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Correlates of under five mortality in Southern Nation Nationalities People Regional State: A spatial data analysis

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Abstract

The main aim of this study was to identify determinants of under-five child mortality, to describe spatial dependence of child mortality and to develop models specifying risk factors used to diagnose of child mortality among districts in Southern Nation Nationalities People Regional State (SNNPRS) of Ethiopia by using 2016 Ethiopia Demographic and Health Survey collected from 75 districts by employing spatial models. Spatial lag and spatial error model were fitted to the data though spatial lag model specification was taken as the best fit for child mortality rate. Accordingly, from global and local spatial analysis, it was found that children mortality rate in one district was directly affected by that of its neighbors. The results revealed that water closet, proportion of children under five, toilet availability, and mothers; basic education attainment, vaccination coverage, size at birth, mother current working status, ORS information, altitude, stunting score and wasting score of children were significant determinants of children mortality rate. Thus, it is suggested that the geographically targeted preparation on accumulation of treatment that can be useful to control and stabilize spillover (nearest area spread) of disease such as diarrhea, malaria, and fever over space is recommended. It can be suggested that the government needs to make intervention to mitigate the spatial variation of the prevalence of mortality across regions.

Keywords: Child Mortality, Spatial Data Analysis, GEODA, Ethiopian Demographic Health Survey, SNNPRS

Introduction

Child mortality is a factor that can be associated with the well-being of a population and taken as one of the development indicators of health and socioeconomic status and also indicates a life quality of a given population, as measured by life expectancy as (Desta, 2011). Thus, it is an area that many researchers focus and that has attracted the attention of policymakers and program implementers worldwide. One of the most important targets of Millennium Development Goals (MDGs) that was introduced in 2000 at the United Nations Millennium Summit was reducing infant and under-five child mortality rates by two thirds from the 1990 levels by 2015. In 2000, the Ethiopian government announced the intention by signed the millennium declaration committing to achieve the MDGs by 2015, many of which overlap with the 2015 national policy goals, for instance, in 2000 the Ethiopian administer prepared child survival strategy and implementation plan to reduce under-five mortality of 140/1000 live births to 67/1000 live births by 2015 (Tilahun et al., 2015).

The main reason for this as they noted is the dawn ward of agriculture, the increase of urbanization which accelerates the economic performance of the country. In 2010, 7.6 million children under five died, down from 8.1 million in 2009 8.8 million in 2008, and 12.4 million in 1990. About half of child deaths occur in Africa (Tilahun et al., 2015). Approximately 60 countries make up 94% of under-five child deaths as reported by UNCEF (2011). Death is often preceded by illness (morbidity). As a result, the state of health of individuals and societies is the prime determinant of mortality differences. However, variations in the types and About 472,000 Ethiopian children die each year before their fifth birthday, which places Ethiopia sixth among the countries of the world in terms of the absolute number of child deaths. Yet, there are effective low-cost interventions to prevent two-thirds of these deaths (Darmstadt et al., 2013). Children in the third world, especially in sub-Saharan Africa, usually suffer from more than one disease at a time. In most Countries of sub-Saharan Africa, the main causes of under-five deaths are more or less the same. Ethiopia is a sub-Saharan Africa country with a land area of 1.14 million square kilometers. The size of the country and its location has accorded it with diverse topography, geographic and climatic zones and resources. With a projected population of 75.1 million in 2006, Ethiopia is the second most populous country in Sub-Saharan Africa (SSA).

About 85% of the population resides in rural areas while the rest live in urban areas. According to the data of Millennium Development Goals Indicators Collected by the United Nations, Infant mortality Rate (IMR) in 2007 at world level is 47; this rate is 5 for developed regions whereas 51 for the developing countries. Poverty is one of the most important factors affecting the under-five mortality rate in Africa. Ethiopia is one of the poorest African countries with, according to UNCEF report, with a Gross National Income per capita of about $220 in 2007. Infant and child mortality rates remain high, with most deaths being caused by easily preventable diseases, such as malaria, pneumonia and diarrhea. Therefore, the objectives of this study were to identify determinants of child mortality, to describe spatial dependence of morality rate and to develop spatial models specifying risk factors used to diagnose morbidity in SNNP Regional State.

Methods and materials

Study area description

The Southern Nations, Nationalities and People's Region (SNNPR) is located in the Southern and south-western part of Ethiopia. It is bordered with Kenya in south, the Sudan in southwest, Gambella region in northwest and surrounded by Oromia region in northwest, north and east directions. The total area of the region estimated to be 110,931.9 km^2 which is 10% of the country. Since 2007 the region total population is about 15,042,531 accounting nearly 20% of the total population of the country; of population 49.7 % are male and 50.3% are females. The population density of the region became 142 persons per sq. km, which makes the region one of the most densely populated parts of the country. The region is a multination, which consists of about 56 ethnic groups with their own distinct geographical location, language, cultures, and social identities living together. Among which Omotic and Cushetic are the most populous and diversified ones with the largest area coverage in region respectively.

Target population

The populations studied in this research were under-five children in SNNPR. A sample of 1277 children with their mother were used in 2016 Ethiopia demographic and health survey (EDHS, 2016).

Variables included in the study

In this study we employed two types of variables; these are dependent and independent variables.

Dependent variable

The dependent variable of child mortality (under-five mortality rate) is relative risk of dying in a specific age of below five years range of childhood)

Independent variables

I used independent variables in study which was expected to cause child mortality in study area.

Spatial data analysis

In classical linear regression model $Y=X\beta+\varepsilon$, the response variable Y is assumed to be independent normal or Gaussian distributed and covariates, $X_1 \ldots X_P$ act linear on the response. By assumption the conditional expectation of Y is

$$\mu = E(Y/X_1, X_2 \ldots X_p) = \beta_0 + x_1\beta_1 + \ldots + x_p\beta_p \quad (1)$$

Where Y is vector of dependent variable, X is designed matrix of predicators, β is vector of parameters (coefficient) and **ε** is vector of independently and identically distributed error terms.

$$Y = \begin{pmatrix} y_1 \\ y_2 \\ . \\ . \\ . \\ y_n \end{pmatrix}, \quad X = \begin{pmatrix} 1 & x_{11} & x_{12} & . & . & . & x_{1k} \\ 1 & x_{21} & x_{22} & . & . & . & x_{2k} \\ . & . & . & . & & & . \\ . & . & . & & . & & . \\ . & . & . & & & . & . \\ 1 & x_{n1} & x_{n2} & . & . & . & x_{nk} \end{pmatrix}, \beta = \begin{pmatrix} \beta_o \\ \beta_1 \\ . \\ . \\ . \\ \beta_k \end{pmatrix}, \text{ and } \varepsilon = \begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ . \\ . \\ . \\ \varepsilon_n \end{pmatrix}$$

In addition the regression coefficient $\beta_1 \ldots \beta_P$ determines the strength of influence of the covariate, and the linear predictor μ is the sum of the covariate effect. Here each observation has an underlining mean of $\sum x_{ij}\beta_i$ and normally distributed random error term ε. Generally, the random error term $\varepsilon_1\ \varepsilon_{2\ldots}\varepsilon_p$ has zero mean and uncorrelated variance covariance matrix ε~N $(0,\delta^2 I)$ where δ^2I=Var (y) and an I is pxp identity matrix the assumption of independent observation also implies that $E(\varepsilon_i\varepsilon_j) = E(\varepsilon_i)E(\varepsilon_j)$ (Freund et al., 2006).

Quantification of locations/positions

Contiguity information is quantified as contiguity (spatial neighbors) matrix that contains the elements 1and 0.

$$C = \begin{pmatrix} c_{11} & c_{12} & . & . & . & c_{1n} \\ c_{21} & c_{22} & . & . & . & c_{2n} \\ . & . & . & & & . \\ . & . & & . & & . \\ . & . & & & . & . \\ c_{n1} & c_{n2} & . & . & . & c_{nn} \end{pmatrix}$$

Where: n is number of districts /locations under study c_{ij} is element of C represents quantity local position of i^{th} and j^{th} districts for i, j =1, 2…n. Contiguity matrix C is constructed based on linear contiguity: define as $c_{ij}=1$ for entities that share common edge to the immediate right or left of region of interest otherwise 0.

Spatial regression model

In the spatial linear regression model, spatial dependence can be incorporated in two distinct ways: as an additional regression in the form of a spatially lagged dependent variable (C*Y) provide spatial lag model, or in the error structure (Cε) provides spatial error model. To test for spatial effects in models, spatial weights matrices are constructed and then included in a specified regression model. Thus, inference on the parameters allows one to explain the pattern for all locations as a function of exogenous variables (Cressie, 2015).

Spatial lag model

This is type of spatial regression which appropriate when the focus of interest is the assessment of the existence and strength of spatial interaction; suitable to filter out spatial dependence that comes from spatial spillovers. The matrix notation of the model is

$$Y = \rho C^{*}Y + \mathbf{X}\beta + \varepsilon \qquad (2)$$

Where ρ is a spatial autoregressive coefficient of the lag variable CY called spatial lag operator and given as $CY = \sum_j C_{ij} Y_j$ where C_{ij} is row standardized weight matrix corresponding to community pair i, j hence $\sum_j C_{ij} = 1, \forall i$. A random vector of error terms; ε is independent and identically normally distributed with mean zero and constant variance $\delta^2 I_n$, for all I, Y is vector of dependent variables, X is a designed matrix of explanatory variables and β is vector of coefficients of regression model. The single notation of the model is $Y_i = \rho c_i Y + x_i \beta + \varepsilon_i$, where c_i is the i^{th} row of C. Parameters (β, δ^2) are estimated using maximum likelihood method of log likelihood function of transformed model and regressions was carried out along with a univariate parameter optimization of the concentrated likelihood function over values of the autoregressive parameter ρ.

Given the above model as Y = ρC*Y + Xβ + ε, then the transformed model: A*Y = Xβ + u implies Y= $A^{-1}X\beta + A^{-1}u$ with ε ~ N (0, $\delta^2 I$), A= (I- ρC) and C is row standardized spatial weights matrix. The log likelihood functions of transformed equation.

$$\ln L(\beta,\rho,\sigma) = -\left(\frac{n}{2}\right)\ln 2\pi - \left(\frac{n}{2}\right)\ln\sigma^2 + \ln\|A\| - \frac{1}{2\sigma^2}\left[\left(A*Y - X\beta\right)'\left(A*Y - X\beta\right)\right]$$

Where, $\|A\|$ is determinant of matrix A, and n is number of district under study. Or

$$L(\beta,\delta,\rho) = \ln|I-\rho C| - \frac{n}{2}\ln(2\pi) - \frac{n}{2}\ln(\delta^2) - \frac{1}{2\delta^2}\left(\left(Y-\rho C*Y - X\beta\right)'\left(Y-\rho C*Y-X\beta\right)\right)$$

Maximizing the likelihood with respect to β, δ, and ρ gives the values of parameters that provide the highest likelihood of the joint occurrence of the sample dependent variable. Anselin (1988) suggest a way to maximize the log likelihood and get estimator for β:

$$\hat{\beta}_{sl} = (X'X)^{-1}X'A*Y = (X'X)^{-1}X'X*Y - \rho(X'X)^{-1}X'C*Y$$

$$\hat{\beta}_{sl} = \hat{\beta}ols - \rho\hat{\beta}_L = (X'X)^{-1}X'(Y - \rho C*Y)$$

Where, $\hat{\beta}_{ols} = (X'X)^{-1}X'X*Y$ is coefficient vector from Ordinary Least Squares (OLS) regression of Y on X with corresponding residual e_{ols}=Y-X $\hat{\beta}_{ols}$, and $\hat{\beta}_l$-is the from OLS regression of C*Y=Y' on X and its corresponding residual $\mathbf{e}_L$=Y'-X $\hat{\beta}_l$.

Maximum likelihood estimator of δ^2 is $s^2 = \frac{1}{n}\left(e_{ols} - \rho e_L\right)'\left(e_o - \rho e_L\right)$ when ρ is known.

We can now use all these to write down a version of the log-likelihood function in terms of ρ only, the result is the Concentrated log-likelihood (lnL*)

$$\ln L* = CO - \frac{n}{2}\ln\left[\frac{1}{n}\left(e_{ols} - \rho e_L\right)'\left(e_{ols} - \rho e_L\right)\right] + \ln\|A\|$$

CO doesn't involve unknown parameters and estimate of ρ is obtained by maximizing lnL* with respect to ρ. Besides covariance-variance matrix of estimated parameters is estimated by maximum likelihood for large sample that attains Cramer's Rao lower bound. Moreover, clearly, we should be hesitant to make inferences about the effects of a covariate x_i in a spatially lagged Y model without considering the spatial multiplier and the variation that will exist across spatial units (Ertur et al., 2007).

Results and discussion

Descriptive results of determinants

The child mortality rate ranges from 0.00% (no mortality within 15 in that district) to 14.55 % (highly rate of mortality district) with mean 4.2 children died out of 100 live children and standard deviation of 5.59% in the Regional State. The drinking water closet in district varies from 2 minute to 996 minute with mean 123.81 minutes and standard deviation of 186.71 minutes. Percentage of mother who attended basic education ranges from 1% to 98% with mean 38.77% and standard deviation 26.63%. Proportion of children ever vaccinated among district varies from 2.63% to 84.21% with mean 34.38% and standard deviation16.36%. Birth interval time from preceding and succeeding children ranges from 41.50 month to 88.00 month with mean birth interval 62.16 month and standard deviation 9.68 month. Table 1 also provided maximum, minimum, mean and standard deviation in percentage for factors: Proportion of household having protected toilet, Proportion of households disposing younger children stools when not using toilet, Proportion of children whose size at birth is below average, Proportion of children under five, Proportion of respondents heard about ORS, Percentage mother employed (Table 1).

From nutritional factor point of view stunting score and wasting score show that that stunting score ranges from -2.28 (severely stunted area) to 3.70 (normal) with overall mean -1.124 and variance 0.57, and wasting score ranges from -1.99(severely wasted area) to 3.5416(normal) with mean -1.11 and standard deviation 0.77. District's altitude also varies from 979 meter (low altitude) to 3012 meter (high altitude). And Mean wealth index factor score ranges from -78404.00 to 255217 with mean -32043.64 and standard deviation 58895.95.

Table 1: Descriptive statistics of child mortality variation in districts and variables considered under study (EDHS, 2016)

Variables	N	Minimum	Maximum	Mean	Std. Dev.
Mortality Rate	75	0.00	14.55	4.20	5.59
Water source proximity in minutes	75	1.92	996.29	123.81	186.71
Mother basic education attainment	75	1.00	98.00	38.77	26.63
Proportion of Children vaccinated	75	2.63	84.21	34.38	16.36
Proportion of HH having toilet	75	0.50	100.00	65.82	30.11
Proportion of HH disposing stools	75	5.88	100.00	65.242	22.01
Birth interval	75	41.50	88.00	62.16	9.68
Proportion of respondent heard ORS	75	0.50	99.50	59.72	24.85
Mother employed	75	0.50	99.00	39.77	22.02
Wealth index factor score	75	-78405.00	255416.60	-32043.70	895.95
Percentage of mother currently working	75	2.00	90.60	32.77	31.02
Proportion of children below average size	75	1.00	62.10	23.91	12.36
Proportion of children under five	75	14.58	41.07	29.61	4.84
Number of HH members	75	3.73	7.89	5.94	0.78
Number of children under five	75	1.50	2.67	1.75	0.33
Altitude	75	979.00	3012.00	_	_
Stunting score	75	-2.28	3.70	-1.13	0.57
Wasting score	75	-1.99	3.54	-1.11	0.78

Exploratory spatial data analysis results

As presented in Table 2, the Moron's I scatter statistic for mortality shows those districts with above average mortality rates share boundaries with neighboring districts that also have above average infection rates (High-High). It also shows those districts with below average mortality rates shares boundaries with neighboring districts that also have below average infection rates (Low-Low). Therefore, it leads us to observe that there is spatial autocorrelation in diarrheal rates in the regions.

Table 2: Moron's statistics of child mortality rate

Variable	Moron's *I*	Standardized value	P-value
Mortality rate	0.5665	11.73211	0.001

The theoretical mean of moron's stat is -0.072 and standard dev. 0.0489 for all variable obtained by -1/N-1

Spatial regression analysis results

In this section a statistical model that incorporates spatial dependence raised from spatial lag explicitly by adding a spatially lagged dependent variable $Y^{'}=CY$ on the right hand side of the OLS regression equation $Y=X\beta+\varepsilon$ where C is spatial weight matrix is described. As a consequence, findings of this section allow us to understand which variable among the independent variables are related to the variation in mortality rates, and to explore the forms of these relationships.

Table 3 reported maximum likelihood estimate for determinants of diarrhea prevalence rate in spatial lag model, test statistic with corresponding p-value, and their standard errors that come from the heteroskedasticity consistent estimator of the covariance matrix of the maximum likelihood parameters. The significance of the coefficient of the spatially lagged dependent variable (ρ) suggests that neighboring districts mortality rates are important determinants of a given district's mortality rate. This result is consistent with the findings of Frank (2006). More specifically, geographic spillover effects are important in our model of diarrhea morbidity rate variation.

Variables with positive and statistically significant effect on mortality rate are water closet (WC) ,proportion of children under five (PCU5), proportion children born below average size (PCBAV SIZE), whereas variables with negative effect and statistically significant coefficients at 5% level of significance are proportion of children ever vaccinated (VACOV_100),proportion of household having controlled toilet (TOILET_100),proportion of households disposing younger disposal when not using toilet (DISPOSAL YOUNG_100), proportion of respondent heard about ORS (HEARD ORS), stunting score, wasting score and altitude.

Positive effect means that for a unit change in explanatory variable increase mortality rate in certain district by magnitude of estimate of parameter for that explanatory variable controlling for the effect of neighbor districts and other variable, whereas negative effect mean that for unit change in explanatory variable decrease mortality rate in district by magnitude of estimate of parameter for explanatory variable conditioning the neighbor districts mortality rate effect and other variable constant. For example for one minute increase in time to get drinking water (WC) in certain district increase mortality rate in that district by 0.00417% keeping other variable fixed. In another word, as the a distance to drinking water in a particular district increases by one minute, the possibility of mortality in that district increased by 0.00417% .This result is similar with study conducted in Nekemte town, western Ethiopia, by Girma et al. (2008) and Chabala and Mamo (2001) that showed risk factors including distance of drinking water source (time taken to-and-from the source) appeared to be significantly associated with under-five childhood diarrheal morbidity.

The change in proportion of house hold having protected toilet and disposing young children stools were found to be negative and significant (at 5% level). This result is similar with findings of Girma et al. (2008) and study done in SSA countries which showed that children in SSA living in households with some kind of toilet facility are less likely to experience diarrhea morbidity than children in households that do not have toilet facilities.

The parameter estimate 0.0542 for proportion of children under five (PCU5) indicates that a unit increase in proportion of children under five in district increases mortality in that district by 0.0542% keeping the effect of other independent variable constant. The sign tells that high proportion of children (below 5) in one district may aggravate population in the same area to participate in productivity discharge their responsibility to care them. These results share idea of (Berisha, 2011; Fahrrmeir and Khatab, 2007).

The coefficient estimate -0.0121 indicates that 1% increase proportion of household having protected toilet (TOILET_100) decreases mortality in distinct by 0.0121% remaining other variable influence constant.

The parameter estimate -0.005 for proportion of children ever vaccinated indicates that for 1% increase in proportion of children ever vaccinated in certain district decrease mortality rate in that particular district by 0.005% keeping others variables fixed. And Proportion of children born below average size (PCBAV SIZE) is significant and has positive effect on mortality rate of districts. This is due the fact that the greater the proportion of the children born below average size in district, higher the probability morbidity and mortality finally. Children who had low birth weight were more likely to be sick longer than infants who had appropriate birth weight or children born below average size can't defend childhood disease such as diarrhea, fever and malaria. This result is consistent with study done Teshager (2011) using 2005 EDHS and similar with the study done in Northeast Brazil by Lira et al. (1996) who showed that children with low birth size experienced 33% more days with diarrhea and 32% more days with vomiting.

In basic knowledge point of view proportion of mothers who attained basic education (EDAT_100), proportion of respondents who heard about ORS (HEARD_ ORS) both have negative and significant effect among district. Nevertheless percentage mother educated primary and above determine mortality rate in certain district, some mothers have no basic education skills which of course necessarily need education for mother. The same interpretation was given for ORS information.

The negative coefficient and significant value for stunting score and wasting score indicates that the less stunt score or waste score the higher mortality rate. Most literature shows that stunting and wasting are problem that highly correlated with childhood morbidity. A vicious cycle between mortality and stunting means that children with stunted were more likely to attacked by diarrhea .The results may be due to shortage of nutrition leads to non-health (more vulnerable to diarrhea).

For altitude interpretation is slightly different because it is fixed for certain district and is fixed effect to diarrhea prevalence in certain district; therefore, coefficient can be interpreted as districts with high altitude are less likely to be infected by diarrhea. This is may be due to polluted water flow from high to low (see discussion part for more details).

Table 3 also presents measures of fit for models in discussion part. R-square = 0.5682 which tells us that 56.82% of variation in diarrhea prevalence rate was explained due to variation in the explanatory variable in the model and spatial lag dependent variable.

Table 3: Maximum likelihood estimate for factors of mortality rate in Spatial Lag Model (EDHS, 2016)

Variable	Coefficient	Std. Error	z-value	Probability
C-Y(ρ)	0.7694	0.06381	12.058	0.000
CONSTANT	-0.5934	0.34348	-1.729	0.042
WC	0.00417	0.00038	10.887	0.0000
TOILET_100	-0.0121	0.00116	-10.431	0.0000
DISPOSAL _100	-0.0142	0.157	-9.045	0.0000
VACOV_100	-0.0050	0.00064	-7.723	0.0030
PCBAV SIZE	0.0100	0.00240	4.170	0.0001
PCU5	0.0542	0.00438	12.383	0.0000
HEARD ORS	-0.0179	0.00726	-2.458	0.006
EDA_100	$-1.59X10^{-5}$	$4.9X10^{-6}$	-3.245	0.004
STUNT_SCORE	-0.0447	0.01260	-3.454	0.0002
WASTE_SCORE	-0.0464	0.01560	-2.975	0.0014
ALTITUDE	-0.0284	0.00940	-3.021	0.0013

Number of Observations (N):	75	Degrees of Freedom:	60
R-squared:	0.5682	Log likelihood:	-60.830
S.E of regression:	0.3422	Akaike info criterion:	147.653
Sigma-square:	0.1172	Schwarz criterion:	186.261

Finally, Table 3 contains Diagnostics Tests Spatial lag Model of Mortality Rate. Three measures that, those included to maintain comparability with the fit of spatial lag models that are the log likelihood (-60.83), the Akaike information criteria (147.653) and Schwarz criteria (186.261). These three measures are based on assumption of multivariate normality and corresponding likelihood function for standard regression model. The higher log likelihood, the better the fit (less negative). For the AIC and SC information criteria the direction is opposite, the smaller the measure, the better the fit.

Conclusion

Geographically, close districts with similar socio-economic and demographic characteristics and vulnerability dimensions are more conducive to grouping forces, such as using of unprotected drink water. The clustering of underlying disease dimensions might be due to a number of reasons including sanitation that has been applied to groups of areas or socio-economic issues that lead to spatial clustering of mortality rate. Our estimation results of spatial lag model for mortality rate indicate that water closet, proportion of children under five, toilet availability, mothers basic education attainment, vaccination coverage, size at birth, Oral Rehydration Salts ORS information, altitude from sea level, stunting score and wasting score of children have significant influence in explanation of mortality rate differentials across districts in the regions.

Based on the findings, the following recommendations were forwarded to mitigate regional mortality:

The expanded program on immunization should be spread out to reduce child mortality in study area. The study suggests that efforts should be made to build public and private toilet facilities. Improvements in access to clean water and adequate sanitation, along with the promotion of good hygiene practices can help to prevent childhood diarrhea morbidity and mortality in turn. The study also suggest that basic education to mother, improve the nutritional status of children, community participation on hygiene and sanitation will be important measure in geographically targeted preparation to reduce possibilities of occurrence morbidity. Further study will recommend to be conducted by incorporating time or employing other forms of spatial models and including other excluded districts. Thus, the most effective policy mix for alleviating differences amongst the regions districts mortality rate, balancing hospital composition and providing sanitation, and encouraging community to participate in sanitation and environment protection. Furthermore, reducing average family, encouraging mother to take basic education in regions may reduce morbidity of child and mortality in turn.

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