SPATIAL MODELLING OF UNDER-FIVE MORTALITY AND ASSOCIATED RISK FACTORS IN ETHIOPIA ADMINISTRATIVE ZONES

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Abstract

Background: *Under-five mortality rate is the probability that a child will pass away before reaching the age of five, represented as a* rate every 1,000 live births. *It is one of the benchmarks towards the Millennium Development Goals' (MDGs') goal of reducing child mortality. Thus, this study aimed to identify the risk factors by incorporating spatial variation on under-five child among Ethiopian administrative zones.*

Method: *This study was used the Ethiopian Demographic and Health survey (EDHS) data which were collected using a two-stage sampling method. The spatial regression model was employed to account spatial effect in 65 administrative zones in Ethiopia.*

Results: *The general nesting spatial and spatial Durbin error regression model was good fit for the data that had the smallest AIC and BIC compared with other spatial models.* The estimate of the spatial covariates, **λ** and **ρ** was -0.1039* and 0.1060* which statistically significant ($p<=0.05$). *According to the model results, the increase in the percentage of child who was not vaccinated (*0.1680*, $p<=0.05$*), and unemployment status of women (*0.7034**, $p<=0.01$*),womens who use media exposure (*-0.9284*, $p<=0.05$*), Children not currently breastfeeding (*0.6654*, $p<=0.05$*), and ANC visit at least 4 times (*-0.7962*, $p<=0.05$*) contributed to the statistically significant effect on the under-five mortality in Ethiopia administrative zones.*

Conclusions: *The under-five mortality risk factors are spatially differ across 65 administrative zones in Ethiopia. There exist spatial variation in under-five mortality among in zones, which are affected by spatially neighborhoods of the zones. Hence our study give special importance the need* *to take spatial neighborhoods context into account when planning under-five mortality preventation.*

Keywords: *Under-five children mortality, Ethiopia, Spatial regression model*

1. BACKGROUND

Under-five mortality rate is the probability that a child will pass away before reaching the age of five, represented as a rate per 1,000 live births. It is one of the indicators of the millennium development goals (MDGs) for the child mortality reduction aim [1].The primary goals of the fourth and fifth Millennium Development Goals (MDG 4 and 5) are to decrease the mortality rate among children under the age of five and to enhance maternal health, which will subsequently increase the likelihood that children will survive [2]. In 2018 there were 5.3 million children who died before turning five worldwide [3].

The WHO African region continues to have the greatest rate of under-five mortality (76 per 1000 live births), while the WHO European region has the lowest rate (9 per 1000 live births). While they only account for 53% of live births worldwide, Sub-Saharan Africa and southern Asia will be responsible for more than 80% of the 5 million deaths of children under the age of five in 2020. Only five nations—Nigeria, India, Pakistan, the Democratic Republic of the Congo, and Ethiopia—accounted for half of all fatalities among children under the age of five in 2020. Nearly a third of all deaths are caused by Nigeria and India alone [4]. At an average of 78 fatalities of children under-five per 1,000 live births, one in every 13 children dies before their fifth birthday in the sub-Saharan African region. This frequency is 16 times higher than the risk of infants born in high-income nations [1].

Various studies on under-five child mortality in Ethiopia have been carried out in the past [5-13]. However, without taking into account geographical variation, these studies focused exclusively on the risk factors for under-five child death. The literature does not adequately address the spatial heterogeneity of under-five child mortality across zones in Ethiopia.

Children's health status has improved between 2000 and 2016, according to the trend in demographic and health data from the EDHS. Ethiopia has seen a decline in early childhood mortality, which includes all neonatal death, postnatal mortality, infant mortality, child mortality, and under-five mortality. For instance, the mortality rate for children under five has dropped from 123 deaths per 1000 live births in 2005 to 88 deaths per 1000 live births in 2011 and 67 percent deaths per 1000 live births in 2016 [14]. Even so, the rate of mortality decline is still too slow and insufficient to meet the GTP and SDG.

There is very little information as to why under-five child mortality rates in Ethiopia have not decreased as intended despite multiple interventions and action plans. It is essential to have a comprehensive understanding of the variables behind the high rates of mortality in Ethiopia that dedicated to attaining the GTP and SDG on reducing child mortality [6]. Therefore, based on data from the 2000-2016 Ethiopia Demographic and Health Survey, this study aims to address the determinants of the major risk factors of under-five mortality by taking into account various maternal, environmental, spatial, and socioeconomic characteristics and their impact on child mortality in Ethiopia administrative zones.

2. Method and statistical analysis

The data was be obtained from 65 administrative zones in Ethiopia. Ethiopia shares borders with Eritrea in the north, Djibouti and Somali in the east, Sudan and South Sudan in the west, and Kenya in the south. The World meter estimated that the country had about 120 million people. Administratively, Ethiopia is divided into 11 exclusive units (regions) including Addis Ababa, the capital city of the country and 72 administrative zones as CSA reported in 2013 [15] (Figure 1).

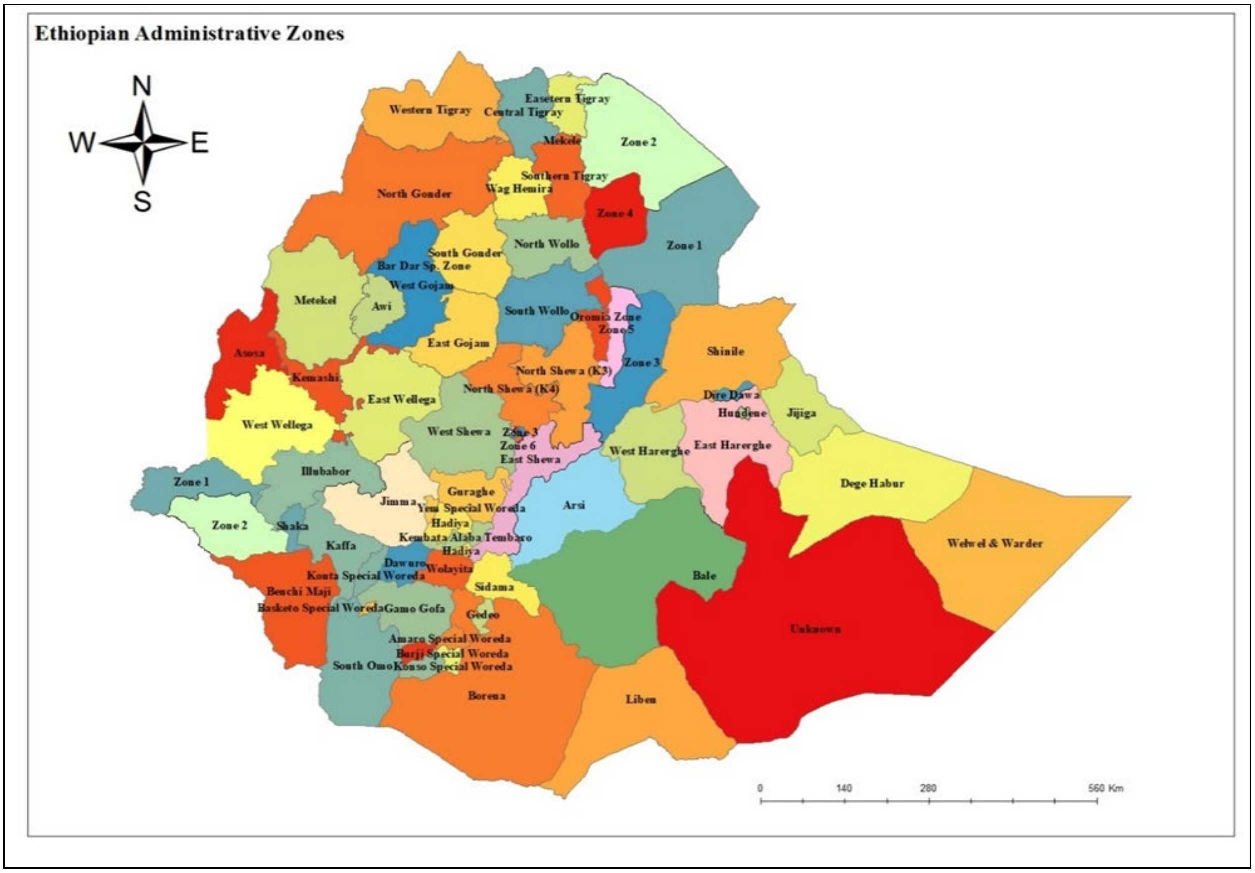


Figure 1. Map of Ethiopia Administrative Zones

The study was conducted on 43,029 children consisting of 10641 from 2016, 11654 from 2011, 9861 from 2005, and 10873 children from the 2000 EDHS respectively.

2.1 variables of the study

The outcome variables in this study was the proportion of under-five child mortality (U5M) for the Ethiopian administrative zones. As predictor variables, the following demographic, social, geographic, and environmental factors have been guided by existing literature of study the determinant of child under age five. We may utilize the percentage of dependent and independent variables that have binary categories for the spatial and space-time dynamic model. We can collapsed the variables by administrative zones to get a proportion of the variables. In order to do this, we used the geographical variables from the GPS dataset of the demographic and health survey data and connected them to the DHS row dataset. Finally, utilizing both the EDHS and geographical variables, we were able to predict the under-five mortality at the zonal level.

3 Statistical Methodology

To undertake spatial analysis and better comprehend the world and inform decisions, spatial modeling is a crucial tool. Models of space are formally define used to explain spatial process mechanisms and create analytical workflows to comprehend these processes. The growth of science has made a variety of accessible geographical models and modelling techniques, giving the phrase "spatial model" a variety of connotations [16]. An overview of popular spatial model types, modeling methods, and related applications is given in this entry. Analysis of geographical data and spatial processes is possible with the help of spatial regression models. Nevertheless, a variety of model specifications are possible, each assuming a particular kind of spatial dependence [17].

Spatial regression models are statistical models that incorporate the spatial relationships between observations in a dataset. These models are particularly useful in situations where the variables of interest are influenced by spatial factors, such as location, distance, or neighborhood effects.

To determine which units j are neighbors of unit i for all units i = 1, 2... N, or more accurately, to characterize the spatial relationship between the observational units. To do this, a neighbor weights matrix $n \times n$ is created, with all elements $w_{ij} > 0$ for all neighboring units i and j ($i \neq j$) and 0 otherwise. Based on a row-normalized contiguity weights matrix (queen), all units in this study are considered neighbors if they share at least one shared border. There are several **W** standards, such as the k nearest neighbor or distance-based methods [17]. The spatial model indicated how the mistake words interact with one another separating the outcome interaction effects between the explained variable, the covariate interaction effects between the explanatory factors, and the three additional forms of interactions.

Let, $\mathbf{y}=(y_1,y_2,\ldots,y_n)^T$, $\boldsymbol{\epsilon} = (\epsilon_1, \epsilon_2,.., \epsilon_n)^T$, with ϵ_i iid $\epsilon_i \sim N(0, \delta^2)$, be an $n \times p$ and $q \times 1$ matrix where each row consists of $\mathbf{X}_i^T$ and $\mathbf{Z}_i^T$ respectively. Moreover, $\boldsymbol{\beta}$ and $\boldsymbol{\theta}$ are the px1 and qx1 parameters of vectors (Figure 2).

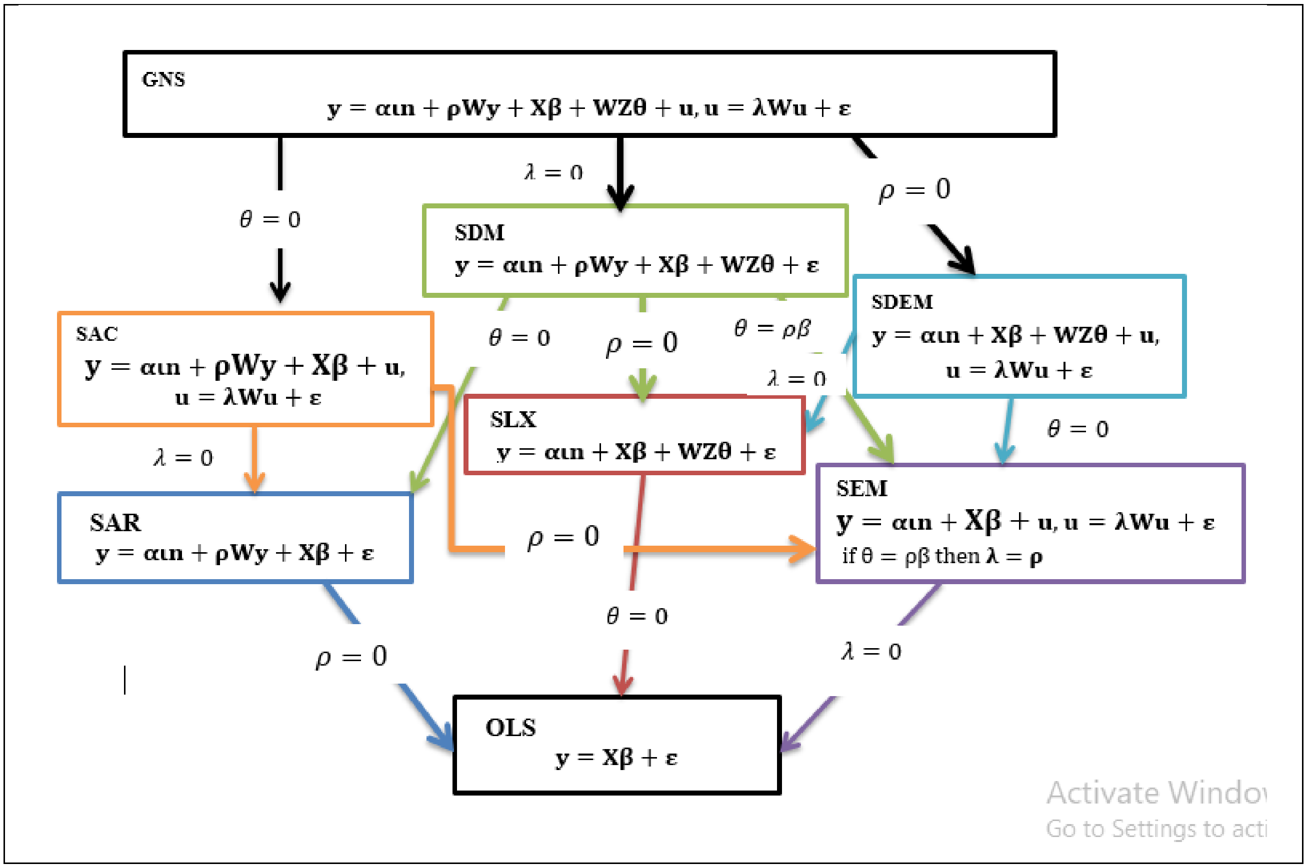


Figure 2. The relationship between different spatial regression models

4. RESULTS

4.1 Spatial Analysis

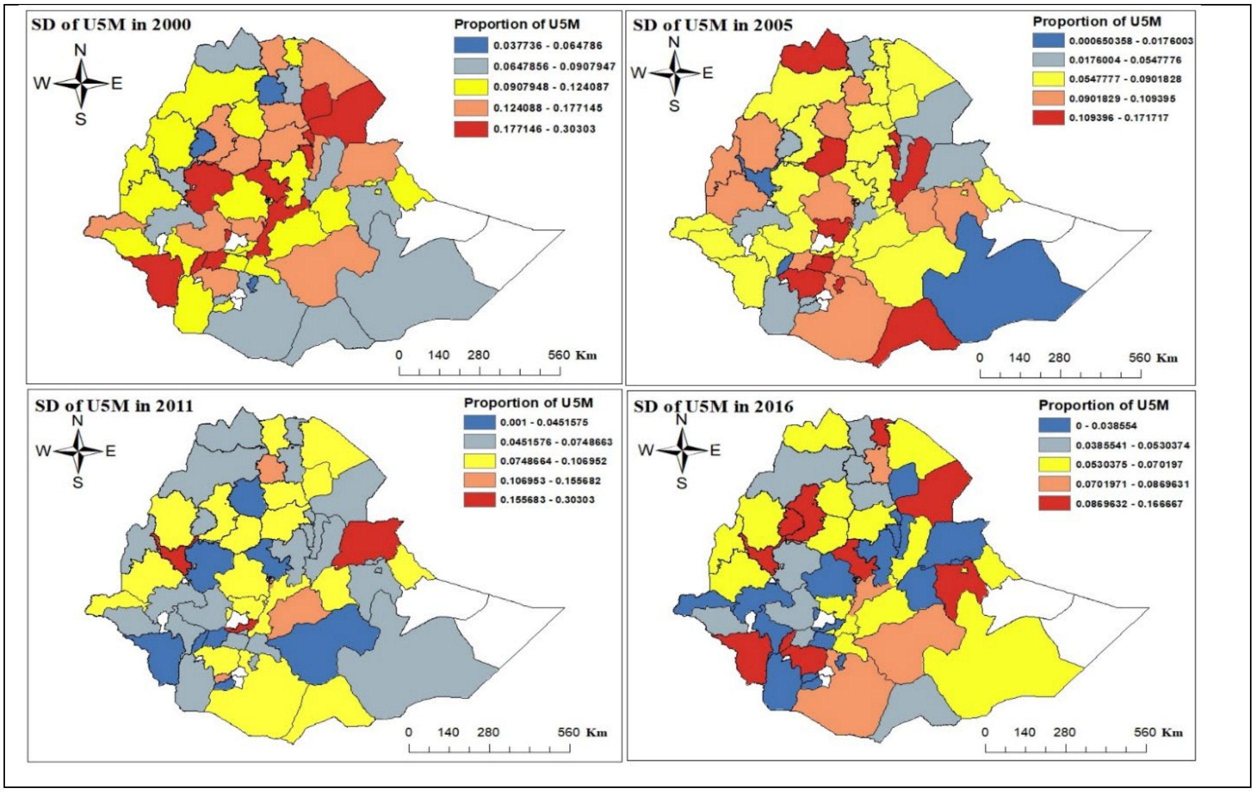
4.1.1 Spatial Autocorrelation Analysis of U5M of Children

Results of the Global Moran's I showed a statistically significant positive spatial autocorrelation of the proportion of under-five mortality in Ethiopian zones in all EDHS survey years. The Moran index from 2000-2016 was MI=0.1319, P-value=0.0471, and MI=0.0461, P-value =0.0059, and MI= -0.2041, P-value =0.0908 (MI was dispersed in 2011 and P-value was significant at 0.10), and MI=0.186697, p-value 0.042606 respectively. The Z-scores 1.9856, 3.4364, -1.6916, and 2.0276 a clustered and dispersed pattern.

Spatial Distribution of U5M across Administrative Zones

In all EDHS survey, Ethiopian zones had different proportions of under-five child mortality. The spatial map of the observed under-five child mortality distribution for all EDHS surveys is shown below in Figure 3 for the various years across administrative zones.
From 2000 to 2016 EDHS year throughout, the proportion of under-five child mortality observed increased in the North Shewa, Kemash, Awi, Eastern Tigray, Southern Tigray, Mekele, Gamo Gofa, and East Gojjam zone.

In Jimma, Illubabor, Konso Special Woreda, Zone2, Zone4, and Zone5 in Afar, North Shewa, Zone1, Zone2 in Gambela, and Dire Dawa zone, the percentage of under-five child mortality fell from 2000 to 2016 EDHS year. However, from 2000 to 2016 EDHS year, the rate of under-five child mortality was consistently observed in Jijiga and Hundene zone (Figure 3).This was may be due data used and the cause of factors.



SD-indicates Spatial Distribution of U5M in Ethiopian Administrative Zones

Figure 3. Observed spatial distribution of under-five mortality in Ethiopian administrative zones from 2000-2016 EDHS.

Hot Spot Analysis of Under-five Mortality from 2000-2016 EDHS Survey

The red color indicates significant hot spot (high-risk) areas for under-five child mortality at 95% and 99% confidence intervals. The green color indicates the cold spot (low-risk) areas of under-five child mortality at 95% and 99% confidence intervals. The Hotspot of under-five child mortality at 95% and 99% confidence interval was observed in the zones of Konta-special woreda, yem-special woreda, Gedeo, Hadiya, in SNNP, and Zone 1 in Afar Region, and East shewa, Arsi zones in Oromiya region, and Metekel zone in Benshangul-Gumuz region, North shewa, Awi, Oromiya liyu, and West Gojjam zone in Amhara region are hotspot areas from 2000 to 2016 EDHS year (Figure 4).

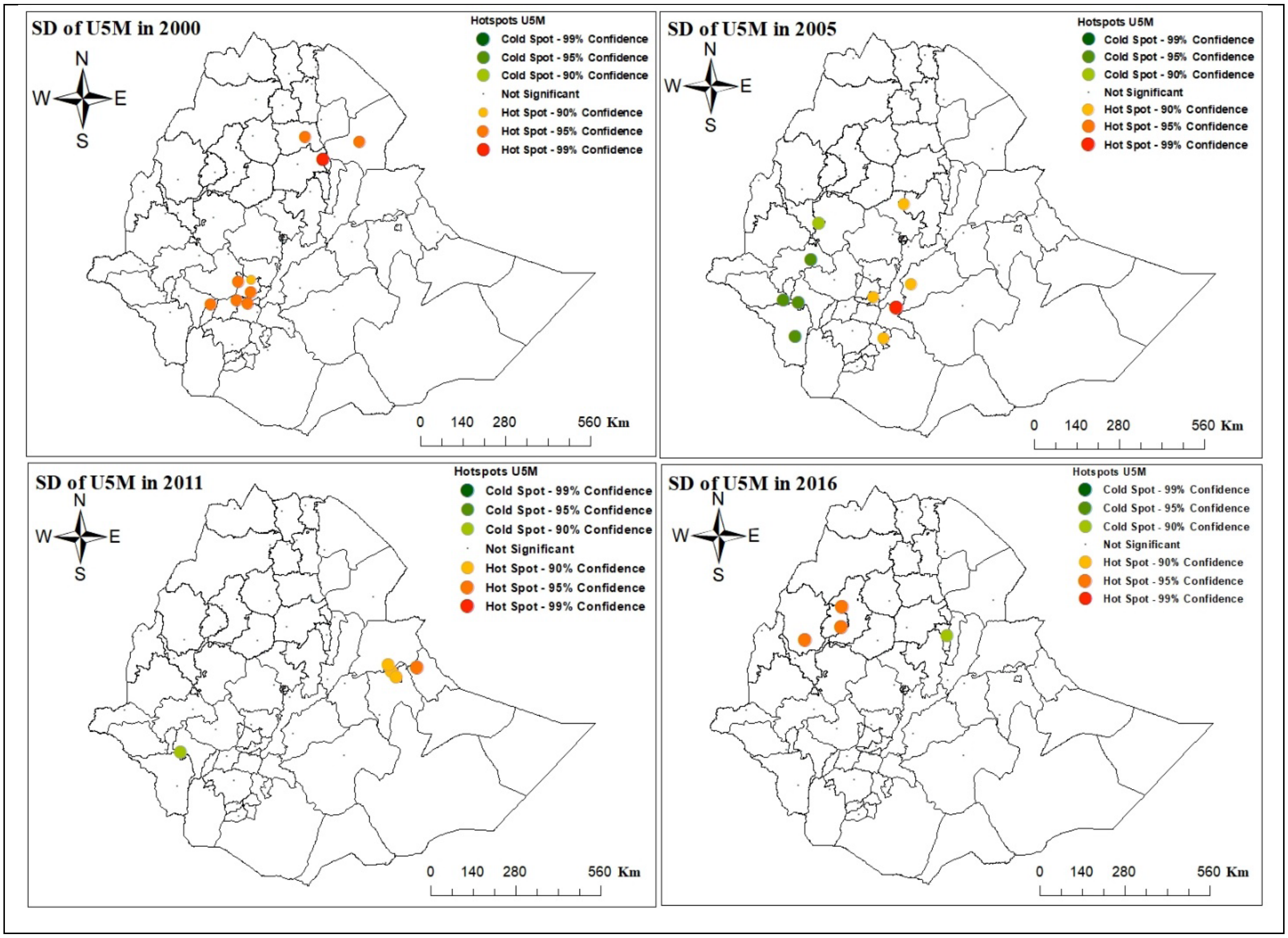


Figure 4. Spatial hotspot analysis in Ethiopian Administrative zones from 2000-2016.

Spatial Interpolation of Under-five Mortality

Based on spatial Ordinary kriging interpolation prediction (used incase of smallest MSE compared with other methods), the high-risk area were indicated by red color and the prediction of lower-risk areas was presented by blue color. Zone1, Zone3, and Zone5 in Afar region, South Wollo, Awi, and South Gonder zone in the Amhara region, Kambata Alamba Tambaro, Shaka, and Hadiya zones in SNNP Region, Unknowns zone , Shinile zone in the Somalia region, were predicted as more risky zones compared to other zones in 2000-2016 EDHS years.

In the Zone1, Zone3, and Zone5 in the Afar region, the under-five child mortality rate was high in 2000 and 2011, although it fell in 2005 and the 2016 EDHS year. In Jimma, Shaka, Konta Special Woreda, Benchi-maji, and Hadiya zone the percentage of under-five child mortality fell from 2000 to 2016 EDHS year. However, from 2000 to 2016 EDHS year, the rate of under-five child mortality was increased in Awi, East Gojjam, Metekel, and Asosa zone (Figure 5).

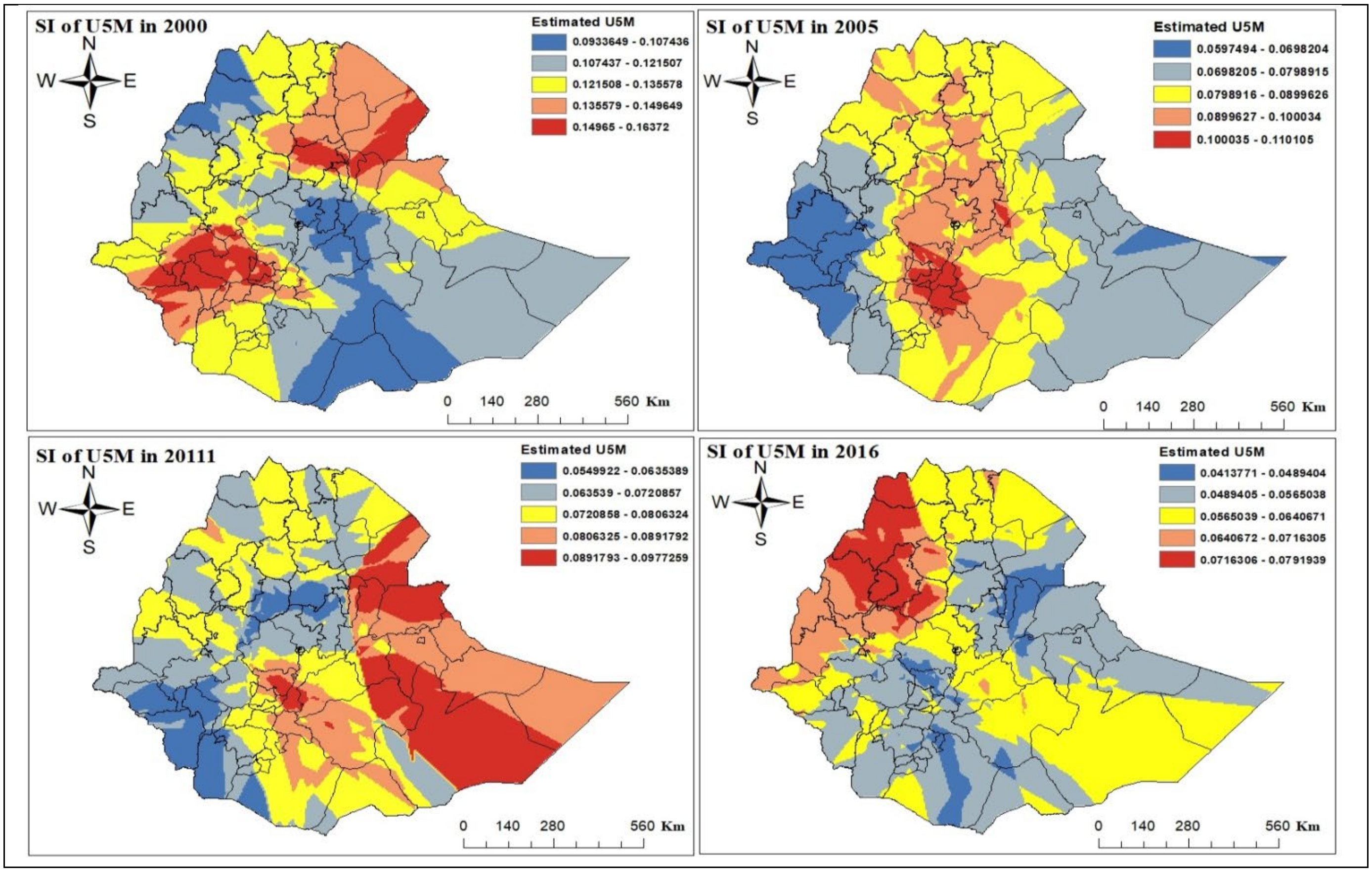


Figure 5. Spatial interpolation of under-five mortality in Ethiopian Administrative zones in 2000-2016.

Selection of Spatial Models for the four EDH survey data

Different spatial models were fitted for four (2000-2016) EDHS data sets, and from those models that have the smallest AIC, BIC, and largest log-likelihood were selected. In 2000 and 2016 EHDS general nesting spatial model was good fit for the data that had the smallest AIC (-248.727, and -326.361) and BIC (-213.293, and -135.659). In 2005 and 2011 EDHS spatial Durbin error model was best fit data and had the smallest AIC (-343.557, and -329.053), and BIC (-230.488, and -215.9849) compared with other spatial models.

4.3 Spatial models for four EDHs years

The general nesting spatial model (GNSM) and Spatial Durbin error model (SDEM) succeed over the other spatial models for four datasets in accordance with the model selection criteria of AIC, BIC, and Log-likelihood from the result in Table 2. Table 3 shows the results after choosing the fitted models.

Table 3: Results of general nesting spatial model (GNSM) and Spatial Durbin error model (SDEM) from 2000-2016 EDHS to administrative zones.

Year of dataset	**2000**		**2005**		**2011**		**2016**	
Characteristics	**GNSM**		**SDEM**		**SDEM**		**GNSM**	
Intercept	-1.888**	**Xlag(θ)**	2.78***	**Xlag(θ)**	-1.074	**Xlag(θ)**	-1.870*	**Xlag(θ)**
Social and Environmental factors								
Father with illiteracy	-0.0590	0.1487*	-0.0344	-0.7561**	0.0986	0.1592	0.1258	0.3008
Unemployment status of women	-0.0668	0.1557*	-0.0469	0.7530*	0.0825	0.6568*	-0.0076	0.7034**
Child was rural	0.0196	-0.0566	-0.0443	0.6049**	-0.0244	0.5601.	0.0982	0.8669*
Family with wealth status was poor	-0.0643	0.2322**	0.0354	-0.2127	0.0953	0.0518	0.0348	-0.0138
Access unimproved source water	0.0384	-0.3024	0.0569	0.4660***	-0.0116	-0.0474	-0.0168	-0.4946.
Unimproved toilet facility	0.0347	0.2963**	0.0452	0.1398	-0.1345.	0.5359*	-0.0438	0.8954.
Women with media exposures	-0.1034	-0.6685**	-0.0171	-0.6564**	-0.2002**	0.1330	0.0063	-0.9284*
Mother with illiteracy	-0.1034	0.2378*	0.1034	0.2113**	-0.0679	0.0888	-0.1675	0.9636.
Demographic factors								
Age at first marriage<=16	-0.0038	0.1854**	-0.0876	-0.4283*	0.0906.	0.0681	0.0306	-0.0464
Child was Male	0.0819	0.3314**	0.0966	0.1429*	0.2354	0.1284.	0.1246	0.4200
Family with household sizes>6	0.0447	0.1899*	-0.0183	0.0941	0.0299	0.1862	-0.0953	0.5163
Birth order of child>3	0.0292	0.5604*	0.0042	-0.3712.	-0.1035	0.4764	-0.0790	0.1114**

Marital status with married	-0.0466	-0.1818.	-0.2846*	-0.1367**	-0.8106*	-0.5530	-0.3343*	0.1137
Preceding birth interval in month<=36	-0.1222	0.1039**	-0.1339	0.1016**	0.2908*	0.5592*	-0.0318	0.9797*
Religions with Christian	-0.0618	0.7362**	-0.0179	-0.0871	0.1150.	0.2373	0.0614.	-0.1795
Geographical factors								
Mean max temperature	0.0034	0.0654**	-0.0050	-0.0502*	0.0032	-0.0333**	-0.0587	0.0264.
Mean wet days	-0.0048	-0.0349*	0.0057	0.0478*	-0.0023	0.0396**	0.0063	-0.0292.
Mean annual precipitation	0.0014*	-0.0300*	-0.0068	0.0026	-0.0080	-0.0063**	-0.0045	0.0028*
Mean malaria prevalence	-0.0004	0.0002*	-0.0019	0.0035.	0.0004	0.0054***	0.0003	0.004*
Maternal and Health factors								
Women's with contraceptive use	-0.0995	-0.2050*	-0.1314.	-0.9521*	-0.1834*	0.6823.	0.0046	-0.0718
Children not breastfeeding	0.3519*	0.1457**	-0.0036	0.0717	0.0045	0.3989.	-0.0256	0.6654*
Delivery with at health center	0.0168	0.1223	-0.0950	-0.1500*	-0.3309	-0.1016*	0.1895.	-0.8409.
Child was not vaccinated	0.0275	0.1020*	-0.0498	0.3389	-0.0682	0.0508	0.2845*	0.1680*
ANC visit at least 4 times	0.1378	-0.4660**	-0.0409	-0.1888	-0.2760*	-0.6244	-0.0561	-0.7962*
ρ	0.4299**						0.1060*	
λ	-0.4368**		0.9430**		-0.5887***		-0.1039*	

Key: Signif. Codes: ***P<0.001, **P< 0.01, *P< 0.05, .P< 0.1

Any change in a zone connected to any explanatory variable has an impact on that zone directly (direct effect) and may have an indirect impact on all other zones (indirect effect). The average increase in maximum temperature is associated with a 0.0654% increase in the under-five child mortality, and the increase in average maximum temperature of neighbouring zones is associated with a 0.033% decrease in under-five mortality through spatial dependence (Table 3).

The average proportion of children with not current breastfeeding increase in neighbouring zones is associated with a 0.6654% increase in under-five child mortality through spatial proximity, holding other variables are constant.

The proportion of age at first marriage is less than sixteen is an increase in neighbouring zones is associated with 0.1854% increase in under-five child mortality through spatial proximity, holding all other variables constant. We note that the average proportion of women with media exposure increases in neighboring zones is related to a 0.9284% decrease in under-five mortality of children through spatial spillover.

Similarly, the proportion of unimproved toilet facility user's increase in the average of neighbouring zone is associated with a 0.5359% increase under-five child mortality through spatial dependence, holding other variables constant.

The percentage of the household size increase in a neighbouring zone is associated with a 0.1899 % increase in under-five child mortality through spatial dependence. Furthermore, the coefficient for the wealth status of the families may also be 0.2322 and statistically significant, indicating that the percentage of poor families' wealth status increase in the neighborhood zones would increase under-five child mortality through spillover (Table 3).

Since higher children die when their mothers are illiterate, there would be high under-five child mortality in neighboring zones. According to the coefficient for mother illiteracy, which is the average effect of the neighbouring change in under-five child mortality was 0.2378. The average indirect impact of malaria prevalence on child mortality under age five of all neighbouring zones is 0.0054, averaging all spatial units.

The average influences of variables that are wet days (0.1487), and illiteracy of the father (0.0349) are statistically significant impacts on children who die (Table 3).

The average neighboring effect of ANC visit at least 4 times, marital status, and father education on under-five child mortality is 0.7962, 0.7362 and 0.1487 in neighboring administrative zones respectively. The average of a one percent increase in the Christian religion follower's in neighbouring zone is associated with a 0.7362% increase in under-five mortality through spatial spillover.

In the estimates of father illiteracy was negative (-0.7561) it mean that the proportion of father illiteracy increase in neighbouring zone, under-five mortality was decrease by 0.7561. This contradicts with truth, so this was due to data of the survey. Similarly, some other variables had the same data problem like age at first marriage of neighbouring effect.

The estimate of the spatial covariates, λ was 0.9430 which statistically significant ($p<=0.01$) which tells the dependence of spatial disturbance in the model for the Durbin error spatial model. It indicates that the average effect of neighboring zones' disturbance on the under-five child mortality is 0.9430 which improves the efficiency (Table 3).

One percent increase in the average under-five mortality of neighbouring zone is associated with a 0.4299% increase in under-five mortality through spatial dependence. The average strength of the spatial dependence of the under-five mortality was 0.4299.

The average proportion of the birth order increase in neighbouring zone is associated with a 0.1114% increase in the coefficient of birth order which leads to an increase in child mortality, holding the other variables constant (Table 3).

The models employed identified that the zone-level variations of potential risk factors that facilitate disparities in under-five child mortality distributions. The under-five child mortality was highest from 2000-2016 in zone 1, Shinile, Liben, East gojjam, Kemash, and Awi zones after considering risk factors.

After taking into account the impact of risk factors, under-five child mortality was shown to vary both geographically and temporally, showing that between the years 2000-2016 of the EDHS, under-five child mortality was somewhat higher in the Somali regions of Unknown, Borena, Bale, East Hararghe, and Sidama Zone (Figure 6).

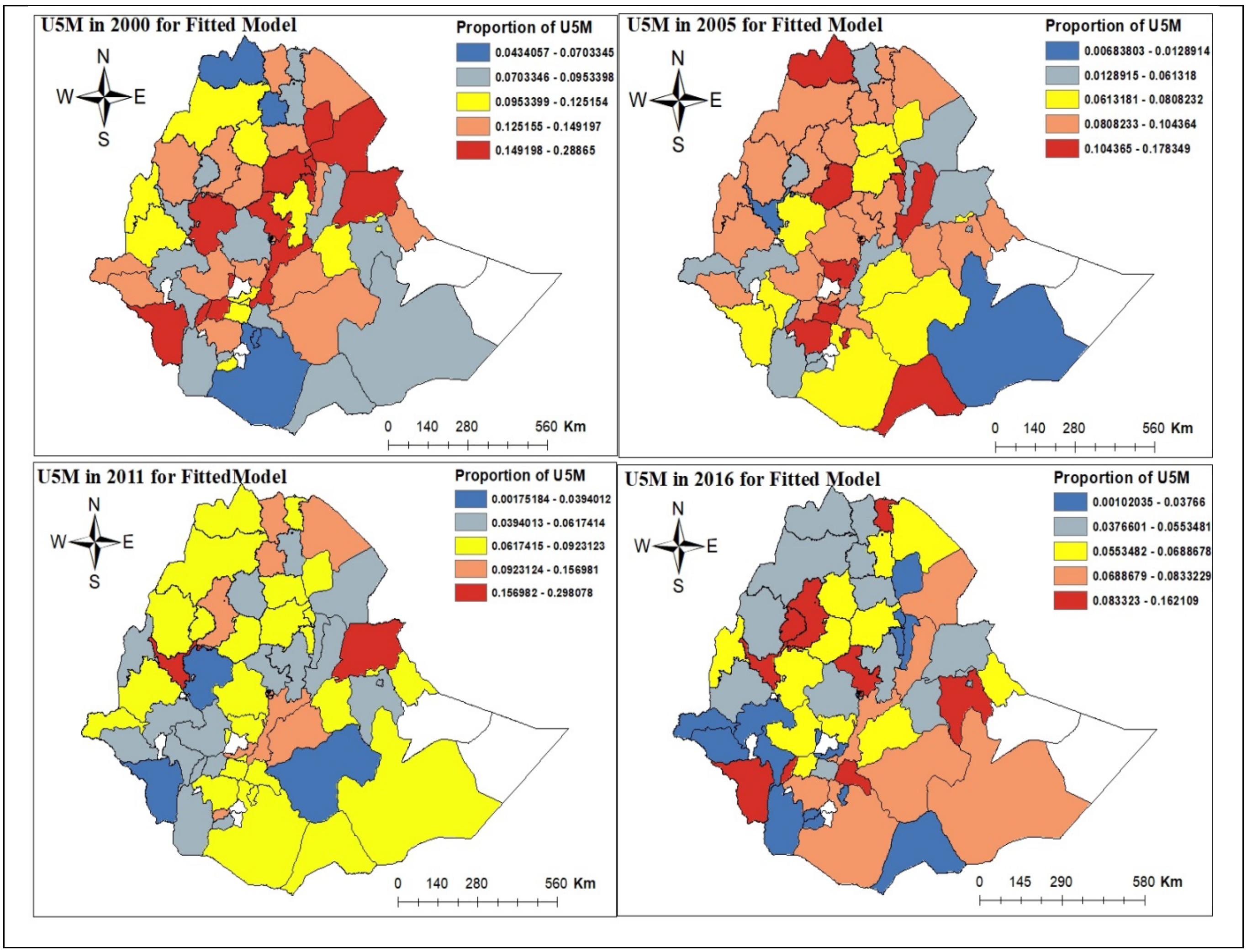


Figure 6. Mapping fitted model analysis in Ethiopian Administrative zones from 2000-2016.

CONCLUSIONS

The purpose of this study was to explore the spatial distribution, identify the spatial pattern, and assess the effect of risk factors by incorporating spatial variation on under-five child mortality in Ethiopian administrative zones.

The under-five child mortality rate is rapidly declining over the four EDHS year data from 2000 to 2016 in administrative zones of Ethiopia. From the study, we concluded that the spatial and temporally variation of under-five child mortality was significantly differ among administrative zones in Ethiopia's. This finding investigated that Konta-special woreda, yem-special woreda, Dawuro zone, Kambata Alaba Tambaro, Hadiya, Gedeo, and Guraghe zone, Oromia liyu zone, Awi zone, East Gojjam zone, North Shewa, East Shewa, East Wallega zone, zone1, zone5, Shinile, Kemeshi, and Eastern Tigray zones were high-risk zones of under-five mortality.

The general nesting spatial model and spatial Dynamic error model are more appropriate for describing the dependent nature of under-five mortality (U5M) in administrative zones and it showed that child not vaccinated, illiteracy of mother, unemployment status, preceding birth interval <=36 month, illiteracy of father, ANC visit at least 4 times, child was rural, child was male, use of contraceptive method, marital status was married were significant risk factors .

Furthermore, this study concluded that facilitating rural areas to get improved drinking water near to homes helps to reduce the burden of under-five child mortality and to be in line with sustainable development goal.

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