Spatial modelling of the relationship between socio-economic disadvantage and child health in Namibia

L. Kazembe

Department of Statistics and Population Studies, University of Namibia

340 Mandume Ndemufayo Avenue, Pionerspark, Windhoek, Namibia

Private Bag 13301, Windhoek, Namibia

Tel: +264 61 206 4515

Fax: +264 61 206 3446

E-mail: lkazembe@yahoo.com

ABSTRACT:

Socio-economic disadvantage (SED) is an established risk factor or effect modifier of child health status. Motivated by concerns of addressing health inequalities and social justice, this paper examined the place-specific association of SED with child health in Namibia. We explored this aspect by generating two local indicators of SED: material and earnings deprivation, and used a space-varying coefficients model, to estimate their effects on three child health outcomes (i.e, low birthweight, stunting and under-five mortality) in Namibia. Our findings, not only confirm that children from extremely disadvantaged households were more likely to be of low birthweight, stunted or die in the first five years of life, but also demonstrated the spatial varying association of SED and health. Results provide empirical evidence for designing interventions and policies that are targeted and focal.

Keywords: socio-economic disadvantage, child health, spatial modelling, space-varying coefficient models; Namibia.

1 Introduction

An old African proverb says "a child does not choose which family is born". Children are born to different types of family of varying socio-economic backgrounds. These backgrounds present conditions which considerably affect life-course health outcomes on the child (Gwynn et al., 2012; Van Rossem et al., 2013; Dugmore and Rock, 2005; Graham and Power, 2004). Socio-economic inequalities in child health have been well studied in many countries (Butler et al., 2013; Valery et al., 2013; Blackburn et al., 2013; Flouri et al., 2013; Congdon, 2014). An emerging pattern is that children in socially disadvantaged families or neighbourhoods are at increased risk of adverse health. There is now a body of evidence which has shown a link between mortality in childhood and socio-economic status (Antai and Moradi, 2010; Kazembe et al., 2012). Differences in severity of illness, frequency of hospitalizations and health care utilization, young children's psychopathology, and disabilities seem to be related to socio-economic inequality (Muhajarine and Vu, 2009; Flouri et al., 2010; Vu and Muhajarine, 2010; Emerson 2012; Larranaga et al., 2013; Ansari et al., 2014).

Despite the vast evidence of a relationship between socio-economic inequalities and health, such studies are largely missing in Namibia. In our literature search, only few such studies have been documented. Brockerhoff and Hewett (2000) examined inequality of child mortality using ethnic groups, as social strands, in sub-Saharan African including Namibia. Zere et al. (2011) considered inequalities in skilled attendance at birth in Namibia using decompositional analysis. However, evidence coming from other African studies confirm that socio-economic determinants of health are critical for designing interventions. For example, a recent study in Nigeria, provided evidence that maternal literacy skills is emerging as a key determinant of children's health and survival (Smith-Greenaway, 2013). Abuya et al. (2012) further showed that maternal education had an impact on child nutritional status in the slums of Nairobi. In another study, Antai and Moradi (2010) showed that urban area disadvantage, a consequence of rapid urbanization, was associated with increasing childhood risk of mortality. McIntyre and Gilson (2000), using a South Africa example, proved that promoting vertical equality addresses socio-economic disadvantage, hence has potential benefits on childhood health. Much earlier studies in Tanzania did not show any remarkable differentials in infant and child mortality by socio-economic groups (Mturi and Curtis, 1995). The authors attributed this achievement to post-independence health policies of Tanzanian government. However, we can relate this to a much narrower definition of social disadvantage to socio-economic group.

Related studies provided evidence that polygonous contexts, family structure and infant mortality are linked in sub-Saharan Africa (Smith-Greenaway and Trinitapoli, 2014). They demonstrated that polygny prevalence is arguably reflective of lack of economic and social resources over and above cultural factors, and therefore presents a survival disadvantage for children. While this is the first such study in Africa, the effect of family structure, e.g., unmarried parenthood, single headed female households, young female headed households have been documented to have excess mortality in USA and across Europe (Emerson, 2012; Butler et al., 2013). Further to this ethnicity and marital status, as other strands of social groupings, have been established as predictors of child behaviour and health, e.g. obesity-related behaviour, developmental disabilities, physical activities and diseases (Dugmore and Rock, 2005; Gwynn et al., 2012; van Rossem et al., 2012; Valery et al., 2013). By and large, social determinants of health demonstrate a disproportionate disadvantage to the young in many countries, be it through cross-sectional or prospective studies (Njoku et al., 2013; Blackburn et al., 2013; Congdon, 2014).

These disparities have been shown to vary in space. Small area variation in health outcomes and the effect of social exclusion have been quantified. The place-specific association between social indicators and health create pockets of high risk, spatial imbalances towards achieving equitable distribution of resources. The spatial variability thus established in health outcomes is in part a result of spatially varying social gradients. These have been seen in African settings. An extensive research on spatial models appeared in a recent edition by Kandala and Ghilagaber (2014). For example, Ghilagaber et al (2013) modelled spatial effects of child mortality in Nigeria via a geo-additive Bayesian discrete-time survival model, whereas Khatab (2013) used a mixed latent variable models was investigate spatial effects of child health in Egypt. Manda (2013) applied a flexible spatial mixture model to estimate macro determinants of childhood survival in South Africa. These studies and the chapters therein established that location has an effect on child health be it at micro or macro-scale. In addition, in Malawi (Kazembe 2013), Senegal, Rwanda and Uganda (Kazembe et al., 2012), as well as in South Africa (McIntyre et al., 2002), widening health inequalities by areas-based socio-economic measures were evidenced. However, extensive examples appear in developed countries. See for example, Congdon (2010) in Europe, Butler et al. (2013) in Australia, Congdon (2014) in USA.

Comparatively, such social gradients have not been explored and are rare in developing countries, particularly to depict areas of high risk. In this study, we try to answer the following questions: What is the degree of association between child health and social disadvantage? How does the risk due to social disadvantage vary in space? Are there any clusters of increased risk of childhood due to social advantage? We examine these questions by fitting space-varying coefficient regression models at small area level, using data from Namibia as a case study. We argue that understanding the needs of socially-disadvantaged groups, by highlighting where the high risk clusters are, might assist to accelerate achievement of national developmental goals, through geographical targeting of limited resources. Our modelling approach goes beyond mere establishing the association between an outcome and risk factors, but does explicitly show how the outcome-risk factor relationship is modified by geographical location.

2 Methodology

2.1 Source of Data

Our study used data collected as part of the 2006/7 Namibia Demographic and Health Survey (MoHSS and Macro, 2008). NDHS was designed to provide estimates of health and demographic indicators at national and regional levels, and allow for regional and urban-rural comparisons. A two-stage stratified sampling design was implemented to collect the data. A total of 500 enumeration areas (EAs), 212 in urban and 228 in rural areas, were selected from a sampling frame of 3,750 EAs demarcated in the Namibia Population and Housing Census of 2001. The EAs were selected with sampling probability proportional to the population of the region and stratified by urban/rural status. From the selected EAs, a fixed number of households were randomly sampled, and all women aged 15-49 years were eligible for a face-to-face questionnaire interview. Children's health status was assessed through a child health module asked from the women interviewed. Data were realized through an interviewer - administered questionnaire. Participation in the survey was voluntary and informed consent was obtained from all participants.

2.1.1 Outcome Variables

Three primary outcomes were considered in this study: under-five mortality, stunting and low birth weight. These were measured as follows. Under-five mortality was based on reported deaths and imputed age at death from the interviewed women. All deaths reported to have occurred before the fifth birthday of life were classified as under-five mortality. Stunting is a measure of chronic undernutrition, which was based on the transformed Z scores on the height-for-age and weight-for-age measurements respectively carried on the child, as given in the data. The Z scores are computed based on the World Health Organization (WHO) child growth standards (MoHSS and Macro, 2008). A child was considered stunted if the respective Z score was $Z < -2$. Low birth weight was defined as birth weight of 2500 grams or less. The birth weights were extracted from health cards or from parental recall with birth classified as very large, larger than average, average, smaller than average or very small. About 90.7% of the birth weights were from health cards, while 9.3% were from parental-recall.

2.1.2 Measures of Social Disadvantage

Socio-economic disadvantage (SED) consisted of two components, with the first component measuring deprivation related to housing and assets, which we called SED I, to capture material deprivation, while the second, called SED II, measured earnings deprivation (summarizing education, employment status, type of occupation, seasonality/stability of employment). Material deprivation was based on 14 of socio-economic disadvantage: 1) household without toilet, 2) household with unsafe water, 3) household with polluting cooking fuel, 4) household without electricity, 5) household without telephone, 6) household without radio, 7) household without television, 8) household without refrigerator, 9) household without a bicycle, 10) household without motorbike, 11) household without a car/truck, 12) household with rudimentary floor, 13) household with rudimentary/unfinished wall; and 14) household with rudimentary/unfinished roof. Note that some of these variables are often used to calculate the well-known wealth index (Rutstein, 2004).

Low or unstable earnings index was based on 6 indicators including: 1) mother is not working, 2) father is not working; 3) mother working in seasonal occupation, 4) father working in seasonal job, 5) mother working in agricultural sector, 6) father working in agricultural sector.

The indicator variables were then categorized to score 1 for "disadvantage" and 0 for "no disadvantage", then were suitably standardized to generate a factor analysis scores. The observed factor scores were used to construct quartiles (four levels of disadvantage) ranging from (I): low disadvantage; (II): mild disadvantage; (III): moderate disadvantage; to (IV): extreme disadvantage, that is, higher levels suggest increased levels of socio-economic deprivation (SED).

2.1.3 Control variables

We considered the following variables which are often used as predictors in study of child health (Mturi and Curtis, 1995; Kazembe, 2013; Smith-Greenaway, 2014). The child demographic variables included were: (1) age of the child categorized as: 1–5 months, 6–11 months, 12–23 months, 24–35 months, and 36–59 months (reference group); (2) birth order (categorized as: 1st born, 2nd or 3rd born, 4th to 6th born, 7th born or higher); and (3) birth interval (categorized as: $<$ 2 years, 2-3 years, 4 years or more). Maternal factors considered included (4) maternal education, which was captured as none, primary school or secondary and higher education levels; (5) maternal age which was classified as $<$ 20 years, 20-29, 30-39 and 40-49 years; and (6) antenatal care categorized as zero visits, one visit, 2 to 3 visits or 4 and more visits during pregnancy. An additional socio-economic variable included in the analysis was: (7) type of place of residence (rural=1, urban=0).

To determine the geographical patterns of health outcomes (LBW, stunting, under-five mortality) and SED indicators (material and earnings deprivation), for our case study, there were 107 contiguous sub-regions, called constituencies, to which a household belonged. Constituencies were identified by using centroids of the EAs, which were recorded at the time of the survey. The minimum and maximum number of EAs in the sampled constituencies were 3 and 16 respectively, with a mean of 7. These constituencies were used as the unit for the spatial analysis.Figure 1 displays maps of prevalence of LBW, stunting and under-five mortality, while Figure 2 shows the geographical distribution of SED indicators.

2.2 Statistical Analysis

2.2.1 Approach to the Analysis

The spatial modelling approach adopted here is conceptualized using the *hazards-of-place* model of vulnerability (Cutter et al., 2003). As highlighted in the introduction, our modelling approach goes beyond mere establishing the association between an outcome and risk factors, but does explicitly show how the outcome-risk factor relationship is modified by geographical location. Accordingly, we estimate the place-specific association between SED and child health based on the *hazards-of-place* framework.

Thus, our analysis preceded as follows. First, for exploratory purposes, bivariate logistic regression models were fitted with all variables, including the two SED indicators, assumed as fixed effects. Second, variables significant at $p < 0.2$, were included in a multiple logistic model adjusting for spatial random effects, giving a univariate spatial hierarchical model. This model included areas (i.e. constituency) as spatially structured and unstructured random effects, while maintaining all covariates, including the two SED indicators, as fixed effects. Third, we relaxed the univariate model by allowing for space-varying coefficients in the two SED indicators.

2.2.2 Univariate spatial model

Consider a typical univariate disease mapping study. Assume Y_i is the health status (0/1) for child i, then the outcome is modelled using a binary logistic regression model,

$$\eta_i = \alpha + \sum_{j=1}^{r} \beta_j F_{ji} + \sum_{k=1}^{q} \gamma_k V_{ki} + \theta_i + \phi_i \tag{1}$$

where α is the intercept, while $\beta_j, j = 1, \ldots, r$ are regression coefficients corresponding to the effect of the SED indicators F_{ji}. In addition we have individual covariates $V_{ki}, k = 1, \ldots, q$, with corresponding fixed effects γ_k. To account for extra-binomial variation we introduce random effects θ_i and ϕ_i to represent spatially structured and unstructured random effects, respectively. Random effects try to capture differential inequalities in unmeasured or unobserved factors existing in an area that may cause geographically structured variations in health outcomes. For example, unobserved community and family factors such as cultural or traditional factors that tend to differ with ethnic groupings may influence adverse health.

In modelling spatially structured random effects, an intrinsic conditional autoregressive (CAR) prior was chosen (Besag et al., 1991). This assumes that the mean for each area θ_i, conditional on the neighbouring areas, has a normal distribution with mean equal to the average of neighbouring areas θ_l, and variance inversely proportional to the number of neighbours m_i. Under contiguity, with $w_{il} = 1$ if areas i and l are adjacent and $w_{il} = 0$ otherwise, the CAR prior has the form,

$$\theta_i | \{\theta_l; l \sim i\} \sim N\left(\frac{1}{m_i} \sum_{l \sim i} \theta_l, \frac{\sigma_\theta^2}{m_i}\right) \tag{2}$$

where $l \sim i$ denotes adjacency of areas l and i on the map, σ_θ^2 is a spatial variance, which controls the degree of smoothness. At a further step of hierarchy σ_θ^2 is modelled using the inverse Gamma (IG) with known hyperparameters $a = 0.5, b = 0.005$. This gives a weakly informative but proper prior. For moderate to large data sets results are rather insensitive to the choice of a and b. However, because of the known concerns about this prior's possible informativity, a sensitivity analysis was carried out. The unstructured extra-binomial heterogeneity was estimated using an exchangeable normal prior, $\phi_i \sim N(0, \sigma^2_\phi)$, where σ^2_ϕ measures the degree of heterogeneity, which again was assigned an IG hyperprior.

2.2.3 Spatially-varying coefficient spatial model

The second model fitted is an extension of Model (1), in which we allow the SED indicators to spatially vary. Here spatially smoothed, rather than observed, SED indicators, F_j, are now used in the regression model.

$$\eta_i = \alpha + \sum_{j=1}^{r} \beta_j F_{ji} + \sum_{k=1}^{q} \gamma_k V_{ki} + \theta_i + \phi_i \tag{3}$$

where β_j is now considered as space-varying coefficients, obeying the same process as in Equation (2), i.e,

$$\beta_j | \{\beta_l, j \neq l, \sigma^2_{\beta_j}\} \sim N\left(\bar{\beta}_j, \frac{\sigma^2_{\beta_j}}{m_j}\right) \tag{4}$$

with parameters σ^2, and m_j defined as before. Similarly the components θ_i and ϕ_i assumed the same process as described in section (2.2.2).

2.3 Implementation

To implement the model we applied the full Bayesian estimation technique because of numerically intractable models. Model fitting used Markov Chain Monte Carlo simulation techniques to draw samples from the posterior distribution and was implemented in `BayesX` 1.4 (Brezger *et al.*, 2005). Convergence was monitored by visual examination of time series plots of the samples for each chain, and confirmed by plotting the Gelman-Rubin statistic. The first 10,000 samples were discarded as a "burn-in" and then each chain was run for a further 30,000 iterations. Because of autocorrelation within the three chains, every 10th subsequent iteration was stored, yielding 3,000 sub-samples for parameter estimation.

3 Results

3.1 Exploratory analysis

In a sample of 6636 children, the prevalence of low-birth-weight, stunting and under-five mortality were 8.2, 10.3 and 5.6% respectively. Figure 1 shows the geographical variation in the three health outcomes. Generally, there was low prevalence of all three outcomes, with may areas recording near zero values. However, stunting prevalence was registered to have had few areas of close to 60% prevalence. About 55% of children were from rural areas, and 32% were infants (Figure 1). The majority of children (70%) were either first-borns or at second and third order. Most children were born to mothers who attained some formal education (31% attained primary, while 52% achieved secondary or higher).

Extreme material deprivation was higher compared to earnings deprivation, with mean prevalence of 30.4% (range: 0-85.7%) and 13.02% (0-84.0%) respectively. Figure 2 displays the geographical distribution of extreme socio-economic disadvantage. The highest prevalence of extreme disadvantage for both indicators was observed in the north of Namibia. The spatial patterning is somewhat correlated with the three health outcomes. The correlation between low-birth-weight and the SED indicators was low (LBW and SED I was 0.07; LBW and SED II was 0.11 respectively), whereas for stunting and the two SED indicators were 0.39 (SED I) and 0.45 (SED II), while for under-five mortality were 0.27 and 0.23 for SED I and SED II respectively.

Table 1 presents results of the bivariate regression analysis of the relationship between the three outcomes and risk factors. Low birth-weight was associated with material and earnings deprivation. Both risks of stunting and under-five mortality increased with increasing levels of material deprivation, however, there was reduced risk of stunting and under-five mortality with earnings deprivation. Although rural resident children were at at high risk of LBW, stunting and under-five mortality, significant association was only observed with stunting. Child specific characteristics like age of child and birth order, and maternal covariates such birth interval, maternal education, maternal age and antenatal use were all associated with the three health outcomes.

3.2 Fixed effects of low-birth-weight, stunting and under-five mortality

We next present model estimates from the multivariate spatial model, again, fitting the two SED indicators as fixed effects (Table 2). Low birth-weight increased with extreme material deprivation (OR=1.39, 95% CI: 1.03, 1.88) compared to low material deprivation. However, with earnings deprivation we observed a U-shaped relationship in risk (OR=1.32, 95% CI: 1.05–1.66) for class II compared to class I, and OR=1.54 (95% CI: 1.14-2.09) for class III relative to class I, nevertheless the risk was reversed at the extreme level of earnings deprivations (OR=1.25). Furthermore, the odds of LBW was higher for those children whose mothers only visited the antenatal clinic once (OR=1.77, 95% CI: 1.10, 2.84) or used the services twice or thrice (OR=1.25, 95%CI: 1.03-1.52) compared to those who used ANC for the recommended four or more times.

We also established a positive relationship between stunting and material deprivation (Table 2), with increasing risk with increased material deprivation (OR=1.78, 2.52 and 3.31 for class II, III and IV respectively). With regards to earnings deprivation, no significant relationship was observed, although a higher risk was observed at extreme levels of disadvantage (Table 2). Stunting was equally associated with child's age, maternal education, maternal age and birth order. The likelihood of stunting was lower at young age (OR=0.18, 95% CI: 0.14, 0.23), and increased with increasing age of the child with some indication of a nonlinear relationship between stunting and age of the child (OR=0.62, for the 7-11 months, 1.82 for those at 12-23 months and 1.20 for children in age range 24-35 months respectively). For maternal education, children who had mothers of no formal or primary education were at a higher risk of stunting (OR=1.71, 95% CI: 1.36-2.15 and OR=1.57, 95% CI: 1.34-1.83 respectively) compared to having secondary or higher education. Children born to young mothers were at a relatively high risk compared to much older women (OR=2.27, 95% CI: 1.50-3.33), and this decreased with increasing maternal age (OR=1.92, 95% CI: 1.43-2.56 and OR=1.39, 95% CI:1.08-1.79 respectively).

Turning to under-five mortality, the risk of death was OR=1.38(95% CI: 1.09-1.73) for class II of material deprivation compared to class I. The risk increased as the level of material deprivation increased (OR=1.48, 95% CI: 1.16-1.91 at class III; and OR=1.61, 95% CI: 1.11-1.99 for upper class respectively). A high risk of death was also associated with earnings deprivation, OR=1.09 (95% CI:0.8801.36) at lower class II, OR=1.58 (95% CI:1.18-2.11) for medium class III, and OR=1.04 (95% CI:0.84-1.30) for the upper class IV. Under-five mortality was associated with maternal education, maternal age and antenatal care visits. Results indicate that children of mothers of primary education were at increased risk (OR= 1.42, 95% CI:1.19-1.68) compared to those whose mothers had secondary or higher education. Young mothers were more likely to experience under-five mortality than much older mothers (OR=1.66 and 1.32 for mothers aged $\leq$ 20 years and 20-29 years respectively). Non-use or fewer visits for antenatal care increased the risk of under-five mortality (OR=2.12, 95% CI: 1.39-3.28 for lack of no antenatal use; OR=1.54, 95% CI: 0.77-3.09 for only one use; and OR=1.71, 95% CI: 1.37-2.19 for 2 or 3 antenatal visits).

3.3 Space-varying coefficients of SED I and SED II

Figures 3 and 4 present results for the socio-economic disadvantage indicators fitted as space-varying coefficients. Figure 3 shows odds ratios of association of SED I with low-birth-weight, stunting and under-five mortality (maps a, c, and e) and corresponding probability maps (b, d and f). The probability maps highlight areas where OR>1 is above 80% or below 20%, in other words, the map shows areas where spatial clusters of risk occur based on Richardson's criterion (Richardson *et al*, 2006). This criterion recommends that probabilities over 80% be deemed positively significant (black colour in the map), those below 20% be judged negatively significant (white colour in the map), while those between 20 and 80% be considered not significant (gray colour in the map).

In Figure 3a, the risk of low birth weight due to material deprivation was 1% to 9%, relatively higher than the average, across all areas in the country (OR ranging between 1.01-1.09). The probability map (Figure 3b) show that the risk was significant higher in most central areas of Namibia, except for the capital, Windhoek, which is indicated by a white dot in the middle of the map. The varying effect of material deprivation on stunting is given in Figure 3c. The risk, as measured by the odds ratio, showed a marked difference across the country (OR= 1.15 to 2.43). This difference is confirmed by the probability map (Figure 3d). Again, material deprivation did not show a positive relationship for areas in Windhoek indicated by white colour in the centre of the country. The varying effect of material deprivation on under-five mortality display estimates of OR ranging between 1.13 and 1.81 across the country (Figure 3e). However, this variation was not significant (Figure 3f).

Figure 4 displays the varying effects of SED II (earnings deprivation) for low birth weight, stunting and under-five mortality. With regards to the risk of low birth weight and SED II, the range of odds ratios is 0.89 to 1.35. Similar patterns emerged in which the southern part has a higher risk imposed by SED II, and was attenuated as we move northward (Figure 4a). However, only the south and central parts of country depict significant association (Figure 4b). For stunting, Figure 4c, most of the measured high risk areas were in the north, but the odds ratios varied from 0.98 to 3.89. Considerable significant association was observed in many parts of the country, as depicted by the corresponding probability map (Figure 4d). Now turning to under-five mortality, the odds ratio varied from 1.028 to 1.03 (Figure 4e), suggesting little difference as supported by the probability map (Figure 4f).

3.4 Total residual spatial effects

Total residual spatial effects, after accounting for fixed and space-varying effects still remained significant for some outcomes, and are plotted in Figures 5 and 6. Figure 5a shows the spatial effects in the LBW model and the corresponding posterior probabilities map at 80% nominal level (Figure 5b). There is little evidence of spatial variation in risk of LBW in Namibia, having controlled for the space-varying effect of SED I. It is clear that areas at the center of Namibia, which is mostly urban, reported reduced risk, whereas those in Caprivi had increased risk, and most of the country showed no significant risk associated with location. For stunting, areas of increased risk still remained (Figure 5c,d), with odds ratios ranging between 0.47 and 2.14. With regards to under-five mortality, there were fewer clusters of elevated risk, located in Caprivi region (Figure 5e), however, none of these remained significant (Figure 5f).

Figures 6a and 6b show the residual spatial effects of LBW, after controlling for space-varying effects of SED II. Here we observed clusters of positive association in the north-eastern region, along Caprivi, and low clusters in the south and northern areas. For stunting, as shown in panel 6c and 6d, there was evidence of positive clustering in the the Kunene, Kavango and Caprivi regions, and isolated constituencies in Otjozondjupa. The residual effects for under-five mortality are given in panel 6e. Similar patterns of positive association were obtained in the northern constituencies, bordering Angola, but more elevated again in Caprivi. Nevertheless, none of these effects were significant (Figure 6f).

4 Discussion

Inequalities in child health are of a major public concern for policy makers. Many governments have made commitments to examine inequalities in health outcomes, based on studies assessing the association between socio-economic factors and population health. The reduction of social health inequality equally ranks high in Namibia. The five-year National Development Plan IV (2011-2016), which contextualises the Namibian Vision 2030 (the country's development blueprint), explicitly includes health as one of its pillars to achieve development goals. The Namibia Vision 2030 is based on the principle of inclusivity, such that essential health services are of universal coverage, through decentralized governance. The aggregate goal is to attain health standards in Namibian populace as enjoyed by their counterparts in developed countries. The means of governments to respond to social inequality and injustice, and more broadly, to improve population health largely requires identification, and targeted application of interventions. This study aimed to fill such a gap.

In this paper, we used the spatial modelling approach to study the effect of socio-economic disadvantage on child health, focussing on estimating the space-varying effect of SED on child health in Namibia. Two measures of SED were considered: material deprivation and earnings deprivation. The spatial structure of SED was modelled by assuming a conditional autoregressive model. The main underlying reason for this is that, for each measure of SED, its effect may not be constant in space, but for some reason, neighbourhood contextual factors may impose some modifying effects on the association that exists between material and earnings deprivation on each of the health outcomes. This addition evidently show that while SED may be an important risk factor on child health (Muhajarine and Vu, 2009; Flouri et al., 2010; Butler et al., 2013; Valery et al., 2013; Blackburn et al., 2013), geographical location can act as a mitigating factors for some or may exacerbate such risk for others (Butler et al., 2013; Njoku et al., 2013; Congdon, 2014). The place-specific association between SED and child health would assist in making targeted and focal interventions.

The models have been applied to three most challenging child indicators: low birthweight, stunting and under-five mortality. These indicators have remained stubborn and stagnant for many years in Namibia (MoHSS and Macro, 2008; WHO, 2012). We must emphasize, though that LBW, stunting and early child mortality are not a huge public health problem in Namibia compared to other countries in the sub-Saharan region, however, substantial disparities exist at sub-regional level. Highlighting such geographical clusters, and the influence of socio-economic disadvantages is important to inform appropriate policy action, especially for resource allocations to achieve development goals, e.g. the national development plan and millennium development goals (Alegana *et al.*, 2012; Kazembe *et al.*, 2012).

We observed persistent high risk in the north of Namibia, which is predominantly rural. Increased risk in rural areas may be an influence of different factors. For example, unavailability or inaccessibility of health facilities, as well as inadequate skilled health personnel, may increase the risk of rural children (Zere *et al.*, 2010, 2011). Health seeking behaviour also plays a critical role in accessing prompt and effective care (Alegana *et al.*, 2012). Scaling-up of interventions or health promotions should be emphasised in rural areas, which have difficulties in accessing care or more inclined towards home remedies.

In addition, social, cultural and other environmental factors which may impose a cumulative effect on childhood health may be worthwhile investigating, particularly in high risk clusters (Antai and Moradi, 2010). For instance, continuous shortages of rainfall, a common phenomenon in Namibia, leads to food insecurity, resulting in childhood malnutrition. This is another important risk factor of childhood co-morbidity and mortality (Caulfield *et al.*, 2004), which may warrant further research. Deepening poverty levels in some parts of the country may also explain the spatial variation in childhood health. The Namibia Statistics Agency report of 2012, further reported that areas in the North-east part of the country were worst-off as regards incidence of poverty (NSA, 2012). Our analysis showed a clear geographical clustering of high risk in the health outcomes in these areas.

We now highlight a few limitations of this study. First, the data used in this analysis was based on cross-sectional study and therefore the relationship is associative. Second, this study include the measurement of births and deaths, which can suffer from recall bias. The accuracy of births and deaths estimates depends on the sampling variability of the estimates and non-sampling error. The most serious in recall data is under-reporting. Typically, such recall may introduce measurement errors, thus distorting the apparent spatial pattern of risk. The possible occurrence and remedies of these data problems in 2007 Namibia DHS is discussed in the survey report (MoHSS and Macro, 2008). In summary, to limit the bias, questions were limited to the last birth that have occurred within three years preceding the survey, following the standard practice used in DHS surveys. In addition, child health is affected by many factors, and our list is not exhaustive, however, the analysis is limited by the DHS data available. In fact, the control variables used are standard in child health in low-medium-income countries, in which DHS programme collects the data. Further limitations, which is related to future research directions, is that the three health outcomes may be related at small-area level, and therefore spatial models dealing with multiple health outcomes could be appropriate. Examples of such techniques appear in Kazembe et al (2009), Feltbower and Manda (2012) and Manda et al (2012). Nevertheless, the correlation across the three outcomes considered here were not strong to warrant multivariate spatial models.

In conclusion, there are few main policy implications to addressing the clustering of LBW, stunting and under-five mortality in northern Namibia. First, there is need for increased social support for the socially disadvantaged communities, for example, through child support grants and food subsidies. Second, there is need to provide good nutrition, health education, and health and preventive care facilities, adequate social and economic resources, and reduce the risk of malnutrition in children. Cost-effective implementation of control can be achieved if some of these interventions are applied in an integrated manner, probably through simultaneous spatial targeting of resources. In fact, the Integrated Management of Childhood Illnesses strategies now recommend multi-faceted targeting of interventions. The geographical impact of location when implementing interventions must be recognized as it affects the epidemiology of diseases or interventions coverage. Therefore decision makers should devised policies and programmes that are targeted and focal to high risk areas thus identified.

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Table 1: Bivariate logistic regression results: Fixed effects (95% confidence interval) for risk factors of low-birth-weight, stunting and under-five mortality in Namibia, 2006/07 NDHS.

Variable	Low birth weight		Stunting		Under-five mortality	
	Odds ratios	(95% CI)	Odds ratios	(95% CI)	Odds ratios	(95% CI)
Material Deprivation (SED I)						
Class I (low)	1.00		1.00		1.00	
Class II	1.23	(1.04, 1.45)	2.05	(1.70, 2.47)	1.39	(1.13, 1.72)
Class III	1.35	(1.15, 1.59)	3.60	(2.57, 3.65)	1.66	(1.36, 2.02)
Class IV (extreme)	1.16	(0.98, 1.37)	3.96	(3.36, 4.73)	1.61	(1.31, 1.97)
Earnings Deprivation (SED II)						
Class I (low)	1.00		1.00		1.00	
Class II	1.24	(1.05, 1.51)	0.62	(0.54, 0.71)	0.82	(0.67, 0.99)
Class III	1.52	(1.23, 1.88)	0.56	(0.46, 0.67)	0.64	(0.74, 1.21)
Class IV (extreme)	1.15	(0.96, 1.37)	0.49	(0.43, 0.57)	0.87	(0.72, 1.06)
Place of residence						
Rural	1.02	(0.91, 1.14)	1.75	(1.56, 1.95)	1.11	(0.97, 1.28)
Urban	1.00		1.00		1.00	
Age of Child						
$\leq$ 6 months	5.79	(1.58, 21.19)	0.22	(0.17, 0.28)	0.06	(0.04, 0.09)
7-11 months	0.09	(0.02, 0.43)	0.69	(0.56, 0.89)	0.06	(0.04, 0.09)
12-23 months	0.32	(0.08, 1.33)	1.19	(1.64, 2.22)	0.12	(0.08, 1.21)
24-35 months	1.24	(0.25, 6.08)	1.19	(1.01, 1.41)	0.76	(0.46, 1.06)
$\geq$ 36 months	1.00		1.00		1.00	
Birth order						
1st born	1.36	(1.06, 1.75)	0.69	(0.35, 0.86)	0.49	(0.38, 0.64)
2nd-3rd born	1.13	(0.88, 1.95)	0.97	(0.78, 1.19)	0.58	(0.46, 0.74)
4th-6th born	0.91	(0.69, 1.19)	1.16	(0.94, 1.44)	0.73	(0.57, 0.94)
>6th born	1.00		1.00		1.00	
Birth interval						
<2years	0.78	(0.64, 0.97)	1.03	(0.86, 1.23)	1.53	(1.25, 1.87)
2-3 years	0.82	(0.69, 0.96)	1.40	(1.23, 1.59)	1.05	(0.88, 1.26)
>3 years	1.00		1.00		1.00	
Maternal education						
None	0.79	(0.64, 0.97)	2.56	(2.20, 2.97)	1.57	(1.26, 1.95)
Primary school	0.89	(0.79, 1.02)	1.76	(1.57, 1.97)	1.75	(1.51, 2.03)
Secondary/Higher	1.00		1.00		1.00	
Maternal age						
<20years	3.58	(2.66, 4.82)	4.78	(3.69, 6.21)	0.62	(0.43, 0.89)
20-29	3.99	(3.27, 4.86)	4.09	(3.41, 4.92)	0.54	(0.46, 0.65)
30-39	2.35	(1.91, 2.90)	2.87	(2.38, 3.47)	0.74	(0.62, 0.87)
40-49	1.00		1.00		1.00	
Antenatal care visits						
None	1.62	(1.15, 2.26)	3.15	(2.46, 4.04)	1.59	(1.09, 2.32)
Once	3.09	(2.10, 4.53)	2.58	(1.77, 3.76)	0.99	(0.52, 1.94)
2-3 times	2.48	(2.12, 2.90)	2.09	(1.80, 2.43)	1.18	(0.94, 1.48)
>3 times	1.00		1.00		1.00	

Table 2: Multiple spatial logistic regression results: Fixed effects (95% confidence interval) for risk factors of low-birth-weight, stunting and under-five mortality in Namibia, 2006/07 NDHS.

Variable	Low birth weight		Stunting		Under-five mortality	
	Odds ratios	(95% CI)	Odds ratios	(95% CI)	Odds ratios	(95% CI)
Material Deprivation (SED I)						
Class I (low)	1.00		1.00		1.00	
Class II	1.19	(0.95, 1.50)	1.78	(1.42, 2.23)	1.38	(1.09, 1.73)
Class III	1.26	(0.98, 1.63)	2.52	(1.98, 3.21)	1.48	(1.16, 1.91)
Class IV (extreme)	1.39	(1.03, 1.88)	3.31	(2.51, 4.35)	1.61	(1.11, 1.99)
Earnings Deprivation (SED II)						
Class I (low)	1.00		1.00		1.00	
Class II	1.32	(1.05, 1.66)	0.99	(0.83, 1.18)	1.09	(0.88, 1.36)
Class III	1.54	(1.14, 2.09)	1.23	(0.95, 1.60)	1.58	(1.18, 2.11)
Class IV (extreme)	1.25	(0.97, 1.60)	1.00	(0.73, 1.29)	1.04	(0.84, 1.30)
Place of residence						
Rural	1.08	(0.82, 1.42)	1.00	(0.78, 1.29)	0.77	(0.58, 1.01)
Urban	1.00		1.00		1.00	
Age of Child						
$\leq$ 6 months	0.88	(0.70, 1.11)	0.18	(0.14, 0.23)	0.05	(0.03, 0.07)
7-11 months	0.83	(0.63, 1.07)	0.62	(0.49, 0.78)	0.05	(0.03, 0.07)
12-23 months	0.95	(0.78, 1.17)	1.82	(1.54, 2.14)	0.11	(0.07, 0.17)
24-35 months	1.03	(0.83, 1.28)	1.20	(1.00, 1.45)	0.85	(0.50, 1.45)
$\geq$ 36 months	1.00		1.00		1.00	
Birth order						
1st born	0.97	(0.63, 1.13)	0.61	(0.42, 0.88)	0.47	(0.33, 0.67)
2nd-3rd born	0.94	(0.65, 1.35)	0.92	(0.67, 1.26)	0.58	(0.43, 0.77)
4th-6th born	0.85	(0.60, 1.19)	1.18	(0.90, 1.57)	0.69	(0.57, 0.90)
>6th born	1.00		1.00		1.00	
Birth interval						
<2years	0.86	(0.65, 1.13)	0.99	(0.79, 1.24)	1.18	(0.94, 1.48)
2-3 years	0.83	(0.66, 1.00)	1.12	(0.95, 1.33)	0.83	(0.68, 1.02)
>3 years	1.00		1.00		1.00	
Maternal education						
None	1.10	(0.82, 1.48)	1.71	(1.36, 2.15)	1.29	(0.98, 1.69)
Primary school	1.15	(0.96, 1.39)	1.57	(1.34, 1.83)	1.42	(1.19, 1.68)
Secondary/Higher	1.00		1.00		1.00	
Maternal age						
<20years	0.64	(0.40, 1.00)	2.23	(1.50, 3.33)	1.66	(1.06, 2.62)
20-29	1.02	(0.73, 1.40)	1.92	(1.43, 2.56)	1.32	(1.02, 1.72)
30-39	0.97	(0.73, 1.30)	1.39	(1.08, 1.79)	1.30	(1.07, 1.60)
40-49	1.00		1.00		1.00	
Antenatal care visits						
None	0.81	(0.44, 1.10)	0.81	(0.58, 1.12)	2.12	(1.39, 3.28)
Once	1.77	(1.10, 2.84)	1.06	(0.68, 1.65)	1.54	(0.77, 3.09)
2-3 times	1.25	(1.03, 1.52)	0.91	(0.76, 1.06)	1.71	(1.33, 2.19)
>3 times	1.00		1.00		1.00	

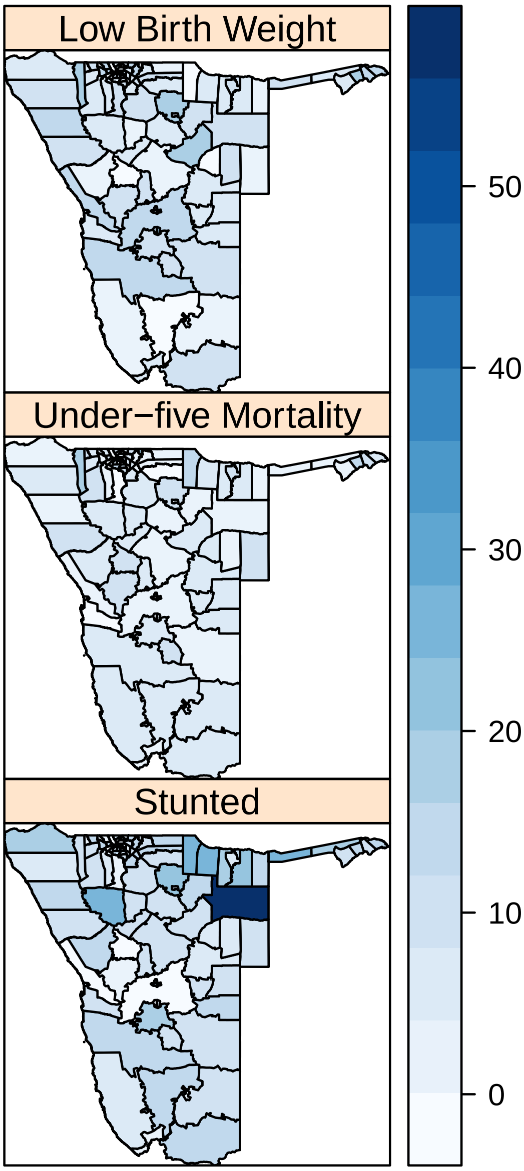

Figure 1: Geographical variation in observed child health outcomes: low-birth weight, under-five mortality and stunting.

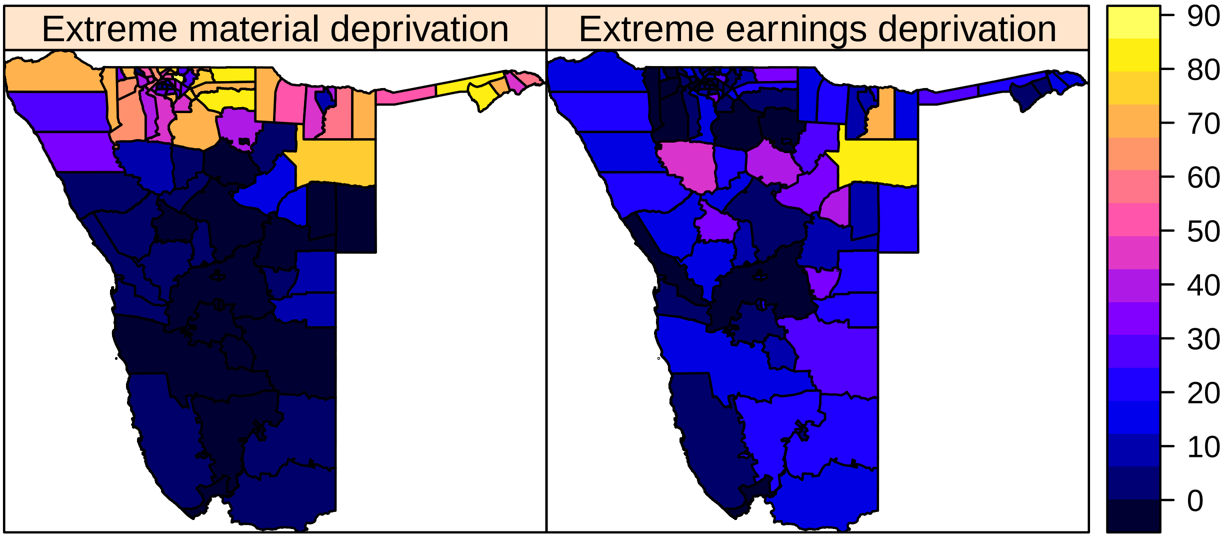

Figure 2: Prevalence of extreme socio-economic disadvantage: (a) material deprivation (SED I); (b) earnings deprivation (SED II).

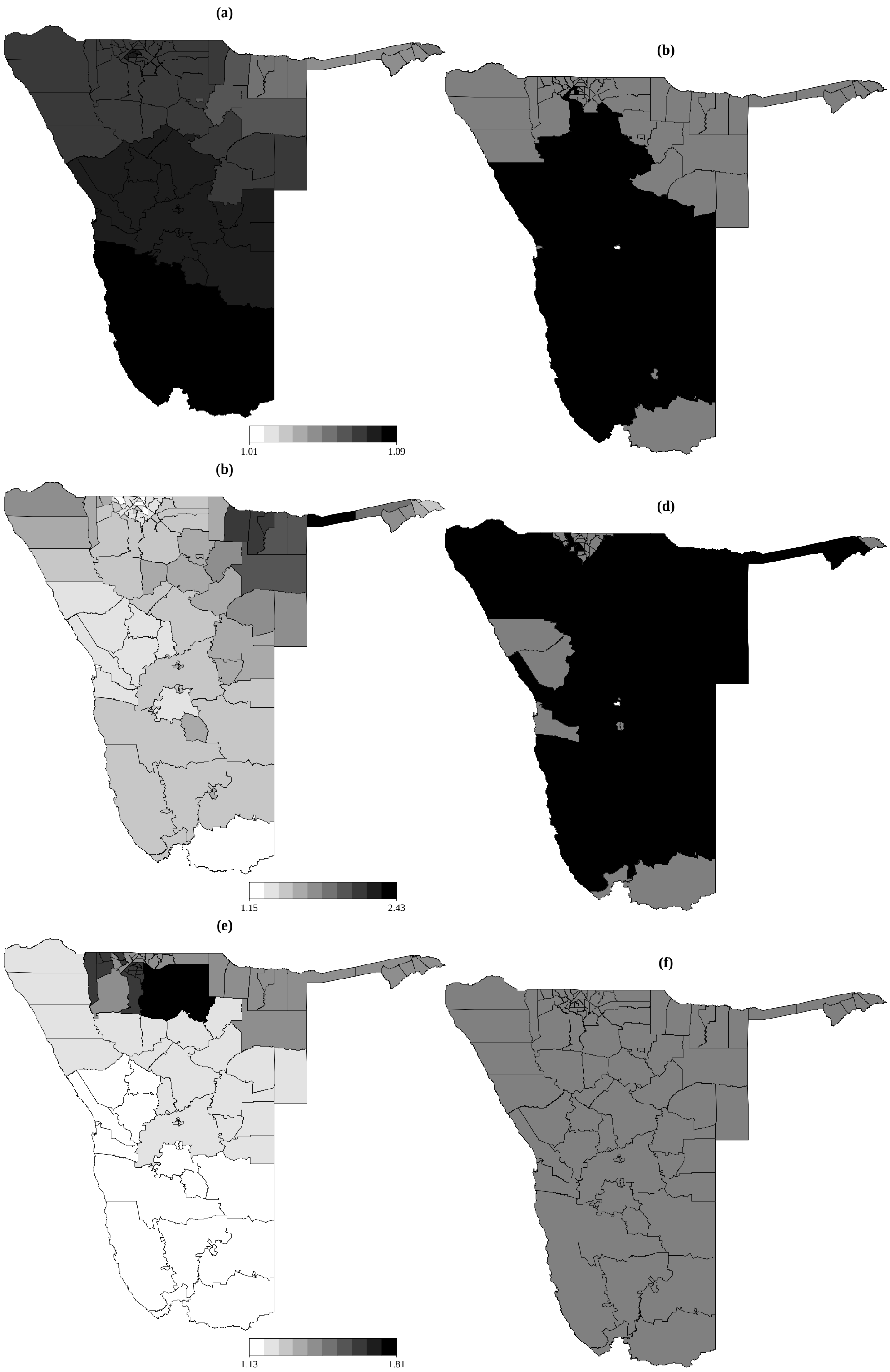

Figure 3: Space-varying coefficients of SED I (material deprivation) on the three child outcomes: low birth weight (map a), stunting (map c), and under-five mortality (map e), and the corresponding probability maps. Areas in black show significant positive association, white display significant negative association, and grey areas show areas of no significant association.

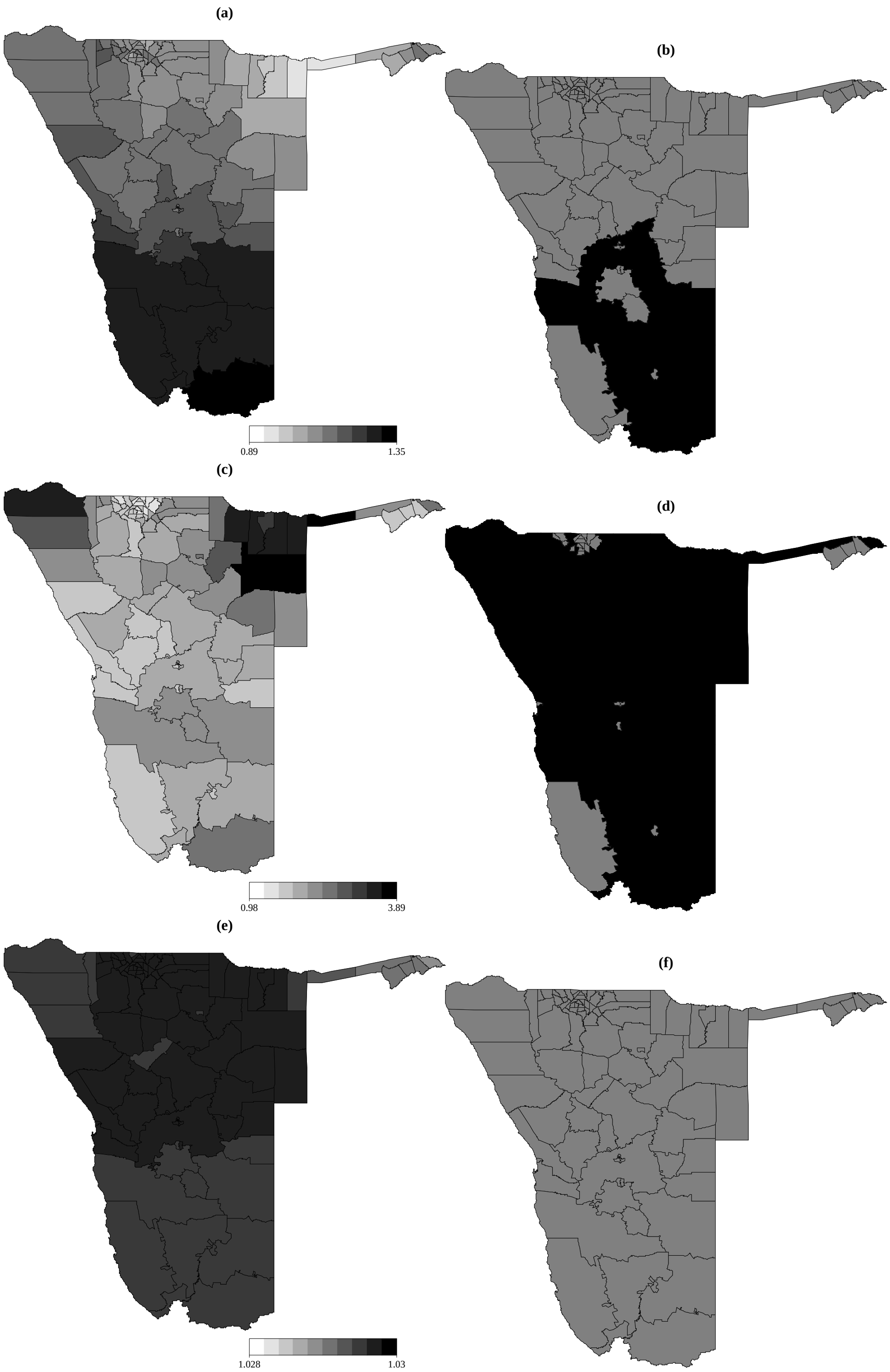

Figure 4: Space-varying coefficients of SED II (earnings deprivation) on the three child outcomes: low birth weight (map a), stunting (map c), and under-five mortality (map e), and the corresponding probability maps. Areas in black show significant positive association, white display significant negative association, and grey areas identify areas of no significant association.

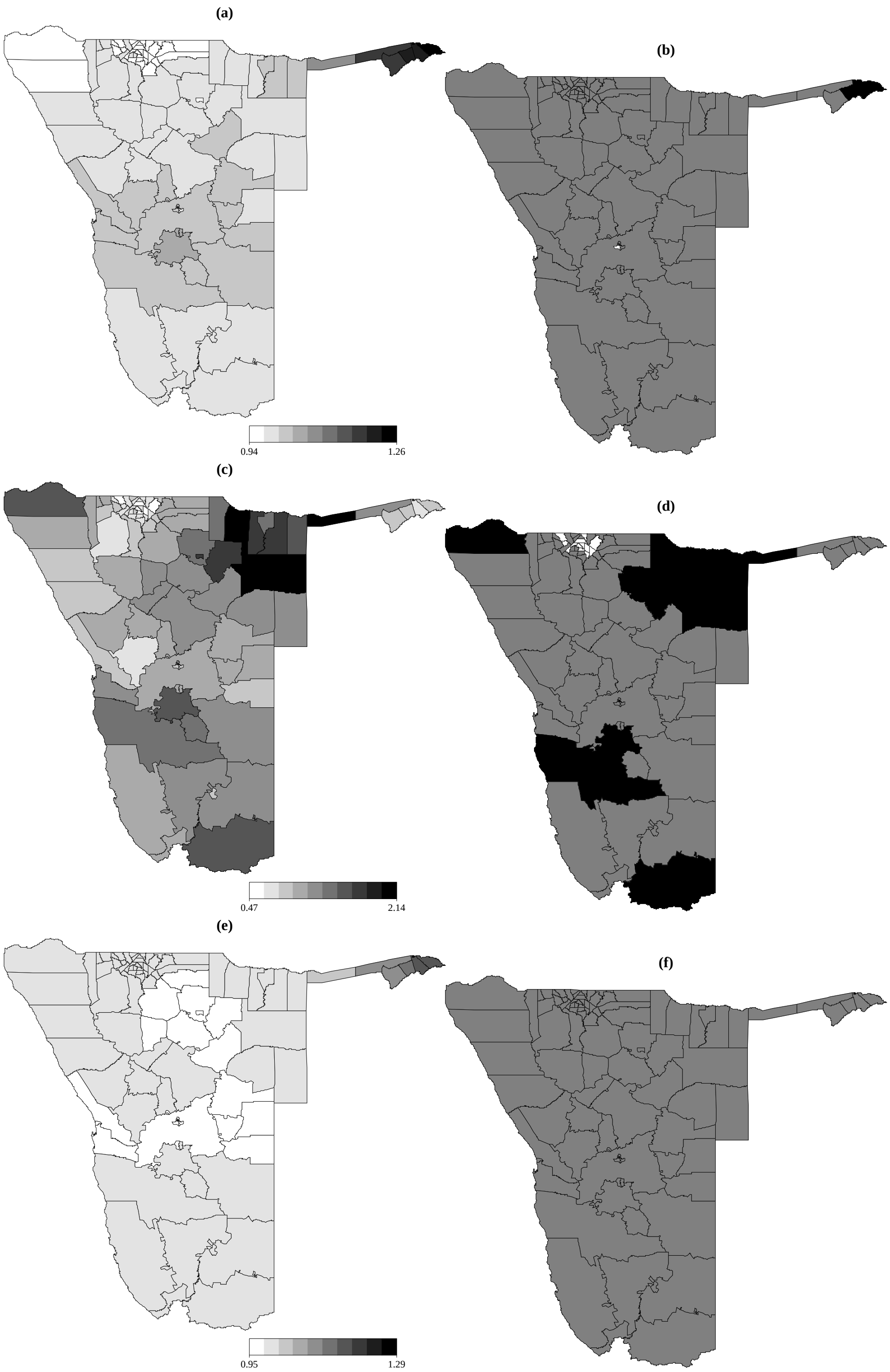

Figure 5: Total residual spatial effects in the model estimating effect of SED I (material deprivation). Shown are the odds (left panel) and associated probabilities (right panel) for: low birthweight (a, b); stunting (c, d); and under-five mortality (e, f).

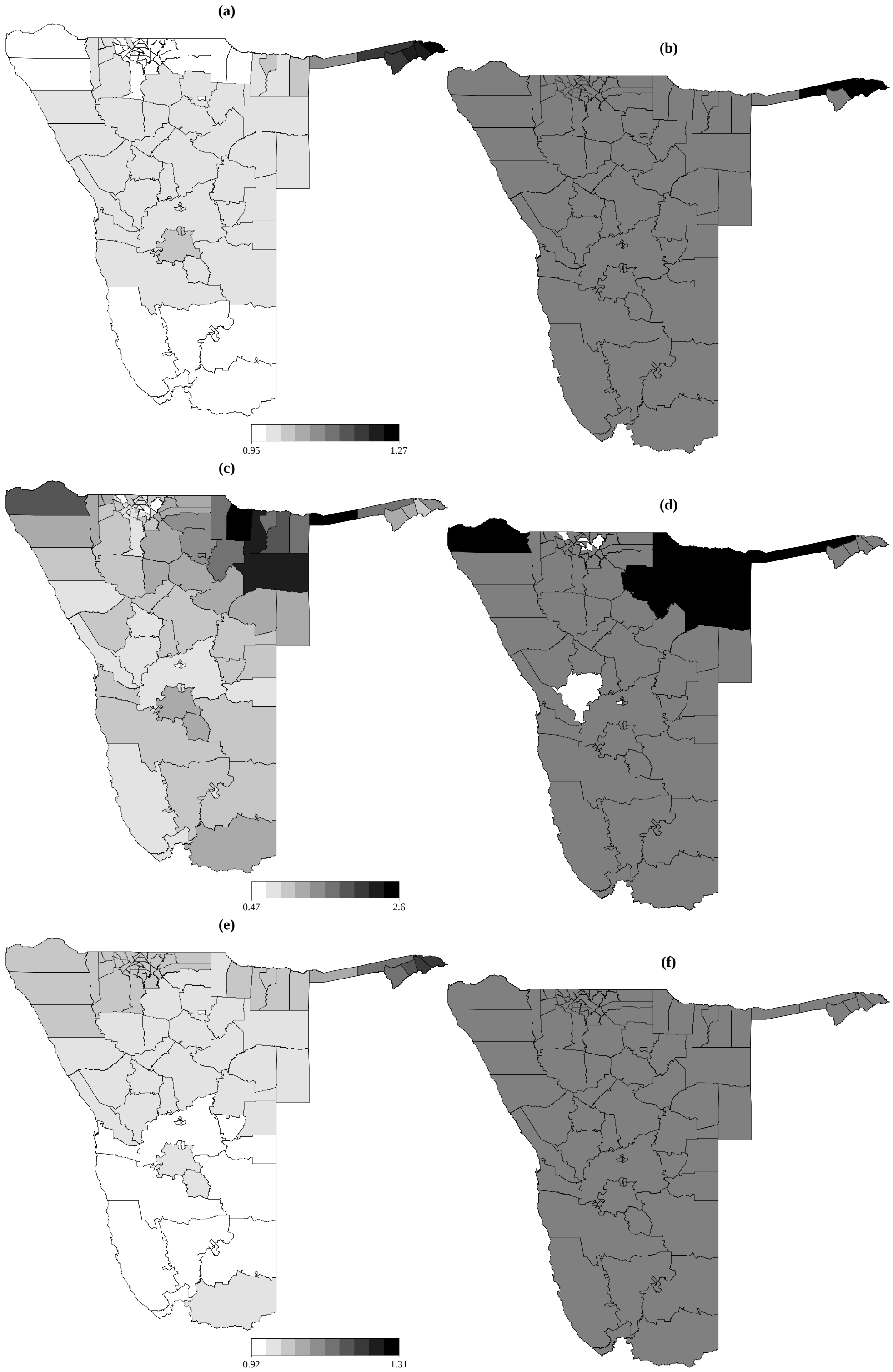

Figure 6: Total residual spatial effects in the model estimating effect of SED II (earnings). Shown are the odds (left panel) and associated probabilities (right panel) for: low birthweight (a, b); stunting (c, d); and under-five mortality (e, f).