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Spatial modeling of geographic inequalities in infant and child mortality across Nepal

Brian Chin [a,*], Livia Montana [b], Xavier Basagaña [c]

[a] Population Studies Center, University of Pennsylvania, 3718 Locust Walk, 239 McNeil Building, Philadelphia, PA 19104, USA
[b] Harvard School of Public Health, Department of Global Health and Population, 655 Huntington Ave., Boston, MA 02115, USA
[c] Centre for Research in Environmental Epidemiology (CREAL), Municipal Institute of Medical Research (IMIM-Hospital del Mar), CIBER Epidemiologia y Salud Publica (CIBERESP), Doctor Aiguader, 88, 08003 Barcelona, Spain

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ABSTRACT

A survival regression model that allows for spatially correlated random effects is used to predict the hazard of dying among 12,714 children born between 1996 and 2006 in Nepal. The maps of fitted hazard rates show that even after accounting for individual and community-level covariates, a residual spatial pattern in infant mortality remains, with higher mortality concentrated in parts of Nepal's Far-Western and Mid-Western development regions. Results suggest a need to consider health policies and programs that reach children in spatially concentrated high-mortality areas.

1. Introduction

Infant and child mortality measures are sensitive indicators of population health and wellbeing, as they reflect a combination of individual, mother, household, community, and environmental factors (Mosely and Chen, 1984). Underscoring the importance of the measure in reflecting population health and development, under-five mortality was adopted as one of the eight Millennium Development Goals by the UN member states in 2000 (United Nations, 2000). Improvements in child mortality reflect national and international health policy and program efforts to raise education levels, combat undernutrition and poverty, and implement immunization campaigns. In spite of increased attention to improve survival of young children, some 9–10 million children still die before their fifth birthday each year (Murray et al., 2007; Loaiza et al., 2008; UNICEF, 2009).

The determinants and correlates of child mortality have been widely studied, and are generally comprised of individual, maternal and household factors, and community or environmental determinants. Biological causes, as well as nutrition deficits and illness can contribute to a child's risk of dying, particularly at early ages, though these factors are not addressed in this study. Maternal factors such as age, parity, birth order, education, and socioeconomic status are associated with changing relative risks of child mortality (Hobcraft et al., 1985; Boerma and Bicego, 1992; Rutstein, 1984, 2005, 2008; Wang 2003).

The determinants of mortality have been well-studied using nationally representative data from the MEASURE Demographic and Health Surveys (DHS) program (Mahy, 2003; Wang, 2003). Mother's age at birth typically exhibits a U-shaped relationship with the risks of child deaths. Children born to mothers at young and old ages tend to experience higher risks of dying. Young mothers are more often socioeconomically disadvantaged and less educated, which are associated with increases in the risk of child death, while older mothers may have experienced more pregnancies, increasing the risk of child death as parity increases (Mahy, 2003). Both very young and older mothers may be more likely to have pregnancy and delivery complications, further increasing the risk of child death. Birth intervals of 36–47 months exhibit the lowest risks of neonatal, infant, and under-five mortality, but the benefits of longer intervals seem to diminish after 47 months (Rutstein, 2005, 2008).

Around 2001, DHS began to make available to the public latitude and longitude coordinates for the communities where survey respondents live. Some studies incorporated geographically derived variables into non-spatial models of child mortality or morbidity (Balk et al., 2004; Curtis and Hossain, 1998). Other research explicitly used spatial models to study child mortality with DHS data. Gemperli et al. (2004) investigated spatial patterns of malaria endemicity as well as socioeconomic risk factors on infant mortality in Mali in a Bayesian

* Corresponding author. Tel.: +1 914 434 1316; fax: +1 215 898 2124.
E-mail addresses: brchin@pop.upenn.edu (B. Chin), lmontana@hsph.harvard.edu (L. Montana), xbasagana@creal.cat (X. Basagaña).

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hierarchical geostatistical model. Aside from confirming the expected relationships between individual and maternal factors, the resulting residual spatial pattern of infant mortality showed a clear relation to well-known foci of malaria transmission. However, no effect of estimated parasite prevalence could be demonstrated, possibly due to confounding by unmeasured covariates and sparsity of the source malaria data. Kazembe et al. (2007) studied the influence of individual determinants, malaria endemicity, and group-specific environmental factors approximated by geographical location on child survival in Malawi using a spatial Cox model. The expected socioeconomic effects on infant and child mortality were confirmed; and while malaria endemicity was not associated with the risk of infant mortality, it was an important determinant of child mortality. Kandala and Ghilagaber (2006) used a geo-additive Bayesian child survival model for Malawi that showed district-level socioeconomic characteristics were important determinants of childhood mortality. Residual district-level clustering of childhood mortality suggested the remaining importance of underlying spatial effects.

Nepal has achieved remarkable reduction in child mortality over the past decades, yet the rates are still among the highest in the world. While health and development programs have contributed to the improvements, high rates of mortality persist in Nepal, and further reduction may depend on improved targeting of intervention programs. The individual and socioeconomic determinants of child mortality have been widely studied, yet the methods used in previous research on child mortality in Nepal have not accounted for spatial autocorrelation of community-level effects, nor estimated residual spatial inequalities in mortality (Thapa, 2008; Katz et al., 2003; Gubhaju et al., 1991). The objective of this study is to explain the spatial pattern of child mortality in Nepal as a function of sociodemographic and community characteristics while accounting for potential spatial autocorrelation in covariates at the community level. This study builds on existing methodologies by applying a flexible hierarchical survival model that allows for spatially correlated random effects. The spatial correlation may result from the spatial arrangement of the community locations, because communities in close proximity to each other may be more alike than communities farther away from each other. Model-predicted mortality is then mapped to display the remaining spatial pattern of mortality that remains after accounting for community-level spatial autocorrelation.

1.1. Study area

Nepal is a small country of 29 million people, 80 percent of whom live in rural areas. The annual per capita income is $1530, among the lowest in the world. The geography of the country is highly diverse, ranging from the Himalayan mountain range to the flat *Terai* lowlands along the Indian border. Although under-five mortality rates have declined significantly (48 percent) since 1991, the country still ranks in the bottom third of nations globally (UNICEF, 2009; Ministry of Health and Population [Nepal] et al., 2007). Children under five experience a mortality rate of 61 deaths per 1000 live births (Ministry of Health and Population [Nepal] et al., 2007). Results from the most recent Nepal Demographic and Health Survey (NDHS) show that child mortality varies substantially across the country (Table 1). The Mid-Western development region experiences under-five mortality rates of almost twice that of the lowest region in Nepal. Across the three ecological zones, the Mountain zone experiences under-five mortality rates of about twice that of the Hill zone. Infant and child mortality is also higher in the Mountain zone, and in the Mid- and Far-Western development regions. Maps of infant and child mortality rates (Figs. 1 and 2) display the same pattern of high rates in the West, and lower rates in the East. Yet it is likely that these aggregate estimates mask substantial heterogeneity within these regions.

2. Data

2.1. Population

Data from the Nepal Demographic and Health Surveys carried out in 2001 and 2006 are used for the analysis. These nationally representative surveys were carried out under the USAID-funded MEASURE DHS project in collaboration with the Nepal Ministry of Health and New ERA (Ministry of Health [Nepal] et al., 2002; Ministry of Health and Population [Nepal] et al., 2007). The NDHS samples are two-stage cluster sample surveys, designed to be representative at the national level and for both urban and rural areas. The NDHS data contain latitude and longitude coordinates for the centroid of each primary sampling unit (PSU), corresponding to the communities where the survey respondents live. In the 2001 NDHS, 8634 households in 251 PSUs were surveyed. Within these households, 8885 women between ages of 15 and 49 were interviewed and provided information on a total of 6931 births in the last five years. In the 2006 NDHS, 8707 households in 260 PSUs were surveyed. Within these households, 10,793 women between the ages of 15 and 49 were interviewed. These respondents provided information on 5783 births in the last five years. The combined dataset contains 12,714 children under the age of five.

The DHS data contains detailed information on the mothers (education, health, etc.), other household members, as well as household characteristics and assets. A full birth history was

Table 1
Neonatal, postneonatal, infant, child, and under-five mortality rates for the 10-year period preceding the survey, by background characteristic from the 2006 Nepal DHS.

	Neonatal mortality (NN)	Postneonatal mortality (PNN)	Infant mortality ($_1q_0$)	Child mortality ($_4q_1$)	Under-five mortality ($_5q_0$)
Residence					
Urban	25	12	37	10	47
Rural	40	24	64	21	84
Ecological zone					
Mountain	59	39	99	32	128
Hill	28	18	47	16	62
Terai	42	23	65	21	85
Development region					
Eastern	33	12	45	15	60
Central	35	17	52	17	68
Western	35	21	56	18	73
Mid-Western	57	40	97	28	122
Far-Western	39	35	74	28	100