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Mapping national, regional and local prevalence of hypertension and diabetes in Ethiopia using geospatial analysis

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ABSTRACT

Objectives This study aimed to map the national, regional and local prevalence of hypertension and diabetes in Ethiopia.

Design and setting Nationwide cross-sectional survey in Ethiopia combined with georeferenced ecological level data from publicly available sources.

Participants 9801 participants aged between 15 and 69 years.

Primary outcome measures Prevalence of hypertension and diabetes were collected using the WHO's STEPS survey approach. Bayesian model-based geostatistical techniques were used to estimate hypertension and diabetes prevalence at national, regional and pixel levels (1×1 km^2) with corresponding 95% credible intervals (95% CrIs).

Results The national prevalence was 19.2% (95% CI: 18.4 to 20.0) for hypertension and 2.8% (95% CI: 2.4 to 3.1) for diabetes. Substantial variation was observed in the prevalence of these diseases at subnational levels, with the highest prevalence of hypertension observed in Addis Ababa (30.6%) and diabetes in Somali region (8.7%). Spatial overlap of high hypertension and diabetes prevalence was observed in some regions such as the Southern Nations, Nationalities and People's region and Addis Ababa. Population density (number of people/km^2) was positively associated with the prevalence of hypertension (β: 0.015; 95% CrI: 0.003–0.027) and diabetes (β: 0.046; 95% CrI: 0.020–0.069); whereas altitude in kilometres was negatively associated with the prevalence of diabetes (β: –0.374; 95% CrI: –0.711 to –0.044).

Conclusions Spatial clustering of hypertension and diabetes was observed at subnational and local levels in Ethiopia, which was significantly associated with population density and altitude. The variation at the subnational level illustrates the need to include environmental drivers in future NCDs burden estimation. Thus, targeted and integrated interventions in high-risk areas might reduce the burden of hypertension and diabetes in Ethiopia.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ For the first time, this study presented the spatial distribution of both hypertension and diabetes in Ethiopia at a higher resolution level.

⇒ The study incorporated a range of ecological factors from multiple sources and applied rigorous geospatial techniques to provide the best spatial maps.

⇒ However, the current analysis did not include potential cofounding variables such as healthcare seeking behaviour of participants, food diversity and burden of comorbidities such as cancer and HIV that might better explain spatial variation, as these variables were not available in our dataset.

INTRODUCTION

Cardiovascular diseases (CVDs), cancer, chronic respiratory diseases, hypertension and diabetes are the most common types of non-communicable diseases (NCDs) reported globally. Worldwide, NCDs are the leading causes of mortality, accounting for more than 71% of annual deaths .[1] Overall, three-quarters of NCD-related deaths occur in low-income and middle-income countries.[2] These countries also suffer from the double burden of infectious diseases and undernutrition.[3]

Hypertension is one of the most important causes of premature death globally.[4] A systematic review and meta-analysis conducted in 2015 reported a pooled prevalence of hypertension of 31.1% among adults in Sub-Saharan African countries.[5] Uncontrolled hypertension can lead to CVDs such as stroke, myocardial infarction and congestive heart failure and chronic kidney diseases.[6] Similarly, diabetes increases the risk of CVD, retinopathy, nephropathy and neuropathy.[7]

Being overweight or obese, having a sedentary lifestyle, unhealthy diet, chronic stress, poor sleep habits, smoking and excessive alcohol consumption are known risk factors for both hypertension and diabetes.

Although individual-level factors play a substantial role in developing hypertension and diabetes, several studies point out that ecological level factors are also important determinants.[8 9] A recent systematic review reported that living in neighbourhoods with higher levels of walkability and green space was associated with lower diabetes risk, while higher levels of air pollution and traffic noise were associated with increased diabetes risk.[8]

In Ethiopia, a nationwide cross-sectional survey on NCDs was conducted in 2015 using the WHO STEPS survey approach.[10] The report from this study and several other studies on the prevalence of hypertension and diabetes in Ethiopia documented prevalence estimates by age groups, sex, residence (urban or rural) and region.[11–13] However, the prevalence of both diseases is not spatially mapped for potential geographic clustering. Geospatial mapping of hypertension and diabetes at regional (subnational) and local levels will be important in many ways. It can help to investigate any spatial clustering of these diseases and design targeted interventions for selected high-risk areas. In addition, it can be used as a resource for the whole community, health professionals, policy-makers and researchers to help bring about a better understanding of these diseases.[14] Therefore, the aim of this study is to map the geospatial distribution of national, regional and local prevalence of hypertension and diabetes, and to quantify their relationship with ecological-level factors at the highest resolution level across all regions of Ethiopia.

METHODS

Study design and data sources

This study was conducted using an ecological study design where associations between dependent and independent variables were measured at area levels.

We used data from the 2015 Ethiopian NCD STEPS survey.[15] The survey was carried out by the Ethiopian Public Health Institute in collaboration with the Ethiopian Federal Ministry of Health and the WHO. A detailed description of the survey is available elsewhere.[10] It was the first nationally representative NCD survey conducted across all regions and city administrations of Ethiopia. The survey was conducted in 404 urban and 109 rural areas using a cluster sampling design. The WHO's STEPS instrument was used to collect information from 9801 study participants aged between 15 and 69 years.

Outcome variables

Biochemical measurements were used to assess the proportion of people who had diabetes and raised blood glucose.[10] Blood pressure measurements were obtained three times on the right arm of survey participants in a sitting position, using a Boso-Medicus Uno instrument with a universal cuff and an automatic blood pressure monitor. The mean of three measurements was calculated for this analysis and high blood pressure was defined as a systolic blood pressure≥140 mm Hg and/or a diastolic blood pressure of ≥90 mm Hg or currently taking medication for high blood pressure.[16] Participants were asked to fast for at least 8 hours and capillary blood was taken for glucose measurements using CardioCheck PA Analyser. Diabetes was defined as a fasting blood glucose level≥7.0 mmol/L (126 mg/dL) or if a participant is already taking medication to lower high blood glucose levels.

Independent variables

The independent variables include healthcare access, demographic, environmental and climatic factors. These ecological-level independent variables were selected based on evidence of association with hypertension and diabetes from previous studies and based on the availability of nationally representative data. We used different data sources for the independent variables. Population density (the number of people per grid cell) was obtained from the World Pop database.[17] Climatic variables such as mean temperature and mean precipitation were obtained from the WorldClim database.[18] Data on healthcare access (ie, travel times in minutes to the nearest health facility and travel time to the nearest city) were obtained from the Malaria Atlas Project.[19 20] In addition, data on altitude and distance to the nearest water body were obtained from the Shuttle Radar Topography Mission[21 22] and the Global Lakes and Wetlands Database,[23] respectively. All these data were extracted at a spatial resolution of 1 km^2. A polygon shapefile for the Ethiopian administrative boundaries was obtained from the Database for Global Administrative Areas.[24] The data sources of the independent variables with their definitions are provided in the online supplemental table S1.

Statistical analysis

The prevalence of hypertension and diabetes were calculated at national and regional levels. Since the independent variables have different units and scales of measurement with unknown threshold effects, they were standardised to a Z-scale based on their mean and SD. This method also helped with identifiability in the estimation of the posterior distribution of the coefficients. All independent variables were tested for multicollinearity, and those variables with a variance inflation factor>5 were excluded from the geospatial model. The dependent variables, prevalence of hypertension and diabetes were georeferenced and linked to the area-level covariates using ArcGIS (ESRI, Redlands, California, USA) geographical information system software.

Geospatial analysis

Geospatial analysis was carried out at the pixel level (ie, at a resolution of 1 km^2) for both hypertension and diabetes, and their relationship with ecological level factors was quantified. Bayesian model-based geostatistics was constructed using covariate fixed effects and spatial random effects.[25] Two models were constructed separately for hypertension and diabetes. Here, detailed modelling steps are presented for the prevalence of hypertension, although a similar approach was employed for the prevalence of diabetes.

We modelled the number of hypertension cases (Y_j) among a sample (n_j) for a given observation as a binomial variable: $Y_j \sim \text{Binomial}\left(n_j, p_j\right)$. Mean predicted hypertension prevalence was modelled via a logit link function to a linear predictor defined as:

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

;where α is the intercept, β is a matrix of covariate coefficients, $\boldsymbol{X}$ is a design matrix of z covariates and ζ_j are spatial random effects modelled using a zero-mean Gaussian Markov random field 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, and σ, which is the marginal SD.[26 27] Non-informative priors were used for α (uniform prior with bounds –∞ and ∞) and we set normal priors with mean=0 and precision (the inverse of variance)=1×10^{-4} for each β. We used default priors for the parameters of the spatial random field.[28] Parameter estimation was done using the Integrated Nested Laplace Approximation (INLA) approach in R (R-INLA).[26 27] Sufficient values (ie, 150 000 samples) from each simulation run for the variables of interest were stored to ensure full characterisation of the posterior distributions. The Widely Applicable Information Criterion (WAIC) statistic was used to select the best-fitting model (online supplemental table S2). The spatial prediction surfaces for both diseases were overlaid to determine areas of coendemicity. Similar modelling approaches have been used previously in several epidemiological studies to map the prevalence of diseases at local levels.[29 30] The geospatial analysis and the descriptive analysis were conducted using R statistical software.

RESULTS

Prevalence of hypertension and diabetes at national and regional levels

Table 1 shows the observed prevalence of hypertension and diabetes at national and regional levels in Ethiopia. The national prevalence of hypertension and diabetes are estimated to be 19.2% (95% CI: 18.4% to 20.0%) and 2.8% (95% CI: 2.4% to 3.1%), respectively. The highest prevalence of hypertension was observed in Addis Ababa (30.6%), followed by Southern Nations, Nationalities and People's (SNNPR) (25.8%) and Amhara (19.7%) regions while Tigray (11.0%) and Afar (9.2%) regions reported the lowest prevalence. The highest prevalence of diabetes was observed in Somali (8.7%) region, followed by Harari (5.1%) and SNNPR (4.2%) regions, while Tigray (1.1%) and Benshangul-Gumuz (1.1%) regions reported the lowest prevalence of diabetes. Maps showing the prevalence of hypertension and diabetes mellitus at a local level are presented in figure 1.

Spatial clusters of hypertension and diabetes

Figure 2 shows the predicted prevalence of hypertension and diabetes in Ethiopia at a pixel level. The predicted prevalence of hypertension and diabetes varied considerably between and within regions. Hypertension was spatially clustered, with the highest prevalence (ie, hotspot areas) in Addis Ababa, SNNPR and Amhara regions. As depicted in figure 2, the capital and regional cities of the country (eg, Addis Ababa, Harari, Hawassa and Bahir Dar) had the highest prevalence of hypertension, while

Table 1 National and regional prevalence of hypertension and diabetes in Ethiopia, 2015

	Hypertension			Diabetes		
Regions	Participants screened for hypertension, n	Participants diagnosed with hypertension, n	Hypertension prevalence (%)	Participants screened for diabetes, n	Participants diagnosed with diabetes, n	Diabetes prevalence (%)
Addis Ababa	788	241	30.6	672	24	3.6
Afar	382	35	9.2	337	12	3.6
Amhara	1814	358	19.7	1627	20	1.2
Benishangul-Gumuz	393	57	14.5	348	4	1.1
Dire Dawa	258	31	12.0	216	4	1.9
Gambela	274	42	15.3	256	4	1.6
Harari	209	33	15.8	176	9	5.1
Oromiya	2263	417	18.4	2092	40	1.9
SNNPR	1685	434	25.8	1586	67	4.2
Somali	612	98	16.0	540	47	8.7
Tigray	933	103	11.0	880	10	1.1
Ethiopia	9611	1849	19.2	8730	241	2.8

SNNPR, Southern Nations, Nationalities and People's Region.

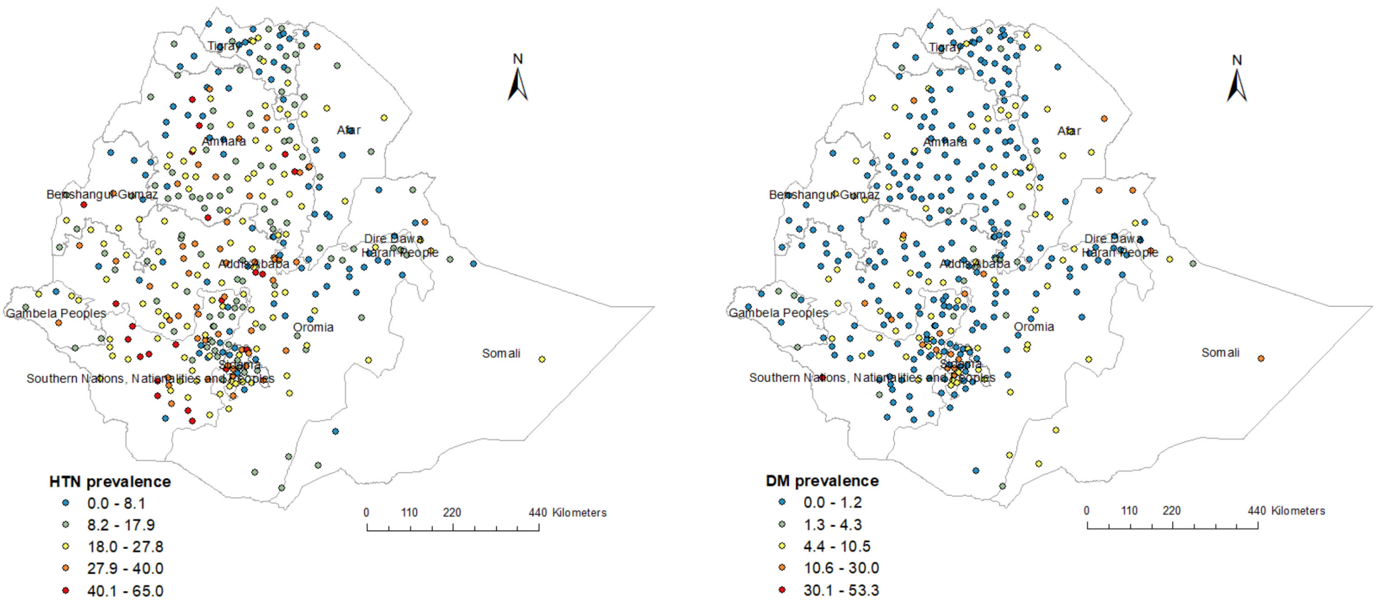

Figure 1 Maps showing the locations of survey and the prevalence of hypertension (HTN) and diabetes mellitus (DM) in Ethiopia.

the northern and eastern parts of the country had the lowest prevalence of hypertension.

High diabetes prevalence was observed in the eastern (eg, Afar and Somali) and southwestern (eg, SNNPR) parts of the country, in Addis Ababa and Hawassa cities (figure 2). In contrast, a low prevalence of diabetes was observed in the central parts of the country. The distribution of covariates used in the models are presented in online supplemental figure S1. Prediction uncertainty, as indicated by a high SD, was greatest in the eastern parts of the country (Afar and Somali regions) for both diseases (online supplemental figure S2).

Spatial codistribution of hypertension and diabetes

The predicted prevalence maps (figure 3) showed that the prevalence of hypertension and diabetes was geographically clustered, and spatial overlap was observed in some parts of the country. For example, the burden of both diseases was high in SNNPR region and Addis Ababa. Geographical overlap of high hypertension and diabetes prevalence was also observed in Harari regional state.

Ecological level factors associated with hypertension and diabetes prevalence

Table 2 shows the results of the Bayesian geostatistical models. Population density (number of people/km^2) was positively associated with hypertension (β: 0.015; 95% credible interval (CrI): 0.003–0.027) and diabetes (β: 0.046; 95% CrI: 0.02–0.059) prevalence. Altitude in km was found to be negatively associated with diabetes prevalence (β: −0.374; 95% CrI: −0.711 to −0.044) (table 2).

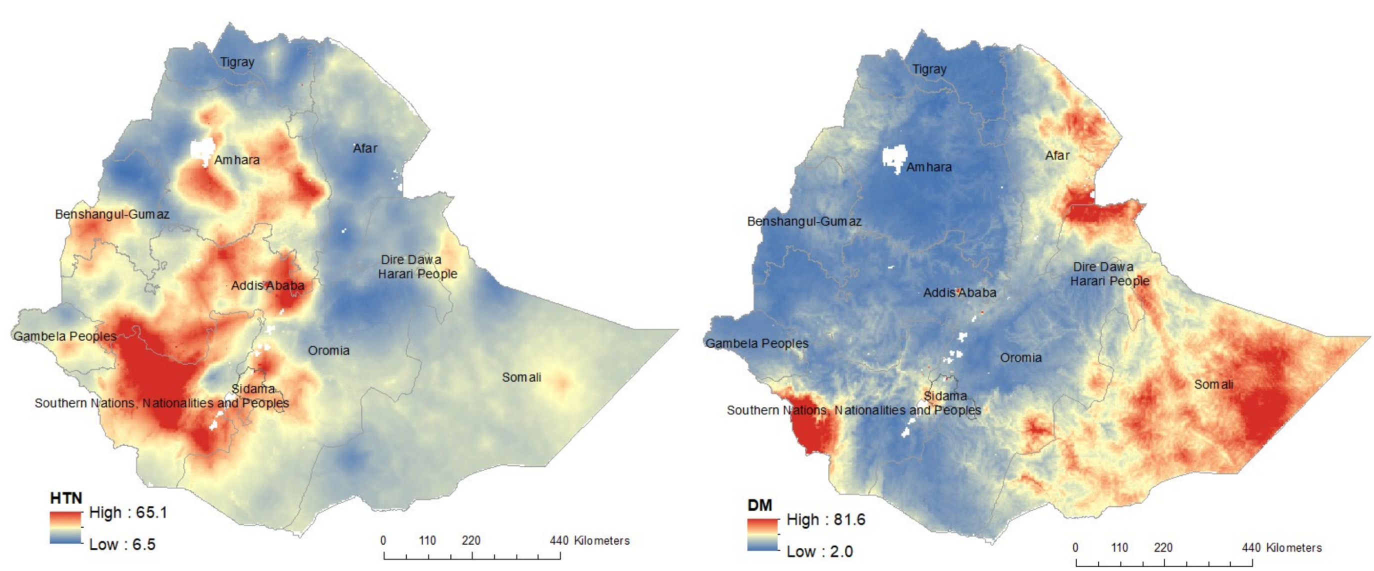

Figure 2 The geospatial predicted prevalence of hypertension (HTN) and diabetes mellitus (DM) in Ethiopia.

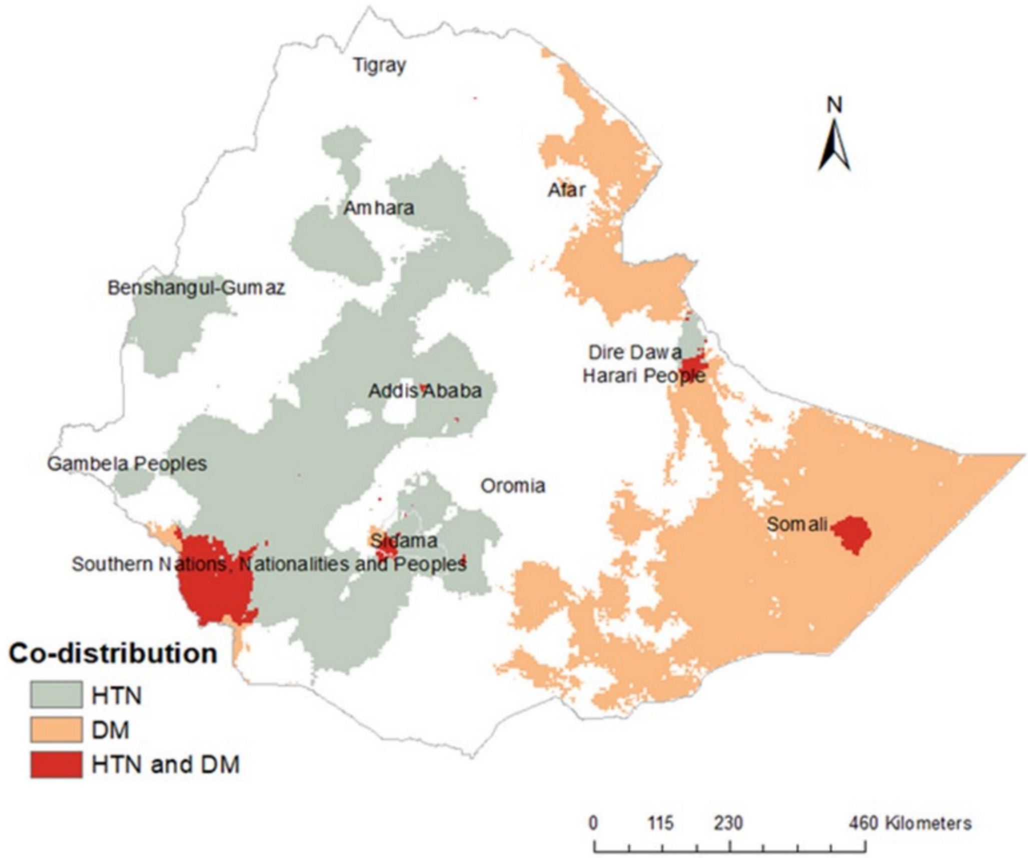

Figure 3 Predicted areas of codistribution for hypertension (HTN) and diabetes mellitus (DM). High prevalence is defined as a prevalence of more than the upper quartile.

The WAIC value corresponding to different model specifications is available in the appendix (online supplemental table S2).

DISCUSSION

This study showed that the national prevalence of hypertension and diabetes in Ethiopia was 19.2% and 2.8%, respectively. We found substantial variation in the prevalence of these diseases across the 11 geographical regions of Ethiopia. While a higher prevalence of hypertension was found in Addis Ababa, SNNPR and Amhara regions, the northern and eastern parts of the country had the lowest prevalence. High diabetes prevalence was observed in the eastern, and southwestern parts of the country, Addis Ababa and Hawassa. While population density was positively associated with both hypertension and diabetes prevalence, altitude was inversely associated with diabetes prevalence.

Table 2 Regression coefficients (mean and 95% credible intervals (CrIs)) of factors included in a Bayesian spatial model with Binomial response for the prevalence of hypertension and diabetes in Ethiopia

Factors	Hypertension Regression coefficients Mean (95% CrI)	Diabetes Regression coefficients Mean (95% CrI)
Precipitation	0.038 (–0.210 to 0.247)	0.047 (–0.379 to 0.534)
Altitude	0.065 (–0.080 to 0.209)	**–0.374 (–0.711 to –0.044)**
Travel time to city	0.036 (–0.112 to 0.182)	0.115 (–0.234 to 0.446)
Population density	**0.015 (0.003 to 0.027)**	**0.046 (0.020 to 0.069)**
Distance to water body	–0.004 (–0.065 to 0.057)	–0.055 (–0.207 to 0.093)
Distance to nearest health facility	–0.004 (–0.208 to 0.197)	0.105 (–0.260 to 0.463)
Intercept	–1.731 (–1.970 to –1.493)	–3.563 (–4.294 to –2.694)

Bold shows statistically significant value based on 95% Bayesian credible interval.

Our findings on the prevalence of hypertension are consistent with findings reported by previous systematic reviews in Ethiopia (19.6%).[31 32] However, this prevalence is lower compared with the overall African (57.0%)[33] and the global average prevalence of hypertension (31.1%).[34] The prevalence of diabetes in Ethiopia was 2.8% (95% CI: 2.4% to 3.1%), which is similar to previous systematic review findings in Ethiopia (2.0% to 6.5%)[35 36] and other African countries such as Sudan (2.6%)[37] and Nigeria (3.0%),[38] but lower than the global diabetes prevalence (9.3%).[39] Differences in population profile, socioeconomic, lifestyle and culture could explain the dissimilarity in the prevalence of hypertension and diabetes between Ethiopia and other African countries.[31] The prevalence of hypertension and diabetes in Ethiopia varied greatly at subnational and local levels, with a substantial portion of the population still at risk of developing these chronic diseases.

Clustering and risk factors of hypertension and diabetes

Substantial spatial variation was observed in both hypertension and diabetes at regional and local levels in Ethiopia. While there were hotspots of hypertension in Addis Ababa and the Amhara, Oromia, SNNPR and Benishangul-Gumuz regions, there was low hypertension prevalence in Afar and Tigray regions. Diabetes hotspots were generally observed in urban areas (eg, Addis Ababa and Harari) and peripheral and less developed regions (Somali and Afar regions). The regions with high diabetes prevalence are located in lowland areas in the eastern part of the country, bordering Somalia and Djibouti, characterised by low healthcare access, low socioeconomic index and pastoral habitats.[40] These demographic and geographic factors (ie, population density and altitude) were identified in our geospatial model as factors associated with diabetes prevalence and had been reported in previous studies as risk factors for diabetes.[41–43]

While previous studies conducted in other countries reported spatial clustering of hypertension and diabetes,[29 44–46] the current study provided a novel insight into the spatial overlapping of the two diseases. For example, the spatial overlap of hypertension and diabetes prevalence was observed in major cities such as Addis Ababa, Hawassa and Harari, and some districts in SNNPR. Although there was overlap in the clustering of hypertension and diabetes in some parts of Ethiopia, this was not the case throughout the country. For instance, while high hypertension prevalence was mostly observed in central parts of Ethiopia, low diabetes prevalence was also seen in these parts of the country. These findings suggested that targeting service integration approaches that consider the profile of diseases at a local level would be more effective than nationwide service integration. Geographically targeted service integration may enhance the efficiency and cost-effectiveness of disease control programmes. Thus, mapping the codistribution of chronic diseases such as hypertension and diabetes would be a key step in strengthening integrated disease control programmes at primary healthcare levels.

Policy implications

The sustainable development goals specifies a target to reduce NCD mortality by a third by 2030 from the 2015 levels.[47] Health service integration has been recommended by the WHO as one strategy to achieve this ambitious target. Integration of hypertension and diabetes services and their preventive programmes has been implemented in many resource-limited countries.[48] Ethiopia has implemented an Integrated Disease Surveillance and Response (IDSR) strategy since 1996.[49] This has made a significant contribution to the prevention of NCDs including hypertension and diabetes by filling the gaps observed in vertical disease control programmes.[50] Our findings supplemented the need for targeted IDSR strategy based on local disease profile.

While this study presented the spatial distribution of both hypertension and diabetes in Ethiopia for the first time, the finding should be interpreted cautiously considering potential limitations of the study. First, we used data collected in 2015, so our results may not reflect the current prevalence of hypertension and diabetes in Ethiopia. However, we believe the results reflect the spatial variation of hypertension and diabetes distribution (derived from ecological-level risk factors) and inform future research to consider the complex ecological natures of hypertension and diabetes. In addition, diabetes was diagnosed using fasting blood glucose values or those taking antidiabetic medications. As, such, the true prevalence of diabetes could be underestimated given oral glucose tolerance test was not available.[51] Second, our model did not include potential cofounding variables such as healthcare seeking behaviour of people, food diversity and burden of comorbidities such as cancer and HIV that might better explain spatial variation, as these variables were not available in our dataset. Third, due to the cross-sectional nature of our data, we could not prove that the inverse association between altitude and diabetes prevalence reflects causality—suggesting the need for additional studies to further investigate this association. Lastly, the survey conducted was not designed for the specific purpose of spatial analysis, and we observed high uncertainty in the predictions where data were spatially sparse, particularly in the Somali and Afar regions where the spatial predictions were likely to be less reliable. Therefore, conducting population surveys in parts of the country where data is spatially sparse would help to assess the spatial variability of hypertension and diabetes prevalence and the extent of areas at risk in Ethiopia. To assist cautious interpretation of findings, we have presented the uncertainty maps using a SD, in addition to the mean predictive prevalence maps (online supplemental figure S2).

CONCLUSION

This study demonstrated that the national prevalence of hypertension and diabetes was high and substantially varied at subnational and local levels. Spatial overlap of hypertension and diabetes prevalence was observed in some parts of the country, with a high prevalence of both diseases observed in major cities such as Addis Ababa, Hawassa and Harari. The spatial clustering of hypertension and diabetes was associated with ecological level factors such as population density and altitude. These findings may guide policy-makers to design geographically targeted and integrated NCDs control programmes to achieve maximum impact. We recommend further research incorporating social, economic and programme characteristics both at national and subnational levels.

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Contributors DNK, KAA, BZ, YAM and YAG conceptualised the study and developed the protocol. DNNK, KAA, YAM, YAG and AAA processed the ethics application. DNK cleaned the data and produced summary data for KAA to design and run the geospatial analysis. DNNK, YAM and KAA drafted the manuscript. DNK, YAM, YAG, BZ, AAA, HGT, EAG, DAE, FHT, HG, AM, AFD and KAA critically reviewed and edited the manuscript and approved the final version to be submitted. DNK and KAA are responsible for the overall content as the guarantors.

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Patient consent for publication Not applicable.

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