Spatial Distribution of Rotavirus Immunization Coverage in Ethiopia

Kendalem Asmare Atalell (kedasmar@gmail.com)
University of Gondar
Kefyalew Alene
Curtin University
Alemneh Mekuriaw Liyew
University of Gondar

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Abstract

Introduction:

Rotavirus immunization prevents severe diarrheal diseases in children, but vaccination coverage is still far from desired targets in many African countries including Ethiopia. Measuring rotavirus immunization coverage at a lower geographic area can provide information for designing and implementing a targeted immunization campaign. This study aimed to investigate the spatial distributions of rotavirus immunizations coverage in Ethiopia.

Methods

Rotavirus immunization coverage data were obtained from the Ethiopian Demographic and Health Survey (EDHS) 2019. Covariate data were assembled from different publicly available sources. A Bayesian geostatistic model was used to estimate the national rotavirus immunization coverage at a pixel level and to identify factors associated with the spatial clustering of immunization coverages.

Result

The national rotavirus immunization coverage in Ethiopia was 52.3% (95% CI: 50.3, 54.3). The immunization coverage varied substantially at the sub-national level with spatial clustering of low immunization coverage observed in the Eastern, Southeastern, and Northeastern parts of Ethiopia. The spatial clustering of the rotavirus immunization coverage was positively associated with altitude of the area (mean regression coefficient (β): 0.38; 95% credible interval (95% CrI): 0.18, 0.58) and negatively associated with travel time to the nearest cities in minutes (mean regression coefficient (β): -0.45; 95% credible interval (95% CrI): (-0.73, -0.18) and distance to the nearest health facilities (mean regression coefficient (β): -0.72; 95% credible interval (95% CrI): (-1.07, -0.37).

Conclusions

This study found that the rotavirus immunization coverage varied substantially at sub-national and local levels in Ethiopia. The spatial clustering of rotavirus immunization coverage was associated with geographic and healthcare access factors such as altitude, distance to health facilities, and travel time to the nearest cities. The immunization program should be strengthened in Ethiopia, especially in the Eastern, Southeastern, and Northeastern parts of the Country. Outreach immunizations services should be also implemented in areas with low coverage.

Introduction

Diarrheal diseases are the second leading cause of death among under-five children globally (1–7), claiming more than 128, 500 death and 2.6 million illness in 2016 (8). Rotavirus is the most common cause of severe diarrheal disease. Ethiopia is among the five countries with the highest rotavirus burden (9). The country accounts for six percent of the global rotavirus deaths (9). The World Health Organization (WHO) introduced an effective two-dose vaccine to prevent diarrheal disease caused by rotavirus (8, 10, 11). In Ethiopia, rotavirus immunization was introduced in the national immunization program in 2013 (9). However, the coverage is still far from the desired target in the country.

According to the WHO report, the estimated rotavirus immunization coverage was 46% globally, and 50% in Africa in 2020 (12, 13). The Ethiopian Demographic and Health Survey (EDHS) reported that the national rotavirus immunization coverage was nearly 47% in 2016 (14–16). Further regional level analysis of the 2016 EDHS showed that rotavirus immunization coverage varied from 14.6% in Afar to 77% in Addis Ababa (15). However, the rotavirus immunization coverage for administrative units such as districts may differ significantly from the regional and national average. Measuring rotavirus immunization coverage at a lower geographic area can provide information for designing and implementing a targeted immunization campaign.

Understanding drivers of the spatial distributions of rotavirus immunization coverage are also essential to inform strategies for improving immunization services. Previous studies have identified various factors that affect different immunization coverage such as measles and influenzas. These factors include climatic conditions and access to health facilities (17–22). However, the impacts of these factors on rotavirus immunization coverage are yet to be quantified in Ethiopia (23). Therefore, this study aimed to estimate the spatial distributions and identify drivers of rotavirus immunization coverage in Ethiopia.

Methods

Study setting

The study was conducted in Ethiopia which is located in east Africa. Ethiopia has a surface area of approximately 1.1 million squares kilometers. The country has a variety of geographical features with altitude ranges from 125 meters below sea level in Danakil depression, Afar region to 4620 meters above sea level in Ras Dajen mountain, Amhara region. Ethiopia is the second-most populous country in Africa with an estimated population size of more than 115 million people in 2020. Of these populations, 16.8 million are children under five years of age (24).

In Ethiopia, rotavirus immunization was introduced into the national immunization program in 2013 (9). More than half of the population in Ethiopia lives more than 10 km far from the nearest health facilities and has no access to immunization programs (25). The Ethiopia health care system has a three-tier system: (1) primary care: composed of health posts, health centers, and primary hospitals; (2) secondary care: composed of general hospitals; and (3) tertiary care: composed of specialized hospitals (26), at which immunizations services are being delivered.

Data sources

Rotavirus immunization coverage data with geographic coordinates were obtained from the mini-Ethiopian demographic and health survey (EDHS-2019). The EDHS-19 survey was conducted between January and June 2019. The survey contains data that is relevant to estimate rotavirus immunizations coverage at a pixel level. A polygon shapefile for the Ethiopian administrative boundaries was obtained from the central statistical agency of Ethiopia-2013. Climatic variables such as mean annual temperature and mean annual precipitation were obtained from the World Clim website (27). Altitude data from the Shuttle Radar Topography Mission (SRTM) (28). Data on travel time to the nearest city and travel times to the nearest healthcare facility in minutes (i.e., hospital or clinic) were obtained from the Malaria Atlas Project (MAP) (29). Population density, estimated as the number of people per grid cell, was obtained from WorldPop (30). Rotavirus immunizations coverages data were linked to area-level covariates data by using ArcGIS software.

Spatial analysis

The spatial continuous estimates of the national rotavirus immunization coverage map were generated by using Bayesian model-based geostatistics at a resolution of 1 km^2. A spatial binomial regression model was fitted for rotavirus immunization coverage survey data including fixed effects for altitude, travel time to the nearest city, distance to the nearest health facilities and population density, and geostatistical random effects (31). The rotavirus immunization coverage was taken at each surveyed location j as the outcome variable, which was assumed to follow a binomial distribution:

$$Y_j \tilde{} Binomial(n_j, p_j);$$

where Y_j is the observed rotavirus immunization coverage, n_j is the total number of vaccinated children and p_j is the predicted rotavirus immunization coverage at location j(j=1, …305). Mean predicted rotavirus coverage was modeled via a logit link function to a linear predictor defined as:

$$logit\left(p_j\right) = \alpha + \sum_{z=1}^{Z} \beta_z \varvec{X}_{z,j} + \zeta_j;$$

where α is the intercept, β is a matrix of covariate coefficients, $\varvec{X}$ is a design matrix of z covariates, and ζ_j are spatial random effects modeled using a zero-mean Gaussian Markov random field (GMRF) with a Matérn covariance function. The covariance function was defined by two parameters: the range ρ, which represents the distance beyond which correlation becomes negligible (about 0.1), and σ, which is the marginal standard deviation (32, 33). Non-informative priors were used for α (uniform prior with bounds $-\infty$ and ∞) and we set normal priors with mean = 0 and precision (the inverse of the variance) = 1 × 10^{-4} for each β. We used default priors for the parameters of the spatial random field (34). Parameter estimation was done using the Integrated Nested Laplace Approximation (INLA) approach in R (R-INLA)(32, 33). Sufficient values (i.e., 150,000 samples) from each simulation run for the variables of interest were stored to ensure full characterization of the posterior distributions.

Predictions of rotavirus immunization coverage at unsampled locations were made at 1 km² resolution by interpolating the spatial random effects and adding them to the sum of the products of the coefficients for the spatially variant fixed effects at each prediction location (35). The intercept was added, and the overall sum was back-transformed from the logit scale to the prevalence scale, providing prediction surfaces that show the estimated rotavirus immunization coverage for all prediction locations. The Watanabe Applicable Information Criterion (WAIC) statistic was used to select the best-fitting model.

Results

National and regional rotavirus immunizations coverage

Table 1 shows the national and regional rotavirus immunization coverage in Ethiopia. The national rotavirus full immunization coverage was 52.3% (95% CI: 50.3, 54.3). Substantial variation was observed at regional levels, with the highest immunization coverage was in Addis Ababa (91.67%), Tigray (70.77%), and Dire Dawa (70.39%). On the other hand, low immunizations coverage was observed in Afar (24.1%) and Somali (26.42%) regions.

Table 1
National and regional rotavirus immunization coverage in Ethiopia.

Region	Rota 1 immunizations coverage %	Rota 2 immunizations coverage %
Tigray	78.08	70.77
Afar	31.03	24.10
Amhara	75.78	68.86
Oromia	62.5	52.81
Somali	33.02	26.42
Benishangul-Gumuz	70.00	61.79
SNNPR	52.74	42.65
Gambela	59.67	51.03
Harari	60.80	46.00
Addis Ababa	92.78	91.67
Dire Dawa	81.12	70.39
Ethiopia	60.77	52.33

SNNPR: Southern Nations, Nationalities and peoples Region

Spatial clusters of rotavirus immunizations

The rotavirus immunization coverage greatly varies within regions of Ethiopia. Spatial clustering (i.e., highest rotavirus immunizations coverage) of high coverage was observed in the Central, Northern, and Northwestern parts of Ethiopia. On the contrary, spatial clustering of low rotavirus immunizations coverage was seen in the Southern, Southeastern, Eastern Northeastern parts of the country (Figure 1).

Figure 2 showed the predicted map of immunization coverage in Ethiopia using the Bayesian model framework. Predicted low rotavirus immunization coverage was observed in Southern, Eastern and Northwestern parts of the country. Whereas the highest predicted immunization coverage was observed in the Northern, Central, and Northeastern parts of Ethiopia.

Drivers of rotavirus immunizations coverage in Ethiopia

The Bayesian geostatistical model found that geographic and climatic factors were associated with the spatial clustering of rotavirus immunization coverage in Ethiopia. The altitude of the area in meter (mean regression coefficient (β): 0.38; 95% credible interval (95% CrI): 0.18, 0.58) was positively associated with rotavirus immunization coverage. Whereas, travel time to the nearest cities in minutes (mean regression coefficient (β): -0.45; 95% credible interval (95% CrI): (-0.73, -0.18) and walking distance to health facilities in minutes (mean regression coefficient (β): -0.72; 95% credible interval (95% CrI): (-1.07, -0.37) were negatively associated with rotavirus immunization coverage in Ethiopia (Table 2).

Table 2
Regression coefficient mean and 95% credible intervals (CrI) of covariates included in a Bayesian spatial model with Binomial response for the rotavirus immunization coverage in Ethiopia, 2019.

Covariates	**Rotavirus immunization coverage** **Regression coefficients of** **Mean (95% CrI)**
Altitude	**0.38 (0.18, 0.58)**
Travel time	**-0.45 (-0.73, -0.18)**
Population density	0.003 (-0.008, 0.01)
Distance to health facilities	**-0.718 (-1.07, -0.37)**
Intercept	-0.96 (-1.32, -0.62)

CrI: credible interval; bold fonts show ‘statistically significant’ results within a Bayesian framework (no zero within the 95% CrI).

Model fitness was checked by using the Widely Applicable Information Criterion (WAIC) statistic, the model that contained the smallest value (i.e., the model which contain all covariates) was the best-fitting model for immunization coverage (Supplementary Table 1).

Discussion

Rotavirus immunization coverage was 52.3% (95% CI: 50.3, 54.3) in Ethiopia, which is slightly higher than the rotavirus immunization coverage reported in the 2016 EDHS (36). The rotavirus immunization coverage was also higher than the global (46%) (37) and Africa (50%) (13) estimates. This might be because of the strong commitment of the Ethiopian government in the past few years to improve access to and utilization of immunizations through training a large number of health extension workers, which deliver vaccines at the community level both in rural and urban districts. Moreover, expansion of health posts and primary health cares in the country may provide vaccines and increase coverage. However, rotavirus immunization coverage in our study is lower than a study conducted in developed countries such as the USA (60.4%) (22) and Canada 84% (38). The discrepancy in the USA and Canada study might be due to the difference in accessibility and utilization of health services. It could also be due to the difference in community awareness towards vaccine programs and difference in infrastructure including distance to health facilities (39, 40). The accessibility and utilization of health services including immunization services in Ethiopia are unevenly distributed. The health service is low in the rural parts of Ethiopia, where greater than 80% of the population lives.

Consistent with other spatial studies (41, 42), the current study revealed significant spatial clustering of rotavirus immunization in Ethiopia. Spatial clustering of low rotavirus immunization coverage was observed in the Eastern, South-eastern, and North-eastern parts of the county. This might be due to poor mother's healthcare-seeking behavior, inadequate knowledge of childhood immunization, poor access to vaccines, and misconceptions towards immunization in pastoral regions like Somalia and Afar regions (43, 44).

Our study found that altitude was positively associated with rotavirus immunization coverage. This might be because most kebeles in the highland area have access to transportation. Moreover, districts in the highland areas have relatively better healthcare access than districts in lowland areas such as in Afar and Somali regions (40, 45). In addition to low coverage, the efficacy of the vaccine might be also poor in lowland areas due to high environmental temperature. There could be vaccines supply but keeping the vaccine in a cold chain would be a major problem in many districts (46).

Travel time to the nearest cities and distance to health facilities were negatively associated with rota vaccine coverage. This finding is consistent with previous pieces of studies conducted in Ethiopia (40, 45) and other African countries such as Tanzania (47), Malawi (48), Nigeria (49), and Kenya (50). This might be since access to health facilities and poor infrastructure are the major challenges for health care providers to provide proper health care services including immunization (51). In addition, if there is no access to health facilities, mothers and caregivers of a child might not visit health facilities for immunizations services. Moreover, people living away from the cities and health facilities have low access to information and health educations which could, in turn, lead to poor health care utilization including child immunization (52). Designing and implementing a targeted immunization campaign in areas with low rotavirus immunization coverage would be important.

This study provides important information that would help to minimize the geographic disparity of rota vaccine uptake in Ethiopia. The study identified high-risk areas and underline factors of rotavirus immunization coverage in Ethiopia. Such information is important for integrated intervention to achieve Sustainable Development Goal targets for child survival. Immunization has a significant impact on advancing sustainable development goals (53). Its contribution to building a productive workforce (SDG8) makes it to be the main driver of the economic development of a given country (54).

The strength of this study was using nationwide data which could produce reliable estimates with advanced geostatistical analysis. However, this study had some limitations, due to the cross-sectional nature of the data, it might be difficult to indicate the temporal relationship between geospatial covariates and the outcome variable. In addition, important factors were not included due to a lack of data.

Conclusion

This study found that the national immunization coverage varied substantially at sub-national and local levels. Spatial clustering of low rotavirus immunization coverage was observed in the Eastern, Southeastern, and Northeastern parts of Ethiopia. Access to health facilities and geographic factors such as altitude, distance to health facilities, and travel time to the nearest cities were factors associated with the spatial clustering of rotavirus immunization coverage in Ethiopia. Therefore, the health extension works in Ethiopia should strongly implement outreach immunization campaigns in areas with low immunization coverage.

Declarations

Conflicts of interest

The authors have no conflicts of interest to declare.

Author contributions

KAA_1 conceived and designed the study, run the analysis, and drafted the manuscript. KAA_2 checked the analysis. AML and KAA_2 made substantial contributions in reviewing the design of the study and the draft manuscript. All authors critically reviewed the manuscript for important intellectual content and contributed to the final approval of the version to be submitted.

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Figures

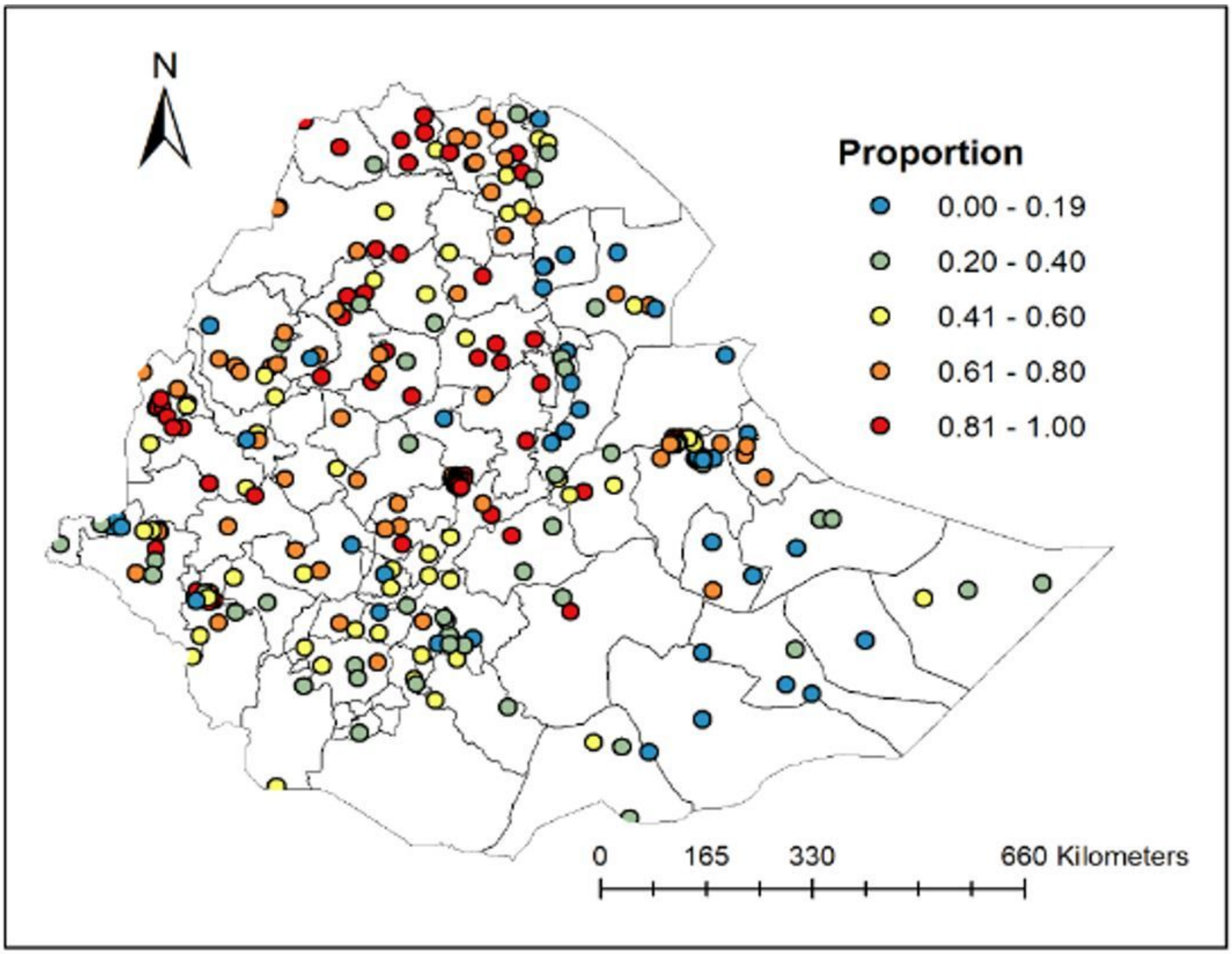

Figure 1

Geographical locations of data points and rotavirus immunization coverage in Ethiopia.

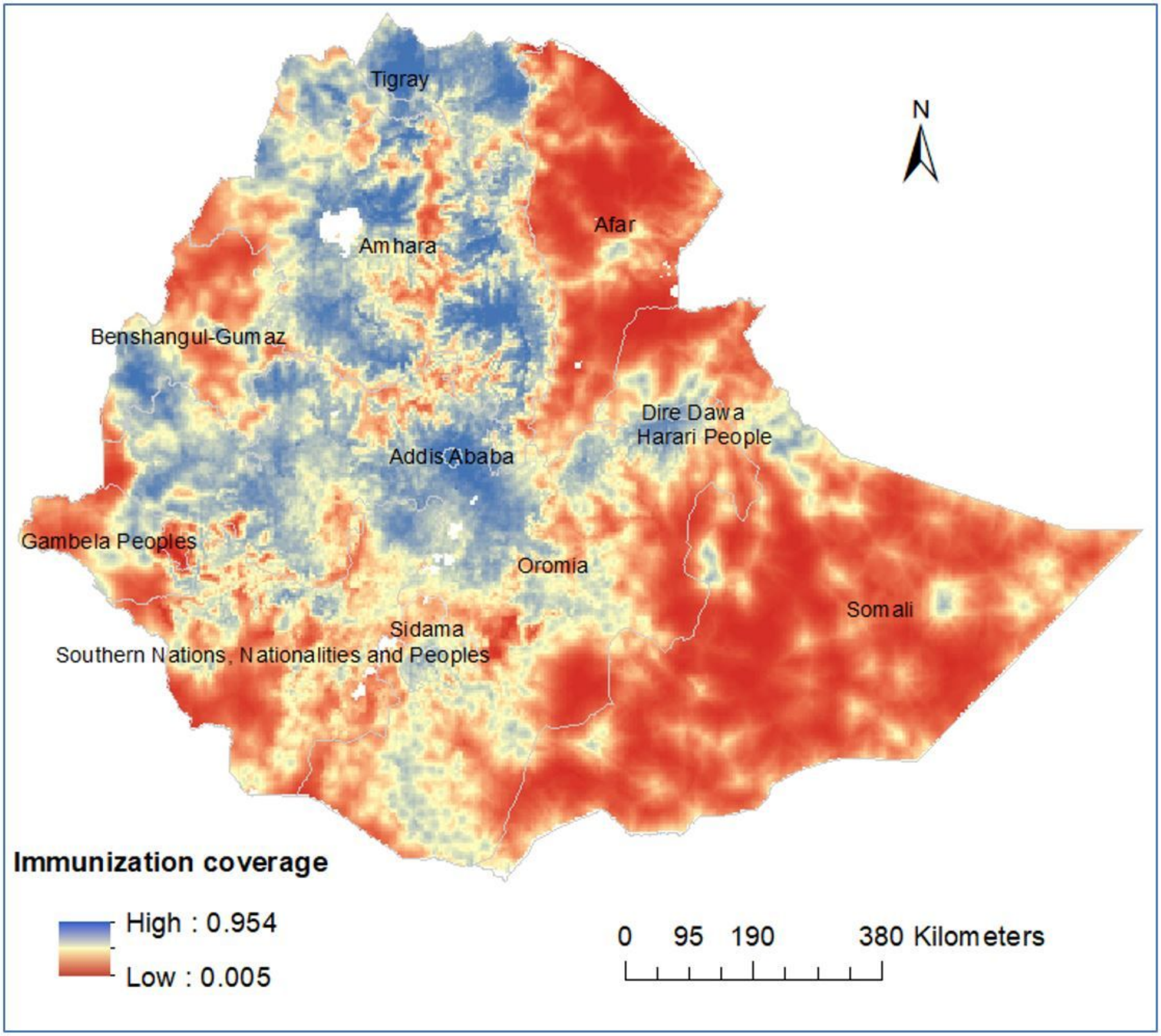

Figure 2

The predicted geospatial map for rotavirus immunization coverage in Ethiopia.

Supplementary Files

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- Supplementaryinformation.docx