Spatial Modeling of Child Mortality in Nepal[1]

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Abstract

Nepal has achieved remarkable reduction in child mortality over the last 15 years, yet the rates are still among the highest in the world. About one of every 11 children dies before reaching age five. Using the Nepal Demographic and Health Survey 2001 and other geographic data, this paper describes the spatial pattern of child mortality in Nepal by modeling child mortality as a function of individual and geographic covariates in a multivariate generalized additive model. The analysis considers household and individual predictors of mortality, as well as contextual indicators of access to health services and the biophysical and built environments. Results show a strong east-west spatial pattern in child mortality which remains after accounting for individual and household level covariates. This study demonstrates a new approach to analyzing child mortality from DHS data. The results can inform policies to address health inequalities and improve access to underutilized health services.

Background

Nepal is home to 27 million people, 80% of whom live in rural areas. The annual per capita income is US$ 265. Child mortality in Nepal ranks among the highest in the South Asia region. Children under five experience a mortality rate of 91 deaths per 1,000 live births (NDHS 2001). Figure 1 indicates the crude cluster level child mortality rate using the NDHS 2001 survey data. As can be seen from the map, there appears to be a substantial variation in mortality across the country. Curative and preventive health care, thought to influence child mortality, is organized primarily by the Ministry of Health through hospitals located at central, regional and district levels, and at primary health centers (PHCs), health posts (HPs), and sub-health posts (SHPs) located in the community. Figure 2 shows the distribution of public health facilities throughout the country. Hospitals and clinics exist mostly in urban areas; especially the capital, Kathmandu. Figure 3 shows the locations of SHPs with 10 kilometer buffers. Missionary and not-for-profit hospitals also operate in a few areas (MOH 2003). Nepal spends about 5% of its GDP on health, of which only one quarter comes from the public sector; the remainder is paid for by individual households (Hotchkiss et al. 1998, WHO 2006). Approximately 66% of the total amount of public funds spent on health comes from the government; the remainder is covered by donors. Health insurance is almost non-existent, except for a few small-scale community-based financing schemes.

Physical accessibility

Geographic location affects peoples' health, nutrition, and access to health care services. The spatial component of the study employs spatial analyses to improve our understanding of how coverage of and accessibility to health facilities and distance to major roads affect health. Utilization is increasingly being viewed as a function of accessibility and various studies that have examined the physical access to health services using GIS in developing countries (Entwisle et al. 1997, Noor et al. 2003, Black et al. 2004, NoorAli et al. 2005). The issue of equity is raised when the there are barriers to access to health. Before utilization can be realized, health facilities, goods, and services must be accessible.

The situation is striking in Nepal where outside of urban centers soil footpaths connect remote villages in the mountainous terrain limiting access to health facilities. Health facilities ought to be within physical reach for all sections of the population, especially vulnerable or marginalized groups, such as ethnic minorities and indigenous populations, women, children, etc. Accessibility also implies that medical services and underlying determinants of health, such as safe and potable water and adequate sanitation facilities, are within safe physical reach, including in rural areas (CESCR General Comment 14, 2000).

Previous studies examining socio-demographic determinants in Nepal have mainly been involved in describing the use of maternal health services (Matsumura et al. 2001, Furuta et al. 2006). Access to health services studies by financing and quality in Nepal have been geographically limited to a few villages or regions (Niraula 1994). In a study of western and mid-western hill region of Nepal in 2000, Archarya et al. found that effects of access as measured by travel time to nearest health post and coverage by outreach workers are modest, and quality of static services as defined in an index of structural terms: physical infrastructure, number of staff, availability of drugs and holding of special maternal and child health clinics is more important.

Previous research which attempted to take into account geographic location in modeling child mortality using DHS data has not employed spatial modeling (Balk et al. 2003). This may be due to the fact that the DHS data only relatively recently began to make the lat/long coordinates available to the public. This is an exploratory effort to apply spatial modeling to the distribution of child mortality in Nepal.

Research questions

- What is the sub-national spatial pattern of child mortality in Nepal?
- How much of the variation in child mortality is explained by non-spatial factors (such as mother and household characteristics)?
- How much of the variation in child mortality is explained by spatial attributes (geographic location, geographic accessibility to roads, health facilities, distance and characteristics of neighbors?

Data

Population

The Nepal Demographic and Health Survey 2001 data contains 251 latitude and longitude coordinates or primary sampling units (PSU) based on census enumerated population centroids for communities where the survey respondents live. The sample design is a two-stage cluster sample survey representative at the national level and for both urban and rural areas. In those communities, 8,634 valid households were surveyed (about 34 per PSU), 8,885 women between ages of 15-49, and 6,931 births in the last 5 years for these women. The data allow for an effective 10-year mortality rate, which provides more stable rates for modeling child mortality. The 10-year time frame is standard for direct mortality estimates using DHS data.

The DHS data contains detailed information on children under five (immunizations, height and weight, etc.), their mothers (education, health, etc.), and individuals in the household as well as household characteristics and goods. Individual level variables are not collected for the children who died, which limits the covariates that can be used to predict the probability of dying. The variables included in this analysis are detailed in Table 1 (Appendix), and include mother’s education, age, partner’s education, multiple birth, birth order, and the wealth index for the household (Rutstein and Johnson, 2004).

Geographic

Geographic variables including distance to nearest public health facility, hospital, or major highway were constructed. The distance to road variable was calculated from a detailed road network which was classified by type of road (1:250,000, MENRIS-ICIMOD 2005). Distance to health facilities were calculated using latitude and longitude coordinates of public health facilities obtained from the Health Management Information System of the Ministry of Health and Population (HMIS/MoHP 2005). See Table 2 (Appendix) for detailed description and sources.

Methods

A two stage modeling process was carried out. First, a binomial generalized additive logit model was fitted at the individual (child) level (Model 1). The binary response is Y which equals to 1 if the individual died or 0 if he or she is currently alive. The predictor variables included the following binary variables: respondent (mother) had primary education or not, respondent had secondary education or not, partner/spouse of mother had partial secondary education or not, whether the child was a multiple birth or not, whether the birth was second, third or forth parity (compared to first birth), whether the mother was young (20-34) or old (35+) at time of birth, whether the household ranked among the top quintile in wealth status, and the cluster b_i as a fixed effect. See the equation for Model 1 below:

Model 1: Binomial generalized additive logit model

$$Y \sim B(invlogit[b_i cluster_j + \beta_1 respried_{ij} + \beta_2 resseced_{ij} + \beta_3 partpried_{ij} + \beta_4 partseced_{ij} + \beta_5 multipleb_{ij} + \beta_6 birthorder2_{ij} + \beta_7 birthorder3_{ij} + \beta_8 birthorder4p_{ij} + \beta_9 age2034_{ij} + \beta_{10} age35p_{ij} + \beta_{11} wealthq5_{ij}])$$

In Model 2, the predicted fixed effects for each cluster from Model 1 denoted by $\hat{b}_i$, holding the DHS individual and household level covariates at zero, were then modeled in two spatial generalized additive models (Model 2 and Model 3, see below). There were 248 sample clusters for these two models. Model 2 included spatial explanatory variables extracted from ancillary datasets at the same location as the DHS sample clusters. These included distance to highway, altitude of the cluster, distance to health facilities, distance to hospitals, and the number of SHPs within a 10 kilometer buffer. A smoothed spatial term $g(s_i)$ for cluster latitude and longitude coordinates was included in this model using 150 knots.

Model 2: Gaussian generalized additive model

$$\hat{b}_i \sim g(s_i) + \alpha_1 disthiway_j + \alpha_2 altitude_j + \alpha_3 disthf_j + \alpha_4 disthosp_j + \alpha_5 tenkmshp_j + \varepsilon_i, \quad \varepsilon_i \sim N(0,\sigma^2)$$

Finally, Model 3 contained only the smoothed spatial term for the x and y coordinates. The purpose of this model is to be able to identify the contribution of the spatial location on its own. The response variable was the same as for Model 2, where the predicted fixed effect for the cluster was modeled.

Model 3: Generalized additive model with only the spatial term

$$\hat{b}_i \sim g(s_i) + \varepsilon_i, \quad \varepsilon_i \sim N(0,\sigma^2)$$

Results

In Model 1 results (see Table 3 in Appendix), most of the DHS variables are highly significant in explaining child deaths. Only the richest wealth quintile and respondent's education are not significant. Though it would have been expected that the mother's education would be a significant predictor of child deaths, it seems that including the partner/spouse's education absorbs this effect.

In Model 2, cluster-level spatial covariates are used to predict the cluster level predicted effects. Only the distance to main highway term is significant in the model (see Figure 4 for a map of highway locations and crude child mortality rates). The spatial covariates may soak up the variation that would have otherwise been explained by the smoothed spatial term, which is not significant in this model.

In Model 3, the smoothed spatial term without cluster level spatial covariates is highly significant. This suggests that even after accounting for the variation in child mortality due to the individual and household level effects in Model 1, there is still a significant spatial trend in the data which persists. This suggests that above and beyond child mortality when individual and household covariates are held at zero, there is still a significant spatial trend in the probability of dying. Figure 5 shows a surface of predicted probability of child mortality from Model 3. The map shows a strong east to west spatial trend of mortality. The map shows higher probability of dying in the western part of the country, after subtracting off mortality which can be explained when all the individual and household level covariates are held constant at zero. The predicted probabilities of mortality denoted by $\pi = \Pr(Y = 1)$ were calculated by taking the log odds prediction from Model 3 in the following formula where -1.6392 is the intercept or average log odds of dying:

$$\pi = \frac{e^{\hat{b}_i - 1.6392}}{1 + e^{\hat{b}_i - 1.6392}}$$

The resulting prediction grid was mapped in ArcView 9.1. The DHS sample clusters are plotted on the surface. It can be seen that the predictions at the far northwestern and northern edges of the map should be interpreted with caution since there are few points and the estimates may have higher errors due to edge effects. The general trend shows higher probability of dying for children living in the far west, over and above mortality which can be explained when individual and household covariates are held constant at zero. This result seems to agree with the general perceived negative health status in that region, due to limited accessibility in this region, and relative proximity to Maoist rebel activity. The main highway map shows that there are no major roads in this area. Even though there may be health facilities in the region, there is no indication of whether those health facilities are functioning effectively in that area.

Conclusions

Under-5 child mortality is a relatively rare event, even in Nepal which has a very high mortality rate. Individual and household level covariates are significant predictors of child mortality. However, a substantial significant spatial trend remains after holding these individual and household level predictors constant. This suggests that targeted policies or interventions to address child mortality might be needed in the far-western part of the country, over and above what might be needed in the rest of the country. Surprisingly, only one of the geographic covariates was significant in the spatial model. The inclusion or exclusion of this term did not make a difference in the overall deviance explained in the model. It could be that because of such a strong east to west pattern, none of the extra spatial variables are needed or can add to the explanation of the variance in the data.

The variation explained by these models was fairly low, but this is a confirmation of the difficulties in predicting child mortality with very limited cross-sectional data. Because of the wide coverage of DHS surveys, this is an important exploratory contribution to attempt this type of modeling. Furthermore, because mortality is such a rare event, it is increasingly important to try to identify methods of predicting risk or probabilities by geographic area so that effective interventions can be planned and implemented.

The results of this analysis are consistent with the overall aim of explaining the pattern of child mortality, rather than explaining the risk of mortality for specific individuals as a function of individual or household indicators. The potential usefulness of this approach could be improved by perhaps adopting a random cluster effect rather than a fixed effect approach, which could be more efficient. Another concern is the very large standard errors for fixed effects, which are a result of small sample size and few child deaths. It would be useful to try the approach in a larger DHS survey where the method could be cross-validated more easily, and/or in a country with higher total fertility which would give a larger sample of children per cluster. Nonetheless, it is a useful approach to try to estimate and account for spatial pattern in health outcomes.

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APPENDIX

Table 1. Descriptive statistics for NDHS

	Death (n=515, 7.4%)		Survival (n=6,416, 92.6%)	
	n	%	n	%
No education	470	6.8%	5,417	78.2%
Primary education	45	0.6%	753	10.9%
Secondary education	0	0.0%	246	3.5%
Partner's no education	313	4.5%	3,311	47.8%
Partner's primary education	151	2.2%	2,041	29.4%
Partner's secondary education	39	0.6%	943	13.6%
Not multiple birth	486	7.0%	6,359	91.7%
Multiple birth	29	0.4%	57	0.8%
Birth order 1	144	2.1%	1,513	21.8%
Birth order 2	96	1.4%	1,486	21.4%
Birth order 3	79	1.1%	1,098	15.8%
Birth order 4+	196	2.8%	2,319	33.5%
Age 15-19	78	1.1%	947	13.7%
Age 20-34	362	5.2%	4,801	69.3%
Age 35+	75	1.1%	668	9.6%
Wealth quintile 1	160	2.3%	1,646	23.7%
Wealth quintile 2	121	1.7%	1,335	19.3%
Wealth quintile 3	101	1.5%	1,212	17.5%
Wealth quintile 4	90	1.3%	1,229	17.7%
Wealth quintile 5	43	0.6%	994	14.3%

Table 2. Geographic data and sources

Data	Source	Year
Nepal Demographic and Health Survey	New Era, Kathmandu, Nepal; ORC Macro, Calverton, MD	2001
HMIS/MoHP Health facilities	Health Management Information System/Ministry of Health and Population, Kathmandu, Nepal	2005
MENRIS-ICIMOD Nepal Road network	Mountain Environment and Natural Resources' Information Systems-International Centre for Integrated Mountain Development (MENRIS-ICIMOD), Kathmandu, Nepal	2005
Gridded Population of the World	Socioeconomic Data and Applications Center (SEDAC), Center for International Earth Science Information Network (CIESIN) of the Earth Institute at Columbia University	2005
Administrative boundaries	Digital Chart of the World, U.S. Defense Mapping Agency	1992

Table 3. Regression results

Model 1. Binomial generalized additive logit model

	β	SE	t
Primary education	0.07438	0.2040	0.3650
Secondary education	-11.5297	51.0420	-0.2260
Partner's primary education	-0.1309	0.1208	-1.0840
Partner's secondary education	-0.4846**	0.2035	-2.3820
Multiple birth	1.9928***	0.2743	7.2660
Birth order 2	-0.6006***	0.1560	-3.8500
Birth order 3	-0.6547***	0.1724	-3.7970
Birth order 4+	-0.7969***	0.1602	-4.9730
Age 20-34	0.2865*	0.1666	1.7200
Age 35+	0.7685***	0.2335	3.2910
Wealth quintile 5	-0.27288	0.2454	-1.1120
(intercept)	-1.6392**	0.7689	-2.1320
Adj. R-sq. = 0.0336		Dev. expl. = 12.90%	
n = 6,931			
*** *p* < 0.001, ** *p* < 0.05, * *p* < 0.1			

Model 2. Gaussian generalized additive model

	β	SE	t
Distance to highway	4.12E-05**	1.73E-05	2.375
Altitude	2.90E-04	8.20E-04	0.353
Distance to any health facility	1.12E-04	1.38E-04	0.809
Distance to hospital	3.46E-06	1.71E-05	0.202
No. SHPs within 10km buffer	-2.53E-02	3.77E-02	-0.67
(intercept)	-5.00E+00***	1.12E+00	-4.479
	edf	rank	F
s(point_x, point_y)	3.004	7	0.978
Adj. R-sq. = 0.0508		Dev. expl. = 8.15%	
n = 248			
*** *p* < 0.001, ** *p* < 0.05, * *p* < 0.1			

Model 3. Generalized additive model with only the spatial term

	β	SE	t
(intercept)	-3.6388***	0.3277	-11.11
	edf	rank	F
s(point_x, point_y)	4.066**	9	2.232
Adj. R-sq. = 0.0508		Dev. expl.= 8.15%	
n = 248			
*** *p* < 0.001, ** *p* < 0.05, * *p* < 0.1			

Figure 1. Crude child mortality rates

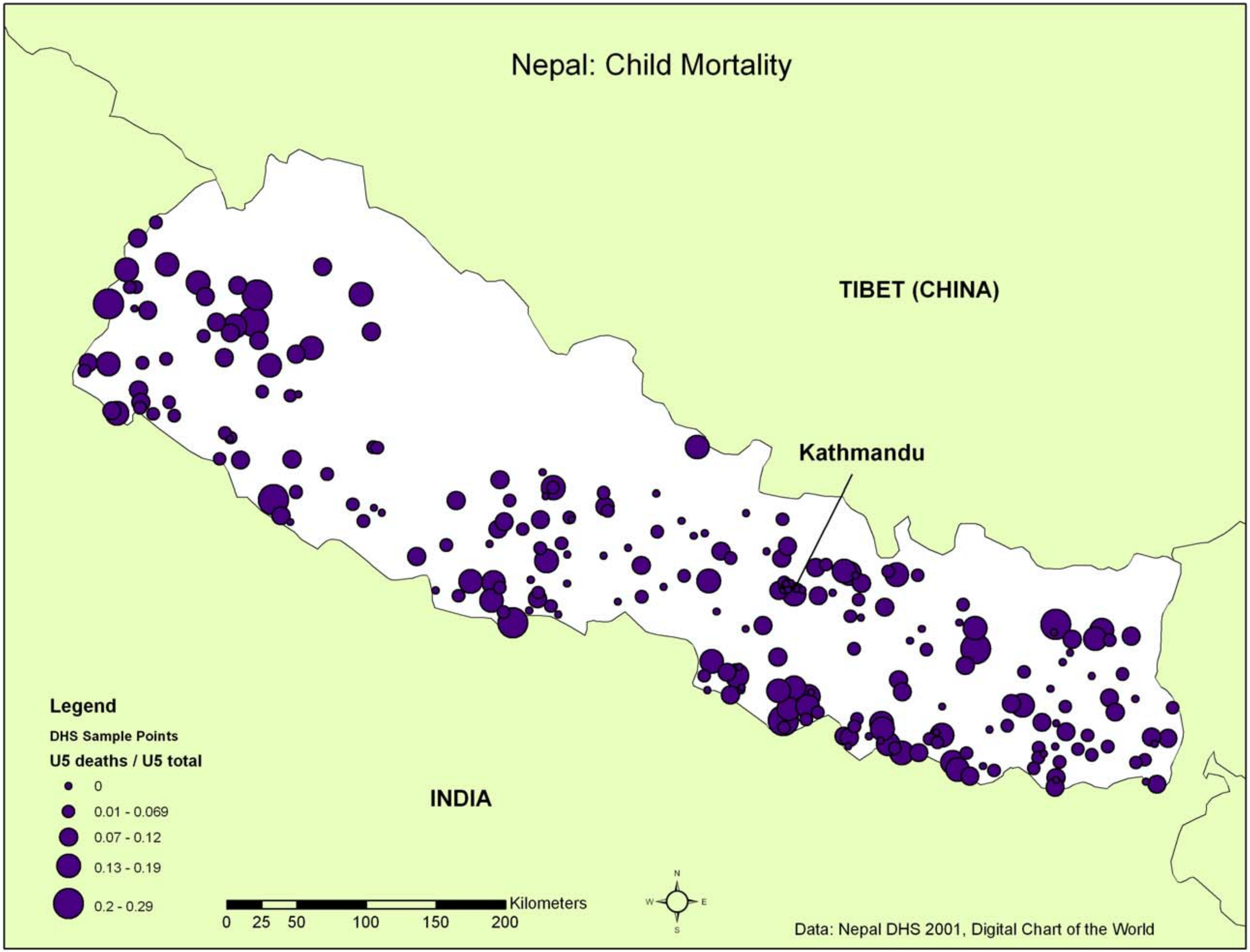

Figure 2. Distribution of public health facilities

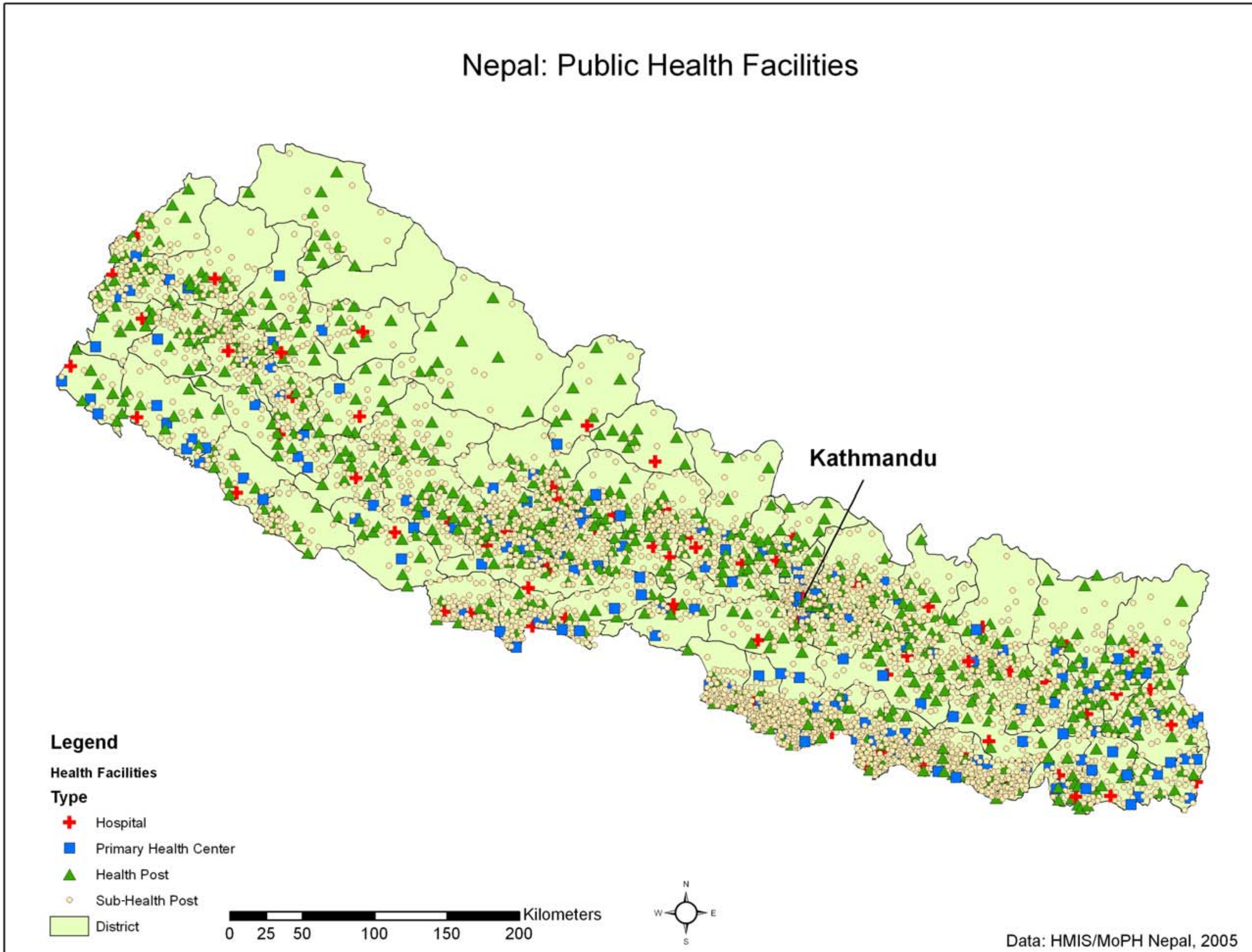

Figure 3. Distribution of Sub-Health Posts and 10km buffers around DHS sample points

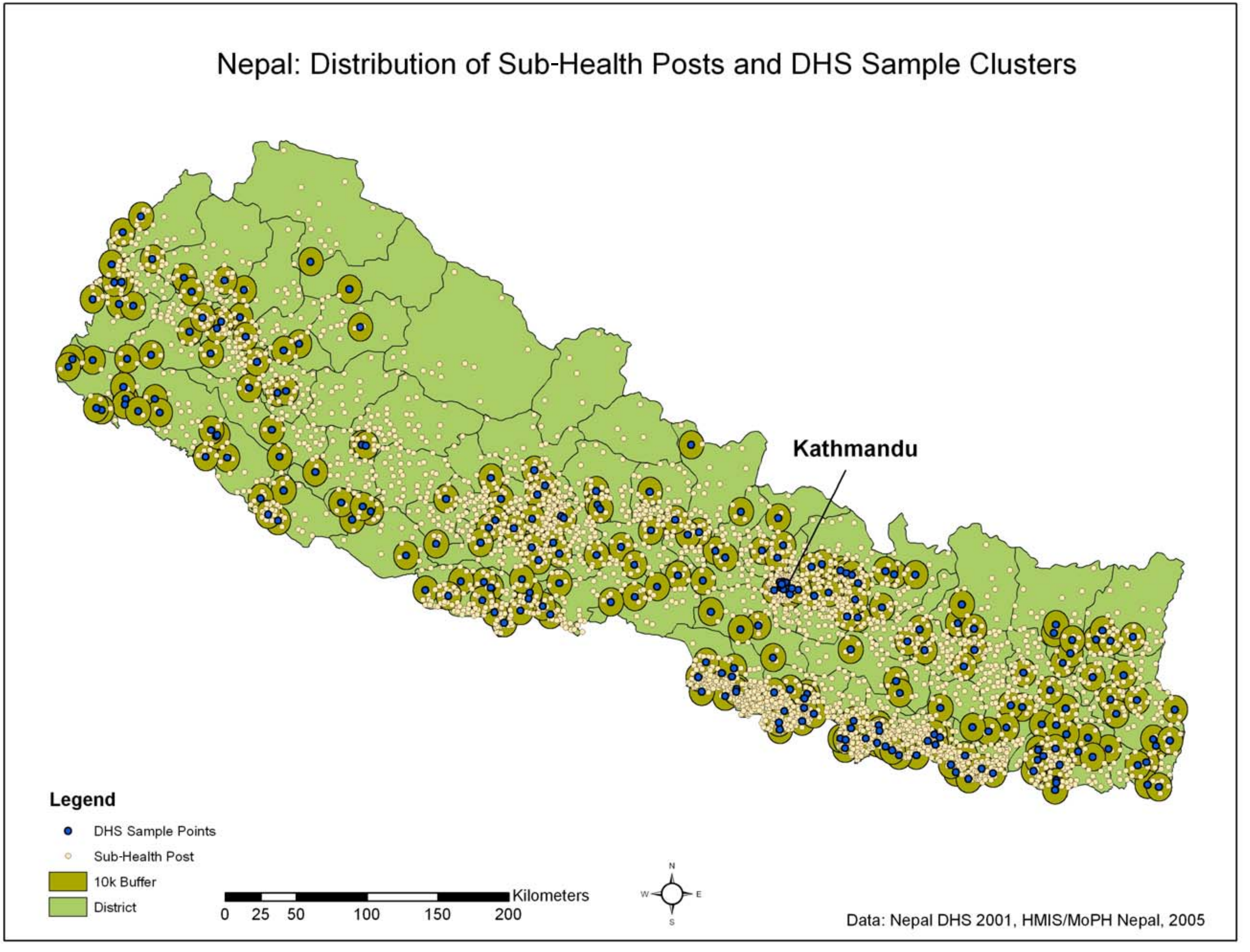

Figure 4. Highway network

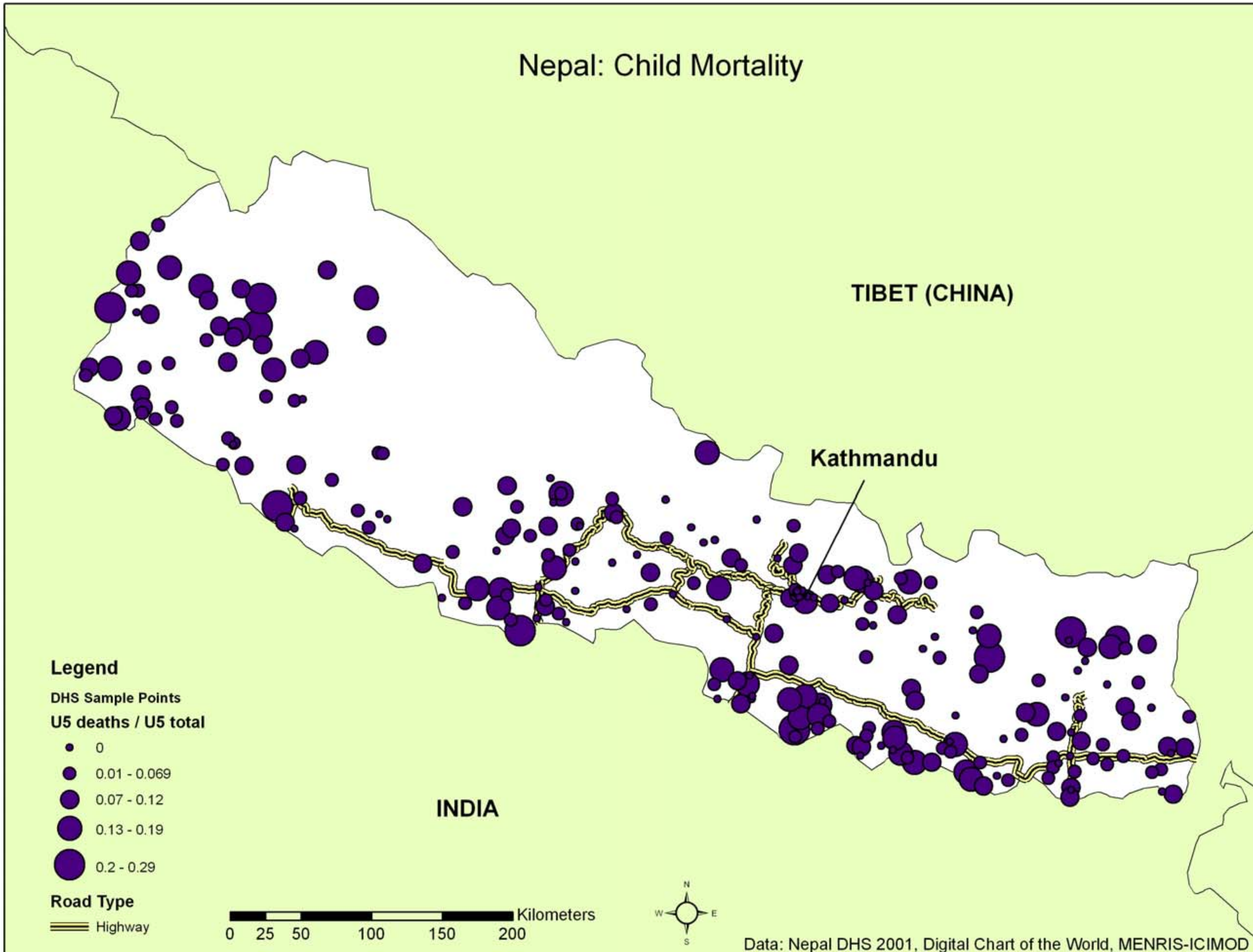

Figure 5. Predicted child mortality map