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

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

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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: 9,801 participants aged between 15 and 69 years.

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

Results

The national prevalence was 19.2% (95% CI: 18.4, 20.0) for hypertension and 2.8% (95% CI: 2.4, 3.1) for diabetes. Substantial variation was observed in the prevalence of these diseases at sub-national 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 (SNNPR) and Addis Ababa. Population density (number of people/km²) 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, -0.044).

Conclusions

Spatial clustering of hypertension and diabetes was observed at sub-national 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.

Keywords

Hypertension, diabetes, NCD, prevalence, spatial analysis, 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 confounding 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.

Introduction

Cardiovascular diseases (CVD), 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 globally.¹ Overall, three-quarters of NCD-related deaths occur in low- 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 recent systematic review and meta-analysis 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 World Health Organisation (WHO) STEPS survey approach.¹⁰ While there are several other studies on the prevalence of hypertension and diabetes in Ethiopia,¹¹⁻¹³ 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, policymakers, 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 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 (EPHI) in collaboration with the Ethiopian Federal Ministry of Health (FMOH) and the WHO. A detailed description of the survey is available elsewhere.¹⁶ 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 9,801 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 mmHg and/or a diastolic blood pressure of ≥ 90 mmHg or currently taking medication for high blood pressure.¹⁷ 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.¹⁸ Climatic variables such as mean temperature and mean precipitation were obtained from the WorldClim database.¹⁹ Data on healthcare access (i.e., travel times in minutes to the nearest health facility and travel time to the nearest city) were obtained from the Malaria Atlas Project (MAP).^{20 21} In addition, data on altitude and distance to the nearest water body were obtained from the Shuttle Radar Topography Mission (SRTM)^{22 23} and the Global Lakes and Wetlands Database (GLWD)²⁴, respectively. All these data were extracted at a spatial resolution of 1 km². A polygon shapefile for the Ethiopian administrative boundaries was obtained from the Database for Global Administrative Areas (GADM).²⁵ The data sources of the independent variables with their definitions are provided in the supplementary information (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 standard deviation. 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 (VIF) > 5 were excluded from the geospatial model. The dependent variables, prevalence of hypertension and diabetes, were geo-referenced and linked to the area-level covariates using ArcGIS (ESRI, Redlands, CA) geographical information system (GIS) software.

Geospatial analysis

Geospatial analysis was carried out at the pixel level (i.e., at a resolution of 1 km²) for both hypertension and diabetes, and their relationship with ecological level factors was quantified. Bayesian model-based geostatistics (MBG) was constructed using covariate fixed effects and spatial random effects.²⁶ Two models were constructed separately for hypertension and diabetes. Here, detailed modelling steps are present for the prevalence of hypertension, although a similar approach was employed for the prevalence of diabetes.

The proportion of hypertension cases at each surveyed location j as the outcome variable was assumed to follow a binomial distribution: $Y_j \sim \text{Binomial}(n_j, p_j)$;

where Y_j is the observed hypertension prevalence, n_j is the number of individuals tested for hypertension and p_j is the predicted hypertension prevalence at location j ($j=1, \dots, 412$). Mean predicted hypertension prevalence was modelled via a logit link function to a linear predictor defined as:

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

where α is the intercept, β is a matrix of covariate coefficients, \mathbf{X} is a design matrix of z covariates, and ζ_j are spatial random effects modelled 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, and σ , which is the marginal standard deviation.^{27 28} 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 variance) = 1×10^{-4} for each β . We used default priors for the parameters of the spatial random field²⁹. Parameter estimation was done using the Integrated Nested Laplace Approximation (INLA) approach in R (R-INLA).^{27 28} 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. The Widely Applicable Information Criterion (WAIC) statistic was used to select the best-fitting model (Table S2). The spatial prediction surfaces for both diseases were overlaid to determine areas of co-endemicity. The geospatial analysis and the descriptive analysis were conducted by 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, 20.0) and 2.8% (95% CI: 2.4, 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 (i.e., hotspot areas) in Addis Ababa, SNNPR and Amhara regions. As depicted in Figure 2, the capital and regional cities of the country (e.g., Addis Ababa, Harari, Hawassa, and Bahir Dar) had the highest prevalence of hypertension, while the northern and eastern parts of the country had the lowest prevalence of hypertension.

High diabetes prevalence was observed in the eastern (e.g., Afar and Somali) and southwestern (e.g., 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 Figure S1. Prediction uncertainty, as indicated by a high standard deviation (SD), was greatest in the eastern parts of the country (Afar and Somali regions) for both diseases (Figure S2).

Spatial co-distribution 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/km2) was positively associated with hypertension (β : 0.015; 95% 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, -0.044) (Table 2). The WAIC value corresponding to different model specifications is available in the appendix (Table S2).

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

Regions	Hypertension			Diabetes		
	Number of people screened for hypertension	Number of people diagnosed with hypertension	Hypertension prevalence (%)	Number of people screened for diabetes	Number of people diagnosed with diabetes	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

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

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

CI: credible interval; bold fonts showed statistically significant value based on 95% Bayesian credible interval.

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 the highest 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.

Our findings on the prevalence of hypertension are consistent with findings reported by a previous systematic review in Ethiopia (19.6%).³⁰ However, this prevalence is lower compared to the overall African (57.0%)³¹ and the global average prevalence of hypertension (31.1%).³² The prevalence of diabetes in Ethiopia was 2.8% (95% CI: 2.4, 3.1), which is similar to previous systematic review findings in Ethiopia (2.0% to 6.5%)^{33 34} and other African countries such as Sudan (2.6%)³⁵ and Nigeria (3.0%)³⁶, but lower than the global diabetes prevalence (9.3%).³⁷ The prevalence of hypertension and diabetes in Ethiopia varied greatly at sub-national 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 (e.g. 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 health care access, low socioeconomic index and pastoral habitats.³⁸ These demographic and geographic factors (i.e., 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.³⁹⁻⁴¹

While previous studies conducted in other countries reported spatial clustering of hypertension and diabetes,⁴²⁻⁴⁴ 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 programs. Thus, mapping the co-distribution of chronic diseases such as hypertension and diabetes would be a key step in strengthening integrated disease control programs at primary healthcare levels.

Policy implications

The sustainable development goals (SDGs) specifies a target to reduce NCD mortality by a third by 2030 from the 2015 levels.⁴⁵ 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 programs has been implemented in many resource-limited countries.⁴⁶ Ethiopia has implemented an Integrated Disease Surveillance and Response (IDSR) strategy since 1996.⁴⁷ This has made a significant contribution to the prevention of NCDs including hypertension and diabetes by filling the gaps observed in vertical disease control programs.⁴⁸ 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, our model did not include potential confounding 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. Second, 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.

Conclusion

Our study demonstrates that the national prevalence of hypertension and diabetes was high and substantially varied at sub-national 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 policymakers to design geographically targeted and integrated NCDs control programs to achieve maximum impact. We recommend further research incorporating social, economic and programme characteristics both at national and sub-national levels.

Ethics approval

Permission to use the data for this analysis was obtained from EPHI and the study was approved by the Human Research Ethics Committee of Curtin University (HREC: HRE2020-0477).

Patient consent for publication

Not applicable

Availability of data and materials

The survey data used and/or analysed in the current study are available from the Ethiopian Public Health Institute on reasonable request.

Authors' contributions

DNK, KAA, BMZ, YAM and YAG conceptualised the study. DNK cleaned the data and produced summary data for KAA to design and run the geospatial analysis. DNK, YAM and KAA drafted the manuscript. All authors critically reviewed, edited, and approved the final manuscript for submission.

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Competing interests

None declared.

Patient and public involvement

Patients and/or the public were not involved in the design, conduct, reporting, or dissemination plans of this research.

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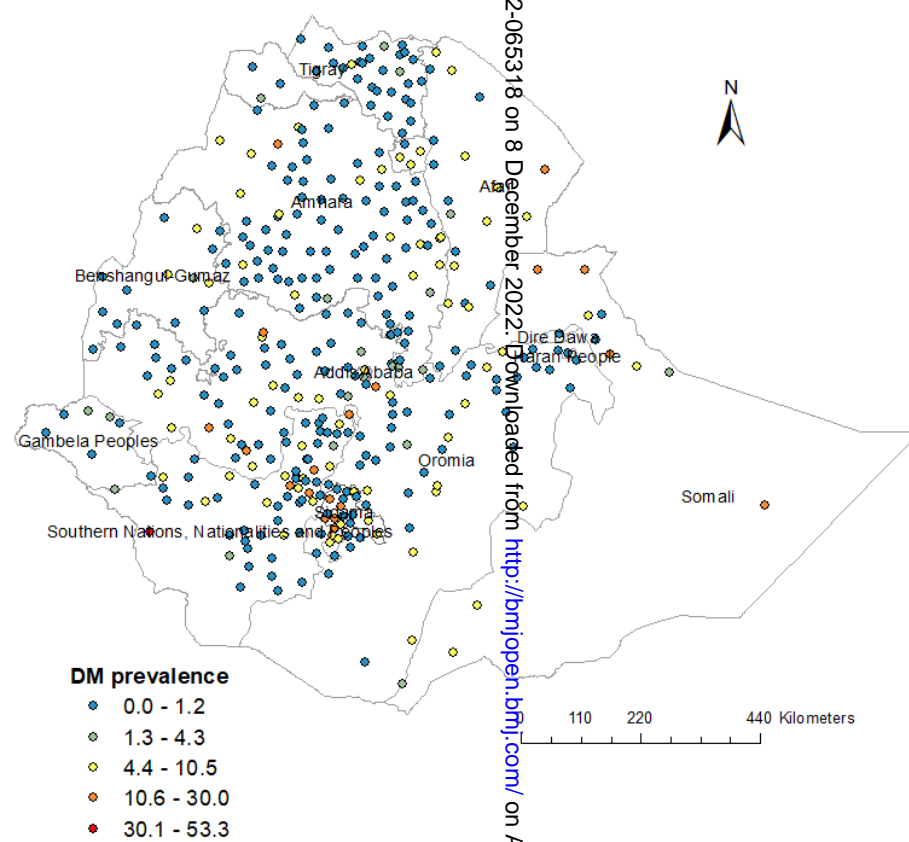
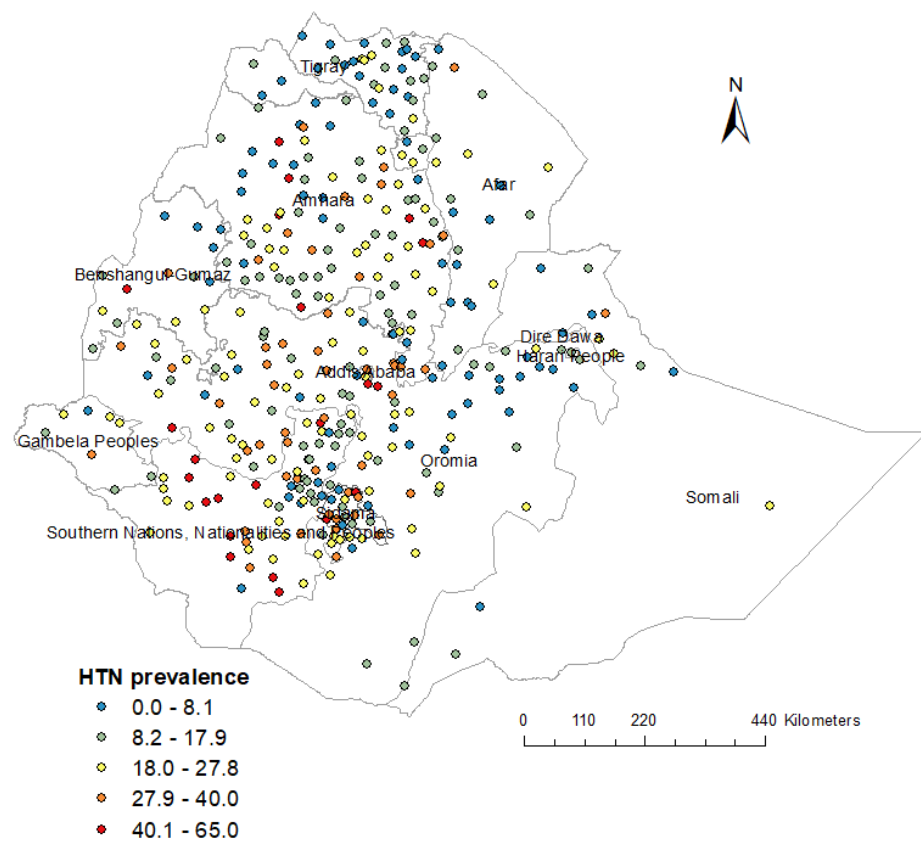
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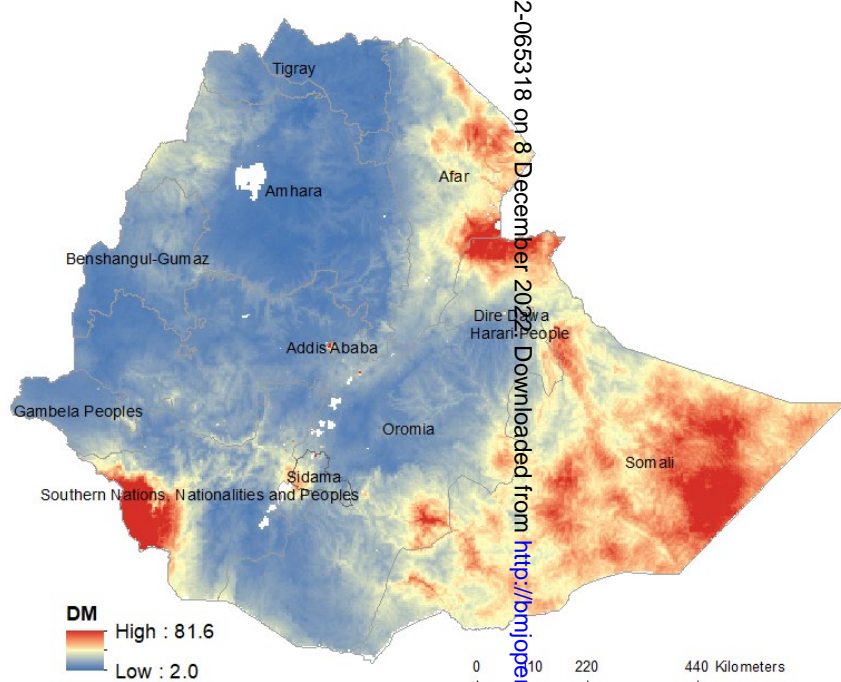
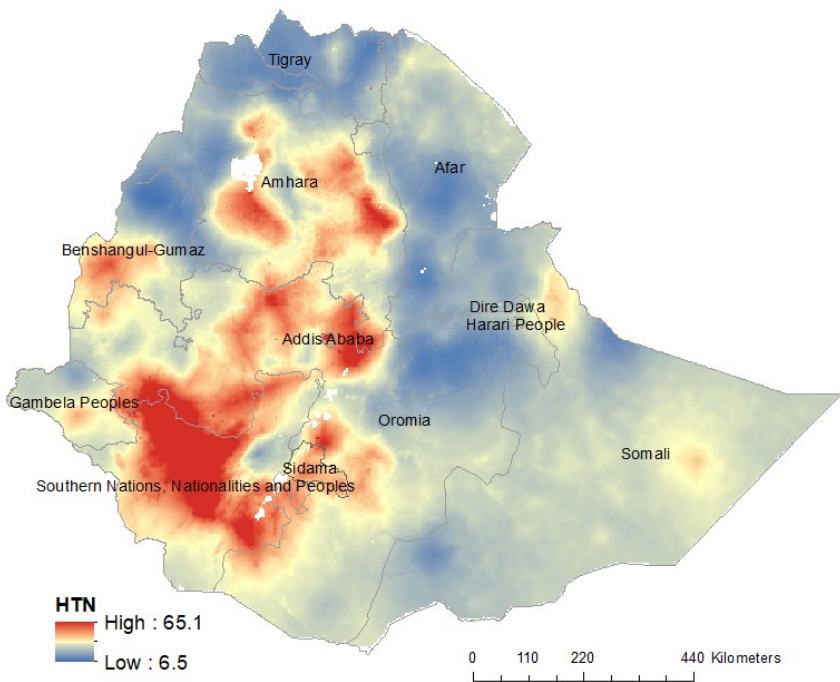
Figure Legends

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

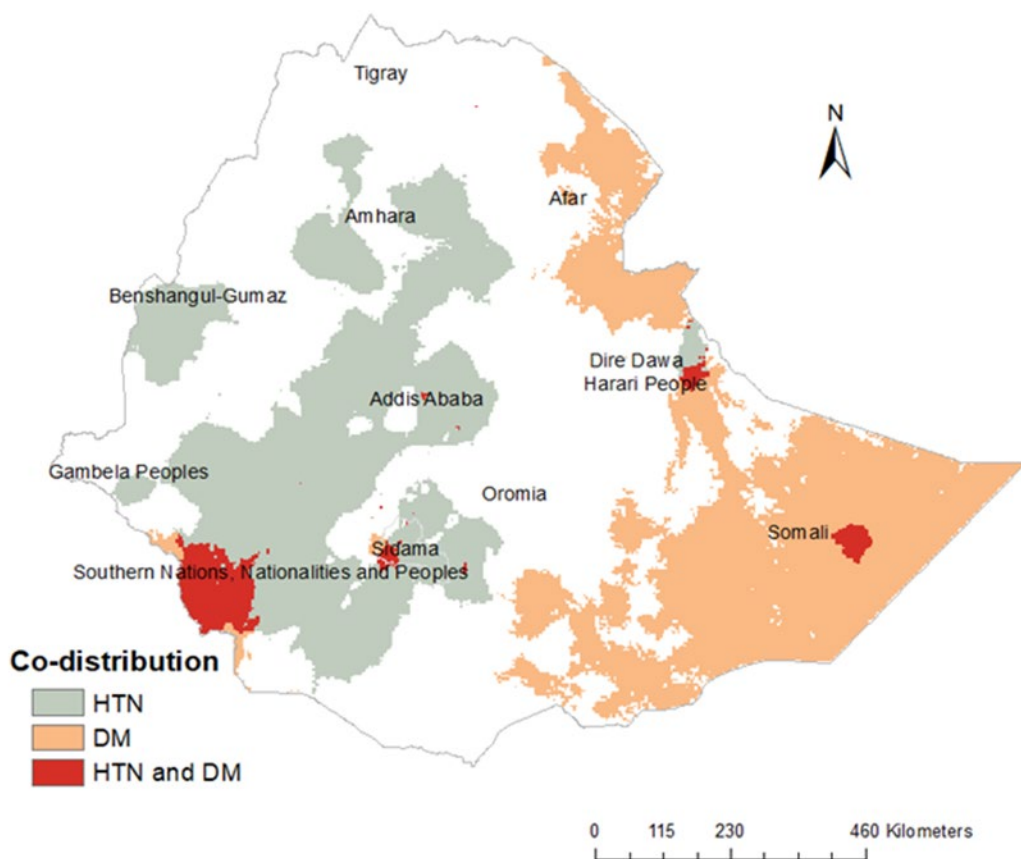
Figure 2: The geospatial predicted prevalence of hypertension (HTN) and diabetes mellitus (DM) in Ethiopia.

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





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Supplementary information

Supplementary tables

Table S1: Data sources and definitions of covariates

Covariates	Data sources	Definitions
Population density	WorldPop	Number of people per square kilometre (grid) [18]
Travel times to cities	Malaria Atlas Project (MAP)	Travel time in minutes to the nearest city with a population of more than 50,000 [21]
Temperature	WorldClim	Annual mean environmental air temperature (°C) [19]
Precipitation	WorldClim	Annual mean rainfall (mm) [19]
Altitude	Shuttle Radar Topography Mission (SRTM)	Elevation of the earth land surface in km [22]
Distance to water body	Global Lakes and Wetlands Database (GLWD)	Distance to permanent and semi-permanent water based on presence of lakes, wetlands, rivers and streams, and accounting for slope and precipitation [24]
Access to healthcare facilities	Malaria Atlas Project (MAP)	Walking travel times in minutes to the nearest hospital or clinic [20]

Table S2: Watanabe-Akaike information criterion (WAIC) values corresponding to different model specifications.

Model specifications	WAIC	
	Hypertension	Diabetes
Precipitation	1861.4	758.1
Precipitation + Altitude	1862.4	759.0
Precipitation + Altitude + Travel time to urban setting/town	1863.8	760.1
Precipitation + Altitude + Travel time to city + Population density	1862.7	748.7
Precipitation + Altitude + Travel time to city + Population density + distance to water body	1864.7	749.8
Precipitation + Altitude + Travel time to city + Population density + Distance to water body + Access to health care	1866.6	752.9

Temperature was removed from the model as it was correlated with altitude.

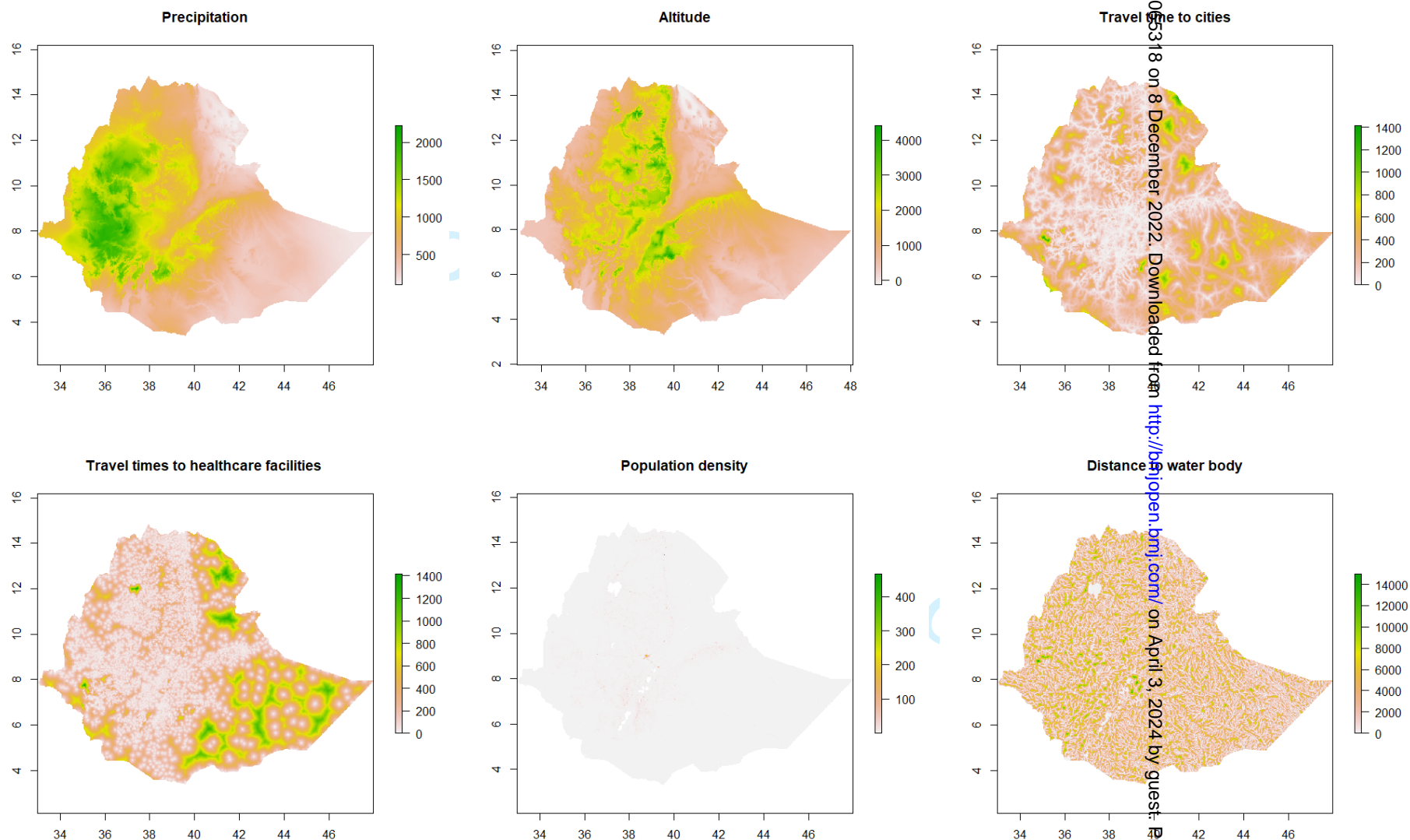


Figure S1: Maps showing the distribution of covariates used in our model: mean annual precipitation (mm), altitude (m), travel time to cities (minutes), population density (per km²), distance to water body (meter), and access to healthcare facilities (travel times in minutes)

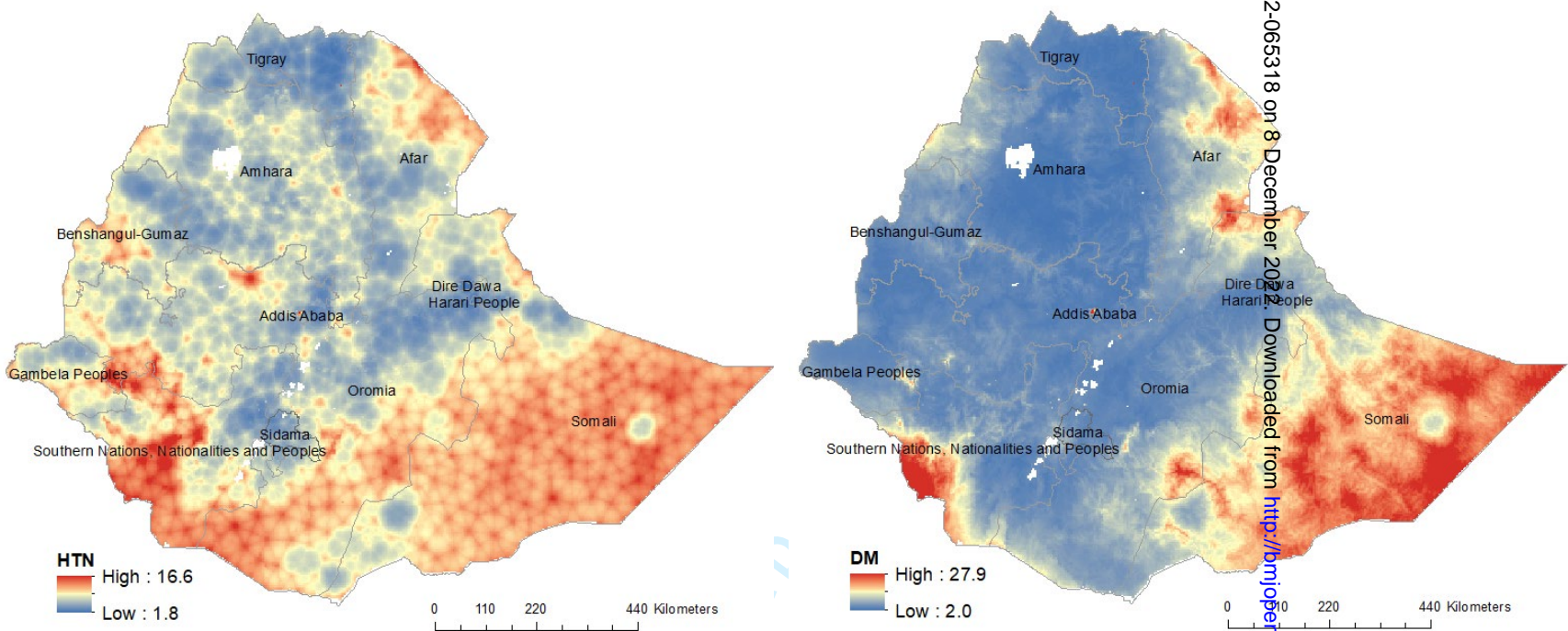


Figure S2: Standard deviation of the predicted prevalence of (a) hypertension (HTN) and (b) diabetes mellitus (DM) in Ethiopia.

STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

	Item No	Recommendation	Page No
Title and abstract	1	(a) Indicate the study’s design with a commonly used term in the title or the abstract	2
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants	5
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	5-6, 20
Bias	9	Describe any efforts to address potential sources of bias	6
Study size	10	Explain how the study size was arrived at	N/A
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	6-7
		(b) Describe any methods used to examine subgroups and interactions	6-7
		(c) Explain how missing data were addressed	N/A
		(d) If applicable, describe analytical methods taking account of sampling strategy	N/A
		(e) Describe any sensitivity analyses	N/A
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	N/A
		(b) Give reasons for non-participation at each stage	N/A
		(c) Consider use of a flow diagram	N/A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	8, Table 1
		(b) Indicate number of participants with missing data for each variable of interest	N/A
Outcome data	15*	Report numbers of outcome events or summary measures	8

Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	8-9
		(b) Report category boundaries when continuous variables were categorized	N/A
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	N/A
Discussion			
Key results	18	Summarise key results with reference to study objectives	9
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	9-12
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	9-12
Generalisability	21	Discuss the generalisability (external validity) of the study results	9-12
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	11

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.

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

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

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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: 9,801 participants aged between 15 and 69 years.

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

Results

The national prevalence was 19.2% (95% CI: 18.4, 20.0) for hypertension and 2.8% (95% CI: 2.4, 3.1) for diabetes. Substantial variation was observed in the prevalence of these diseases at sub-national 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 (SNNPR) and Addis Ababa. Population density (number of people/km²) 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, -0.044).

Conclusions

Spatial clustering of hypertension and diabetes was observed at sub-national 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.

Keywords

Hypertension, diabetes, NCD, prevalence, spatial analysis, 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 confounding 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.

Introduction

Cardiovascular diseases (CVD), 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 globally.¹ Overall, three-quarters of NCD-related deaths occur in low- 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 World Health Organisation (WHO) STEPS survey approach.¹⁰ The report from this study and several other studies on the prevalence of hypertension and diabetes in Ethiopia reported 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, policymakers, 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 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 (EPHI) in collaboration with the Ethiopian Federal Ministry of Health (FMOH) and the WHO. A detailed description of the survey is available elsewhere.¹⁶ 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 9,801 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 mmHg and/or a diastolic blood pressure of ≥ 90 mmHg or currently taking medication for high blood pressure.¹⁷ 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.¹⁸ Climatic variables such as mean temperature and mean precipitation were obtained from the WorldClim database.¹⁹ Data on healthcare access (i.e., travel times in minutes to the nearest health facility and travel time to the nearest city) were obtained from the Malaria Atlas Project (MAP).^{20 21} In addition, data on altitude and distance to the nearest water body were obtained from the Shuttle Radar Topography Mission (SRTM)^{22 23} and the Global Lakes and Wetlands Database (GLWD)²⁴, respectively. All these data were extracted at a spatial resolution of 1 km². A polygon shapefile for the Ethiopian administrative boundaries was obtained from the Database for Global Administrative Areas (GADM).²⁵ The data sources of the independent variables with their definitions are provided in the supplementary information (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 standard deviation. 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 (VIF) > 5 were excluded from the geospatial model. The dependent variables, prevalence of hypertension and diabetes, were geo-referenced and linked to the area-level covariates using ArcGIS (ESRI, Redlands, CA) geographical information system (GIS) software.

Geospatial analysis

Geospatial analysis was carried out at the pixel level (i.e., at a resolution of 1 km²) for both hypertension and diabetes, and their relationship with ecological level factors was quantified. Bayesian model-based geostatistics (MBG) was constructed using covariate fixed effects and spatial random effects.²⁶ Two models were constructed separately for hypertension and diabetes.

Here, detailed modelling steps are present 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: $Y_j \sim \text{Binomial}(n_j, p_j)$ Mean predicted hypertension prevalence was modelled via a logit link function to a linear predictor defined as:

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

where α is the intercept, β is a matrix of covariate coefficients, \mathbf{X} is a design matrix of z covariates, and ζ_j are spatial random effects modelled 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, and σ , which is the marginal standard deviation.^{27 28} 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 variance) = 1×10^{-4} for each β . We used default priors for the parameters of the spatial random field.²⁹ Parameter estimation was done using the Integrated Nested Laplace Approximation (INLA) approach in R (R-INLA).^{27 28} 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. The Widely Applicable Information Criterion (WAIC) statistic was used to select the best-fitting model (Table S2). The spatial prediction surfaces for both diseases were overlaid to determine areas of co-endemicity. Similar modelling approaches have been used previously in several epidemiological studies to map the prevalence of diseases at local levels.^{30 31} The geospatial analysis and the descriptive analysis were conducted by 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, 20.0) and 2.8% (95% CI: 2.4, 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 (i.e., hotspot areas) in Addis Ababa, SNNPR and Amhara regions. As depicted in Figure 2, the capital and regional cities of the country (e.g., Addis Ababa, Harari, Hawassa, and Bahir Dar) had the highest prevalence of hypertension, while the northern and eastern parts of the country had the lowest prevalence of hypertension.

High diabetes prevalence was observed in the eastern (e.g., Afar and Somali) and southwestern (e.g., 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 Figure S1. Prediction uncertainty, as indicated by a high standard deviation (SD), was greatest in the eastern parts of the country (Afar and Somali regions) for both diseases (Figure S2).

Spatial co-distribution 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/km2) was positively associated with hypertension (β : 0.015; 95% 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, -0.044) (Table 2). The WAIC value corresponding to different model specifications is available in the appendix (Table S2).

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

Regions	Hypertension			Diabetes		
	Number of people screened for hypertension	Number of people diagnosed with hypertension	Hypertension prevalence (%)	Number of people screened for diabetes	Number of people diagnosed with diabetes	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

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

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

CI: credible interval; bold fonts showed statistically significant value based on 95% Bayesian credible interval.

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 the highest 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.

Our findings on the prevalence of hypertension are consistent with findings reported by previous systematic reviews in Ethiopia (19.6%).^{32 33} However, this prevalence is lower compared to the overall African (57.0%)³⁴ and the global average prevalence of hypertension (31.1%).³⁵ The prevalence of diabetes in Ethiopia was 2.8% (95% CI: 2.4, 3.1), which is similar to previous systematic review findings in Ethiopia (2.0% to 6.5%)^{36 37} and other African countries such as Sudan (2.6%)³⁸ and Nigeria (3.0%)³⁹, but lower than the global diabetes prevalence (9.3%).⁴⁰ Differences in population profile, socio-economic, lifestyle and cultural differences could explain the difference in the prevalence of hypertension and diabetes between Ethiopia and other African countries.³² The prevalence of hypertension and diabetes in Ethiopia varied greatly at sub-national 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 (e.g. 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 health care access, low socioeconomic index and pastoral habitats.⁴¹ These demographic and geographic factors (i.e., 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.⁴²⁻⁴⁴

While previous studies conducted in other countries reported spatial clustering of hypertension and diabetes,^{30 45-47} 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 programs. Thus, mapping the co-distribution of chronic diseases such as hypertension and diabetes would be a key step in strengthening integrated disease control programs at primary healthcare levels.

Policy implications

The sustainable development goals (SDGs) specifies a target to reduce NCD mortality by a third by 2030 from the 2015 levels.⁴⁸ 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 programs has been implemented in many resource-limited countries.⁴⁹ Ethiopia has implemented an Integrated Disease Surveillance and Response (IDSR) strategy since 1996.⁵⁰ This has made a significant contribution to the prevention of NCDs including hypertension and diabetes by filling the gaps observed in vertical disease control programs.⁵¹ 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.⁵² Second, our model did not include potential confounding 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 standard deviation, in addition to the mean predictive prevalence maps (Figure S2).

Conclusion

Our study demonstrates that the national prevalence of hypertension and diabetes was high and substantially varied at sub-national 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 policymakers to design geographically targeted and integrated NCDs control programs to achieve maximum impact. We recommend further research incorporating social, economic and programme characteristics both at national and sub-national levels.

Ethics approval

Permission to use the data for this analysis was obtained from EPHI and the study was approved by the Human Research Ethics Committee of Curtin University (HREC: HRE2020-0477).

Patient consent for publication

Not applicable

Availability of data and materials

The survey data used and/or analysed in the current study are available from the Ethiopian Public Health Institute on reasonable request.

Authors' contributions

DNK, KAA, BMZ, YAM and YAG conceptualised the study and developed the protocol. DNK, 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. DNK, YAM and KAA drafted the manuscript. DNK, YAM, YAG, BMZ, AAA, HGT, EAG, DAE, FHT, HAG, AM, AFD and KAA critically reviewed and edited the manuscript, and approved the final version to be submitted.

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Competing interests

None declared.

Patient and public involvement

Patients and/or the public were not involved in the design, conduct, reporting, or dissemination plans of this research.

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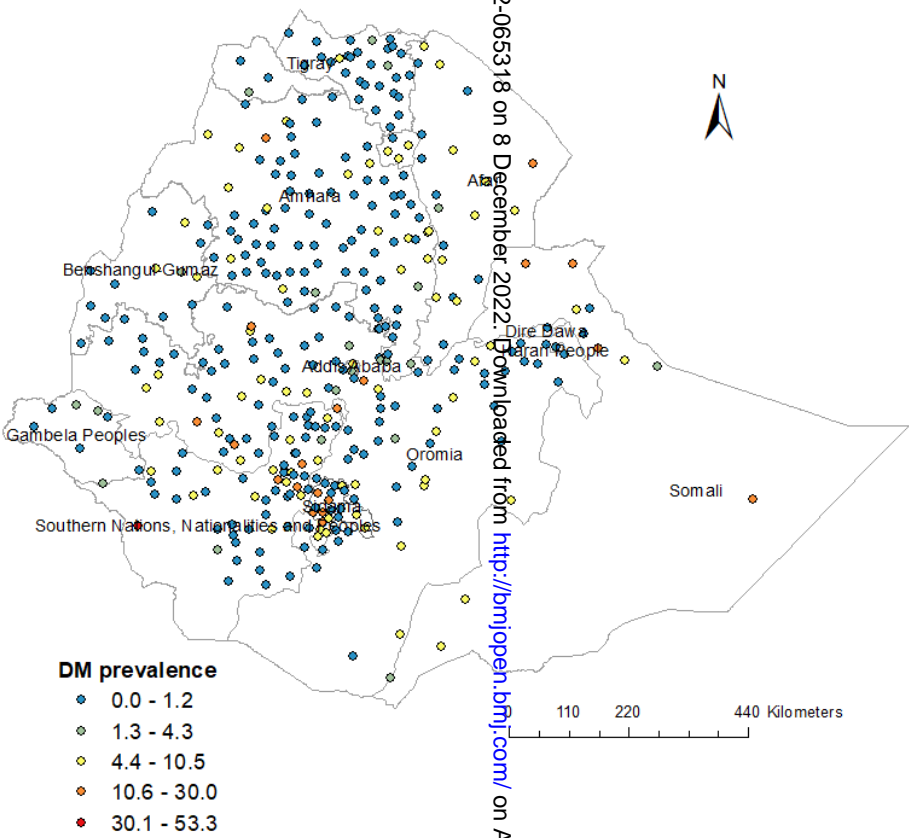
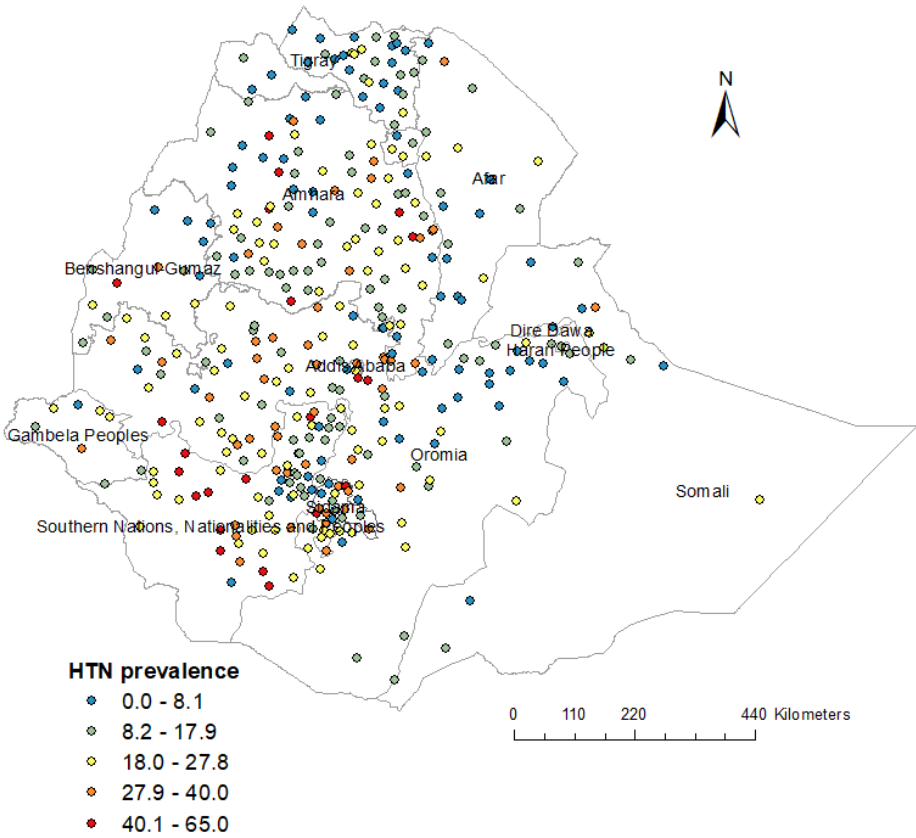
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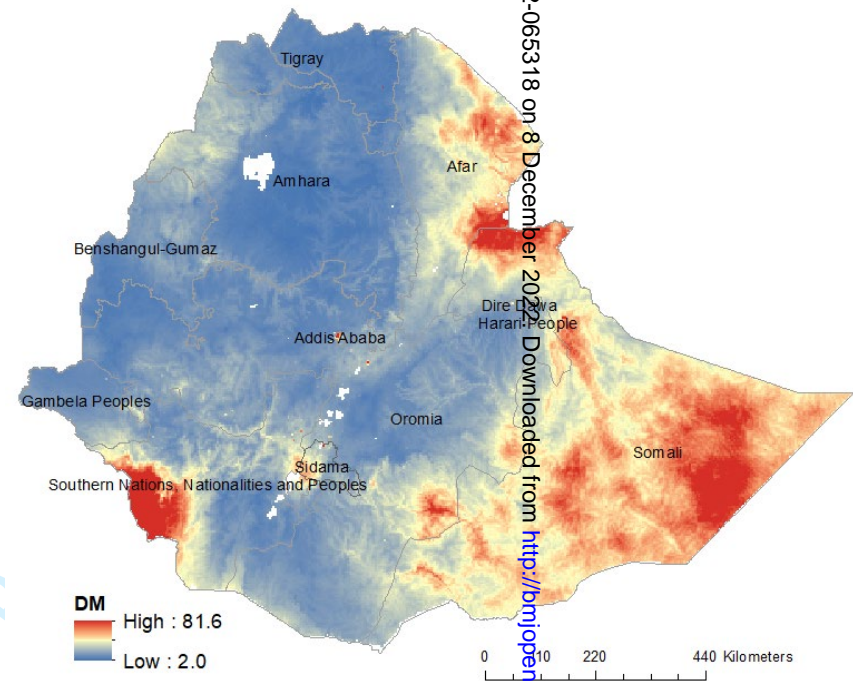
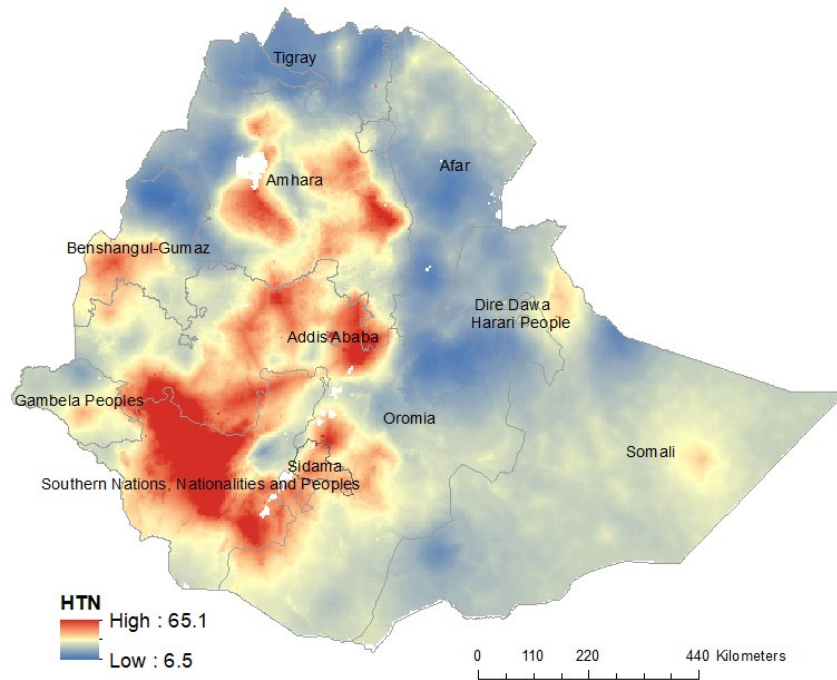
Figure Legends

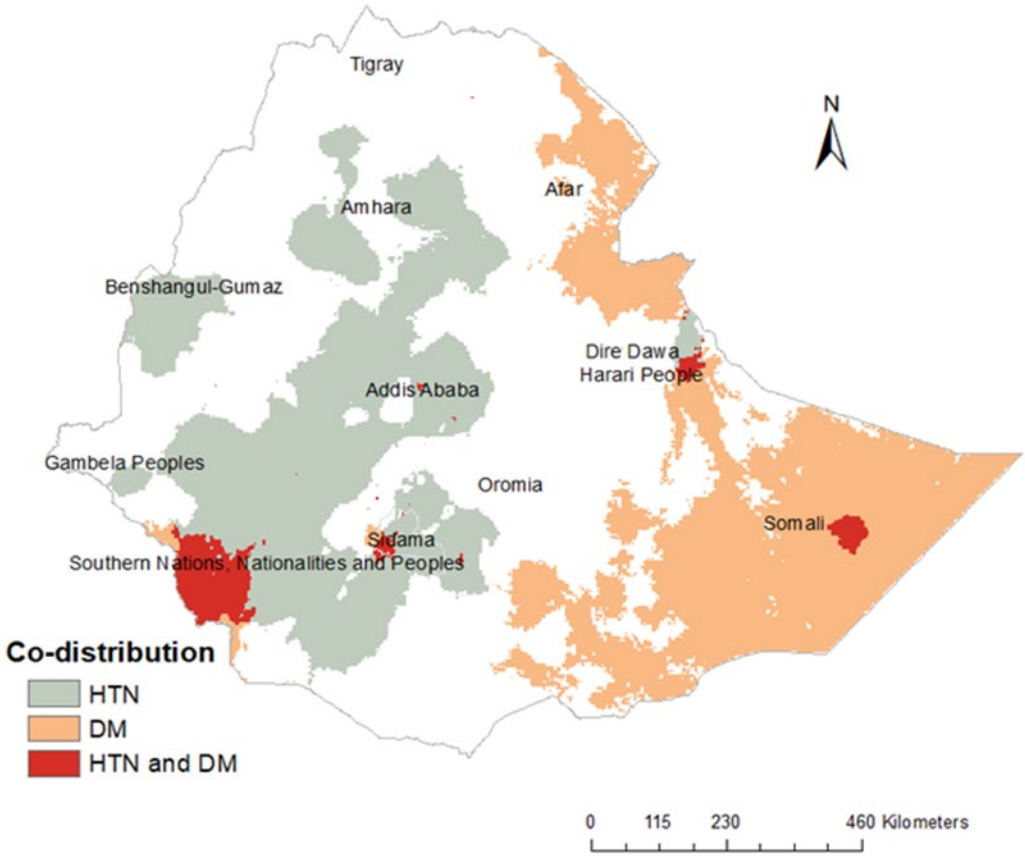
Figure 1: Maps showing the locations of survey and the prevalence of hypertension (HTN) and diabetes mellitus (DM) in Ethiopia.

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

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







Supplementary information

Supplementary tables

Table S1: Data sources and definitions of covariates

Covariates	Data sources	Definitions
Population density	WorldPop	Number of people per square kilometre (grid) [18]
Travel times to cities	Malaria Atlas Project (MAP)	Travel time in minutes to the nearest city with a population of more than 50,000 [21]
Temperature	WorldClim	Annual mean environmental air temperature (°C) [19]
Precipitation	WorldClim	Annual mean rainfall (mm) [19]
Altitude	Shuttle Radar Topography Mission (SRTM)	Elevation of the earth land surface in km [22]
Distance to water body	Global Lakes and Wetlands Database (GLWD)	Distance to permanent and semi-permanent water based on presence of lakes, wetlands, rivers and streams, and accounting for slope and precipitation [24]
Access to healthcare facilities	Malaria Atlas Project (MAP)	Walking travel times in minutes to the nearest hospital or clinic [20]

Table S2: Watanabe-Akaike information criterion (WAIC) values corresponding to different model specifications.

Model specifications	WAIC	
	Hypertension	Diabetes
Precipitation	1861.4	758.1
Precipitation + Altitude	1862.4	759.0
Precipitation + Altitude + Travel time to urban setting/town	1863.8	760.1
Precipitation + Altitude + Travel time to city + Population density	1862.7	748.7
Precipitation + Altitude + Travel time to city + Population density + distance to water body	1864.7	749.8
Precipitation + Altitude + Travel time to city + Population density + Distance to water body + Access to health care	1866.6	752.9

Temperature was removed from the model as it was correlated with altitude.

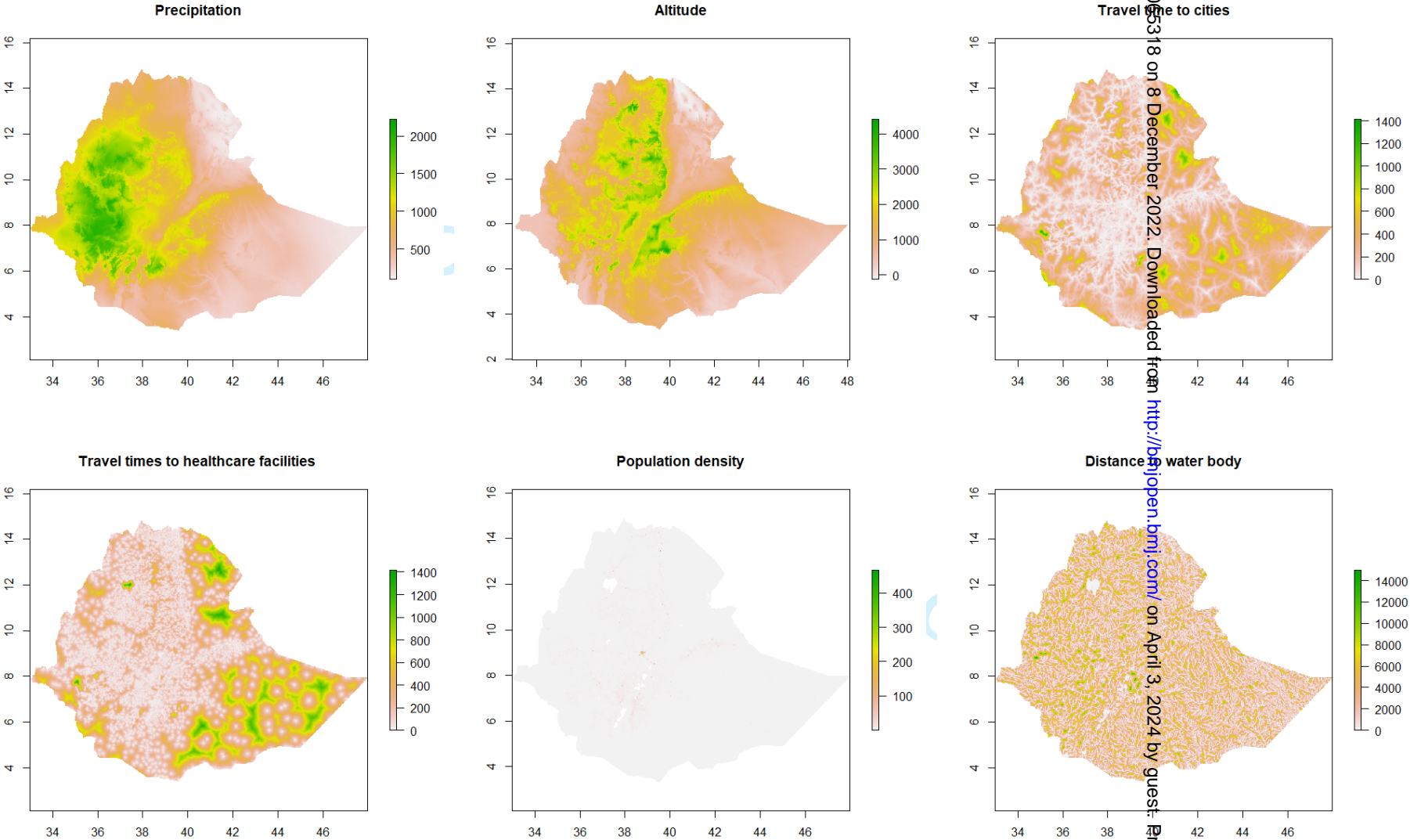


Figure S1: Maps showing the distribution of covariates used in our model: mean annual precipitation (mm), altitude (m), travel time to cities (minutes), population density (per km²), distance to water body (meter), and access to healthcare facilities (travel times in minutes)

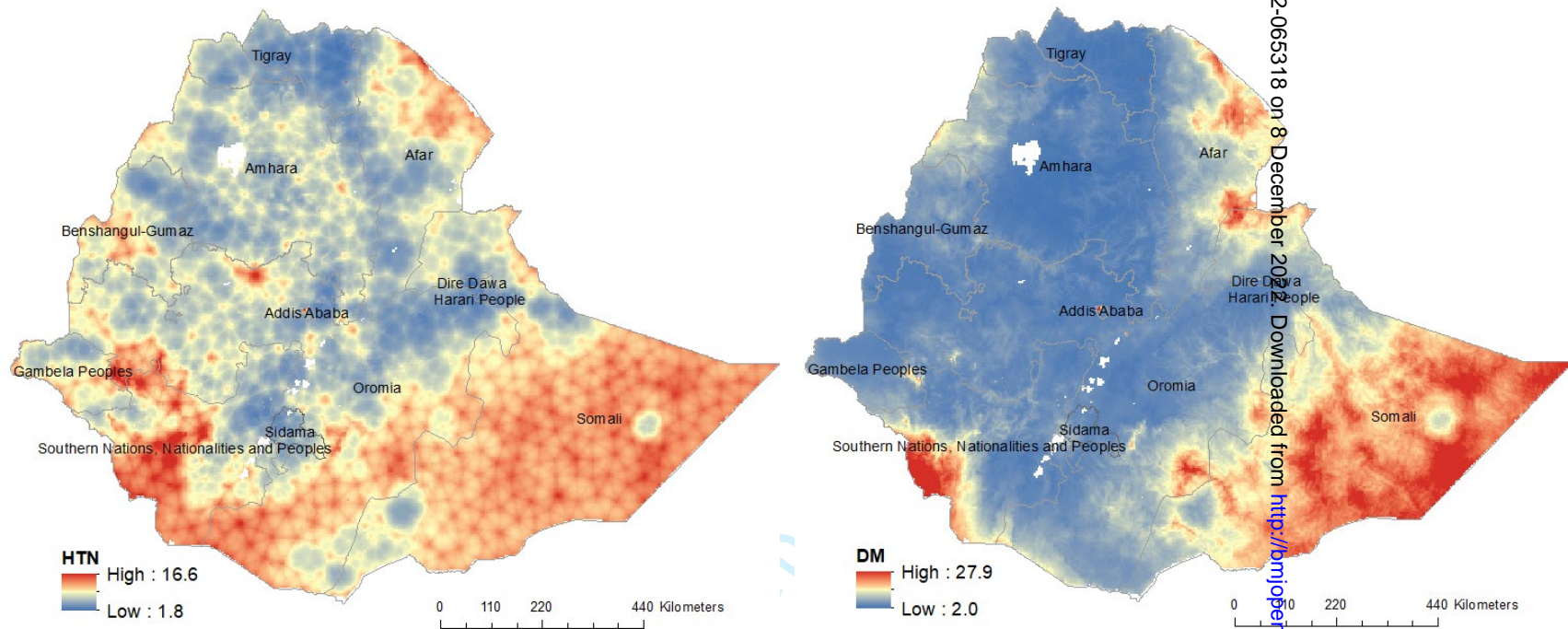


Figure S2: Standard deviation of the predicted prevalence of (a) hypertension (HTN) and (b) diabetes mellitus (DM) in Ethiopia.

STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

	Item No	Recommendation	Page No
Title and abstract	1	(a) Indicate the study’s design with a commonly used term in the title or the abstract	2
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants	5
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	5-6, 20
Bias	9	Describe any efforts to address potential sources of bias	6
Study size	10	Explain how the study size was arrived at	N/A
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	6-7
		(b) Describe any methods used to examine subgroups and interactions	6-7
		(c) Explain how missing data were addressed	N/A
		(d) If applicable, describe analytical methods taking account of sampling strategy	N/A
		(e) Describe any sensitivity analyses	N/A
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	N/A
		(b) Give reasons for non-participation at each stage	N/A
		(c) Consider use of a flow diagram	N/A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	8, Table 1
		(b) Indicate number of participants with missing data for each variable of interest	N/A
Outcome data	15*	Report numbers of outcome events or summary measures	8

Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	8-9
		(b) Report category boundaries when continuous variables were categorized	N/A
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	N/A
Discussion			
Key results	18	Summarise key results with reference to study objectives	9
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	9-12
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	9-12
Generalisability	21	Discuss the generalisability (external validity) of the study results	9-12
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	11

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.

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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: 9,801 participants aged between 15 and 69 years.

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

Results

The national prevalence was 19.2% (95% CI: 18.4, 20.0) for hypertension and 2.8% (95% CI: 2.4, 3.1) for diabetes. Substantial variation was observed in the prevalence of these diseases at sub-national 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 (SNNPR) and Addis Ababa. Population density (number of people/km²) 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, -0.044).

Conclusions

Spatial clustering of hypertension and diabetes was observed at sub-national 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.

Keywords

Hypertension, diabetes, NCD, prevalence, spatial analysis, 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 confounding 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.

Introduction

Cardiovascular diseases (CVD), 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 globally.¹ Overall, three-quarters of NCD-related deaths occur in low- 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 World Health Organisation (WHO) STEPS survey approach.¹⁰ The report from this study and several other studies on the prevalence of hypertension and diabetes in Ethiopia reported 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, policymakers, 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 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 (EPHI) in collaboration with the Ethiopian Federal Ministry of Health (FMOH) and the WHO. A detailed description of the survey is available elsewhere.¹⁶ 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 9,801 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 mmHg and/or a diastolic blood pressure of ≥ 90 mmHg or currently taking medication for high blood pressure.¹⁷ 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.¹⁸ Climatic variables such as mean temperature and mean precipitation were obtained from the WorldClim database.¹⁹ Data on healthcare access (i.e., travel times in minutes to the nearest health facility and travel time to the nearest city) were obtained from the Malaria Atlas Project (MAP).^{20 21} In addition, data on altitude and distance to the nearest water body were obtained from the Shuttle Radar Topography Mission (SRTM)^{22 23} and the Global Lakes and Wetlands Database (GLWD)²⁴, respectively. All these data were extracted at a spatial resolution of 1 km². A polygon shapefile for the Ethiopian administrative boundaries was obtained from the Database for Global Administrative Areas (GADM).²⁵ The data sources of the independent variables with their definitions are provided in the supplementary information (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 standard deviation. 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 (VIF) > 5 were excluded from the geospatial model. The dependent variables, prevalence of hypertension and diabetes, were geo-referenced and linked to the area-level covariates using ArcGIS (ESRI, Redlands, CA) geographical information system (GIS) software.

Geospatial analysis

Geospatial analysis was carried out at the pixel level (i.e., at a resolution of 1 km²) for both hypertension and diabetes, and their relationship with ecological level factors was quantified. Bayesian model-based geostatistics (MBG) was constructed using covariate fixed effects and spatial random effects.²⁶ Two models were constructed separately for hypertension and diabetes.

Here, detailed modelling steps are present 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: $Y_j \sim \text{Binomial}(n_j, p_j)$ Mean predicted hypertension prevalence was modelled via a logit link function to a linear predictor defined as:

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

where α is the intercept, β is a matrix of covariate coefficients, \mathbf{X} is a design matrix of z covariates, and ζ_j are spatial random effects modelled 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, and σ , which is the marginal standard deviation.^{27 28} 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 variance) = 1×10^{-4} for each β . We used default priors for the parameters of the spatial random field.²⁹ Parameter estimation was done using the Integrated Nested Laplace Approximation (INLA) approach in R (R-INLA).^{27 28} 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. The Widely Applicable Information Criterion (WAIC) statistic was used to select the best-fitting model (Table S2). The spatial prediction surfaces for both diseases were overlaid to determine areas of co-endemicity. Similar modelling approaches have been used previously in several epidemiological studies to map the prevalence of diseases at local levels.^{30 31} The geospatial analysis and the descriptive analysis were conducted by 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, 20.0) and 2.8% (95% CI: 2.4, 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 (i.e., hotspot areas) in Addis Ababa, SNNPR and Amhara regions. As depicted in Figure 2, the capital and regional cities of the country (e.g., Addis Ababa, Harari, Hawassa, and Bahir Dar) had the highest prevalence of hypertension, while the northern and eastern parts of the country had the lowest prevalence of hypertension.

High diabetes prevalence was observed in the eastern (e.g., Afar and Somali) and southwestern (e.g., 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 Figure S1. Prediction uncertainty, as indicated by a high standard deviation (SD), was greatest in the eastern parts of the country (Afar and Somali regions) for both diseases (Figure S2).

Spatial co-distribution 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/km2) was positively associated with hypertension (β : 0.015; 95% 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, -0.044) (Table 2). The WAIC value corresponding to different model specifications is available in the appendix (Table S2).

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

Regions	Hypertension			Diabetes		
	Number of people screened for hypertension	Number of people diagnosed with hypertension	Hypertension prevalence (%)	Number of people screened for diabetes	Number of people diagnosed with diabetes	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

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

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

CI: credible interval; bold fonts showed statistically significant value based on 95% Bayesian credible interval.

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 the highest 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.

Our findings on the prevalence of hypertension are consistent with findings reported by previous systematic reviews in Ethiopia (19.6%).^{32 33} However, this prevalence is lower compared to the overall African (57.0%)³⁴ and the global average prevalence of hypertension (31.1%).³⁵ The prevalence of diabetes in Ethiopia was 2.8% (95% CI: 2.4, 3.1), which is similar to previous systematic review findings in Ethiopia (2.0% to 6.5%)^{36 37} and other African countries such as Sudan (2.6%)³⁸ and Nigeria (3.0%)³⁹, but lower than the global diabetes prevalence (9.3%).⁴⁰ Differences in population profile, socio-economic, lifestyle and cultural differences could explain the difference in the prevalence of hypertension and diabetes between Ethiopia and other African countries.³² The prevalence of hypertension and diabetes in Ethiopia varied greatly at sub-national 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 (e.g. 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 health care access, low socioeconomic index and pastoral habitats.⁴¹ These demographic and geographic factors (i.e., 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.⁴²⁻⁴⁴

While previous studies conducted in other countries reported spatial clustering of hypertension and diabetes,^{30 45-47} 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 programs. Thus, mapping the co-distribution of chronic diseases such as hypertension and diabetes would be a key step in strengthening integrated disease control programs at primary healthcare levels.

Policy implications

The sustainable development goals (SDGs) specifies a target to reduce NCD mortality by a third by 2030 from the 2015 levels.⁴⁸ 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 programs has been implemented in many resource-limited countries.⁴⁹ Ethiopia has implemented an Integrated Disease Surveillance and Response (IDSR) strategy since 1996.⁵⁰ This has made a significant contribution to the prevention of NCDs including hypertension and diabetes by filling the gaps observed in vertical disease control programs.⁵¹ 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.⁵² 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 standard deviation, in addition to the mean predictive prevalence maps (Figure S2).

Conclusion

Our study demonstrates that the national prevalence of hypertension and diabetes was high and substantially varied at sub-national 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 policymakers to design geographically targeted and integrated NCDs control programs to achieve maximum impact. We recommend further research incorporating social, economic and programme characteristics both at national and sub-national levels.

Ethics approval

Permission to use the data for this analysis was obtained from EPHI and the study was approved by the Human Research Ethics Committee of Curtin University (HREC: HRE2020-0477).

Patient consent for publication

Not applicable

Availability of data and materials

The survey data used and/or analysed in the current study are available from the Ethiopian Public Health Institute on reasonable request.

Authors' contributions

DNK, KAA, BMZ, YAM and YAG conceptualised the study and developed the protocol. DNK, 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. DNK, YAM and KAA drafted the manuscript. DNK, YAM, YAG, BMZ, AAA, HGT, EAG, DAE, FHT, HAG, AM, AFD and KAA critically reviewed and edited the manuscript, and approved the final version to be submitted.

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Competing interests

None declared.

Patient and public involvement

Patients and/or the public were not involved in the design, conduct, reporting, or dissemination plans of this research.

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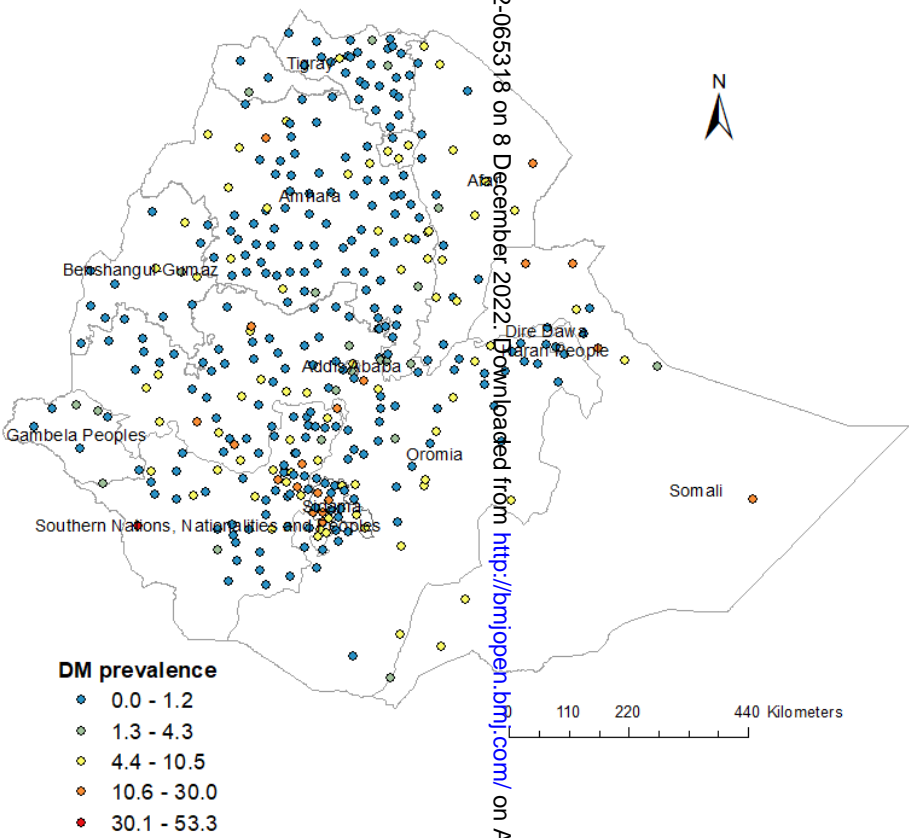
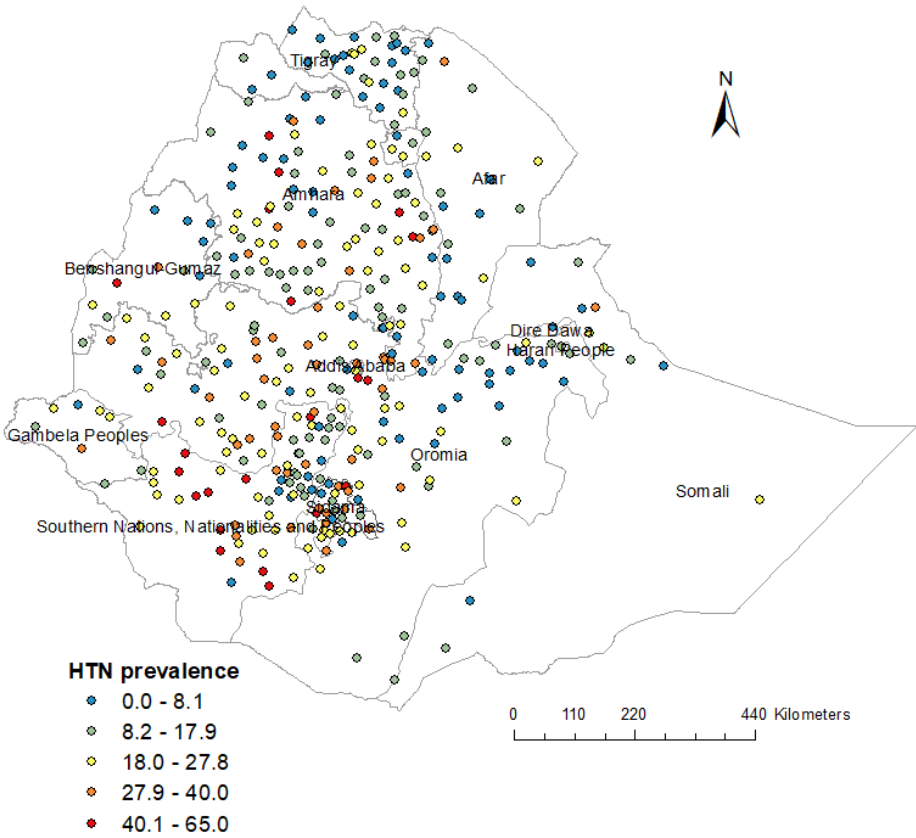
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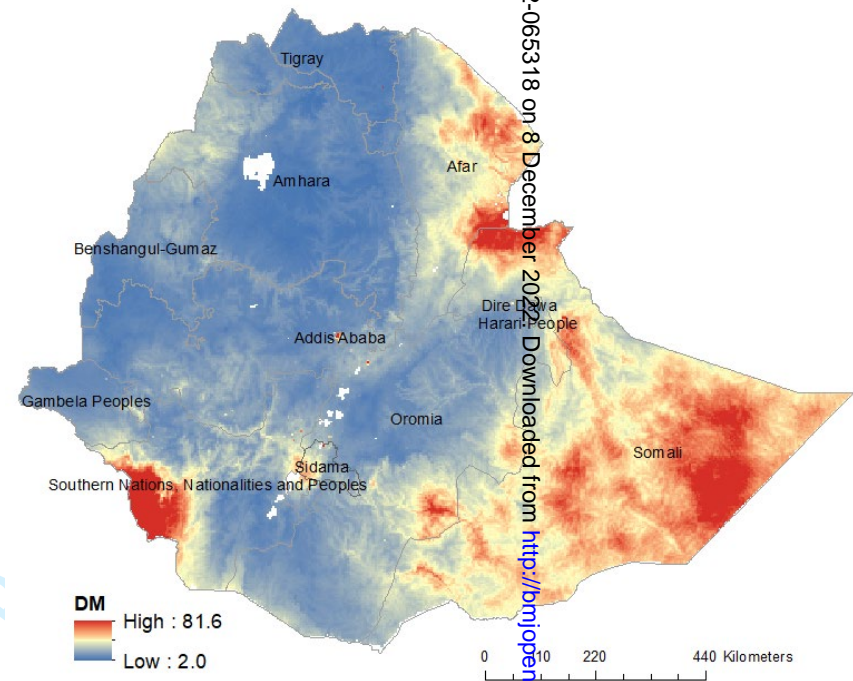
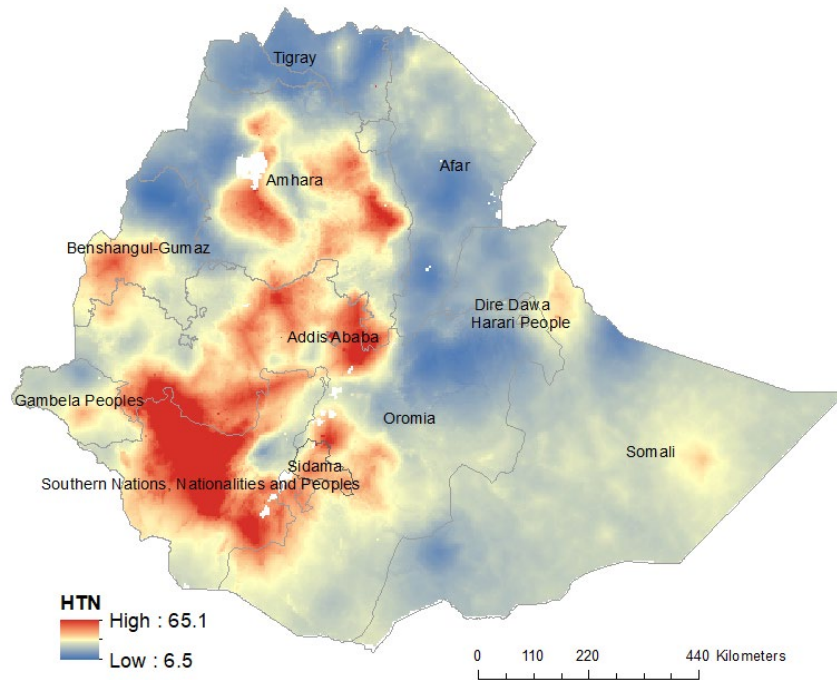
Figure Legends

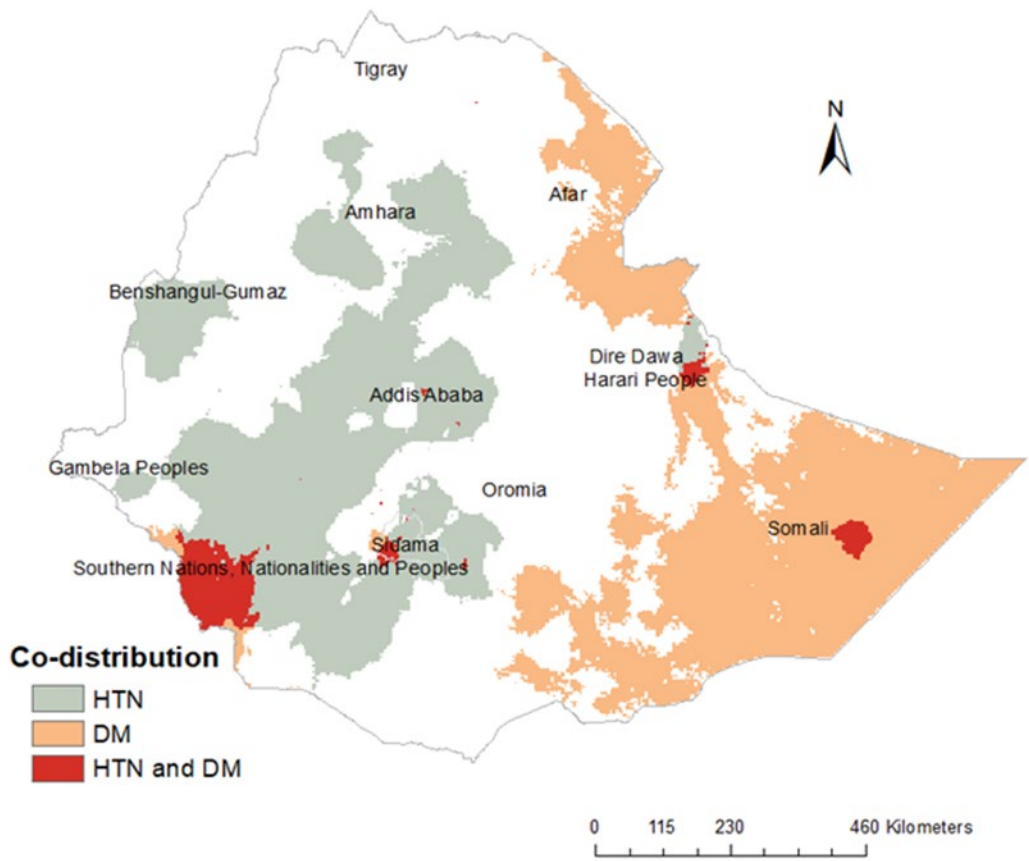
Figure 1: Maps showing the locations of survey and the prevalence of hypertension (HTN) and diabetes mellitus (DM) in Ethiopia.

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

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







Supplementary information

Supplementary tables

Table S1: Data sources and definitions of covariates

Covariates	Data sources	Definitions
Population density	WorldPop	Number of people per square kilometre (grid) [18]
Travel times to cities	Malaria Atlas Project (MAP)	Travel time in minutes to the nearest city with a population of more than 50,000 [21]
Temperature	WorldClim	Annual mean environmental air temperature (°C) [19]
Precipitation	WorldClim	Annual mean rainfall (mm) [19]
Altitude	Shuttle Radar Topography Mission (SRTM)	Elevation of the earth land surface in km [22]
Distance to water body	Global Lakes and Wetlands Database (GLWD)	Distance to permanent and semi-permanent water based on presence of lakes, wetlands, rivers and streams, and accounting for slope and precipitation [24]
Access to healthcare facilities	Malaria Atlas Project (MAP)	Walking travel times in minutes to the nearest hospital or clinic [20]

Table S2: Watanabe-Akaike information criterion (WAIC) values corresponding to different model specifications.

Model specifications	WAIC	
	Hypertension	Diabetes
Precipitation	1861.4	758.1
Precipitation + Altitude	1862.4	759.0
Precipitation + Altitude + Travel time to urban setting/town	1863.8	760.1
Precipitation + Altitude + Travel time to city + Population density	1862.7	748.7
Precipitation + Altitude + Travel time to city + Population density + distance to water body	1864.7	749.8
Precipitation + Altitude + Travel time to city + Population density + Distance to water body + Access to health care	1866.6	752.9

Temperature was removed from the model as it was correlated with altitude.

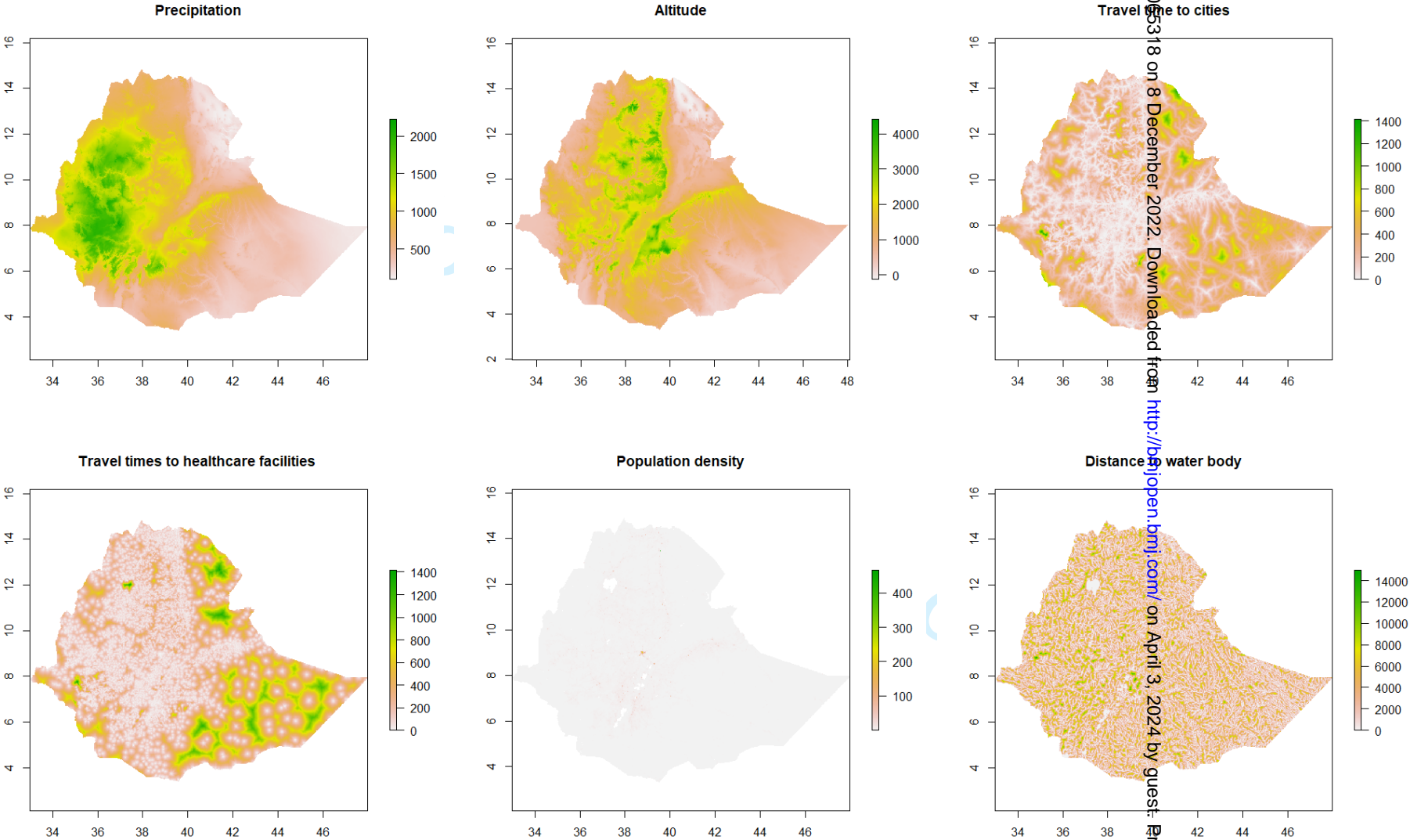


Figure S1: Maps showing the distribution of covariates used in our model: mean annual precipitation (mm), altitude (m), travel time to cities (minutes), population density (per km²), distance to water body (meter), and access to healthcare facilities (travel times in minutes)

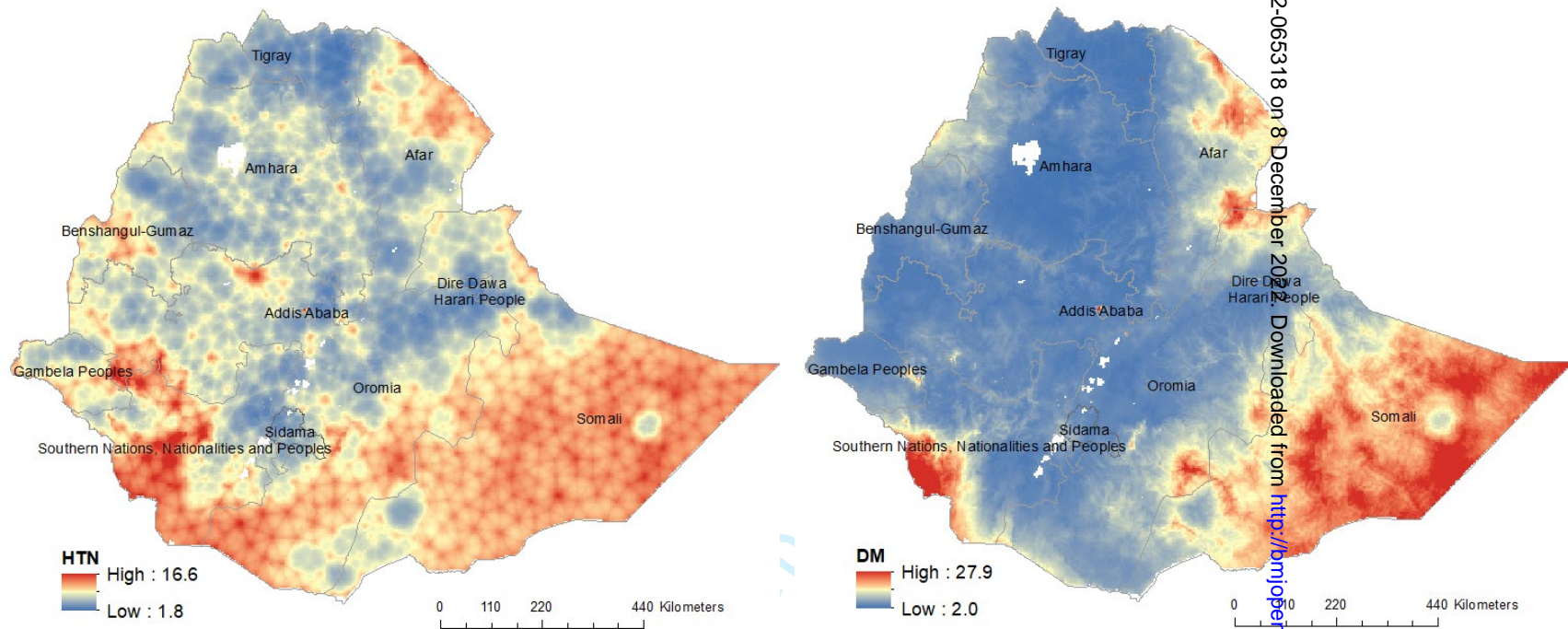


Figure S2: Standard deviation of the predicted prevalence of (a) hypertension (HTN) and (b) diabetes mellitus (DM) in Ethiopia.

STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

	Item No	Recommendation	Page No
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	2
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants	5
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5
Data sources/measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	5-6, 20
Bias	9	Describe any efforts to address potential sources of bias	6
Study size	10	Explain how the study size was arrived at	N/A
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	6-7
		(b) Describe any methods used to examine subgroups and interactions	6-7
		(c) Explain how missing data were addressed	N/A
		(d) If applicable, describe analytical methods taking account of sampling strategy	N/A
		(e) Describe any sensitivity analyses	N/A
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	N/A
		(b) Give reasons for non-participation at each stage	N/A
		(c) Consider use of a flow diagram	N/A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	8, Table 1
		(b) Indicate number of participants with missing data for each variable of interest	N/A
Outcome data	15*	Report numbers of outcome events or summary measures	8

Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	8-9
		(b) Report category boundaries when continuous variables were categorized	N/A
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	N/A
Discussion			
Key results	18	Summarise key results with reference to study objectives	9
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	9-12
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	9-12
Generalisability	21	Discuss the generalisability (external validity) of the study results	9-12
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	11

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.