	Both	Sex, gestational week, weight in grams,
INEGI database of vital statistics (1990-2012) (early neonatal deaths)	Both	Sex, gestational week, weight in grams, mother received prenatal care, alive status of baby at birth, mother's age, mother's occupation, attendant type at birth
Registry of Births (1990-2012)	Both	Total number of live births registered by state and municipality
Birth Certificates (2008-2012)	Both	Total number of live birth certificates by state and municipality

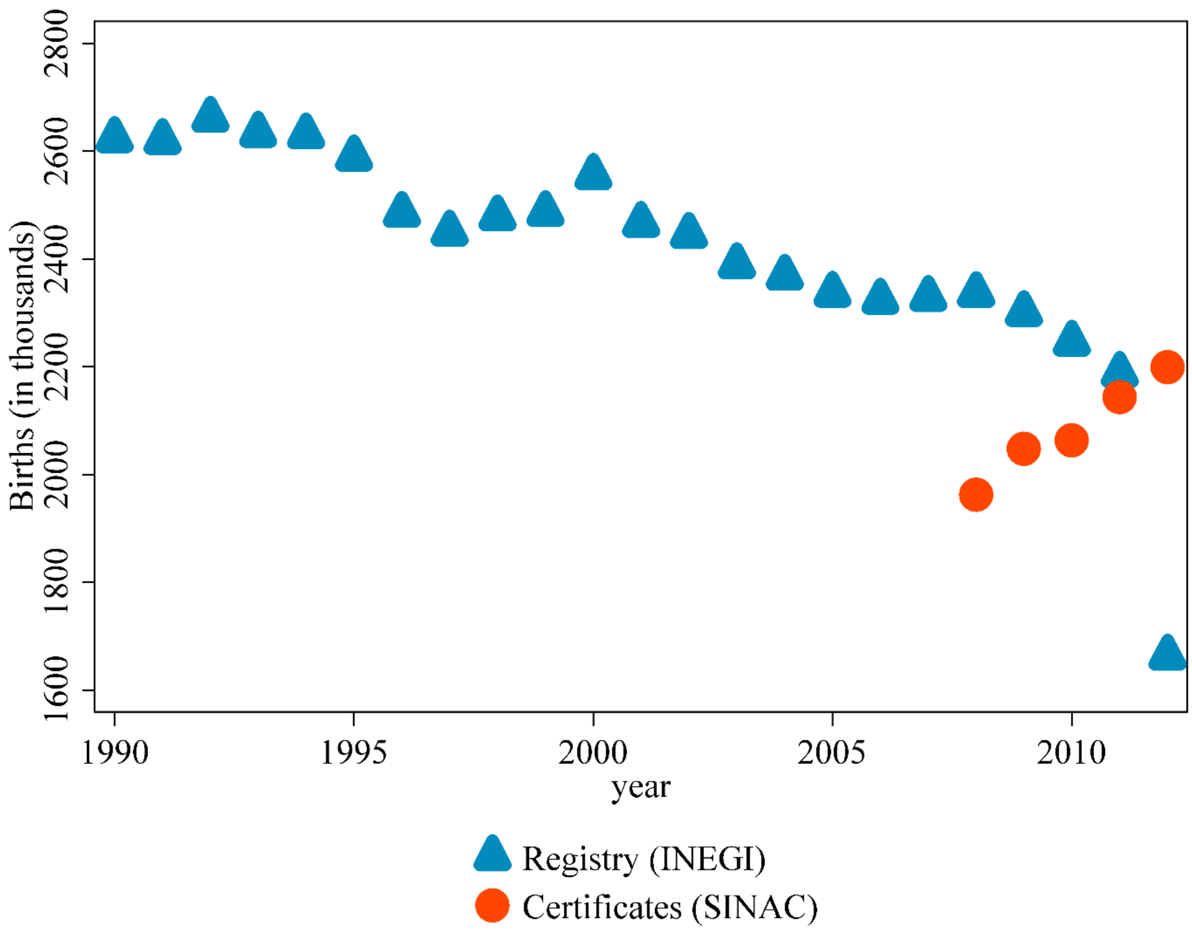
Birth Data

Birth data was obtained from the Birth Registries (INEGI) for the years 1990 to 2012 and from Birth Certificates (SINAC) for the years 2008 to 2012. Although the birth certificate data in Mexico will prove a useful data source in future studies the data from 2008 and 2009 clearly under-recorded births in the system while the data post-2009 was generally similar to the level of births recorded in the registration system.

We evaluated the quality of both of these systems including an assessment of age trends, trends over time, and missingness across variables in the database. The state of residence is used to classify the location of birth. Some observations were missing the sex of the individual, this was not a concern in our study because we are estimating mortality for both sexes combined.

Since the birth registration system gave us a consistent source across time that was of acceptable quality, this is our preferred and used source. Because there are delays in birth registration, we pool all the births registered across any year in our window to the year listed as the birth year. For example, a birth registered in 2005 which lists 2003 as the birth year is counted as a 2003 birth. These delays make the most recent full-year of data, 2012 unreliable and low. This year is dropped from the database. The quality of the 2011 data was included because the level of birth registration was reasonably consistent with other years in the mid- to late-2000's. **Figure 1** below shows the birth data for the two sources of data.

Figure 1: Births Recorded in Mexico by Registration System (INEGI) and Certificates (SINAC)



Early Neonatal Death Data

Deaths occurring in in the first week of life (0 to 6 days) were obtained from the vital registration records of Mexico. For the years 1990 to 1997 deaths were coded using the International Classification of Diseases (ICD) 9. From 1998 to 2012, ICD version 10 was used. As with the birth data, the place of residence is used to assign deaths to a state and municipality.

Fetal Death Data

Fetal death data was obtained from 1990 to 2011. In looking at data quality it was clear that there was both heaping in the reports of gestational age and the weight of the stillborn. For example, we observed substantial heaping at the gestational weight of 500g (and 1000g, 1500g, and 2000g). This is an important data feature given our working definition of a stillbirth as a death at 500g or on/after 22 weeks. We are currently including all registered stillbirths that are either registered as 500g or more or/and have a gestational age of 22 weeks or more. Both these measures can be biased, neither seemed of a higher quality in the registry data so we have incorporated information on both gestation age and reported weight to determine if a death qualifies as a stillbirth. **Figure 2-3** below demonstrates the heaping in the reported weight and gestational age in the registration data.

Figure 2: Weight Reported for Stillbirths

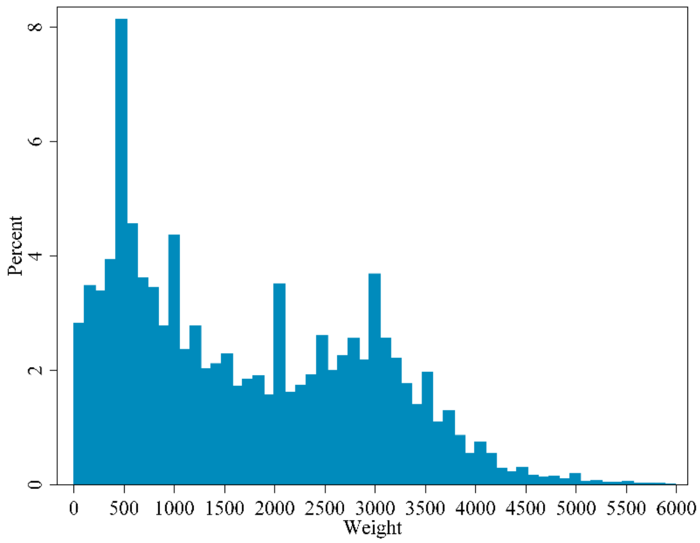
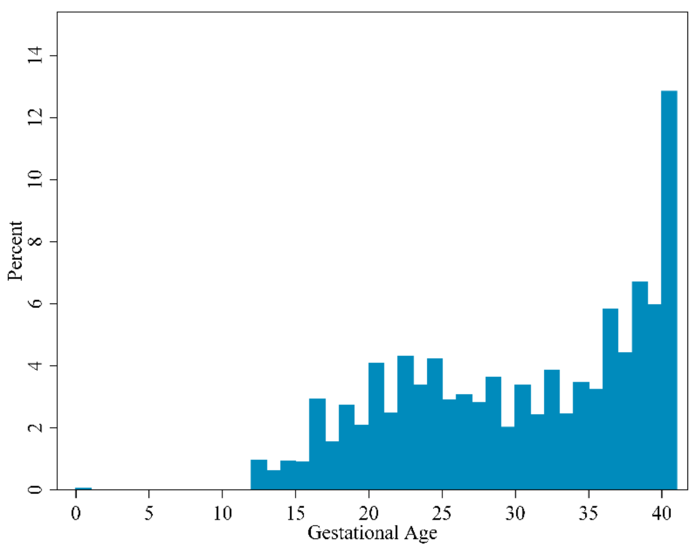


Figure 3: Gestational Age Reported for Stillbirths



It is clear in **Figure 3** that there is a substantial proportion of stillbirths reported at gestational age 40. This makes sense because of the increased risks during the labor process. There is also an alternative explanation that some of these deaths are actually live births which die within minutes or hours of being born and are misclassified as stillbirths. There are incentives in this misclassification relating to the amount of paper work required for an early neonatal death compared to a stillbirth. Since we are looking at the perinatal period as a whole this distinction is not relevant but it is important to consider where disaggregating perinatal information into stillbirth mortality rates and early neonatal mortality rates.

Covariate Data

Covariate data was extracted from the 1990, 2000, and 2010 censuses as well and the 1995 and 2005 CONTEO inter-census surveys. Covariates are meant to add additional information about the characteristics of a given state and municipality to help better predict perinatal mortality rates than is possible from direct calculation using the registration data alone. Further detail regarding what covariates were used in the models and the small-area estimation techniques will be discussed in the Methods section of this report.

Tracking Municipalities over Time

During the time period for this study, 1990 to 2012, several municipalities were created. Some existing municipalities were created from a sub-section of an existing municipality. In other cases new municipalities were created that incorporated land from two or more existing municipalities. For the purpose of this study, municipalities were merged to create a consistent set of municipalities over time. In total there were 86 municipalities merged with one or more other municipalities. Across all years there were 2,487 unique municipalities, the 86 merged municipalities represent 3.5% of the total unique municipalities in Mexico across the time period 1990 to 2013. 31 of the municipality merges happened at or after the year 2000. **Figure 4** below shows the merged municipalities in this study. As of 2013 there are a total of 2,457 municipalities in Mexico.

Figure 4: Merged Municipalities, 1990 to 2013

As of 2013 there are a total of 2,457 municipalities in Mexico. We estimate perinatal mortality for each municipality, reporting the same figures for municipalities which have been combined, those in purple here.

Completeness Assessment

Before calculating perinatal mortality, we first assessed the completeness of the registration system. This is a critical step in the process because it is well documented that registration systems which may be complete for adult ages often under-register deaths under the age of 5. Once we have determined completeness at the state-level, we can up-adjust the mortality rate to better reflect the mortality rate which occurred.

For adult ages, vital registration systems are assessed using a combination of death registries and population information from censuses. These methods are referred to as Death Distribution Methods. Unfortunately, these methods have been shown to be ill-equipped for assessing the completeness of death registries for younger ages. Our methods for assessing completeness in various scenarios is discussed in the subsections below.

Under-5 Completeness

Although this project aims to estimate perinatal mortality by municipality, we use the under-5 mortality rate as a way to initially assess completeness. Under-5 mortality estimates are available in a wide variety of surveys, many of which do not allow for estimation of the early neonatal mortality rate without further modeling.

To determine the completeness of vital registration systems in capturing deaths under the age of 5, we compare the under-5 mortality rate directly calculated using the vital registration data with a gold standard source of estimates during the same period. Since we rarely have a perfect gold standard data source for comparison, we instead typically combine all the information from surveys into a single time trend of under-5 mortality. We then compare the estimates produced by the synthesis of survey under-5 mortality information with the direct estimates from the vital registration system

The distance between the vital registration under-5 mortality rate estimates, in purple, and the synthesized survey under-5 mortality information, the black line, is the estimated completeness. We then took the estimated completeness from each observed vital registration point and smoothed across all completeness estimates using a LOESS regression to gain a final time-trend of completeness for each of the 32 Federal Entities in Mexico.

Estimating the Relationship between Under-5 Completeness and ENN / Infant Completeness

Although we cannot confidently assume that the under-5 death completeness above is a reasonable proxy for early neonatal or stillbirth under-registration it is difficult to apply the same methods described above to these age groups. In the case of under-5 mortality we were able to use information from both Complete and Summary Birth Histories. For the early neonatal period we can only use Complete Birth Histories which explicitly ask dates of death and birth well enough to determine early neonatal deaths. We cannot use Birth Histories at all for estimating Stillbirth death rates from surveys, instead a Pregnancy History would need to be used.

There is only one Complete Birth History available in Mexico (The Demographic and Health Survey, 1988) and it does not include enough information to estimate the early neonatal mortality rate directly, nor was it taken during our study period. Instead of trying to calculate early neonatal completeness directly, we chose to estimate the relationship between early neonatal completeness compared to under-5 mortality completeness.

To do this we pooled all the Complete Birth History estimates we had across all countries where there exists both vital registration data and Complete Birth Histories. We then created a smoothed trend of all available Complete Birth History information for the ages 0-4 years (under-5), 0 years (Infant) and 0-6 days (Early neonatal period). We then compared the smoothed survey information with the directly calculated under-5, infant, and early neonatal mortality rates derived from vital registration systems. This is the same concept as the method described above for the under-5 completeness estimation except that we are no longer using information from Summary Birth Histories and we are now simultaneously conducting the same completeness assessment for 3 age groups.

Once we have completeness estimates we pool all the completeness estimates within a GBD 2013 Super Region and use LOESS regression to find the regional trend in completeness within these three age groups. We calculated the average super region completeness for two time periods, 1990-1999 and 2000-2013. We then used the relationship between the early neonatal completeness and the under-5 completeness in the Latin America and Caribbean region to adjust the under-5 state-level completeness estimates to better suit the mortality rate we are calculating for the perinatal period. We were unable to do a similar analysis for the fetal period so in this case we are assuming that the completeness in the early neonatal period is an appropriate proxy for the fetal death registration completeness, a limitation of the study.

Perinatal Mortality

First we calculated perinatal mortality for each municipality and state in Mexico for the years 1990 to 2011. We then adjusted these rates to reflect under-registration using the under-5 completeness estimates and the early neonatal – under-5 completeness relationship. These adjusted estimates are the input estimates into the small area models described below.

Small Area Estimations Methods

We will use a small-area models to estimate the perinatal mortality rate at the state and municipality level. The models have been previously described and used in the context of hypertension and obesity studies for county-level estimates in the United States (22–24). The method involves two steps, each of which are described in detail below.

Please note that we are still actively developing this portion of the research and although we have included our methods here the results of the small-area model are still under development and will be included in any revisions of this paper.

Modeling Step 1: Apply Logistic Regression Models

Four logistic regression models will be used to estimate the perinatal mortality rate. The models are summarized in the schematic on the next page and discussed in some level of detail in this section. The complete explanation of the model types and the validation method are described elsewhere (24).

The Naïve model includes individual level covariates such as socio-demographic information, a linear time trend, and a municipality level random effect. For the prediction of fetal deaths individual characteristics will be those of the mother. Examples of covariates that we might use in this model are race, age, marital status. For the prediction of early neonatal deaths we will use the characteristics of the child, including birth weight and other relevant covariates.

The second model, the covariate model, includes all of the elements of the naïve model in addition to municipality-level covariates for relevant covariates to behavior and health outcomes. Examples of potential covariates that may be included in this model are: poverty, urban-rural status, presence of a neonatal intensive care unit, etc.

The Geospatial model builds on the base of the naïve model by incorporating a geospatial term. This geospatial term is calculated as the posterior estimates of the municipality-level random effects from the naïve model for all physically adjacent municipalities. It is possible that we could make this more nuanced by incorporating weights for adjacent municipalities based on the ease of access by roadways or the presence of geographic features like mountains or rivers which might limit contact between municipalities.

The fourth model, referred to as the full model, is the same as the covariate model with the addition of a geospatial term calculated from the covariate model. In past small-area studies the version of this full model has included both individual- and community-level race covariates to account for both the direct effects and the context that racial composition can have on a community.

Model 1 (Naïve Model)

- Individual-level covariates (Socio-demographic information)
- Linear time trend
- Municipality-level random

Model 2 (Covariate Model)

- Individual-level covariates (Socio-demographic information)
- Linear time trend
- Municipality-level random

Model 3 (Geospatial Model)

- Individual-level covariates (Socio-demographic information)
- Linear time trend
- Municipality-level random

Model 4 (Full Model)

- Individual-level covariates (Socio-demographic information)
- Linear time trend
- Municipality-level random

We do not believe that trends in perinatal mortality will be necessarily linear over time or that regional patterns will remain constant, the model will be fit on blocks of 5 years of data separately

Modeling Step 2: Model Selection

Out of the four models described above, we will select the best model based the validation process described in Srebotnjak et al (24). All municipalities with a population of at least 900 people with recent years of data will be pooled and used as a gold-standard. Validation populations will then be sampled from each of these municipalities with 10, 50, and 100 individuals. The models will then be fit on these sample datasets and the results will be compared with the gold-standard estimates for the full municipality population using:

- the concordance correlation
- mean relative error
- root mean squared error

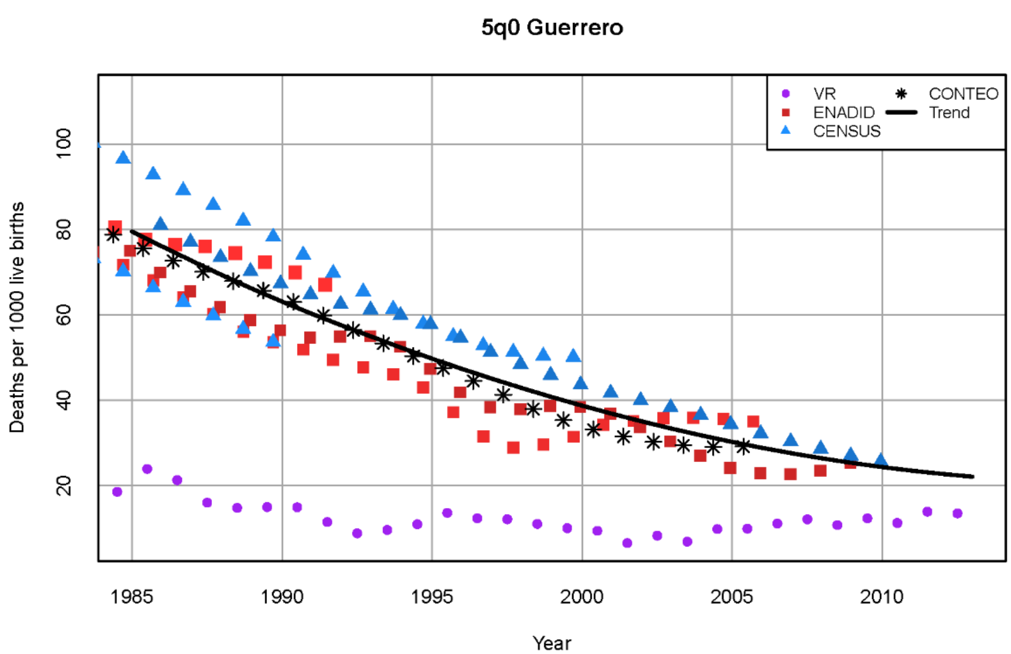
Using this method we will select the best performing of the four available models and report small-area estimates of perinatal mortality using this modeling framework.

Results

Under-5 Completeness

Trends in under-5 completeness are positive, with the general level of completeness increasing over time. Unfortunately, under-5 completeness still lags far behind adult-age death registration completeness with only 4 of the 32 states considered complete (above 95%) in the year 2010. Those states were Guanajuato, Districto Federal, Querétaro and Baja California Sur. **Figure 5** below demonstrates the method for calculating under-5 mortality in the state of Guerrero. There is a clearly different time-trend shown in the synthesized survey data compared to the incomplete registration data, although that disparity diminishes with time.

Figure 5: Under-5 Completeness Assessment, Guerrero



Out of the 32 Federal Entities, we observed an improvement in completeness by at least 5 percentage points from 1990 to 2010 in 17 of the 32 States. We saw declines in completeness 8 states including Oaxaca and Hidalgo. **Figure 6** (next page) shows under-5 completeness by for all the Federal Entities of Mexico (States as well as the Federal District) in 1990 and 2010.

Figure 6: Map of Under-5 Completeness by Federal Entity, 1990 and 2010

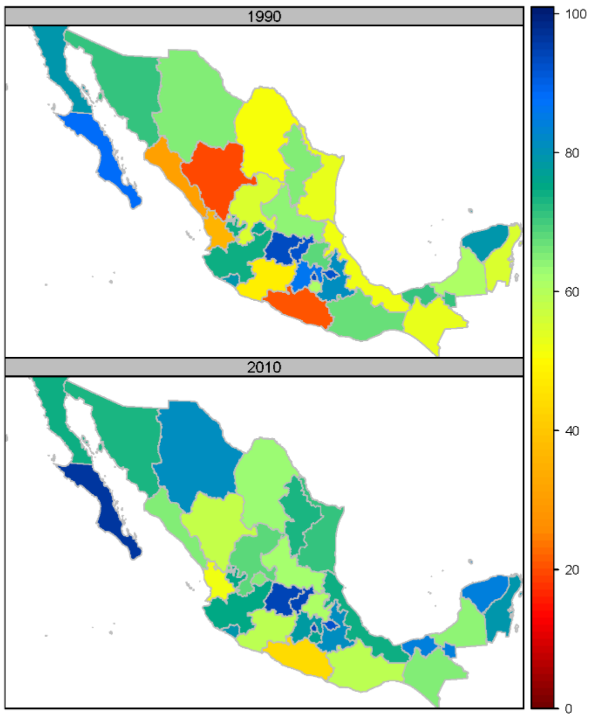
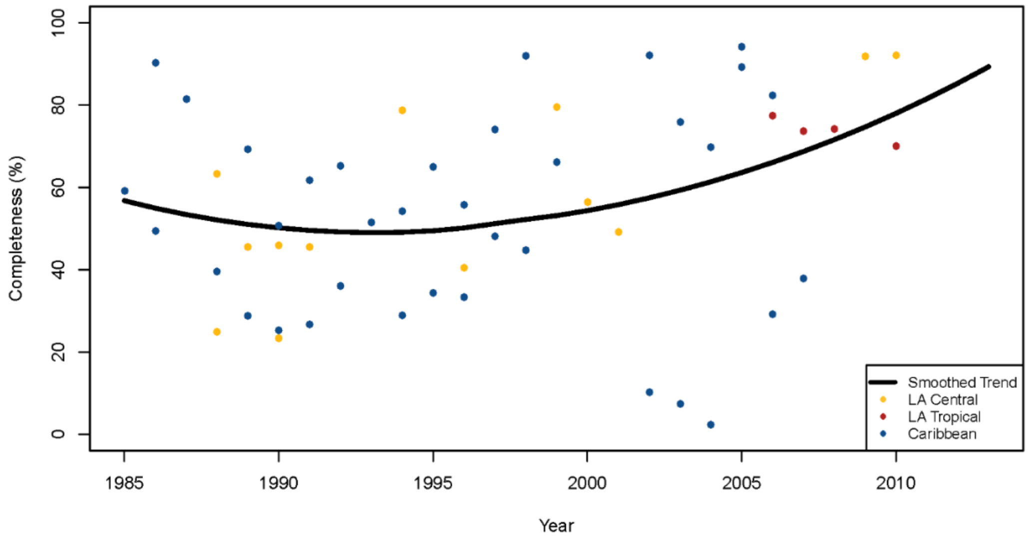


Figure 6 shows improvement and a general positive message, but it also shows that there is still substantial heterogeneity by state and an overall need to continue efforts to elevate completeness levels to those observed in the adult-ages. These estimates of completeness by year form the base completeness estimate which we will use to correct the perinatal mortality rates of each municipality and the state as a whole.

Relationship between Under-5 and ENN/ Infant Completeness

Since we know that completeness can vary within the under-5 period, we have chosen to estimate the relationship between the completeness of registration in ages 0-4 years, 0 years, and 0-6 days. Below **Figure 7** shows our pooled completeness estimates and final time-trend for the Global Burden of Disease and Disability Study (GBD) 2013 Super Region Latin America and Caribbean.

Figure 7: Estimated Early Neonatal Completeness in Latin America and the Caribbean, 1990 to 2013



There are 3 GBD regions contributing, Latin America Central, Latin America Tropical, and The Caribbean. In general we observe a positive trend in completeness, with progress especially in the mid- to late-2000s. It is also important to note how varied the estimates are, this is a difficult measure to accurately capture and there is significant unexplained variation in the estimates.

As with **Figure 7** above, we calculated the regional completeness for both infant and under-5 death registration. The final trend lines for all 3 age groups are shown below in **Figure 8**.

Figure 8: Early Neonatal, Infant, Under-5 Super Region Completeness, L.A. and Caribbean

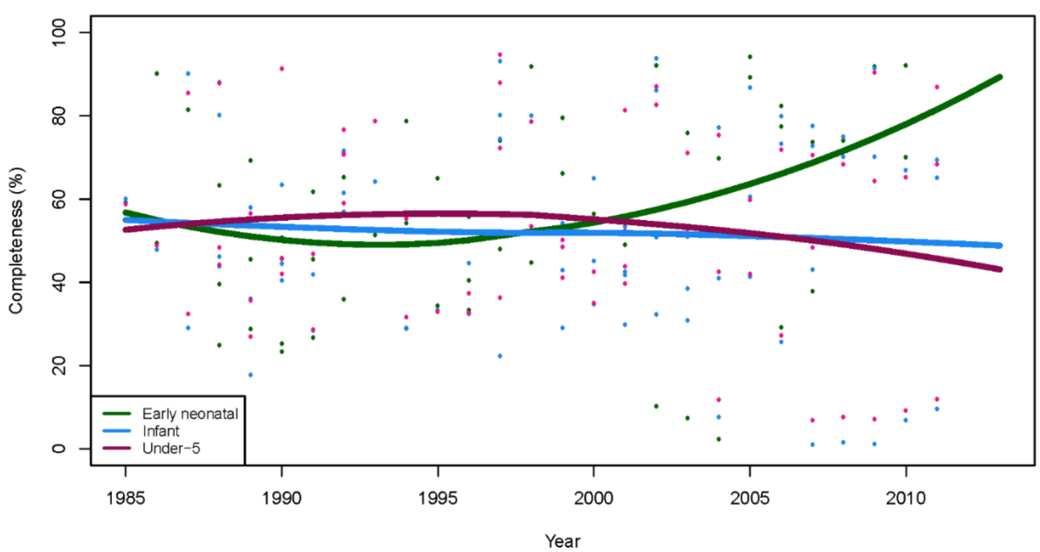


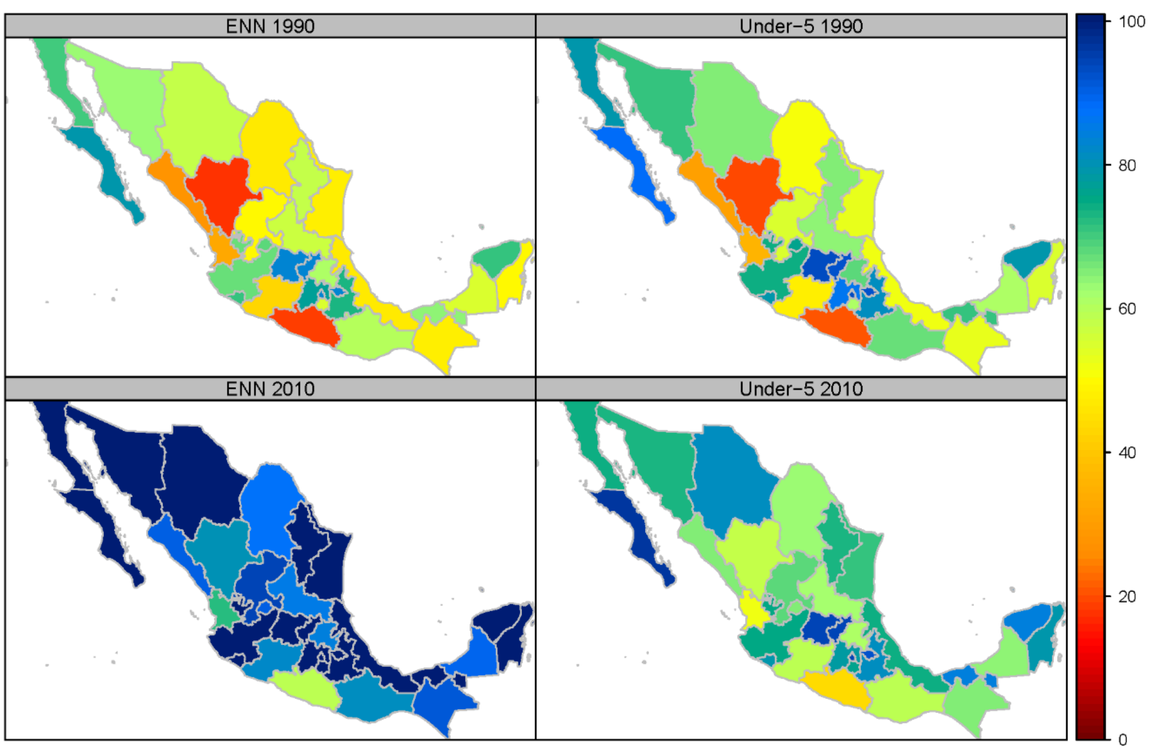
Figure 8 above shows that although improvements have been made in the early neonatal period, the completeness of infant and under-5 deaths has remained relatively stagnant over time. The data used to create these trend-lines is also shown in the graph, with clearly very low estimates in the mid-2000s for infant and under-5 completeness driving this trend. These results have to be viewed cautiously as it is difficult to accurately assess completeness at these disaggregated age groups and there are clearly particular points in the late-2000s which are driving the early neonatal completeness up, while pushing the infant and under-5 trends slightly downwards. **Table 2** shows the average completeness for the time periods 1990-1999 and 2000-2013 in the region.

Table 2: Latin America and Caribbean Average Completeness, by Age and Decade

Decade	Early neonatal	Infant	Under-5
1990	50.3	52.4	56.2
2000	69.1	50.6	50.0

In the 1990s there was higher completeness in the age group under-5 than in infant or early neonatal. Interestingly, this trend has reversed in the more recent period with early neonatal deaths being registered more often as an age group than infant or under-5 deaths. We use these relationships to adjust the under-5 completeness state-level values in Mexico to better reflect the age group of interest here, perinatal deaths. **Figure 9** compares the under-5 completeness estimates with the newly generate state-level early neonatal completeness estimates based on the values listed in **Table 2**.

Figure 9: Early neonatal and Under-5 State-Level Completeness, 1990 and 2010

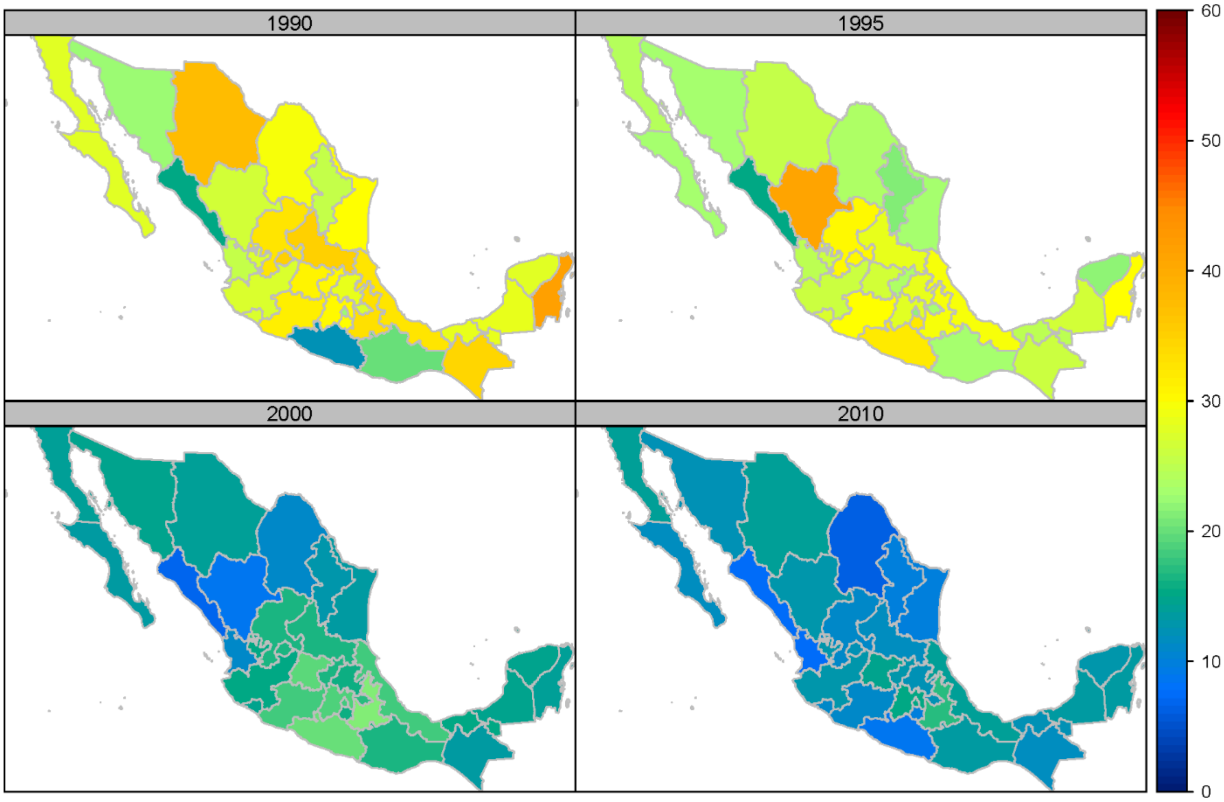


It is clear that the relationships between early neonatal and under-5 registration vastly change the completeness levels 2010 for early neonates compared with under-5 completeness. This has implications for the final results, because it will ultimately predict lower levels of perinatal mortality than would have been generated using the under-5 completeness estimates directly after the year 2000.

Perinatal Mortality

We calculated an unadjusted perinatal mortality rate for all municipalities and states for the time period 1990 to 2011. Once we had our estimates we up-adjusted the perinatal mortality rate base on the completeness estimated at the state-level in a particular year. **Figure 10** below show the state-level perinatal mortality rate estimates adjusted for completeness.

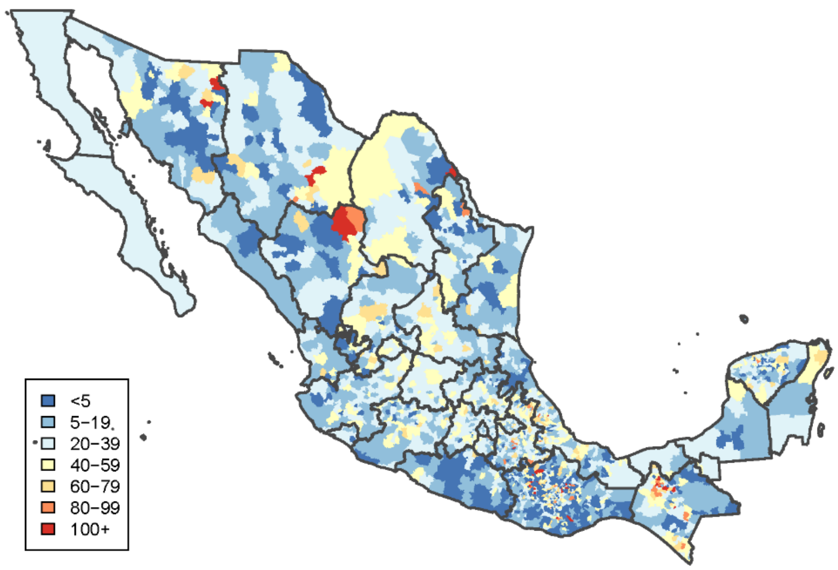
Figure 10: Perinatal Mortality Rate by State, 1990, 1995, 2000 and 2010



There is marked improvement over time in the perinatal rate. This is especially impressive given our completeness estimates in the 2000s are higher. In 1990 the state-level perinatal mortality rate ranged from 13 to 43 deaths per thousand stillbirths and live births. By 2010 that range had shifted to 6-17 deaths per thousand. The highest burden state in 2010 is Puebla with 17 deaths per thousand births (live or stillbirths).

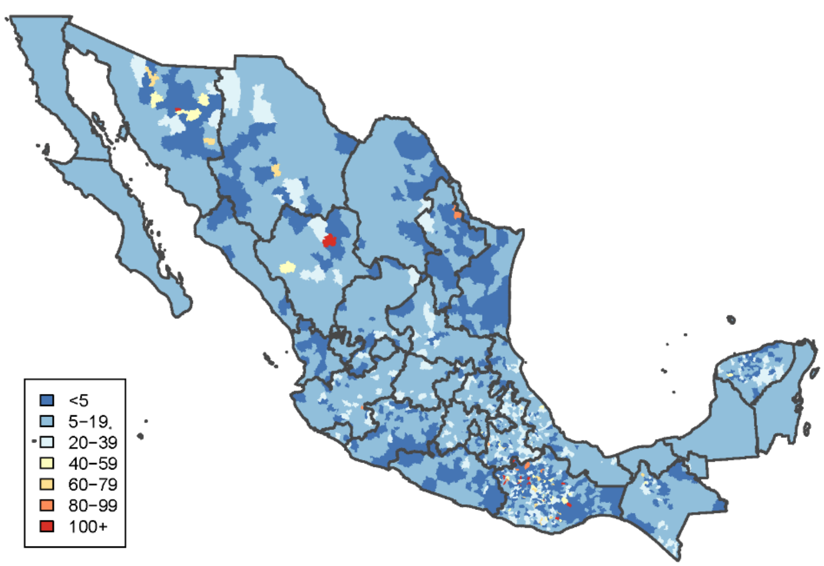
At the municipality level trends are more varied and perinatal rate is difficult to calculate. Often 0 deaths were observed in a municipality-year. It is important to understand if these 0's represent real 0's, a possibility in smaller populations, or if there are unregistered deaths. In the case of the latter, un-registered stillbirth deaths, we have a challenge because the estimates cannot be adjusted for in-complete registration when there are zero observed deaths. This is one of the key reasons why these results represent the inputs into the small-area models rather than the final results themselves. **Figures 11 and 12** show the perinatal mortality rate with the early neonatal completeness adjustment at the municipality level in Mexico for 1990 and 2010.

Figure 11: Perinatal Mortality Rate by Municipality in Mexico, 1990



Although the above picture looks generally positive, it is important to note the scale. Remember that the highest burden state in 1990 was around 43 deaths per 1000. Here that level of perinatal mortality is shown in yellow. There are also outliers above 100 deaths per 1000 during both this period and 2010. Figure 12 below shows improvement from 1990 to 2010 as we would expect based on the state-level analysis but still has a range much higher than the state level estimates, again with outliers above 100 deaths per 1000.

Figure 12: Perinatal Mortality Rate by Municipality in Mexico, 2010



If we change the scale from **Figures 11-12** to better show the variation in burden across municipalities we find that there is great heterogeneity in the perinatal mortality rate measured at the municipality level, with no clear geographic concentration of the burden (**Figures 13 and 14**). We again see improvement over time. Oaxaca is a state of concern with very high values and low values, representing not actual fluctuations in perinatal mortality burden but rather a lack of sufficient data at this administrative level.

Figure 13: Perinatal Mortality Rate by Municipality in Mexico (new scale), 1990

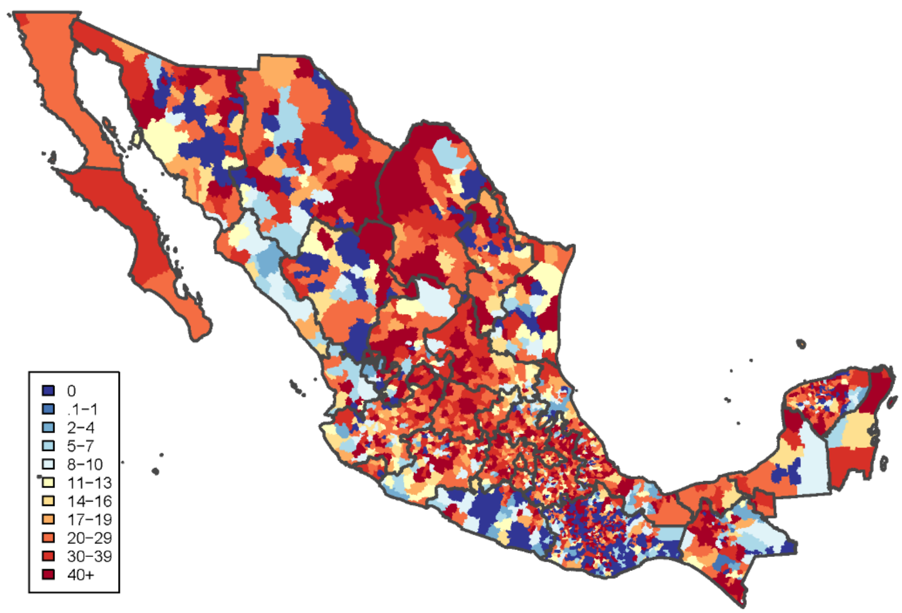
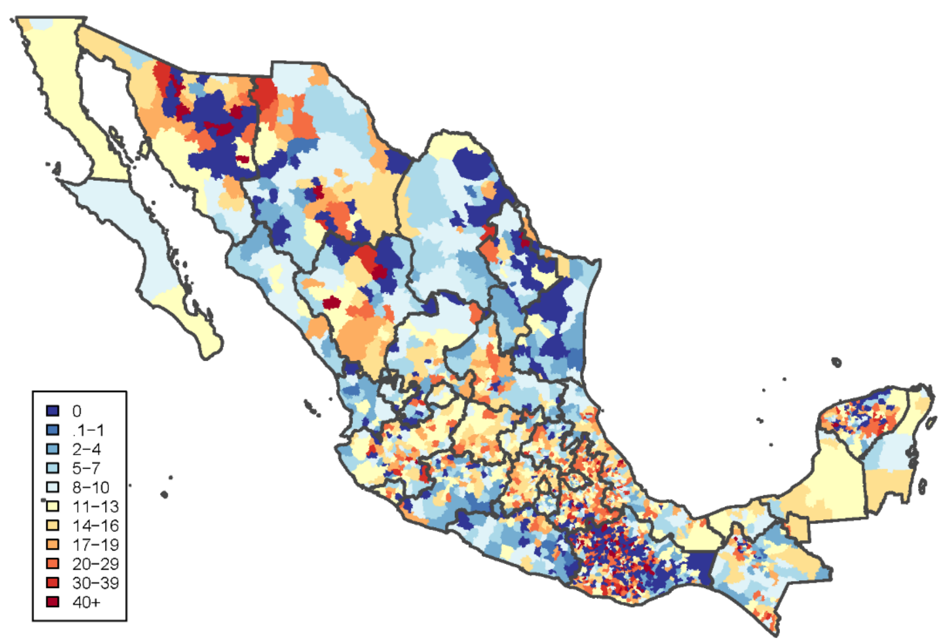


Figure 14: Perinatal Mortality Rate by Municipality in Mexico (new scale), 2010



Since there are over 2,000 municipalities represented here, it is difficult to pull out information for specific municipalities. Appendices have been included in this report to give more information on the state and municipality perinatal mortality estimates represented here.

Perinatal Mortality – Small-Area Estimation Results

This portion of the study is still under active development. It is a critical step in the process given the small number of perinatal events that occur in many municipalities in a given year. This is especially true in the state of Oaxaca which has over 500 municipalities, the most of any Mexican state. We are using covariates available through the census and inter-census CONTEO studies in the development of this portion of the study as was described in further detail in the Methods section of this paper.

Discussion

The research thus far is generally positive at the macro level; we observe the persistent reduction in perinatal mortality as well as improvements in the registration of perinatal deaths over time. Despite the positive time-trends, we also observe that the perinatal mortality burden is still significant and will require continued commitment to health programs which target health during pregnancy and early life. We also observe that the burden is dispersed throughout the country making focused geographic interventions insufficient. Although the evidence from the study thus far promotes continued efforts in areas like Chiapas that have historically faced high mortality and morbidity burden as a state, there is a significant need for improved care in high burden municipalities across all of the 32 states. Although the direct-calculation perinatal mortality estimates (after under-registration correction) largely align with our *a priori* beliefs of where mortality risk will be highest, the large fluctuations in the mortality estimates at the municipality level emphasize how important the use of small-area methods will be in the creation of our final estimates. Since the small-area model of this project is yet unfinished, any comment on which states and municipalities have seen the greatest reductions in perinatal mortality has been omitted here and will be included in later iterations once finalized estimates are ready.

How to measure vital registration completeness in young ages is a long standing open research topic and one that is partially addressed here. It is typical that studies assume that the measured under-5 vital registration completeness is indicative of all age groups under the age of 5. This assumption is likely to lead to errors when specific age groups within the under-5 population are better captured in the registration system than others. Here we have attempted to parse out how younger ages, 0-6 days and infants compare in death registration completeness with the under-5 population as a whole. This is a difficult task. It requires that information from Complete Birth Histories be pooled across large geographic regions. What we find is a shift in the relative completeness between the early neonatal period and the under-5 period for 1990-2000 compared to 2000-2010. In the early decade, under-5 has the highest relative registration while the early neonatal period has the lowest (in the case of Latin America and the Caribbean GBD 2013 Super Region). In contrast, in the 2000s we see that trend reverse with the early neonatal period having the highest relative completeness among these three age groups. This is an important trend reversal and potentially reflects regional efforts to bolster hospital information systems to capture deaths more accurately in hospital settings during the most recent decade. Since many ENN deaths occur within a hospital, improvements in hospital death records is an important system improvement that could explain the relative improvement of ENN registration completeness compared to infant and under-5 registration. An important extension of this work would be to create a statistical model approach that didn't rely on geographic similarity in registration system design and general mortality level. We have not yet found a way to estimate prenatal registration completeness directly and that remains another area for study and improvement. In this case we assume prenatal completeness is constant over time at the level of ENN completeness.

Although a critical portion of this study is still underway, the application of small-area estimation methods, we find the work so far to be a useful benchmark for determining what improvements have been made over time in Mexico at administrative levels that are useful for policy makers. Once the final models are implemented we will be able to look at particular cases where states and municipalities have experienced success and stagnation in perinatal mortality burden from 1990 to 2013.

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