BMJ Open

Temporal trends and spatial heterogeneity of sanitation facilities in Ethiopia: evidence from the 2005-2019 Demographic and Health Surveys

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2024-088211
Article Type:	Original research
Date Submitted by the Author:	30-Apr-2024

Complete List of Authors:	Azanaw, Jember; University of Gondar, Department of Environmental and Occupational Health and Safety Tsegaye, Mesenbet; University of Gondar, Department of General Surgery Mesele, Wodaje; University of Gondar, Department of Orthopaedic and Trauma Surgeon

Keywords:	Infectious diseases & infestations < DERMATOLOGY, International health services < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, Public health < INFECTIOUS DISEASES

I, the Submitting Author has the right to grant and does grant on behalf of all authors of the Work (as defined in the below author licence), an exclusive licence and/or a non-exclusive licence for contributions from authors who are: i) UK Crown employees; ii) where BMJ has agreed a CC-BY licence shall apply, and/or iii) in accordance with the terms applicable for US Federal Government officers or employees acting as part of their official duties; on a worldwide, perpetual, irrevocable, royalty-free basis to BMJ Publishing Group Ltd ("BMJ") its licensees and where the relevant Journal is co-owned by BMJ to the co-owners of the Journal, to publish the Work in this journal and any other BMJ products and to exploit all rights, as set out in our licence.

The Submitting Author accepts and understands that any supply made under these terms is made by BMJ to the Submitting Author unless you are acting as an employee on behalf of your employer or a postgraduate student of an affiliated institution which is paying any applicable article publishing charge ("APC") for Open Access articles. Where the Submitting Author wishes to make the Work available on an Open Access basis (and intends to pay the relevant APC), the terms of reuse of such Open Access shall be governed by a Creative Commons licence – details of these licences and which Creative Commons licence will apply to this Work are set out in our licence referred to above.

Other than as permitted in any relevant BMJ Author's Self Archiving Policies, I confirm this Work has not been accepted for publication elsewhere, is not being considered for publication elsewhere and does not duplicate material already published. I confirm all authors consent to publication of this Work and authorise the granting of this licence.

Temporal trends and spatial heterogeneity of sanitation facilities in Ethiopia: evidence from the 2005-2019 Demographic and Health Surveys

Jember Azanaw[1]*, Mesenbet Tsegaye[2], Wodaje Mesele[3]

[1]Department of Environmental and Occupational Health and Safety, Institute of Public Health, College of Medicine and Health Sciences, University of Gondar, Gondar, Ethiopia

[2]Department of General Surgery, School of Medicine, College of Medicine and Health Sciences, University of Gondar, Gondar, Ethiopia

[3]Department of Orthopaedic and Trauma Surgeon, School of Medicine, College of Medicine and Health Sciences, University of Gondar, Gondar, Ethiopia

***=Corresponding**

jemberazanaw21@gmail.com

Abstract

Background: The main aim of sanitation is to prevent human contact with fecal pathogens to decrease occurrences of diseases. But, no region in the world is on the right track to accomplish SDG 6.2 for universal access to sanitation. SSA, Ethiopia included, is significantly behind in meeting the 2030 SDG 6.2 targets. Hence, this study focused on the spatial and temporal analysis of sanitation in Ethiopia based on four demographic health surveys.

Method: This research was undertaken in Ethiopia based on a weighted sample size. Variables with a p-value below 0.2 in bivariable analysis were incorporated into the multivariable analysis. Subsequently, a 95% CI and a p-value < 0.05 were utilized to assess the statistical significance of the final model. Global and local indicators of spatial correlation were done. Statistical analyses were performed using STATA 17, and ArcGIS 10.7 software.

Results: This study includes 13,721 in 2005 EDHS, 16,702 in 2011 EDHS, 16,650 in 2016 EDHS, and in 2019 EDHS 8,663 participants. The prevalence of improved sanitation facilities in Ethiopia was 20.46%, 25.61%, 25.86%, and 27.45% based on EDHS 2005, 2011, 2016, and 2019, respectively. Global Moran's I spatial autocorrelations, hotspots, and spatial interpolation analysis indicated the inequality of improved sanitation facilities. Educational status of primary (AOR = 2.43, 95% CI :(2.00, 2.95)), secondary (AOR = 2.02, 95% CI :(1.61, 2.54)), and higher (AOR = 4.12, 95% CI :(3.35, 7.54), watching television (AOR= 5.49, 95% CI: (4.37, 6.89)), (AOR= 9.08, 95% CI: (6.69, 12.33), and region were factors statistically associated with sanitation facilities.

Conclusion: The overall finding of this study concludes a very slow increment in sanitation facilities over time and presence of geographical heterogeneity in Ethiopia. Educational status, watching television, wealth index, community-level education, type of residence, and region were factors statistically associated with sanitation facilities.

Keywords: EDHS, Ethiopia, Improved Sanitation, Spatiotemporal variation

Background

Sanitation refers to the endowment of services and facilities for the safe and clean controlling of human excreta, from the toilet to handling and containment to the final end-use or removal [1]. Sanitation is an integral component of basic human rights comparable to food, shelter, and water and is vital for healthy life [2].

According to the United Nations (UN-2018) report, in the world, around 4.5 billion people had no safe sanitation and 1.8 billion use contaminated water by human excreta, and 892 million continue to practice Open Defecation (OD) [3, 4]. Inadequate access to sanitation is a principal reason for poverty in unindustrialized nations because it causes early mortality [5, 6]. According to World Health Organization (WHO) 2019 estimation, drinking water sources of two billion people were contaminated with feces and over 800,000 people die annually from diarrhea caused by poor water, sanitation, and hygiene (WASH) (World Health Organization, 2019). In Eastern and Southern Africa, 340 million people (more than 70 %) have no access to basic sanitation services, 98 million people (19 percent) practice open defecation, 179 million use unimproved facilities, and 63 million shared sanitation facilities [7].

Due to such problems, Sustainable Development Goals (SDGs 6.2) stand to ensure accessibility of equitable sanitation for all by the year 2030 [8]. SDG 6.2 of the United Nations, which emanated in 2015 from the Millennium Development Goals, aims at equitable access to safe and affordable sanitation for all by 2030 (10). The main aim of this SDG is to prevent human contact with fecal pathogens to decrease occurrences of diseases [9, 10]. Nevertheless, no region in the world is on the right track to accomplish SDG 6.2 for universal access to sanitation, and urban sewer connections are increasing at an embarrassingly slow rate of 0.14% annually [11]. Especially, countries in Sub-Saharan Africa (SSA) countries are extremely late to achieve SDG 6.2 2030 agenda due to the rapid population growth rate, without enough investment in sanitation infrastructures [12, 13]. At the same time, inequalities in accessing sanitation facilities were more pronounced among countries in sub-Saharan Africa [14]. There is a disparity within countries, mainly regarding urban and rural residences, which indicated that rural inhabitants access markedly lower levels of sanitation than with urban residences [15]. Such Subnational variation in access to improved sanitation facilities, defined as the range of values from the unit with the highest level of access to the unit with the lowest level or no access, are evident across low and middle income countries [16] . Like other developing countries [17] access to sanitation is a challenge across Ethiopia [18], as well as there are disparities among the regions of the country. On the other hand nations may strengthen or setback the progress of equitable access to improved sanitation facilities.

Previous studies in Ethiopia were based on a single EDHS or only multilevel analysis or spatial analysis in order to investigate improved sanitation facilities [19]. Such studies unable to show the trend of improved sanitation facilities progress overtime. Residence, educational attainment, watching television, household size, region, and wealth index are factors associated with the improved sanitation source as in previous studies [20-22]. Hence, this study focused on the spatial and temporal analysis of sanitation facilities in Ethiopia based on combined multiple (2005, 2010, 2016, and 2019) demographic health surveys for better understanding of the progress and geographic variation within the country.

Methods

Study area and Data source

This study was conducted in Ethiopia, which is nine geographical regions (Tigray, Afar, Amhara, Oromia, Somali, Benishangul-Gumuz, Southern Nations Nationalities and Peoples Region (SNNPR), Gambella, and Harari), and two administrative cities (Addis Ababa and Dire-Dawa) of the country. The country is located in the Horn of Africa with geographical locations 9.145° N latitude and 40.4897° East longitude [23]. This study used the four successive Ethiopian Demographic and Health Surveys (EDHS 2005, 2011, 2016, and 2019) database survey. Therefore, these are nationally representative population-based surveys with large sample sizes at different times. EDHS data is open source and can be retrieved on the DHS website https://www.dhsprogram.com/data/dataset_admin/login_main.cfm.

All EDHS samples were a two-stage stratified cluster sample [24], sampling weights were calculated based on sampling probabilities separately for each sampling stage and each cluster. In 2005 surveys, 540 enumeration areas (EAs) (139 urban and 401 rural areas), 2011 EDHS, 624 EAs (187 urban and 437 rural areas), 2016 EDHS 645 EAs (202 in urban areas and 443 in rural areas), and 2019 EDHS 305 EAs (93 in urban areas and 212 in rural areas) were selected using systematic sampling with likelihood proportional to size.

In the second stage of selection, a fixed number of 30 households per cluster were selected with an equal probability of systematic selection from the newly created household listing. The field practice was conducted in Adama in clusters that were not part of the survey sample. Ethiopian public health institute investigators, an ICF technical specialist, an advisor, and representatives from other organizations, including central statistics agency, the Federal Ministry of Health, the World Bank, and USAID, supported the data collection.

Among included households, 13,721, 16,702, 16, 650, and 8,663 were successfully interviewed in EDHS 2005, 2011, 2016, and 2019, respectively. Weighted by sampling weight was done to do a reliable statistical analysis. The geographical location data were taken from selected respective Enumeration Areas (EAs).

Study Variables

Outcome variables

The dependent variable was the sanitation facilities. The water source categorized as '1' on behalf of 'improved sanitation' which accessed from flush/pour flush to piped sewer systems, septic tanks, or pit latrines; ventilated improved pit latrines, composting toilets or pit latrines with slabs, and '0' for 'unimproved sanitation' when the sanitation facilities from pit latrines without a slab or platform, hanging latrines or bucket latrines and open defecation [25-27].

Predictor variables

Individual level variables: sex of household head (male or female), wealth index (poor, middle, and rich), educational status (no education, primary education, secondary education, and higher education), having a television (yes or no) and radio (yes or no) were individual-level predictor variables.

Community level variables: Community level education (lower/higher), the place of residence (urban/rural), community level media exposure (exposed/unexposed), region (Benishangul-Gumuz, Somali, Gambella, Afar, Oromia, SNNPR, Amhara, Tigray, and Harari) and City administration (Addis Ababa, and Dire Dawa).

Data management and analysis

For data quality assurance purposes, pretests containing in-class training, biomarker training, and field exercise were done. The field exercise was conducted in clusters, which were not included in the EDHS sample. A debriefing session was held with the pretest field staff, and adjustments to the questionnaires were done based on lessons drawn from the field practice. Since the outcome variables were dichotomous, logistic regression analysis was conducted to assess associations of outcome variables and predictor variables. Variables in bivariable analysis with a p-value less than 0.2 were included in multivariable binary logistic regression analysis. 95% confidence interval (CI) and a p-value less than 0.05 were used for identifying statistical significance in the final model [28].

Multilevel Analysis

Four models, a null model (model 0) without any predictor variable, model 1 comprised dependent and individual-level predictors, model 2 incorporated dependent and community-level predictors, and model 3 involved the dependent variables and all individual- and community- level predictors were established. Random effects were measured using cluster variance (Vc), a proportional change in variance ((PCV $((Vc - Vn)/Vc)$) the intraclass correlation coefficient (ICC $(Vc/(Vc + 3.29)$), and the median odds ratio (MOR (exp $[(0.95)\sqrt{Vc}]$)) [29, 30]. The goodness-of-fit for all models was evaluated using AIC, BIC, and Deviance. Then the model with the lower value of deviance, AIC, and BIC, was demonstrating the best-fit model [31]. As well as multicollinearity, the effect of independent variables was measured using the variance inflation factor (VIF).

Spatial analysis

Spatial Autocorrelation

To explore the geographical distribution, both global and local indicators of spatial correlation are the best imperative tools for access to improved sanitation facilities within the specified period.

Global autocorrelations

To proceed with geographical variation identification of access to improved sanitation facilities, Global autocorrelations analysis was done. Global spatial autocorrelation (Moran's I index) was used to detect whether the difference is due to the clustering effect or non-random/dispersion [32, 33]. As well as the simple exploratory spatial analysis was performed to identify the presence of improved sanitation facilities and geographical dependence distribution in the country.

Local statistical analysis

Further investigation using figures and maps is needed since Global autocorrelations indicate a clustering effect (positive spatial autocorrelation) on sanitation facilities' access over the country. Therefore, hotspot analysis (Gettis-Ord Gi*) was performed to identify patterns of spatial variation and emphasize the previously stated using global autocorrelations (cluster effect) on access to sanitation facilities. Cluster and outlier analysis (Anselin local Moran is I) was used to describe the spatial patterns of the dependent variables (access to sanitation facilities). This cluster and outlier analysis was used to confirm and accompaniment to show extreme (the hotspot and cold spot) since it permits the identification of groupings and areas where the differences happen [34].

Results

Socio-demographic characteristics of the study population

This study include 13,721 in 2005 EDHS, 16,702 in 2011 EDHS, 16,650 in 2016 EDHS, and in 2019 EDHS 8,663 participants. In all EDHS, data sets the greater proportion (63.59%, 55.74%, 52.06%, and 47.65%, respectively) of study subjects were no education. The majority (88.30%, 81.68%, 76.98%, and 77.10%) of the participants in the 2005 EDHS, 16,702the in the 2011 EDHS, 16,650 in the 2016 EDHS, and 2019 EDHS, respectively, had no television (Table 1).

Table 1. Socio-demographic characteristics of study Participants in Ethiopia

Variables	EDHS 2005 (N= 13,721) Frequency (%)	EDHS 2011 (N=16,702) Frequency (%)	EDHS 2016 (N= 16,650) Frequency (%)	EDHS 2019 (N= 8,663) Frequency (%)
Sex of HHH				
Male	10,243(74.65)	11,906(71.28)	11,413(68.55)	6,291(72.62)
Female	3,478(25.35)	4,796 (28.72)	5,237(31.45)	2,372(27.38)
Age of HHH				
<30	3,428(24.98)	4,823(28.88)	4,257(25.57)	2,520(29.09)

30-40	3,501(25.52)	4,116(24.64)	4,132(24.82)	2,287(26.40)
41-54	3,756(27.37)	4,047(24.23)	4,230(25.41)	1,717(19.82)
>54	3,036(22.13)	3,716(22.25)	4,031(24.21)	2,139(24.69)
Educational status of HHH				
No education	8,725(63.59)	9,309(55.74)	8,668(52.06)	4,128(47.65)
Primary	2,705(19.71)	5,020(30.06)	4,658(27.98)	2,715(31.34)
Second	1,754(12.78)	1,189(7.12)	1,686(10.12)	963(11.12)
Higher	495(3.61)	1,140(6.83)	1,580(9.49)	857(9.89)
Wealth index				
Poor	5,393(39.30)	6,506(38.95)	7,024(42.19)	3,498(40.38)
Middle	2,055(14.98)	2,364(14.15)	2,057(12.35)	1,285(14.83)
Rich	6,273(45.72)	7,832(46.89)	7,569(45.46)	3,880(44.79)
Share toilet with other households				
Yes	2,712(45.72)	4,467(46.12)	4,727(43.83)	2,222 (38.18)
No	3,204(54.01)	5,204(53.73)	6,059(56.17)	3,598(61.82)
Having radio				
No	8,157(59.45)	9,658(57.83)	11,680(70.15)	6,170 (71.22)
Yes	5,560(40.52)	7,040(42.15)	4,970(29.85)	2,493(28.78)
Having Television				
No	12,116(88.30)	13,643(81.68)	12,818(76.98)	6,679 (77.10)
Yes	1,601(11.67)	3,051(18.27)	3,832(23.02)	1,984(22.90)
Community-level media exposure				
Unexposed	8,105(59.07)	8,973(53.72)	10,024(60.20)	5,195(59.97)
Exposed	5,616(40.93)	7,729(46.28)	6,626(39.80)	3,468(40.03)
Community-level educational status				
Lower	8,730(63.63)	9,309(55.74)	8,726(52.41)	4,308(49.73)
Higher	4,991(36.37)	7,393(44.26)	7,924(47.59)	4,355(50.27)

Residence				
Urban	3,666(26.72)	5,112(30.61)	5,232(31.42)	2,645(30.53)
Rural	10,055(73.28)	11,590(69.39)	11,418(68.58)	6,018(69.47)
Region				
Tigray	1,282(9.34)	1,730(10.36)	1,734(10.41)	714(8.24
Afar	806(5.87)	1,267(7.59)	1,220(7.33)	664 (7.66)
Amhara	2,066(15.06)	2,071(12.40)	1,902(11.42)	1,007(11.62)
Oromia	2,155(15.71)	2,165(12.96)	1,988(11.94)	1,018(11.75)
Somali	796(5.80)	975(5.84)	1,564(9.39)	657(7.58)
Benishangul-Gumuz	869(6.33)	1,323(7.92)	1,280(7.69)	734(8.47)
SNNPR	1,933(14.09)	2,045(12.24)	1,897(11.39)	1,017(11.74)
Gambella	820(5.98)	1,215(7.27)	1,280(7.69)	693(8.00)
Harari	904(6.59)	1,201(7.19)	1,135(6.82)	719(8.30)
Addis Ababa	1,333(9.72)	1,524(9.12)	1,489(8.94)	702(8.10)
Dire Dawa	757(5.52)	1,186(7.10)	1,161(6.97)	738(8.52)
Key: EDHS= Ethiopian demographic health survey, HHH=Household head, SNNPR= South nation Nationalities Republic				

189

190 **Trends of Sanitation facilities in Ethiopia**

191 Figure 1 below presented that the trend of improved sanitation facilities in Ethiopia was 20.46%,
192 25.61%, 25.86%, and 27.45% based on EDHS 2005, 2011, 2016, and 2019, respectively (figure
193 1).

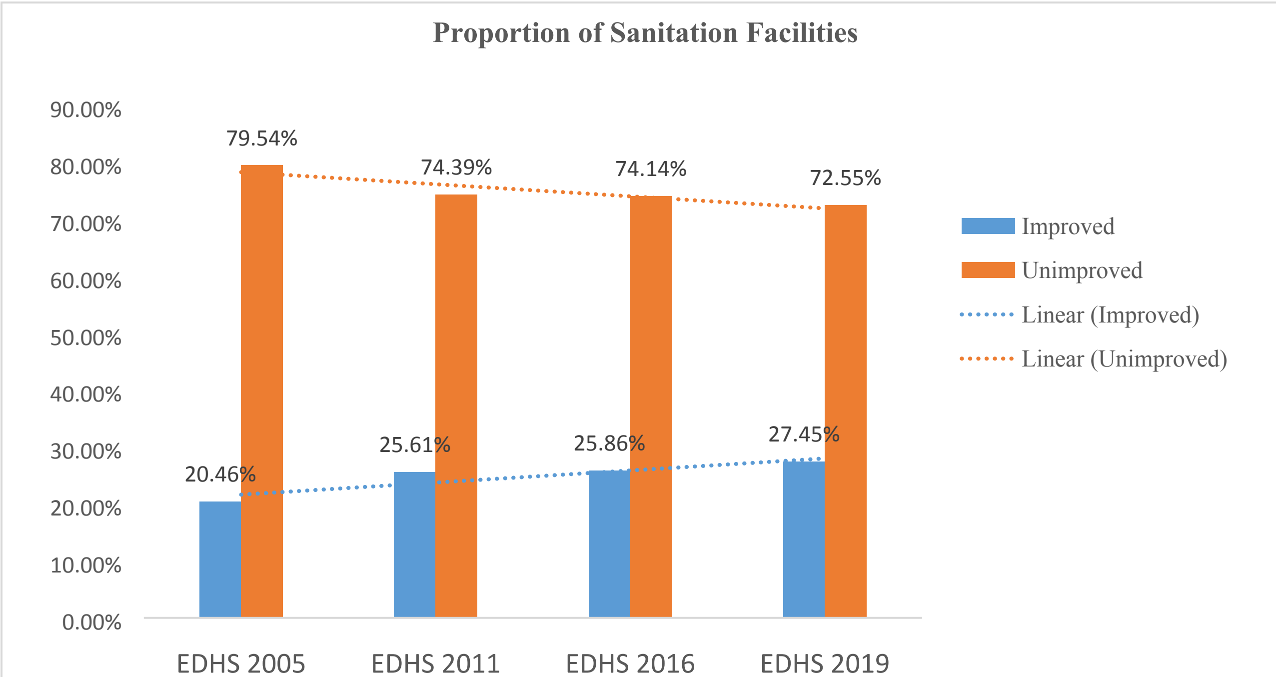


Figure 1: The proportion of sanitation facilities accessibility in Ethiopia using the four EDHS.

Factors Associated with Sanitation Facilities Accessibility

The odds of accessibility to improved sanitation facilities among participants with educational status of primary, secondary, and higher were 2.43 (AOR = 2.43, 95% CI :(2.00, 2.95)), 2.02 (AOR = 2.02, 95% CI :(1.61, 2.54)), and 4.12 (AOR = 4.12, 95% CI :(3.35, 7.54) times more likely respectively, compared to those with no education.

Study participants with wealth status of the middle, and rich were 1.49 (AOR = 1.49, 95% CI :(1.21, 1.83)), and 3.15 (AOR = 3.15, 95% CI :(2.55, 3.89)) times more likely in the odds of accessing improved sanitation facilities respectively, compared to those counterparts poor.

The odds of accessing improved sanitation facilities among study participants watched television were 5.49 (AOR= 5.49, 95% CI: (4.37, 6.89)) more likely compared to counterparts who did no watching television.

Community-level education was a statistically significant predictor variable. The odds of accessing improved sanitation facilities among Communities with higher educational levels were 3.90 (AOR= 3.90, 95% CI: (3.15, 4.82) times more likely compared to the community with lower education.

The chance of accessing improved sanitation facilities among communities exposed to media was 5.61 (AOR= 5.61, 95% CI: (3.84, 10.09)) times more likely than in the community unexposed to the media.

The odds of accessibility-improved sanitation facilities among the study population living in urban areas were 9.08 (AOR= 9.08, 95% CI: (6.69, 12.33) times more likely compared to the o study population living in rural areas.

Communities across various regions, including Tigray (54% less likely, AOR=0.46; 95% CI: 0.37, 0.57), Afar (33% less likely, AOR=0.67; 95% CI: 0.51, 0.86), Somali (77% less likely, AOR=0.23; 95% CI: 0.18, 0.29), Amhara (60% less likely, AOR=0.40; 95% CI: 0.32, 0.49), Benishangul Gumuz (37% less likely, AOR=0.63; 95% CI: 0.49, 0.80), Gambella (55% less likely, AOR=0.45; 95% CI: 0.35, 0.57), Harari (36% less likely, AOR=0.64; 95% CI: 0.52, 0.80), SNNRP (72% less likely, AOR=0.28; 95% CI: 0.22, 0.34), and Dire Dawa (72% less likely, AOR=0.28; 95% CI: 0.22, 0.35), exhibit decreased access to improved sanitation facilities compared to communities in Addis Ababa.

The random variations of sanitation were demonstrated by intra-cluster correlation coefficient (ICC), Proportion Change in Variance (PCV), and median odds ratio (MOR). The ICC in the null model showed that 67.65% of the total variability in accessing improved sanitation facilities was due to differences through cluster areas. Model 1 and Model 2 presented that 59.74% and 26.35% of the Proportion Change in Variance (PCV) of the variation in accessing improved sanitation in the communities was explained by individual and community-level factors, respectively. The MOR between the area at highest in accessing improved sanitation facilities and the area at lowest in accessing improved sanitation facilities if randomly picking out two areas was 7.07.

The goodness fit in model statistics indicated using the lowest values of AIC, DIC, and Deviance. Therefore, the final model had the lowest AIC, DIC, and Deviance, 11151.08, 11282.33, and 11,117.0824, respectively which confirmed the best-fit model (Table 2)

239 Table 2. Multilevel binary logistic regression analysis of predictors towards accessibility of
240 sanitation facilities in Ethiopia, EDHS 2011

Variables	Model 0 (Null model)	Model 1 AOR (95% CI)	Model 2 AOR (95% CI)	Model 3 AOR (95% CI)
Individual level Factors				
Sex of HHH				
Male		0.97(0.82,1.04)		1.01(0.84,1.11)
Female		1	1	1
Age of HHH				
<30		0.97(0.94,1.01)		0.96 (0.20,2.34)
30-40		0.57(0.35,2.02)		1.49(0.13,2.41)
41-54		0.43(0.22,0.61)		1.17(0.86,1.59)
>54		1	1	1
Educational status				
No education		1		1
Primary		3.23 (2.63,3.96)**		2.43(2.00,2.95)**
Secondary		6.36(5.26,7.67)**		2.02(1.61,2.54)**
Higher		8.11 (7.16,9.19)*		4.12(3.35,7.54)**
Wealth index				
Poor		1		1
Middle		2.96 (2.34,4.24)**		1.49 (1.21,1.83)**
Rich		5.48 (3.45,5.89)**		3.15(2.55,3.89)**
Having television				
No		1		1
Yes		4.81(4.16,5.56)**		5.49(4.37,6.89)**
Community level factors				
Community level education				
Higher			6.50(5.82,7.27)**	3.90(3.15,4.82)**
Lower			1	1

Community-level media exposure				
Exposed			6.07(5.42,6.81)**	5.61(3.84,10.09)**
Unexposed			1	1
Type of residence				
Urban			16.74(11.85, 23.65)**	9.08(6.69,12.33)**
Rural			1	1
Region				
Tigray			0.50(0.41,0.62)**	0.46(0.37,0.57)**
Afar			0.86(0.67,1.09)	0.67(0.51,0.86)*
Amhara			0.43(0.35,0.53)**	0.40(0.32,0.49)**
Oromia			0.89 (0.72,1.09)	0.90(0.73,1.12)
SNNRP			0.25(0.20,0.31)*	0.28(0.22,0.34)**
Somali			0.33(0.26,0.41)**	0.23(0.18,0.29)**
Benishangul Gumuz			0.74(0.59,0.94)*	0.63(0.49,0.80)**
Gambella			0.51(0.41,0.64)**	0.45(0.35,0.57)**
Harari				0.64(0.52.0.80)**
Addis Ababa			1	1
Dire Dawa			0.25(0.21,0.31)**	0.28(0.22,0.35)**
VIF		2.35	2.27	2.05
Measures of variations for sanitation				
Variance	6.88(5.84,8.10)	2.77(2.30,3.32)	2.04(1.71,2.44)	1.97(1.65,2.35)
MOR	7.07	4.35	3.82	3.78
PCV	Reference	59.74%	26.35%	3.43 %
ICC	0.6765	0.4571	0.3827	0.3745
Model fitness test statistics				
AIC	12204.07	11338.86	11610.79	11151.08
BIC	12219.51	11454.67	11734.32	11282.33
Deviance	12,200.0736	11,323.6174	11611.497	11,117.0824

1= reference, **P-value < 0.001(Adjusted OR), *P-value < 0.05(Adjusted OR), AIC=Akaike's information criteria, BIC=Bayesian information criteria, HHH =household head, HH=household, Model 0 (Null model) was fitted without predictor variables. ; Model 1 is adjusted for individual-level variables. Model 2 is adjusted for community-level variables; Model 3 is the final model adjusted for both individual- and community-level predictors.

Analysis of spatial heterogeneity

Spatial autocorrelation (Moran's I)

Global Moran's I spatial autocorrelations positive z-scores (with the z-scores of 2005 EDHS 2.374393,2011 EDHS 7.067996, 2016 EDHS 8.9374285, and 2019 EDHS 36.511348) indicated that all EDHS were clustered in accessing improved sanitation facilities through Ethiopia (Figure 2).

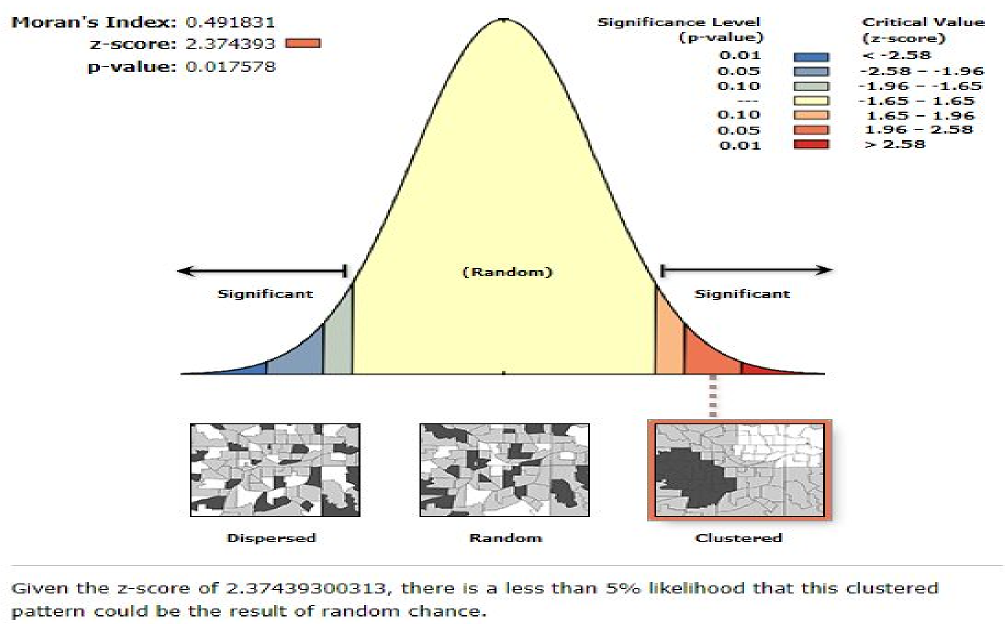


Figure 2A: Global Spatial autocorrelation analysis of accessibility of improved sanitation facilities in Ethiopia, EDHS 2005.

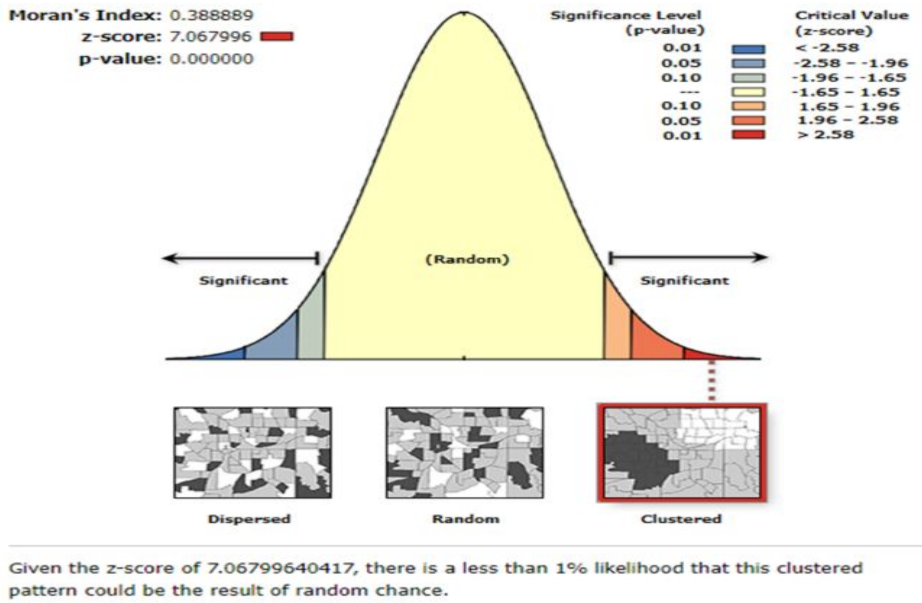


Figure 2B: Global Spatial autocorrelation analysis of accessibility of improved sanitation facilities in Ethiopia, EDHS 2011

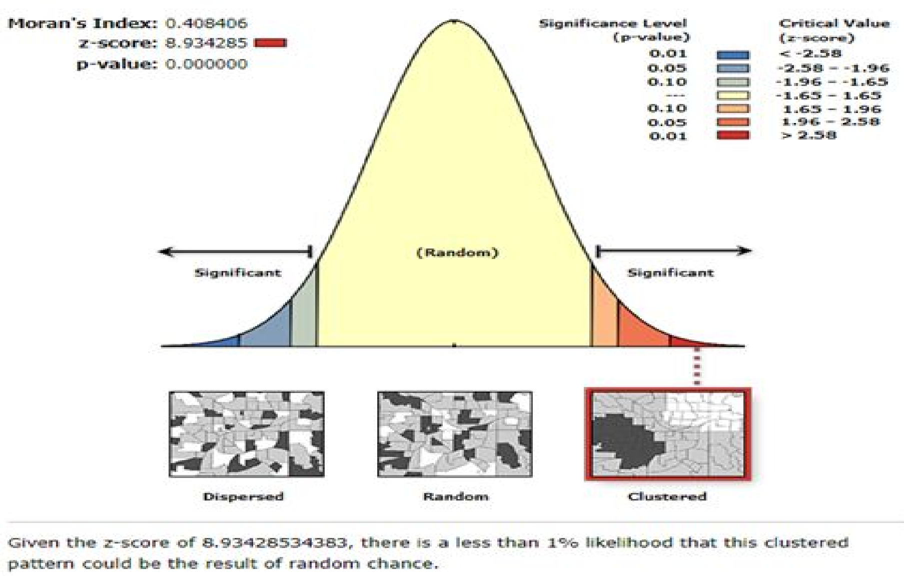


Figure 2C: Global Spatial autocorrelation analysis of accessibility of improved sanitation facilities in Ethiopia, EDHS 2016

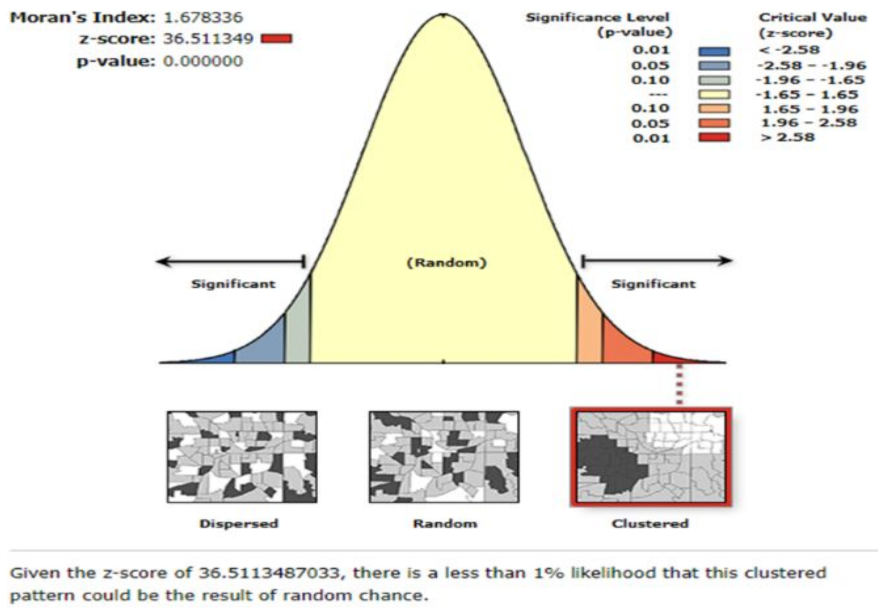


Figure 2D: Global Spatial autocorrelation analysis of accessibility of improved sanitation facilities in Ethiopia, EDHS 2019

Hot and cold spot analysis (Getis-Ord Gi*)

Hot and cold spot analysis revealed that there was the same trend in spatial distribution of improved sanitation facilities through Ethiopia in all EDHS. The figures below show that in all EDHS the percentage of accessing improved sanitation was significantly lower in most parts of the country while this proportion was better only in Addis Ababa, and Dire Dawa (Figure 3).

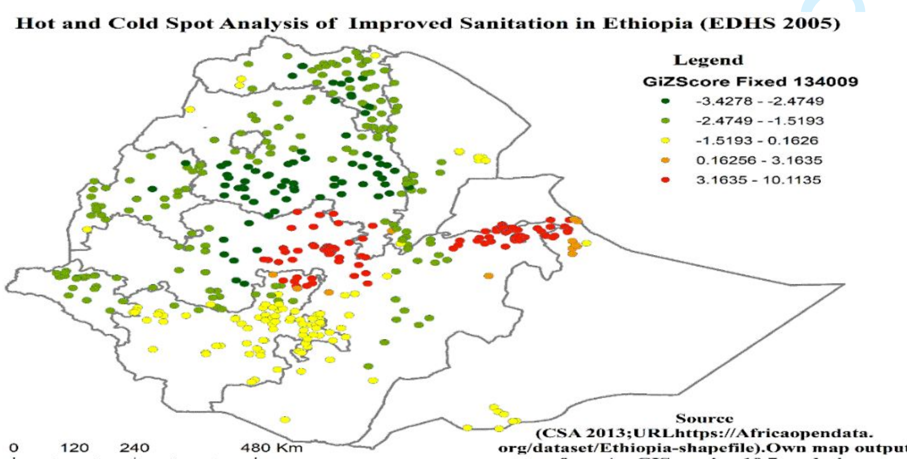


Figure 3A: Hot and cold spot analysis of accessibility of improved sanitation facilities in Ethiopia based on the dataset of EDHS 2005

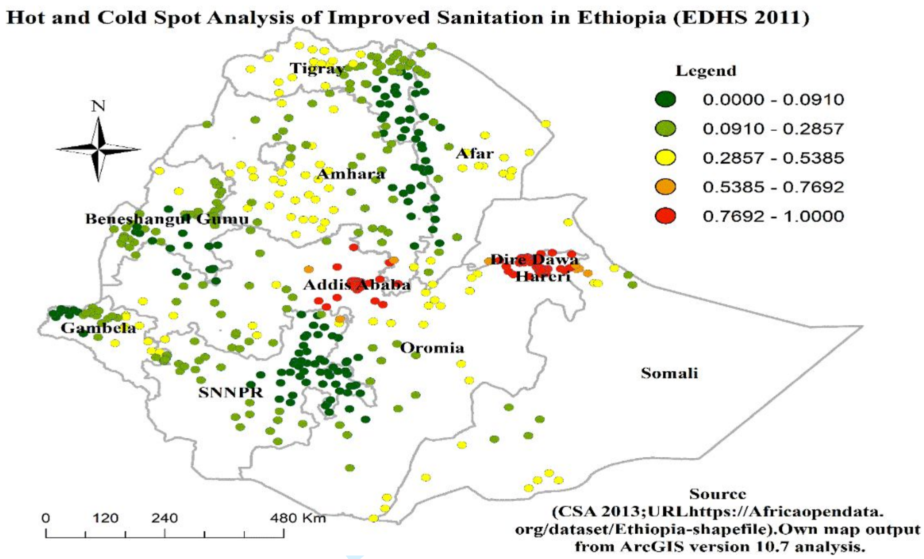


Figure 3B: Hot and cold spot analysis of accessibility of improved sanitation facilities in Ethiopia based on the dataset of EDHS 2011

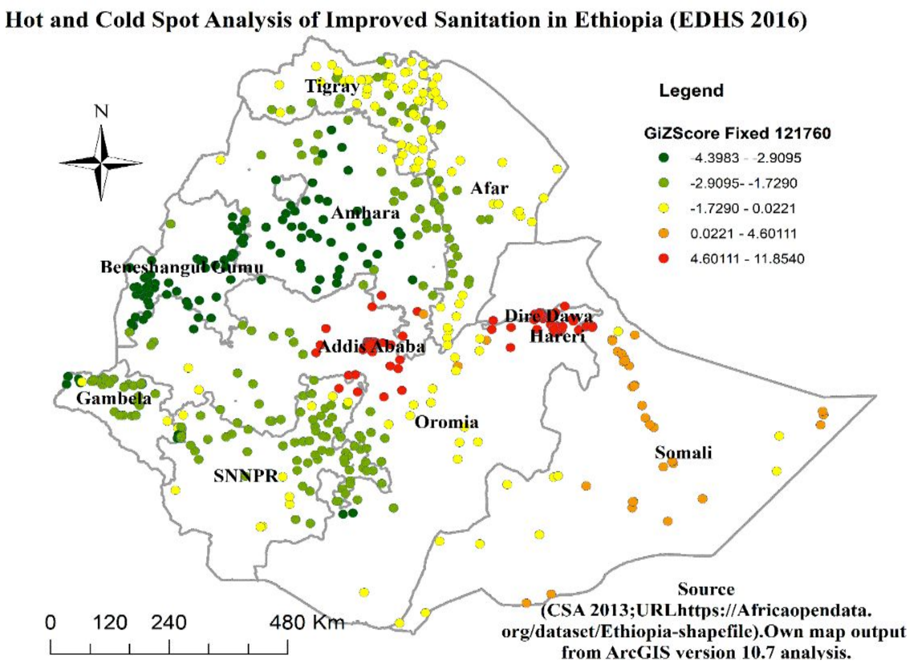


Figure 3C: Hot and cold spot analysis of accessibility of improved sanitation facilities in Ethiopia based on the dataset of EDHS 2016

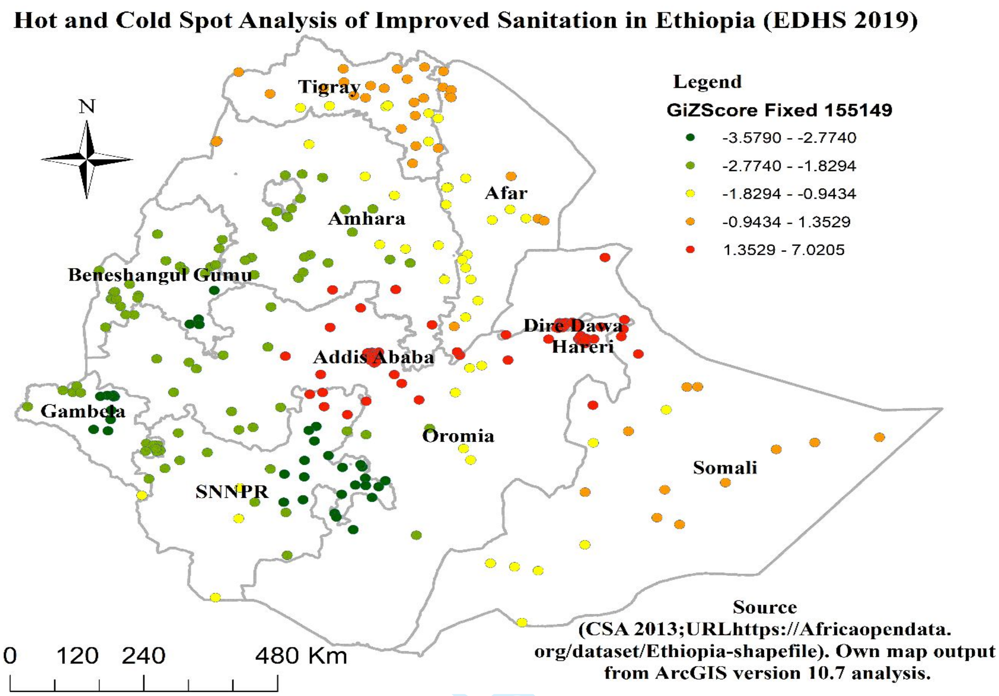


Figure 3D: Hot and cold spot analysis of accessibility of improved sanitation facilities in Ethiopia based on the dataset of EDHS 2019

Spatial interpolation

For the identification part of the country which regions experienced lower improved sanitation accessibility, the spatial kriging interpolation analysis was done. The figures below showed that the red color represents part of the country (Addis Ababa and Dre Dawa) with higher in accessing improved sanitation facilities and on the other hand, the green color (major part of the country) indicated that regions with lower in accessing improved sanitation facilities (figure 4).

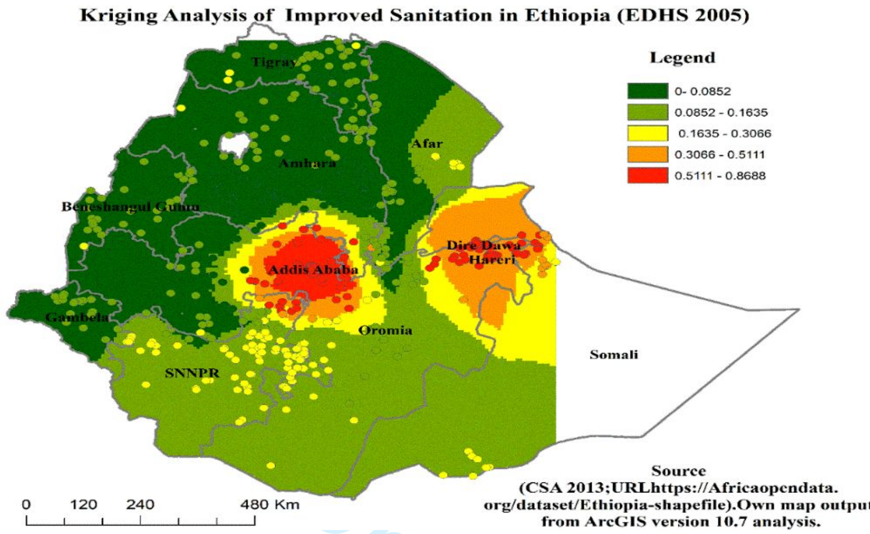


Figure 4A: Kriging interpolation analysis result of improved sanitation facilities accessibility in Ethiopia based on EDHS 2005

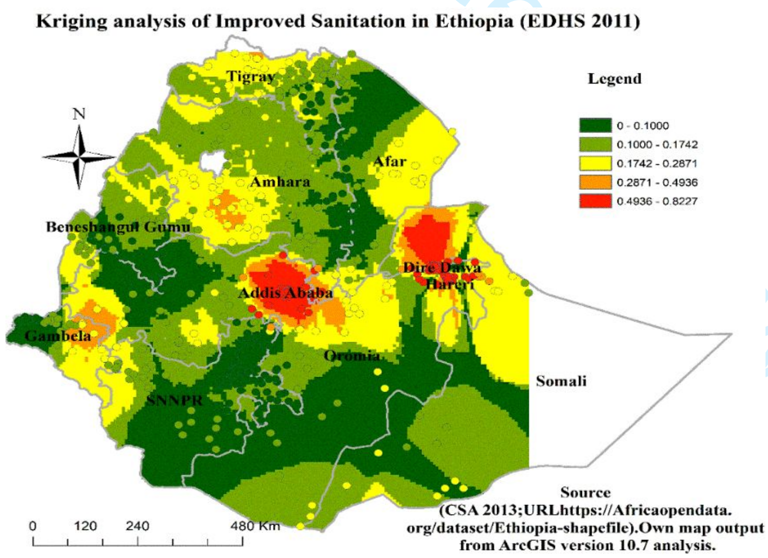


Figure 4B: Kriging interpolation analysis result of improved sanitation facilities accessibility in Ethiopia based on EDHS 2011

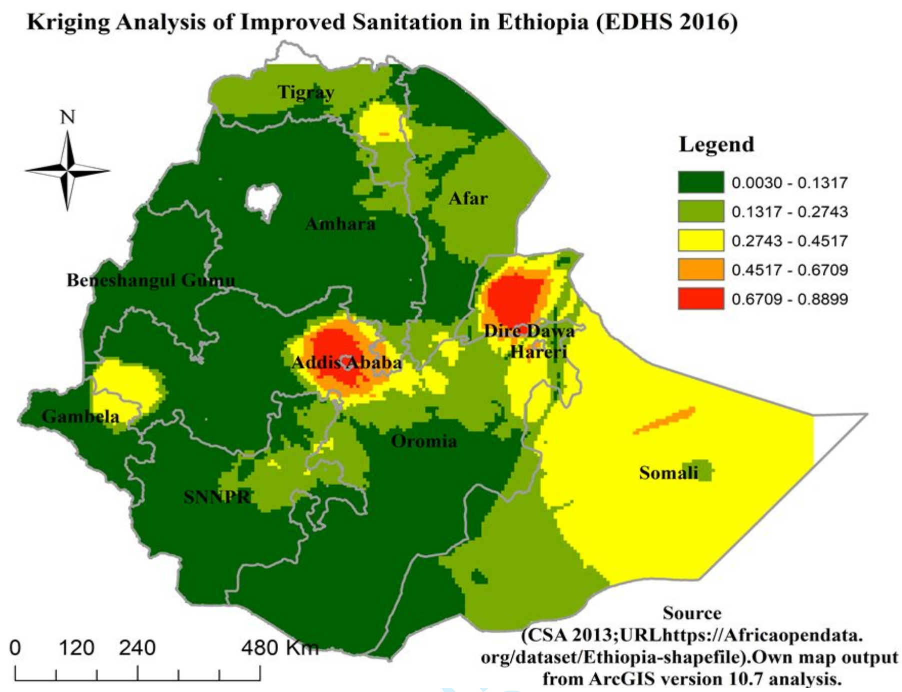


Figure 4C: Kriging interpolation analysis result of improved sanitation facilities accessibility in Ethiopia based on EDHS 2016

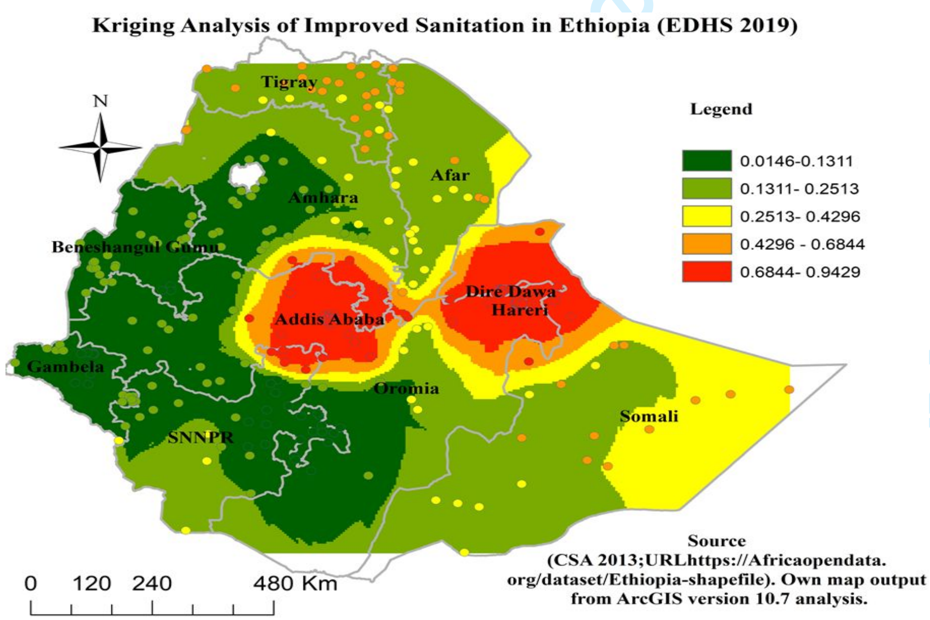


Figure 4D: Kriging interpolation analysis result of improved sanitation facilities accessibility in Ethiopia based on EDHS 2019

Discussion

The uniqueness of the analyses lies in the comprehensive examination of temporal trends and geographic variations in sanitation facilities using multilevel and spatial analysis techniques applied to Ethiopia's 2005-2019 EDHS datasets. The novel contribution stems from their in-depth exploration of how access to sanitation infrastructure has evolved over time and varied across different regions of Ethiopia, shedding light on previously unexplored patterns and disparities. This research provides valuable insights into the dynamic nature of sanitation provision and identifies areas for targeted interventions to address disparities and improve overall sanitation access in Ethiopia.

Sustainable and equitable accessibility of improved sanitation facilities is used to hygienically separate human excreta from human contact which leads to many communicable diseases [35]. The main aim of this study was to investigate the spatiotemporal variation and factors associated with improved sanitation facilities accessibly in Ethiopia based on four consecutive EDHS datasets. These results showed that EDHS 2005, EDHS 2011, EDHS 2016, and EDHS 2019 the proportions of the households with access to improved sanitation facilities were 20.46%, 25.61%, 25.86%, and 27.45%, respectively. There was an increment of 5.15% from 2005 to 2011 but the increase from 2011 to 2016 was only by 0.25%. Based on these findings, very slow increments have been experienced over time in the improvement of access to improved sanitation facilities in Ethiopia from 2005 to 2019. This result is comparable with previous studies, which indicated that some countries have shown high progress toward SDG 6, while others look to be stuck at low levels of sanitation coverage with little or no development [36]. Such setback with little or no development levels of access to improved sanitation facilities is the experience of developing countries including Ethiopia [37]. The possible explanation for this problem could be due to global environmental change, paying less attention due to poverty, instability of the country related with civil war trauma, which lead less attention, by government and non-governmental organization for sanitation facilities development. This finding consistent with other previous studies done in different parts of the world [26, 38-42].

Results of Global Moran's autocorrelation, hotspot, cluster, and kriging in the spatial analysis showed that there were great disparities in accessing improved sanitation facilities in Ethiopia based on four EDHS datasets. Based on the results of hot spot, and kriging analysis in all EDHS Addis Ababa and dire Dawa were a high hot spot of improved sanitation facilities among other parts of the country. This finding put forward that there are significant geographical disparities in access to improved sanitation facilities throughout the country. Which contradicted persistently sustainable development goal 2030 agenda target 6.2 “access to adequate and equitable sanitation for all and end open defecation”[43]. This variation could be the difference in economic growth, overpopulation growth, unplanned urbanization, and inaccessibility of infrastructure, government overload towards other burning daily tasks, socio-political instability, awareness, and adaptability towards sanitation facilities.

Factors associated with access to improved sanitation facilities were the educational status of the household head, having television, and wealth index, in individual-level predictors whereas community-level education, community-level media exposure, type of residence, and region were community-level predictor variables.

In households with a higher educational status, the household head had a greater chance of accessing improved sanitation facilities compared to households with heads who had no education. This finding is supported by the studies done in Ethiopia, Kenya, West and Central Africa, Bangladesh, Benin, and Vietnam [44-47]. The community with higher education accessed improved sanitation facilities than part of the community with lower education. This finding was in line with other previous studies conducted in different parts of the world [20, 48, 49]. The reason for this variation could be that educated individuals might understand the association between health and improved sanitation facilities. If so they are enthusiastic to have these sanitation facilities compared to household heads with lower educational status.

There was a proportional relationship between the levels of wealth status and access to improved sanitation facilities. Rich, and middle households in wealth status were more likely to have access to improved sanitation facilities compared to the poorest households. This finding is supported by the studies done in Ghana, Benin, Vietnam, and Eswatini [45, 50-52]. This difference could be due to the installation of improved sanitation facilities such as septic tanks, pour flush toilet facilities; pit latrines with a slab, and composting toilet facilities might be difficult for the poor to afford them.

Holding other variables constant, households that had television were more likely in accessing improved sanitation facilities compared to households with no television. This might probably be because inhabitants spent their time watching television which acts as an information source visually, including the role of improved sanitation in reducing disease transmission. Community-level media exposure was the other community-level factor statistically significant predictor associated with access to improved sanitation facilities. Household members exposed to community-level media (television, radio, or one of the two) had more chances of accessing improved sanitation in Ethiopia. This finding was in line with previous studies conducted in Ethiopia [19, 20], and sub-Saharan Africa [53].

Households found in the urban area more likely to access improved sanitation facilities than those found in the rural area. This issue was Supported by a previous study done in Ethiopia which indicated that rural areas of Ethiopia are extremely lagging late in the race toward realizing SDG 6.2 [36] and the other study done in Vietnam [50]. Households found in different regions of Ethiopia were accessed different proportions of improved sanitation facilities. The capital city Addis Ababa was better than the regions of the country. This finding is aligns with the studies done in Kenya [54], Nepal [55] and WHO, UNICEF, 2019 report [56] which indicated that persist disparities in access to WASH services in rural versus urban settings. The possible explanation, for this difference might be due to Addis Ababa being the capital city of the country and it is the headquarter of the Africa Union more infrastructure including improved sanitation facilities could be fulfilled. In addition, it could be due to low economic status, socio-political instability among regions, lack of awareness, lower adaptability towards sanitation facilities.[57].

The self-report nature of data collection which leads to interviewer bias, social acceptability bias, recall bias and incompleteness of the recent mini demographic health survey (EDHS 2019) could be potential sources of errors and the limitations of this study.

Conclusion

The overall finding of this study concludes that there was a very slow increment of accessibility of sanitation facilities over time in Ethiopia. As well as, there was statistically significant geographical heterogeneity in accessibility of improved sanitation facilities in the country. The rate of current progress in universal access to sanitation facilities (SDG 6.2) in 2030 should be accelerated to reach the proposed plan. Educational status, watching television, wealth index, community-level education, community-level media exposure, type of residence, and region were factors statistically associated with sanitation facilities accessibility in Ethiopia. This finding suggested for international and local organizations work on solutions that enable the progress in sanitation facilities accessibility for all, especially in developing countries.

Abbreviations

AIC: Akaike's Information Criterion, AOR: Adjusted Odds Ratio, CI: Confidence Interval, DHS: Demographic and Health Survey, EAs: Enumeration Areas, EDHS: Ethiopian Demographic and Health Survey, ICC: Intra Class Correlation, MOR: Median Odd Ratio, PCV: Proportional Change in Variance

Declarations

Ethics approval and consent to participate

This study was based on secondary data from the Ethiopian Demographic and Health Survey and secured the permission letter from the main Demographic Health and Survey. Permission for data access was obtained from a major Demographic and Health Survey through an online request at (https://www.dhsprogram.com/data/dataset_admin/login_main.cfm.). Participant consent was not directly obtained since authors used secondary data.

Consent for publication

Not applicable.

Availability of data and materials

This research was done using a publicly available dataset found at https://www.dhsprogram.com/data/dataset_admin/login_main.cfm. after approval from Data Archivist of the Demographic and Health Surveys (DHS) Program.

Competing interests

There is no any competing interest.

Funding

There is no specific grant for doing this research.

Authors' contributions

JA: **Data curation**

JA: **Formal analysis**

JA, MT, WM: **Investigation**

JA, MT, WM: **Methodology**

JA, WM: **Software**

JA, MT, WM: **Validation**

JA, MT: **Visualization**

JA, WM: **Write-up**

JA, MT, WM: **Review & editing**

All authors read and approved the final manuscript.

Acknowledgments

The author acknowledges the Ethiopian Central Statistical Agency for providing them with the data and shape files for this study.

References

1. Organization, W.H., *World health statistics overview 2019: monitoring health for the SDGs, sustainable development goals*. 2019, World Health Organization.
2. Erridge, M., *Human Right to Sanitation.* Clean Water and Sanitation, 2020: p. 1-11.
3. Water, U., *Sustainable Development Goal 6 Synthesis Report on Water and Sanitation. United Nations*. 2018.
4. Carvalho, D.M., *Tripartite organizational partnerships and the wickedness of the water and sanitation sector in Brazil: an institutional analysis.* 2019.
5. Kumwenda, S., *Challenges to hygiene improvement in developing countries*. Vol. 1. 2019: IntechOpen London, UK.
6. Peter, A.K. and U. Umar, *Combating diarrhoea in Nigeria: the way forward.* J Microbiol Exp, 2018. **6**(4): p. 191-197.
7. Morgan, C., et al., *Water, sanitation, and hygiene in schools: Status and implications of low coverage in Ethiopia, Kenya, Mozambique, Rwanda, Uganda, and Zambia.* International journal of hygiene and environmental health, 2017. **220**(6): p. 950-959.
8. Dickin, S., et al., *Sustainable sanitation and gaps in global climate policy and financing.* NPJ Clean Water, 2020. **3**(1): p. 24.
9. Obani, P., *SDG 6.2 and the right to sanitation: exploring the complementarities and incoherence.* UNIPORT Journal of International and Comparative Law 1, 2020: p. 1-17.
10. Mattos, K.J., et al., *Household water, sanitation, and hygiene practices impact pathogen exposure in remote, rural, unpiped communities.* Environmental Engineering Science, 2021. **38**(5): p. 355-366.

11. Corburn, J., *Water and sanitation for all: Citizen science, health equity, and urban climate justice.* Environment and Planning B: Urban Analytics and City Science, 2022. **49**(8): p. 2044-2053.

12. Tykhomyrova, T., V. Sebko, and V. Babenko, *Sustainable development*. 2022.

13. Hutton, G. and M. Varughese, *The costs of meeting the 2030 sustainable development goal targets on drinking water, sanitation, and hygiene.* 2016.

14. Organization, W.H., *Progress on household drinking water, sanitation and hygiene 2000-2020: five years into the SDGs.* 2021.

15. Walsh, P.P., E. Murphy, and D. Horan, *The role of science, technology and innovation in the UN 2030 agenda.* Technological Forecasting and Social Change, 2020. **154**: p. 119957.

16. Campos Nonato, I., *Mapping geographical inequalities in access to drinking water and sanitation facilities in low-income and middle-income countries, 2000–17*. 2020.

17. Prüss-Ustün, A., et al., *Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: an updated analysis with a focus on low-and middle-income countries.* International journal of hygiene and environmental health, 2019. **222**(5): p. 765-777.

18. Baye, D., *Sustainable development goals (SDG) target 6.2 in Ethiopia: challenges and opportunities.* Open Access Library Journal, 2021. **8**(5): p. 1-28.

19. Demsash, A.W., et al., *Spatial and multilevel analysis of sanitation service access and related factors among households in Ethiopia: using 2019 Ethiopian national dataset.* PLOS Global Public Health, 2023. **3**(4): p. e0001752.

20. Azanaw, J., et al., *A multilevel analysis of improved drinking water sources and sanitation facilities in Ethiopia: Using 2019 Ethiopia mini demographic and health survey.* Frontiers in Public Health, 2023. **11**.

21. Gebremichael, S.G., et al., *Determinants of water source use, quality of water, sanitation and hygiene perceptions among urban households in North-West Ethiopia: A cross-sectional study.* Plos one, 2021. **16**(4): p. e0239502.

22. Adil, S., M. Nadeem, and I. Malik, *Exploring the important determinants of access to safe drinking water and improved sanitation in Punjab, Pakistan.* Water Policy, 2021. **23**(4): p. 970-984.

23. Dwivedi, R., K. Sreenivas, and K. Ramana, *Cover: Land‐use/land‐cover change analysis in part of Ethiopia using Landsat Thematic Mapper data.* International Journal of Remote Sensing, 2005. **26**(7): p. 1285-1287.

24. Anteneh, Z.A. and J.-P. Van Geertruyden, *Spatial variations and determinants of anemia among under-five children in Ethiopia, EDHS 2005–2016.* Plos one, 2021. **16**(4): p. e0249412.

25. Armah, F.A., et al., *Access to improved water and sanitation in sub-Saharan Africa in a quarter century.* Heliyon, 2018. **4**(11): p. e00931.

26. Wang, C., et al., *Geographic inequalities in accessing improved water and sanitation facilities in Nepal.* International journal of environmental research and public health, 2019. **16**(7): p. 1269.

27. Davis, J., et al., *Improving access to water supply and sanitation in urban India: microfinance for water and sanitation infrastructure development.* Water Science and Technology, 2008. **58**(4): p. 887-891.

28. Sun, G.-W., T.L. Shook, and G.L. Kay, *Inappropriate use of bivariable analysis to screen risk factors for use in multivariable analysis.* Journal of clinical epidemiology, 1996. **49**(8): p. 907-916.
29. Goicolea, I. and M. San Sebastian, *Unintended pregnancy in the amazon basin of Ecuador: a multilevel analysis.* International journal for equity in health, 2010. **9**: p. 1-11.
30. Schootman, M., et al., *Geographic clustering of adequate diagnostic follow-up after abnormal screening results for breast cancer among low-income women in Missouri.* Annals of epidemiology, 2007. **17**(9): p. 704-712.
31. Li, F., et al., *Model selection methods for mixture dichotomous IRT models.* Applied Psychological Measurement, 2009. **33**(5): p. 353-373.
32. Roll, U., et al., *Onset of a pandemic: characterizing the initial phase of the swine flu (H1N1) epidemic in Israel.* BMC infectious diseases, 2011. **11**(1): p. 1-13.
33. Blake, S.B., *Exploring Spatial Relationships Among Dairy Farms, Drinking Water Quality, and Maternal-Child Health Outcomes in the San Joaquin Valley*. 2014: University of California, Davis.
34. Sánchez-Martín, J.-M., J.-I. Rengifo-Gallego, and R. Blas-Morato, *Hot spot analysis versus cluster and outlier analysis: An enquiry into the grouping of rural accommodation in Extremadura (Spain).* ISPRS International Journal of Geo-Information, 2019. **8**(4): p. 176.
35. Ritchie, H. and M. Roser, *Clean water and sanitation.* Our world in data, 2021.
36. Bankole, A.O., et al., *Factors affecting sanitation coverage in three income levels and potential toward achieving SDG 6.2.* Water Policy, 2023. **25**(2): p. 146-176.
37. Organization, W.H., *National systems to support drinking-water: sanitation and hygiene: global status report 2019: UN-Water global analysis and assessment of sanitation and drinking-water: GLAAS 2019 report.* 2019.
38. Azage, M., A. Motbainor, and D. Nigatu, *Exploring geographical variations and inequalities in access to improved water and sanitation in Ethiopia: mapping and spatial analysis.* Heliyon, 2020. **6**(4).
39. Pullan, R.L., et al., *Geographical inequalities in use of improved drinking water supply and sanitation across sub-Saharan Africa: mapping and spatial analysis of cross-sectional survey data.* PLoS medicine, 2014. **11**(4): p. e1001626.
40. Armah, F.A., et al., *Access to improved water and sanitation in sub-Saharan Africa in a quarter century.* Heliyon, 2018. **4**(11).
41. Yu, W., et al., *A global perspective on drinking-water and sanitation classification: an evaluation of census content.* PLoS One, 2016. **11**(3): p. e0151645.
42. Ghosh, P., M. Hossain, and A. Alam, *Water, sanitation, and hygiene (WASH) poverty in India: a district-level geospatial assessment.* Regional Science Policy & Practice, 2022. **14**(2): p. 396-417.
43. Hueso, A., *Is 'access to adequate and equitable sanitation' for all by 2030 achievable? Perspectives from sector experts on what needs to change to realise the Sustainable Development Goal.* Journal of Water, Sanitation and Hygiene for Development, 2016. **6**(4): p. 650-657.
44. Koskei, E.C., et al., *Effect of socio-economic factors on access to improved water sources and basic sanitation in Bomet Municipality, Kenya.* Research Journal of Environmental and Earth Sciences, 2013. **5**(12): p. 714-719.

45. Gaffan, N., et al., *Household access to basic drinking water, sanitation and hygiene facilities: secondary analysis of data from the demographic and health survey V, 2017–2018.* BMC Public Health, 2022. **22**(1): p. 1-16.
46. Andualem, Z., et al., *Households access to improved drinking water sources and toilet facilities in Ethiopia: a multilevel analysis based on 2016 Ethiopian Demographic and Health Survey.* BMJ open, 2021. **11**(3): p. e042071.
47. Simen-Kapeu, A., et al., *Prevalence of diarrhoea, acute respiratory infections, and malaria over time (1995-2017): A regional analysis of 23 countries in West and Central Africa.* Journal of global Health, 2021. **11**.
48. Agbadi, P., E. Darkwah, and P.L. Kenney, *A multilevel analysis of regressors of access to improved drinking water and sanitation facilities in Ghana.* Journal of environmental and public health, 2019. **2019**.
49. Kong, Y.-L., et al., *Socio-economic factors related to drinking water source and sanitation in Malaysia.* International Journal of Environmental Research and Public Health, 2020. **17**(21): p. 7933.
50. Tuyet-Hanh, T.T., et al., *Household trends in access to improved water sources and sanitation facilities in Vietnam and associated factors: findings from the Multiple Indicator Cluster Surveys, 2000–2011.* Global Health Action, 2016. **9**(1): p. 29434.
51. Simelane, M.S., et al., *Determinants of households' access to improved drinking water sources: a secondary analysis of eswatini 2010 and 2014 multiple indicator cluster surveys.* Advances in Public Health, 2020. **2020**: p. 1-9.
52. Akpakli, D.E., et al., *Determinants of access to improved sanitation facilities in rural districts of southern Ghana: evidence from Dodowa Health and Demographic Surveillance Site.* BMC research notes, 2018. **11**(1): p. 1-7.
53. Seidu, A.-A., et al., *A multilevel analysis of individual and contextual factors associated with the practice of safe disposal of children's faeces in sub-Saharan Africa.* Plos one, 2021. **16**(8): p. e0254774.
54. Health, M.o., *Kenya environmental sanitation and hygiene strategic framework 2016–2020.* 2015.
55. Dhital, S.R., et al., *Prevalence and Correlates of Water, Sanitation, and Hygiene (WASH) and Spatial Distribution of Unimproved WASH in Nepal.* International journal of environmental research and public health, 2022. **19**(6): p. 3507.
56. Organization, W.H., *Progress on household drinking water, sanitation and hygiene 2000-2017: special focus on inequalities*. 2019: World Health Organization.
57. Deshpande, A., et al., *Mapping geographical inequalities in access to drinking water and sanitation facilities in low-income and middle-income countries, 2000–17.* The Lancet Global Health, 2020. **8**(9): p. e1162-e1185.

BMJ Open

Temporal trends and spatial heterogeneity of sanitation facilities in Ethiopia: evidence from the 2005-2019 Demographic and Health Surveys

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2024-088211.R1
Article Type:	Original research
Date Submitted by the Author:	05-Oct-2024
Complete List of Authors:	Azanaw, Jember; University of Gondar, Department of Environmental and Occupational Health and Safety, Institute of Public Health, College of Medicine and Health Sciences Tsegaye, Mesenbet; Department of General Surgery College of Medicine and Health Sciences, University of Gondar, Gondar, Ethiopia Mesele, Wodaje; Department of Orthopaedic and Trauma Surgeon,Department of General Surgery College of Medicine and Health Sciences, University of Gondar, Gondar, Ethiopia
Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Public health, Global health
Keywords:	Infectious diseases & infestations < DERMATOLOGY, International health services < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, Public health < INFECTIOUS DISEASES, Climate Change, Health Services, Health Education

I, the Submitting Author has the right to grant and does grant on behalf of all authors of the Work (as defined in the below author licence), an exclusive licence and/or a non-exclusive licence for contributions from authors who are: i) UK Crown employees; ii) where BMJ has agreed a CC-BY licence shall apply, and/or iii) in accordance with the terms applicable for US Federal Government officers or employees acting as part of their official duties; on a worldwide, perpetual, irrevocable, royalty-free basis to BMJ Publishing Group Ltd ("BMJ") its licensees and where the relevant Journal is co-owned by BMJ to the co-owners of the Journal, to publish the Work in this journal and any other BMJ products and to exploit all rights, as set out in our licence.

The Submitting Author accepts and understands that any supply made under these terms is made by BMJ to the Submitting Author unless you are acting as an employee on behalf of your employer or a postgraduate student of an affiliated institution which is paying any applicable article publishing charge ("APC") for Open Access articles. Where the Submitting Author wishes to make the Work available on an Open Access basis (and intends to pay the relevant APC), the terms of reuse of such Open Access shall be governed by a Creative Commons licence – details of these licences and which Creative Commons licence will apply to this Work are set out in our licence referred to above.

Other than as permitted in any relevant BMJ Author's Self Archiving Policies, I confirm this Work has not been accepted for publication elsewhere, is not being considered for publication elsewhere and does not duplicate material already published. I confirm all authors consent to publication of this Work and authorise the granting of this licence.

Temporal trends and spatial heterogeneity of sanitation facilities in Ethiopia: evidence from the 2005-2019 Demographic and Health Surveys

Jember Azanaw[1]*, Mesenbet Tsegaye[2], Wodaje Mesele[3]

[1]Department of Environmental and Occupational Health and Safety, Institute of Public Health, College of Medicine and Health Sciences, University of Gondar, Gondar, Ethiopia

[2]Department of General Surgery, School of Medicine, College of Medicine and Health Sciences, University of Gondar, Gondar, Ethiopia

[3]Department of Orthopaedic and Trauma Surgeon, School of Medicine, College of Medicine and Health Sciences, University of Gondar, Gondar, Ethiopia

***=Corresponding**

jemberazanaw21@gmail.com

Abstract

Background: The main aim of sanitation is to prevent human contact with fecal pathogens to decrease occurrences of diseases. But, no region in the world is on the right track to accomplish Sustanaible development goal (SDG) 6.2 for universal access to sanitation. Sub-Sahara Africa, Ethiopia included, is significantly behind in meeting the 2030 SDG 6.2 targets. Hence, this study focused on the spatial and temporal analysis of sanitation in Ethiopia based on four demographic health surveys.

Method: This research was undertaken among households in Ethiopia based on a weighted sample size. Variables with a p-value below 0.2 in bivariable analysis were incorporated into the multivariable analysis. Subsequently, a 95% CI and a p-value < 0.05 were utilized to assess the statistical significance of the final model. Global and local indicators of spatial correlation were done. Statistical analyses were performed using STATA 17, and ArcGIS 10.7 software.

Results: This study includes 13,721 in 2005 EDHS, 16,702 in 2011 EDHS, 16,650 in 2016 EDHS, and in 2019 EDHS 8,663 households. The prevalence of improved sanitation facilities in Ethiopia was 20.46%, 25.61%, 25.86%, and 27.45% based on EDHS 2005, 2011, 2016, and 2019, respectively. Global Moran's I spatial autocorrelations, hotspots, and spatial interpolation analysis indicated the inequality of improved sanitation facilities. Educational status of primary (AOR = 2.43, 95% CI : 2.00, 2.95), secondary (AOR = 2.02, 95% CI : 1.61, 2.54), and higher (AOR = 4.12, 95% CI :3.35, 7.54), watching television (AOR= 5.49, 95% CI: 4.37, 6.89), urban areas (AOR= 9.08, 95% CI: 6.69, 12.33), and region were factors statistically associated with sanitation facilities.

Conclusion: The overall finding of this study concludes a very slow increment in sanitation facilities over time and presence of geographical heterogeneity in Ethiopia. Educational status, watching television, wealth index, community-level education, type of residence, and region were factors statistically associated with sanitation facilities.

Keywords: EDHS, Ethiopia, Improved Sanitation, Spatiotemporal variation

Background

Sanitation refers to the endowment of services and facilities for the safe and clean controlling of human excreta, from the toilet to handling and containment to the final end-use or removal [1]. Sanitation is an integral component of basic human rights comparable to food, shelter, and water and is vital for healthy life [2].

According to the United Nations (UN-2018) report, in the world, around 4.5 billion people had no safe sanitation sand 892 million continue to practice Open Defecation (OD) [3, 4]. Inadequate access to sanitation is a principal reason for poverty in unindustrialized nations because it causes early mortality [5, 6]. According to World Health Organization (WHO) 2019 estimation, drinking water sources of two billion people were contaminated with feces and over 800,000 people die annually from diarrhea caused by poor water, sanitation, and hygiene (WASH) (World Health Organization, 2019). Internationally, sanitation sector are expected to be impacted by climate change, changing precipitation patterns, rapid urbanization, lack of context-specific and pragmatic advice on adaptation measures for sanitation service providers [7-9]. In Eastern and Southern Africa, 340 million people (more than 70 %) have no access to basic sanitation services, 98 million people (19 percent) practice open defecation, 179 million use unimproved facilities, and 63 million shared sanitation facilities [10].

Due to such problems, Sustainable Development Goals (SDGs 6.2) stand to ensure accessibility of equitable sanitation for all by the year 2030 [11]. SDG 6.2 of the United Nations, which emanated in 2015 from the Millennium Development Goals, aims at equitable access to safe and affordable sanitation for all by 2030 (10). The main aim of this SDG is to prevent human contact with fecal pathogens to decrease occurrences of diseases [12, 13]. Nevertheless, no region in the world is on the right track to accomplish SDG 6.2 for universal access to sanitation, and urban sewer connections are increasing at an embarrassingly slow rate of 0.14% annually [14]. Especially, countries in Sub-Saharan Africa (SSA) countries are extremely late to achieve SDG 6.2 2030 agenda due to the rapid population growth rate, without enough investment in sanitation infrastructures [15, 16]. At the same time, inequalities in accessing sanitation facilities were more pronounced among countries in sub-Saharan Africa [17]. There is a disparity within countries, mainly regarding urban and rural residences, which indicated that rural inhabitants access markedly lower levels of sanitation than with urban residences [18]. Such Subnational variation in access to improved sanitation facilities, defined as the range of values from the unit with the highest level of access to the unit with the lowest level or no access, are evident across low and middle income countries [19] . Like other developing countries [20] access to sanitation is a challenge across Ethiopia [21], as well as there are disparities among the regions of the country. On the other hand, nations may strengthen or setback the progress of equitable access to improved sanitation facilities.

Previous studies in Ethiopia were based on a single EDHS or only multilevel analysis or spatial analysis in order to investigate improved sanitation facilities [22]. Such studies unable to show the trend of improved sanitation facilities progress overtime. Residence, educational attainment, watching television, household size, region, and wealth index are factors associated with the improved sanitation source as in previous studies [23-25]. Hence, this study focused on the spatial and temporal analysis of sanitation facilities in Ethiopia based on combined multiple (2005, 2010, 2016, and 2019) demographic health surveys for better understanding of the progress and geographic variation within the country.

Methods

Study area and Data source

This study was conducted in Ethiopia, which is nine geographical regions (Tigray, Afar, Amhara, Oromia, Somali, Benishangul-Gumuz, Southern Nations Nationalities and Peoples Region (SNNPR), Gambella, and Harari), and two administrative cities (Addis Ababa and Dire-Dawa) of the country. The country is located in the Horn of Africa with geographical locations 9.145° N latitude and 40.4897° East longitude [26]. This study used the four successive Ethiopian Demographic and Health Surveys (EDHS 2005, 2011, 2016, and 2019) database survey. Therefore, these are nationally representative population-based surveys with large sample sizes at different times. EDHS data is open source and can be retrieved on the DHS website https://www.dhsprogram.com/data/dataset_admin/login_main.cfm.

All EDHS samples were a two-stage stratified cluster sample [27], sampling weights were calculated based on sampling probabilities separately for each sampling stage and each cluster. In 2005 surveys, 540 enumeration areas (EAs) (139 urban and 401 rural areas) [28], 2011 EDHS, 624 EAs (187 urban and 437 rural areas) [29], 2016 EDHS 645 EAs (202 in urban areas and 443 in rural areas) [30], and 2019 EDHS 305 EAs (93 in urban areas and 212 in rural areas) [31]were selected using systematic sampling with likelihood proportional to size.

In the second stage of selection, a fixed number of 30 households per cluster were selected with an equal probability of systematic selection from the newly created household listing. The field practice was conducted in Adama in clusters that were not part of the survey sample. Ethiopian public health institute investigators, an ICF technical specialist, an advisor, and representatives from other organizations, including central statistics agency, the Federal Ministry of Health, the World Bank, and USAID, supported the data collection in this EDHS data collection [28].

Among included households, 13,721, 16,702, 16, 650, and 8,663 were successfully interviewed in EDHS 2005, 2011, 2016, and 2019, respectively [28, 30]. Weighted by sampling weight was done to do a reliable statistical analysis. The geographical location data were taken from selected respective Enumeration Areas (EAs).

Study Variables

Outcome variables

The dependent variable was the sanitation facilities. The sanitation type categorized as '1' on behalf of 'improved sanitation' which accessed from flush/pour flush to piped sewer systems, septic tanks, or pit latrines; ventilated improved pit latrines, composting toilets or pit latrines with slabs, and '0' for 'unimproved sanitation' when the sanitation facilities from pit latrines without a slab or platform, hanging latrines or bucket latrines and open defecation [32-34].

Predictor variables

Individual level variables: sex of household head (male or female), wealth index (poor, middle, and rich), educational status (no education, primary education, secondary education, and higher education), having a television (yes or no) and radio (yes or no) were individual-level predictor variables.

Community level variables: Community level education (lower/higher), the place of residence (urban/rural), community level media exposure (exposed/unexposed), region (Benishangul-Gumuz, Somali, Gambella, Afar, Oromia, SNNPR, Amhara, Tigray, and Harari) and City administration (Addis Ababa, and Dire Dawa).

Data management and analysis

For data quality assurance purposes, pretests containing in-class training, biomarker training, and field exercise were done. The field exercise was conducted in clusters, which were not included in the EDHS sample. A debriefing session was held with the pretest field staff, and adjustments to the questionnaires were done based on lessons drawn from the field practice. Since the outcome variables were dichotomous, logistic regression analysis was conducted to assess associations of outcome variables and predictor variables. Variables in bivariable analysis with a p-value less than 0.2 were included in multivariable binary logistic regression analysis. 95% confidence interval (CI) and a p-value less than 0.05 were used for identifying statistical significance in the final model [35].

Multilevel Analysis

Four models, a null model (model 0) without any predictor variable, model 1 comprised dependent and individual-level predictors, model 2 incorporated dependent and community-level predictors, and model 3 involved all variables from models 1 and 2. Random effects were measured using cluster variance (Vc), a proportional change in variance ((PCV $((Vc - Vn)/Vc)$) the intraclass correlation coefficient (ICC$(Vc/(Vc + 3.29))$), and the median odds ratio (MOR (exp $[(0.95)\sqrt{Vc}]$)) [36, 37]. The goodness-of-fit for all models was evaluated using AIC, BIC, and Deviance. Then the model with the lower value of deviance, AIC, and BIC, was demonstrating the best-fit model [38]. As well as Multicollinearity, the effect of independent variables was measured using the variance inflation factor (VIF).

Spatial analysis

Spatial Autocorrelation

To explore the geographical distribution, both global and local indicators of spatial correlation are the best imperative tools for access to improved sanitation facilities within the specified period.

Global autocorrelations

To proceed with geographical variation identification of access to improved sanitation facilities, Global autocorrelations analysis was done. Global spatial autocorrelation (Moran's I index) was used to detect whether the difference is due to the clustering effect or non-random/dispersion [39, 40]. As well as the simple exploratory spatial analysis was performed to identify the presence of improved sanitation facilities and geographical dependence distribution in the country.

Local statistical analysis

Further investigation using figures and maps is needed since Global autocorrelations indicate a clustering effect (positive spatial autocorrelation) on sanitation facilities' access over the country. Therefore, hotspot analysis (Gettis-Ord Gi*) was performed to identify patterns of spatial variation and emphasize the previously stated using global autocorrelations (cluster effect) on access to sanitation facilities. Cluster and outlier analysis (Anselin local Moran is I) was used to describe the spatial patterns of the dependent variables (access to sanitation facilities). This cluster and outlier analysis was used to confirm and accompaniment to show extreme (the hotspot and cold spot) since it permits the identification of groupings and areas where the differences happen [41].

Results

Socio-demographic characteristics of the study population

This study include 13,721 in 2005 EDHS, 16,702 in 2011 EDHS, 16,650 in 2016 EDHS, and in 2019 EDHS 8,663 participants. In all EDHS, data sets the greater proportion (63.59%, 55.74%, 52.06%, and 47.65%, respectively) of study subjects were no education. The majority (88.30%, 81.68%, 76.98%, and 77.10%) of the participants in the 2005 EDHS, 16,702the in the 2011 EDHS, 16,650 in the 2016 EDHS, and 2019 EDHS, respectively, had no television (Table 1).

Table 1. Socio-demographic characteristics of study Participants in Ethiopia

Variables	EDHS 2005 (N= 13,721) Frequency (%)	EDHS 2011 (N=16,702) Frequency (%)	EDHS 2016 (N= 16,650) Frequency (%)	EDHS 2019 (N= 8,663) Frequency (%)
Sex of HHH				
Male	10,243(74.65)	11,906(71.28)	11,413(68.55)	6,291(72.62)
Female	3,478(25.35)	4,796 (28.72)	5,237(31.45)	2,372(27.38)
Age of HHH				
<30	3,428(24.98)	4,823(28.88)	4,257(25.57)	2,520(29.09)
30-40	3,501(25.52)	4,116(24.64)	4,132(24.82)	2,287(26.40)
41-54	3,756(27.37)	4,047(24.23)	4,230(25.41)	1,717(19.82)
>54	3,036(22.13)	3,716(22.25)	4,031(24.21)	2,139(24.69)
Educational status of HHH				
No education	8,725(63.59)	9,309(55.74)	8,668(52.06)	4,128(47.65)

Primary	2,705(19.71)	5,020(30.06)	4,658(27.98)	2,715(31.34)
Second	1,754(12.78)	1,189(7.12)	1,686(10.12)	963(11.12)
Higher	495(3.61)	1,140(6.83)	1,580(9.49)	857(9.89)
Wealth index				
Poor	5,393(39.30)	6,506(38.95)	7,024(42.19)	3,498(40.38)
Middle	2,055(14.98)	2,364(14.15)	2,057(12.35)	1,285(14.83)
Rich	6,273(45.72)	7,832(46.89)	7,569(45.46)	3,880(44.79)
Share toilet with other households				
Yes	2,712(45.72)	4,467(46.12)	4,727(43.83)	2,222 (38.18)
No	3,204(54.01)	5,204(53.73)	6,059(56.17)	3,598(61.82)
Having radio				
No	8,157(59.45)	9,658(57.83)	11,680(70.15)	6,170 (71.22)
Yes	5,560(40.52)	7,040(42.15)	4,970(29.85)	2,493(28.78)
Having Television				
No	12,116(88.30)	13,643(81.68)	12,818(76.98)	6,679 (77.10)
Yes	1,601(11.67)	3,051(18.27)	3,832(23.02)	1,984(22.90)
Community-level media exposure				
Unexposed	8,105(59.07)	8,973(53.72)	10,024(60.20)	5,195(59.97)
Exposed	5,616(40.93)	7,729(46.28)	6,626(39.80)	3,468(40.03)
Community-level educational status				
Lower	8,730(63.63)	9,309(55.74)	8,726(52.41)	4,308(49.73)
Higher	4,991(36.37)	7,393(44.26)	7,924(47.59)	4,355(50.27)
Residence				
Urban	3,666(26.72)	5,112(30.61)	5,232(31.42)	2,645(30.53)
Rural	10,055(73.28)	11,590(69.39)	11,418(68.58)	6,018(69.47)
Region				
Tigray	1,282(9.34)	1,730(10.36)	1,734(10.41)	714(8.24
Afar	806(5.87)	1,267(7.59)	1,220(7.33)	664 (7.66)
Amhara	2,066(15.06)	2,071(12.40)	1,902(11.42)	1,007(11.62)
Oromia	2,155(15.71)	2,165(12.96)	1,988(11.94)	1,018(11.75)
Somali	796(5.80)	975(5.84)	1,564(9.39)	657(7.58)
Benishangul-Gumuz	869(6.33)	1,323(7.92)	1,280(7.69)	734(8.47)
SNNPR	1,933(14.09)	2,045(12.24)	1,897(11.39)	1,017(11.74)
Gambella	820(5.98)	1,215(7.27)	1,280(7.69)	693(8.00)
Harari	904(6.59)	1,201(7.19)	1,135(6.82)	719(8.30)
Addis Ababa	1,333(9.72)	1,524(9.12)	1,489(8.94)	702(8.10)
Dire Dawa	757(5.52)	1,186(7.10)	1,161(6.97)	738(8.52)

Key: EDHS= Ethiopian demographic health survey, HHH=Household head, SNNPR= South nation Nationalities Republic

192 **Trends of Sanitation facilities in Ethiopia**

193 Figure 1 below presented that the trend of improved sanitation facilities in Ethiopia was 20.46%,
194 25.61%, 25.86%, and 27.45% based on EDHS 2005, 2011, 2016, and 2019, respectively (figure
195 1).

196 **Factors Associated with Sanitation Facilities Accessibility**

197 The odds of accessibility to improved sanitation facilities among participants with educational
198 status of primary, secondary, and higher were 2.43 (AOR = 2.43, 95% CI :(2.00, 2.95)), 2.02
199 (AOR = 2.02, 95% CI :(1.61, 2.54)), and 4.12 (AOR = 4.12, 95% CI :(3.35, 7.54) times more
200 likely respectively, compared to those with no education.

201 Study participants with wealth status of the middle, and rich were 1.49 (AOR = 1.49, 95% CI :(
202 1.21, 1.83)), and 3.15 (AOR = 3.15, 95% CI :(2.55, 3.89)) times more likely in the odds of
203 accessing improved sanitation facilities respectively, compared to those counterparts poor.

204 The odds of accessing improved sanitation facilities among study participants watched television
205 were 5.49 (AOR= 5.49, 95% CI: (4.37, 6.89)) more likely compared to counterparts who did no
206 watching television.

207 Community-level education was a statistically significant predictor variable. The odds of accessing
208 improved sanitation facilities among Communities with higher educational levels were 3.90
209 (AOR= 3.90, 95% CI: (3.15, 4.82) times more likely compared to the community with lower
210 education.

211 The chance of accessing improved sanitation facilities among communities exposed to media was
212 5.61 (AOR= 5.61, 95% CI: (3.84, 10.09)) times more likely than in the community unexposed to
213 the media.

214 The odds of accessibility-improved sanitation facilities among the study population living in urban
215 areas were 9.08 (AOR= 9.08, 95% CI: (6.69, 12.33) times more likely compared to the o study
216 population living in rural areas.

217 Communities across various regions, including Tigray (54% less likely, AOR=0.46; 95% CI: 0.37,
218 0.57), Afar (33% less likely, AOR=0.67; 95% CI: 0.51, 0.86), Somali (77% less likely, AOR=0.23;
219 95% CI: 0.18, 0.29), Amhara (60% less likely, AOR=0.40; 95% CI: 0.32, 0.49), Benishangul

Gumuz (37% less likely, AOR=0.63; 95% CI: 0.49, 0.80), Gambella (55% less likely, AOR=0.45; 95% CI: 0.35, 0.57), Harari (36% less likely, AOR=0.64; 95% CI: 0.52, 0.80), SNNRP (72% less likely, AOR=0.28; 95% CI: 0.22, 0.34), and Dire Dawa (72% less likely, AOR=0.28; 95% CI: 0.22, 0.35), exhibit decreased access to improved sanitation facilities compared to communities in Addis Ababa.

The random variations of sanitation were demonstrated by intra-cluster correlation coefficient (ICC), Proportion Change in Variance (PCV), and median odds ratio (MOR). The ICC in the null model showed that 67.65% of the total variability in accessing improved sanitation facilities was due to differences through cluster areas. Model 1 and Model 2 presented that 59.74% and 26.35% of the Proportion Change in Variance (PCV) of the variation in accessing improved sanitation in the communities was explained by individual and community-level factors, respectively. The MOR between the area at highest in accessing improved sanitation facilities and the area at lowest in accessing improved sanitation facilities if randomly picking out two areas was 7.07.

The goodness fit in model statistics indicated using the lowest values of AIC, DIC, and Deviance. Therefore, the final model had the lowest AIC, DIC, and Deviance, 11151.08, 11282.33, and 11,117.0824, respectively which confirmed the best-fit model (Table 2 and Table 3)

Table 2. Multilevel binary logistic regression analysis of predictors towards accessibility of sanitation facilities in Ethiopia, EDHS 2011

Variables	Model 0 (Null model)	Model 1 AOR (95% CI)	Model 2 AOR (95% CI)	Model 3 AOR (95% CI)
Individual level Factors				
Sex of HHH				
Male		0.97(0.82,1.04)		1.01(0.84,1.11)
Female		1	1	1
Age of HHH				
<30		0.97(0.94,1.01)		0.96 (0.20,2.34)
30-40		0.57(0.35,2.02)		1.49(0.13,2.41)
41-54		0.43(0.22,0.61)		1.17(0.86,1.59)
>54		1	1	1
Educational status				
No education		1		1
Primary		3.23 (2.63,3.96)**		2.43(2.00,2.95)**
Secondary		6.36(5.26,7.67)**		2.02(1.61,2.54)**

Higher		8.11 (7.16,9.19)*		4.12(3.35,7.54)**
Wealth index				
Poor		1		1
Middle		2.96 (2.34,4.24)**		1.49 (1.21,1.83)**
Rich		5.48 (3.45,5.89)**		3.15(2.55,3.89)**
Having television				
No		1		1
Yes		4.81(4.16,5.56)**		5.49(4.37,6.89)**
Community level factors				
Community level education				
Higher			6.50(5.82,7.27)**	3.90(3.15,4.82)**
Lower			1	1
Community-level media exposure				
Exposed			6.07(5.42,6.81)**	5.61(3.84,10.09)**
Unexposed			1	1
Type of residence				
Urban			16.74(11.85, 23.65)**	9.08(6.69,12.33)**
Rural			1	1
Region				
Tigray			0.50(0.41,0.62)**	0.46(0.37,0.57)**
Afar			0.86(0.67,1.09)	0.67(0.51,0.86)*
Amhara			0.43(0.35,0.53)**	0.40(0.32,0.49)**
Oromia			0.89 (0.72,1.09)	0.90(0.73,1.12)
SNNRP			0.25(0.20,0.31)*	0.28(0.22,0.34)**
Somali			0.33(0.26,0.41)**	0.23(0.18,0.29)**
Benishangul Gumuz			0.74(0.59,0.94)*	0.63(0.49,0.80)**
Gambella			0.51(0.41,0.64)**	0.45(0.35,0.57)**
Harari				0.64(0.52.0.80)**
Addis Ababa			1	1
Dire Dawa			0.25(0.21,0.31)**	0.28(0.22,0.35)**
VIF		2.35	2.27	2.05

1= reference, **P-value < 0.001(Adjusted OR), *P-value < 0.05(Adjusted OR), AIC=Akaike's information criteria, BIC=Bayesian information criteria, HHH =household head, HH=household, Model 0 (Null model) was fitted without predictor variables. ; Model 1 is adjusted for individual-level variables. Model 2 is adjusted for community-level variables; Model 3 is the final model adjusted for both individual- and community-level predictors.

Table 3: Measures variation metrics and the model fitness test statistics used for included models

Metrics	**Model 0 (Null model)**	**Model 1**	**Variables**	**Model 0 (Null model)**
Variance	6.88(5.84,8.10)	2.77(2.30,3.32)	2.04(1.71,2.44)	1.97(1.65,2.35)
MOR	7.07	4.35	3.82	3.78
PCV	Reference	59.74%	26.35%	3.43 %
ICC	0.6765	0.4571	0.3827	0.3745
Model fitness test statistics				
AIC	12204.07	11338.86	11610.79	11151.08
BIC	12219.51	11454.67	11734.32	11282.33
Deviance	12,200.0736	11,323.6174	11611.497	11,117.0824

Analysis of spatial heterogeneity

Spatial autocorrelation (Moran's I)

Global Moran's I spatial autocorrelations positive z-scores (with the z-scores of 2005 EDHS 2.374393,2011 EDHS 7.067996, 2016 EDHS 8.9374285, and 2019 EDHS 36.511348) indicated that all EDHS were clustered in accessing improved sanitation facilities through Ethiopia (Figure 2).

Hot and cold spot analysis (Getis-Ord Gi*)

Hot and cold spot analysis revealed that there was the same trend in spatial distribution of improved sanitation facilities through Ethiopia in all EDHS. The figures below show that in all EDHS the percentage of accessing improved sanitation was significantly lower in most parts of the country while this proportion was better only in Addis Ababa, and Dire Dawa (Figure 3).

Spatial interpolation

For the identification part of the country which regions experienced lower improved sanitation accessibility, the spatial Kriging interpolation analysis was done. The figures below showed that the red color represents part of the country (Addis Ababa and Dire Dawa) with higher in accessing improved sanitation facilities and on the other hand, the green color (major part of the country) indicated that regions with lower in accessing improved sanitation facilities (figure 4).

Discussion

The uniqueness of the analyses lies in the comprehensive examination of temporal trends and geographic variations in sanitation facilities using multilevel and spatial analysis techniques applied to Ethiopia's 2005-2019 EDHS datasets. The novel contribution stems from their in-depth exploration of how access to sanitation infrastructure has evolved over time and varied across different regions of Ethiopia, shedding light on previously unexplored patterns and disparities. This research provides valuable insights into the dynamic nature of sanitation provision and identifies areas for targeted interventions to address disparities and improve overall sanitation access in Ethiopia.

Sustainable and equitable accessibility of improved sanitation facilities is used to hygienically separate human excreta from human contact which leads to many communicable diseases [42]. The main aim of this study was to investigate the spatiotemporal variation and factors associated with improved sanitation facilities accessibly in Ethiopia based on four consecutive EDHS datasets. These results showed that EDHS 2005, EDHS 2011, EDHS 2016, and EDHS 2019 the proportions of the households with access to improved sanitation facilities were 20.46%, 25.61%, 25.86%, and 27.45%, respectively. There was an increment of 5.15% from 2005 to 2011 but the increase from 2011 to 2016 was only by 0.25%. Based on these findings, very slow increments have been experienced over time in the improvement of access to improved sanitation facilities in Ethiopia from 2005 to 2019. This result is comparable with previous studies, which indicated that some countries have shown high progress toward SDG 6, while others look to be stuck at low levels of sanitation coverage with little or no development [43]. Such setback with little or no development levels of access to improved sanitation facilities is the experience of developing countries including Ethiopia [44]. The possible explanation for this problem could be due to global environmental change, paying less attention due to poverty, instability of the country related with civil war trauma, which lead less attention, by government and non-governmental organization for sanitation facilities development. This finding consistent with other previous studies done in different parts of the world [33, 45-49].

Results of Global Moran's autocorrelation, hotspot, cluster, and Kriging in the spatial analysis showed that there were great disparities in accessing improved sanitation facilities in Ethiopia based on four EDHS datasets. Based on the results of hot spot, and Kriging analysis in all EDHS Addis Ababa and dire Dawa were a high hot spot of improved sanitation facilities among other parts of the country. This finding put forward that there are significant geographical disparities in access to improved sanitation facilities throughout the country. Which contradicted persistently sustainable development goal 2030 agenda target 6.2 “access to adequate and equitable sanitation for all and end open defecation”[50]. This variation could be the difference in economic growth, overpopulation growth, unplanned urbanization, and inaccessibility of infrastructure, government overload towards other burning daily tasks, socio-political instability, awareness, and adaptability towards sanitation facilities.

Factors associated with access to improved sanitation facilities were the educational status of the household head, having television, and wealth index, in individual-level predictors whereas community-level education, community-level media exposure, type of residence, and region were community-level predictor variables.

In households with a higher educational status, the household head had a greater chance of accessing improved sanitation facilities compared to households with heads who had no education. This finding is supported by the studies done in Ethiopia, Kenya, West and Central Africa, Bangladesh, Benin, and Vietnam [51-54]. The community with higher education accessed improved sanitation facilities than part of the community with lower education. This finding was in line with other previous studies conducted in different parts of the world [23, 55, 56]. The reason for this variation could be that educated individuals might understand the association between health and improved sanitation facilities. If so, they are enthusiastic to have these sanitation facilities compared to household heads with lower educational status.

There was a proportional relationship between the levels of wealth status and access to improved sanitation facilities. Rich and middle households in wealth status were more likely to have access to improved sanitation facilities compared to the poorest households. This finding is supported by the studies done in Ghana, Benin, Vietnam, and Eswatini [52, 57-59]. This difference could be due to the installation of improved sanitation facilities such as septic tanks, pour flush toilet facilities; pit latrines with a slab, and composting toilet facilities might be difficult for the poor to afford them.

Holding other variables constant, households that had television were more likely in accessing improved sanitation facilities compared to households with no television. This might probably be because inhabitants spent their time watching television, which acts as an information source visually, including the role of improved sanitation in reducing disease transmission. Community-level media exposure was the other community-level factor statistically significant predictor associated with access to improved sanitation facilities. Household members exposed to community-level media (television, radio, or one of the two) had more chances of accessing improved sanitation in Ethiopia. This finding was in line with previous studies conducted in Ethiopia [22, 23], and sub-Saharan Africa [60].

Households found in the urban area more likely to access improved sanitation facilities than those found in the rural area. This issue was Supported by a previous study done in Ethiopia which indicated that rural areas of Ethiopia are extremely lagging late in the race toward realizing SDG 6.2 [43] and the other study done in Vietnam [57]. Households found in different regions of Ethiopia were accessed different proportions of improved sanitation facilities. The capital city Addis Ababa was better than the regions of the country. This finding is aligns with the studies done in Kenya [61], Nepal [62] and WHO, UNICEF, 2019 report [63] which indicated that persist disparities in access to WASH services in rural versus urban settings. The possible explanation, for this difference might be due to Addis Ababa being the capital city of the country and it is the headquarter of the Africa Union more infrastructure including improved sanitation facilities could be fulfilled. In addition, it could be due to low economic status, socio-political instability among regions, lack of awareness, lower adaptability towards sanitation facilities.[64].

The self-report nature of data collection which leads to interviewer bias, social acceptability bias, recall bias and incompleteness of the recent mini demographic health survey (EDHS 2019) could be potential sources of errors and the limitations of this study.

Conclusion

The overall finding of this study concludes that there was a very slow increment of accessibility of sanitation facilities over time in Ethiopia. As well as, there was statistically significant geographical heterogeneity in accessibility of improved sanitation facilities in the country. The rate of current progress in universal access to sanitation facilities (SDG 6.2) in 2030 should be accelerated to reach the proposed plan. Educational status, watching television, wealth index, community-level education, community-level media exposure, type of residence, and region were factors statistically associated with sanitation facilities accessibility in Ethiopia. This finding suggested for international and local organizations work on solutions that enable the progress in sanitation facilities accessibility for all, especially in developing countries.

Strengths and Limitations of this study

The first strength is using multi EDHS data, which enable to show trend analysis of sanitation status in Ethiopia.

The second strength is using data from multiple Demographic and Health Surveys ensures a large, nationally representative sample, which increases the generalizability of findings across Ethiopia.

The third strength, DHS surveys provide detailed information on the types of sanitation facilities, from basic to improved, which allows for a significance understanding of the sanitation countryside in Ethiopia.

The first limitation, there could be social desirable bias since the data were collected through face-to-face interview.

The second limitation, while the quantitative analysis identifies trends and spatial disparities, it may not provide insights into the behavioral, and cultural level factors influencing sanitation adoption and usage.

Abbreviations

AIC: Akaike's Information Criterion, AOR: Adjusted Odds Ratio, CI: Confidence Interval, DHS: Demographic and Health Survey, EAs: Enumeration Areas, EDHS: Ethiopian Demographic and Health Survey, ICC: Intra Class Correlation, MOR: Median Odd Ratio, PCV: Proportional Change in Variance

Declarations

Ethics approval and consent to participate

This study was based on secondary data from the Ethiopian Demographic and Health Survey and secured the permission letter from the main Demographic Health and Survey. Permission for data access was obtained from a major Demographic and Health Survey through an online request at (https://www.dhsprogram.com/data/dataset_admin/login_main.cfm.). Participant consent was not directly obtained since authors used secondary data.

378 **Patient and Public Involvement**

379 Not applicable.

380 **Consent for publication**

381 Not applicable.

382 **Availability of data and materials**

383 This research was done using a publicly available dataset found at
384 https://www.dhsprogram.com/data/dataset_admin/login_main.cfm after approval from Data
385 Archivist of the Demographic and Health Surveys (DHS) Program.

386 **Competing interests**

387 There is no any competing interest.

388 **Funding**

389 The authors have not received any specific grant for this research from public, commercial, or not-
390 for-profit funding agencies

391 **Authors' contributions**

392 JA Engaged in data curation**.** JA Conducted the statistical analysis. JA**,** MT, and WM involved in
393 investigation of the study. JA and WM had full access to all the data in the study and take
394 responsibility for the integrity of the data and the accuracy of the data analysis. JA, MT, and WM
395 done validation and visualization. JA and WM conducted the write-up and drafted the manuscript.
396 All authors involved in review & editing. JA is responsible for the overall content as guarantors.

397 **Acknowledgments**

398 The author acknowledges the Ethiopian Central Statistical Agency for providing them with the
399 data and shape files for this study.

400 **References**

401 1. Organization, W.H., World health statistics overview 2019: monitoring health for the SDGs,
402 sustainable development goals. 2019, World Health Organization.
403 2. Erridge, M., Human Right to Sanitation. Clean Water and Sanitation, 2020: p. 1-11.
404 3. Water, U., Sustainable Development Goal 6 Synthesis Report on Water and Sanitation. United
405 Nations. 2018.

4. Carvalho, D.M., Tripartite organizational partnerships and the wickedness of the water and sanitation sector in Brazil: an institutional analysis. 2019.
5. Kumwenda, S., Challenges to hygiene improvement in developing countries. Vol. 1. 2019: IntechOpen London, UK.
6. Peter, A.K. and U. Umar, Combating diarrhoea in Nigeria: the way forward. J Microbiol Exp, 2018. **6**(4): p. 191-197.
7. Oates, N., et al., Adaptation to climate change in water, sanitation and hygiene. London: Overseas Development Institute.[Google Scholar], 2014.
8. Clemenz, N., R. Boakye, and A. Parker, Rapid Climate Adaption Assessment (RCAA) of water supply and sanitation services in two coastal urban poor communities in Accra, Ghana. Journal of Water and Climate Change, 2020. **11**(4): p. 1645-1660.
9. Hyde-Smith, L., et al., Climate change impacts on urban sanitation: a systematic review and failure mode analysis. Environmental science & technology, 2022. **56**(9): p. 5306-5321.
10. Morgan, C., et al., Water, sanitation, and hygiene in schools: Status and implications of low coverage in Ethiopia, Kenya, Mozambique, Rwanda, Uganda, and Zambia. International journal of hygiene and environmental health, 2017. **220**(6): p. 950-959.
11. Dickin, S., et al., Sustainable sanitation and gaps in global climate policy and financing. NPJ Clean Water, 2020. **3**(1): p. 24.
12. Obani, P., SDG 6.2 and the right to sanitation: exploring the complementarities and incoherence. UNIPORT Journal of International and Comparative Law 1, 2020: p. 1-17.
13. Mattos, K.J., et al., Household water, sanitation, and hygiene practices impact pathogen exposure in remote, rural, unpiped communities. Environmental Engineering Science, 2021. **38**(5): p. 355-366.
14. Corburn, J., Water and sanitation for all: Citizen science, health equity, and urban climate justice. Environment and Planning B: Urban Analytics and City Science, 2022. **49**(8): p. 2044-2053.
15. Tykhomyrova, T., V. Sebko, and V. Babenko, Sustainable development. 2022.
16. Hutton, G. and M. Varughese, The costs of meeting the 2030 sustainable development goal targets on drinking water, sanitation, and hygiene. 2016.
17. Organization, W.H., Progress on household drinking water, sanitation and hygiene 2000-2020: five years into the SDGs. 2021.
18. Walsh, P.P., E. Murphy, and D. Horan, The role of science, technology and innovation in the UN 2030 agenda. Technological Forecasting and Social Change, 2020. **154**: p. 119957.
19. Campos Nonato, I., Mapping geographical inequalities in access to drinking water and sanitation facilities in low-income and middle-income countries, 2000–17. 2020.

20. Prüss-Ustün, A., et al., Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: an updated analysis with a focus on low-and middle-income countries. International journal of hygiene and environmental health, 2019. **222**(5): p. 765-777.
21. Baye, D., Sustainable development goals (SDG) target 6.2 in Ethiopia: challenges and opportunities. Open Access Library Journal, 2021. **8**(5): p. 1-28.
22. Demsash, A.W., et al., Spatial and multilevel analysis of sanitation service access and related factors among households in Ethiopia: using 2019 Ethiopian national dataset. PLOS Global Public Health, 2023. **3**(4): p. e0001752.
23. Azanaw, J., et al., A multilevel analysis of improved drinking water sources and sanitation facilities in Ethiopia: Using 2019 Ethiopia mini demographic and health survey. Frontiers in Public Health, 2023. **11**.
24. Gebremichael, S.G., et al., Determinants of water source use, quality of water, sanitation and hygiene perceptions among urban households in North-West Ethiopia: A cross-sectional study. Plos one, 2021. **16**(4): p. e0239502.
25. Adil, S., M. Nadeem, and I. Malik, Exploring the important determinants of access to safe drinking water and improved sanitation in Punjab, Pakistan. Water Policy, 2021. **23**(4): p. 970-984.
26. Dwivedi, R., K. Sreenivas, and K. Ramana, Cover: Land-use/land-cover change analysis in part of Ethiopia using Landsat Thematic Mapper data. International Journal of Remote Sensing, 2005. **26**(7): p. 1285-1287.
27. Anteneh, Z.A. and J.-P. Van Geertruyden, Spatial variations and determinants of anemia among under-five children in Ethiopia, EDHS 2005–2016. Plos one, 2021. **16**(4): p. e0249412.
28. Central Statistical Agency Addis Ababa, E., Ethiopia Demographic and Health Survey 2005. 2005.
29. Central Statistical Agency Addis Ababa, E.I.I.C., Maryland, USA, Ethiopia Demographic and Health Survey. 2011.
30. Central Statistical Agency Addis Ababa, E., ETHIOPIA Demographic and Health Survey. 2016.
31. Ethiopian Public Health Institute Addis Ababa Federal Ministry of Health Addis Ababa The DHS Program ICF Rockville, M., USA, ETHIOPIA Mini Demographic and Health Survey 2019.
32. Armah, F.A., et al., Access to improved water and sanitation in sub-Saharan Africa in a quarter century. Heliyon, 2018. **4**(11): p. e00931.
33. Wang, C., et al., Geographic inequalities in accessing improved water and sanitation facilities in Nepal. International journal of environmental research and public health, 2019. **16**(7): p. 1269.
34. Davis, J., et al., Improving access to water supply and sanitation in urban India: microfinance for water and sanitation infrastructure development. Water Science and Technology, 2008. **58**(4): p. 887-891.

35. Sun, G.-W., T.L. Shook, and G.L. Kay, Inappropriate use of bivariable analysis to screen risk factors for use in multivariable analysis. Journal of clinical epidemiology, 1996. **49**(8): p. 907-916.

36. Goicolea, I. and M. San Sebastian, Unintended pregnancy in the amazon basin of Ecuador: a multilevel analysis. International journal for equity in health, 2010. **9**: p. 1-11.

37. Schootman, M., et al., Geographic clustering of adequate diagnostic follow-up after abnormal screening results for breast cancer among low-income women in Missouri. Annals of epidemiology, 2007. **17**(9): p. 704-712.

38. Li, F., et al., Model selection methods for mixture dichotomous IRT models. Applied Psychological Measurement, 2009. **33**(5): p. 353-373.

39. Roll, U., et al., Onset of a pandemic: characterizing the initial phase of the swine flu (H1N1) epidemic in Israel. BMC infectious diseases, 2011. **11**(1): p. 1-13.

40. Blake, S.B., Exploring Spatial Relationships Among Dairy Farms, Drinking Water Quality, and Maternal-Child Health Outcomes in the San Joaquin Valley. 2014: University of California, Davis.

41. Sánchez-Martín, J.-M., J.-I. Rengifo-Gallego, and R. Blas-Morato, Hot spot analysis versus cluster and outlier analysis: An enquiry into the grouping of rural accommodation in Extremadura (Spain). ISPRS International Journal of Geo-Information, 2019. **8**(4): p. 176.

42. Ritchie, H. and M. Roser, Clean water and sanitation. Our world in data, 2021.

43. Bankole, A.O., et al., Factors affecting sanitation coverage in three income levels and potential toward achieving SDG 6.2. Water Policy, 2023. **25**(2): p. 146-176.

44. Organization, W.H., National systems to support drinking-water: sanitation and hygiene: global status report 2019: UN-Water global analysis and assessment of sanitation and drinking-water: GLAAS 2019 report. 2019.

45. Azage, M., A. Motbainor, and D. Nigatu, Exploring geographical variations and inequalities in access to improved water and sanitation in Ethiopia: mapping and spatial analysis. Heliyon, 2020. **6**(4).

46. Pullan, R.L., et al., Geographical inequalities in use of improved drinking water supply and sanitation across sub-Saharan Africa: mapping and spatial analysis of cross-sectional survey data. PLoS medicine, 2014. **11**(4): p. e1001626.

47. Armah, F.A., et al., Access to improved water and sanitation in sub-Saharan Africa in a quarter century. Heliyon, 2018. **4**(11).

48. Yu, W., et al., A global perspective on drinking-water and sanitation classification: an evaluation of census content. PLoS One, 2016. **11**(3): p. e0151645.

49. Ghosh, P., M. Hossain, and A. Alam, Water, sanitation, and hygiene (WASH) poverty in India: a district-level geospatial assessment. Regional Science Policy & Practice, 2022. **14**(2): p. 396-417.

50. Hueso, A., Is ‘access to adequate and equitable sanitation’ for all by 2030 achievable? Perspectives from sector experts on what needs to change to realise the Sustainable Development Goal. Journal of Water, Sanitation and Hygiene for Development, 2016. **6**(4): p. 650-657.

51. Koskei, E.C., et al., Effect of socio-economic factors on access to improved water sources and basic sanitation in Bomet Municipality, Kenya. Research Journal of Environmental and Earth Sciences, 2013. **5**(12): p. 714-719.

52. Gaffan, N., et al., Household access to basic drinking water, sanitation and hygiene facilities: secondary analysis of data from the demographic and health survey V, 2017–2018. BMC Public Health, 2022. **22**(1): p. 1-16.

53. Andualem, Z., et al., Households access to improved drinking water sources and toilet facilities in Ethiopia: a multilevel analysis based on 2016 Ethiopian Demographic and Health Survey. BMJ open, 2021. **11**(3): p. e042071.

54. Simen-Kapeu, A., et al., Prevalence of diarrhoea, acute respiratory infections, and malaria over time (1995-2017): A regional analysis of 23 countries in West and Central Africa. Journal of global Health, 2021. **11**.

55. Agbadi, P., E. Darkwah, and P.L. Kenney, A multilevel analysis of regressors of access to improved drinking water and sanitation facilities in Ghana. Journal of environmental and public health, 2019. **2019**.

56. Kong, Y.-L., et al., Socio-economic factors related to drinking water source and sanitation in Malaysia. International Journal of Environmental Research and Public Health, 2020. **17**(21): p. 7933.

57. Tuyet-Hanh, T.T., et al., Household trends in access to improved water sources and sanitation facilities in Vietnam and associated factors: findings from the Multiple Indicator Cluster Surveys, 2000–2011. Global Health Action, 2016. **9**(1): p. 29434.

58. Simelane, M.S., et al., Determinants of households’ access to improved drinking water sources: a secondary analysis of eswatini 2010 and 2014 multiple indicator cluster surveys. Advances in Public Health, 2020. **2020**: p. 1-9.

59. Akpakli, D.E., et al., Determinants of access to improved sanitation facilities in rural districts of southern Ghana: evidence from Dodowa Health and Demographic Surveillance Site. BMC research notes, 2018. **11**(1): p. 1-7.

60. Seidu, A.-A., et al., A multilevel analysis of individual and contextual factors associated with the practice of safe disposal of children’s faeces in sub-Saharan Africa. Plos one, 2021. **16**(8): p. e0254774.

61. Health, M.o., Kenya environmental sanitation and hygiene strategic framework 2016–2020. 2015.

62. Dhital, S.R., et al., Prevalence and Correlates of Water, Sanitation, and Hygiene (WASH) and Spatial Distribution of Unimproved WASH in Nepal. International journal of environmental research and public health, 2022. **19**(6): p. 3507.

63. Organization, W.H., Progress on household drinking water, sanitation and hygiene 2000-2017: special focus on inequalities. 2019: World Health Organization.

64. Deshpande, A., et al., Mapping geographical inequalities in access to drinking water and sanitation facilities in low-income and middle-income countries, 2000–17. The Lancet Global Health, 2020. **8**(9): p. e1162-e1185.

Figure 1: The proportion of sanitation facilities accessibility in Ethiopia using the four EDHS.

Figure 2A: Global Spatial autocorrelation analysis of accessibility of improved sanitation facilities in Ethiopia, EDHS 2005.

Figure 2B: Global Spatial autocorrelation analysis of accessibility of improved sanitation facilities in Ethiopia, EDHS 2011

Figure 2C: Global Spatial autocorrelation analysis of accessibility of improved sanitation facilities in Ethiopia, EDHS 2016

Figure 2D: Global Spatial autocorrelation analysis of accessibility of improved sanitation facilities in Ethiopia, EDHS 2019

Figure 3A: Hot and cold spot analysis of accessibility of improved sanitation facilities in Ethiopia based on the dataset of EDHS 2005

Figure 3B: Hot and cold spot analysis of accessibility of improved sanitation facilities in Ethiopia based on the dataset of EDHS 2011

Figure 3C: Hot and cold spot analysis of accessibility of improved sanitation facilities in Ethiopia based on the dataset of EDHS 2016

Figure 3D: Hot and cold spot analysis of accessibility of improved sanitation facilities in Ethiopia based on the dataset of EDHS 2019

Figure 4A: Kriging interpolation analysis result of improved sanitation facilities accessibility in Ethiopia based on EDHS 2005

Figure 4B: Kriging interpolation analysis result of improved sanitation facilities accessibility in Ethiopia based on EDHS 2011

Figure 4C: Kriging interpolation analysis result of improved sanitation facilities accessibility in Ethiopia based on EDHS 2016

Figure 4D: Kriging interpolation analysis result of improved sanitation facilities accessibility in Ethiopia based on EDHS 2019

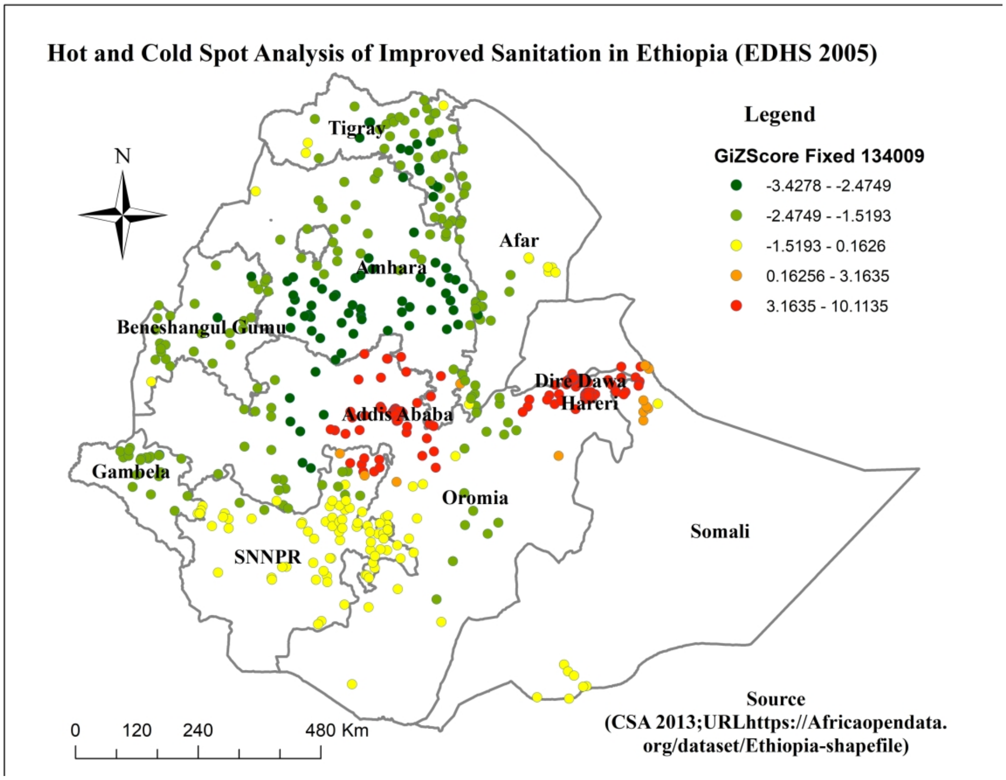


Figure 3A

279x215mm (300 x 300 DPI)

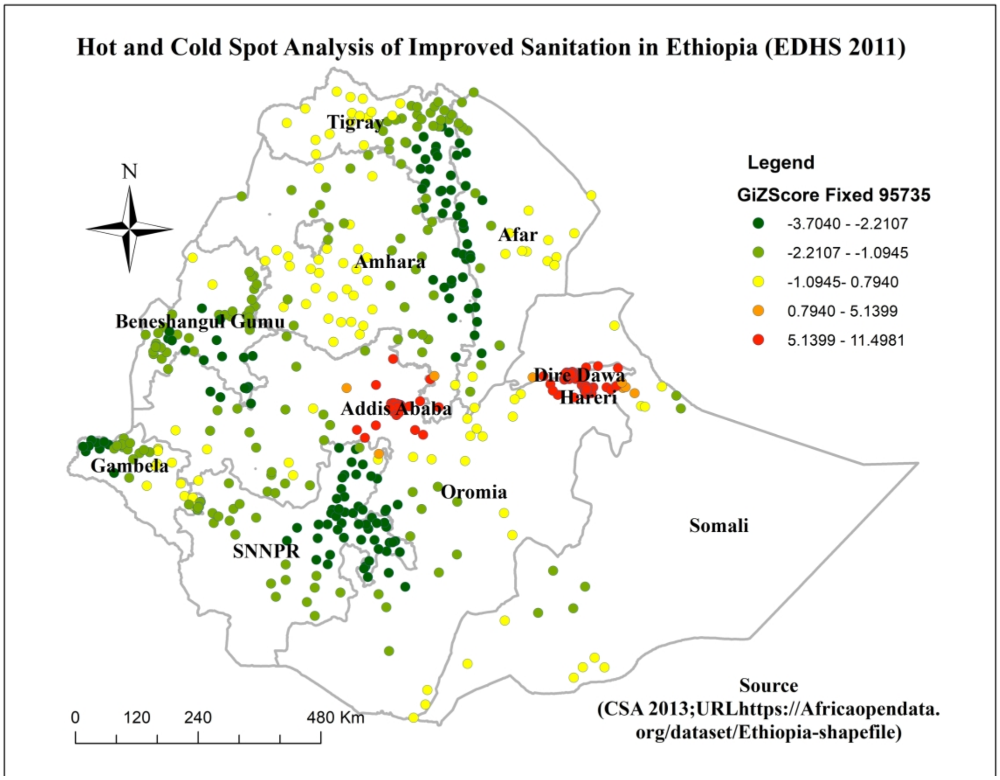


Figure 3B

279x215mm (300 x 300 DPI)

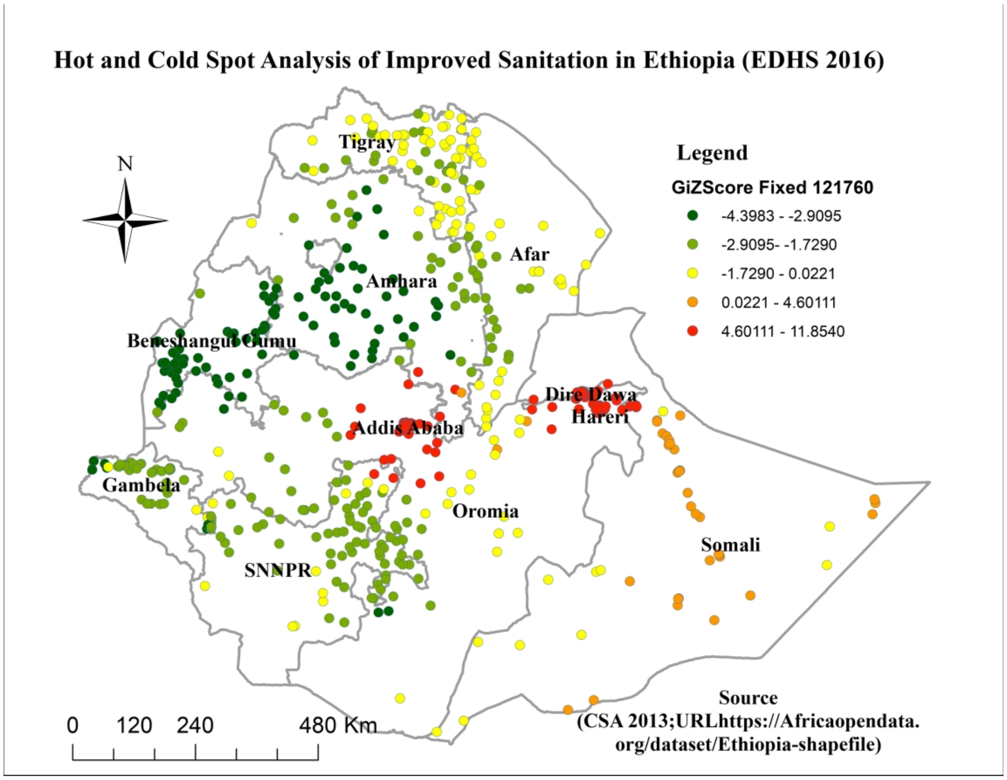


Figure 3C

279x215mm (300 x 300 DPI)

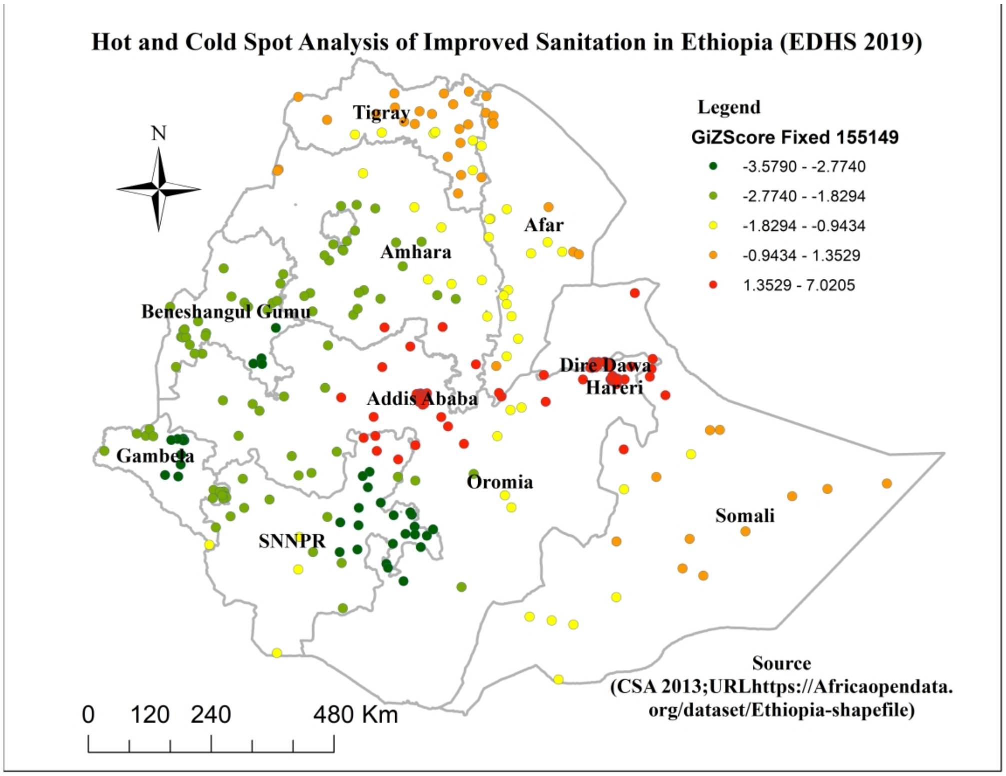


Figure 3D

279x215mm (300 x 300 DPI)

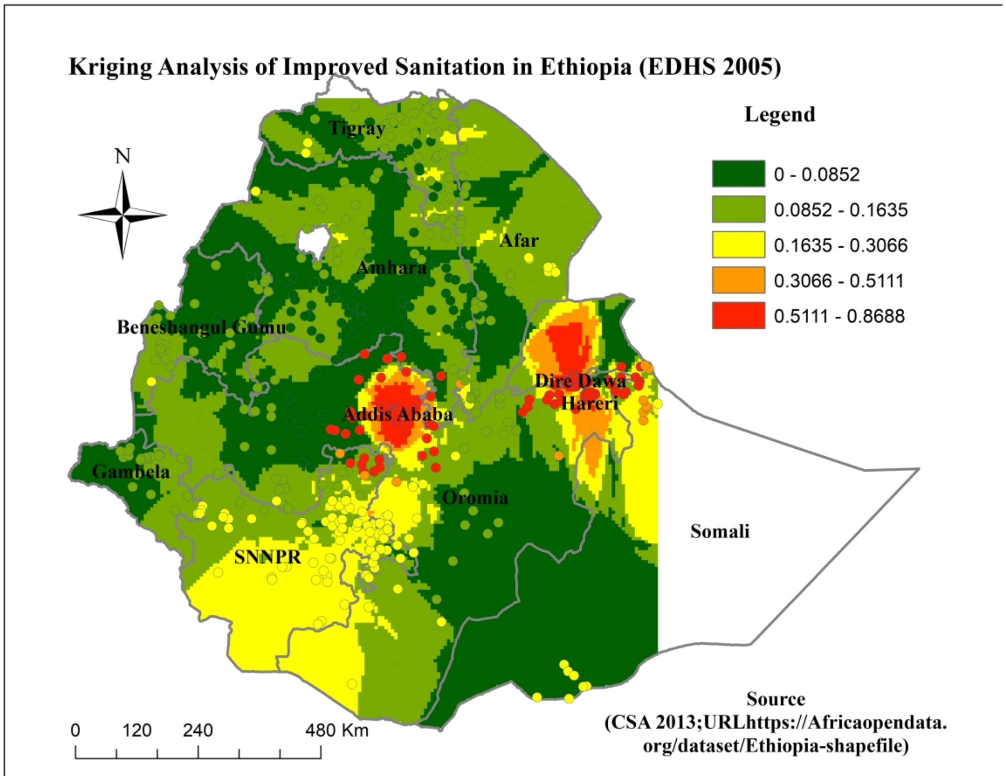


Figure 4A

279x215mm (300 x 300 DPI)

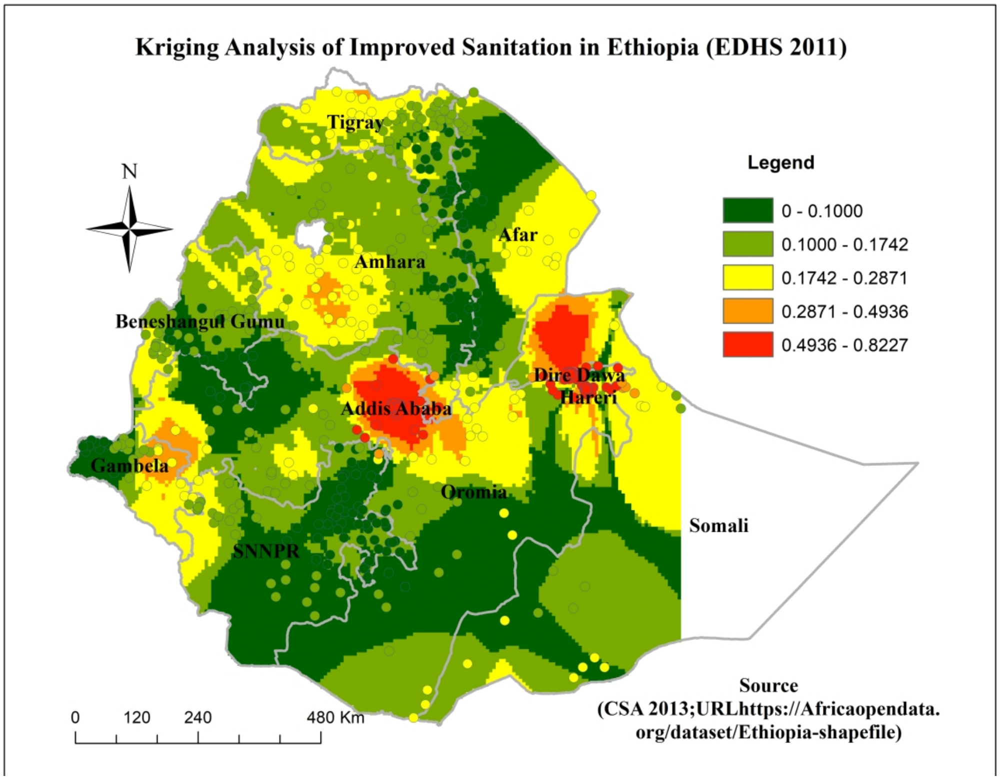


Figure 4B

279x215mm (300 x 300 DPI)

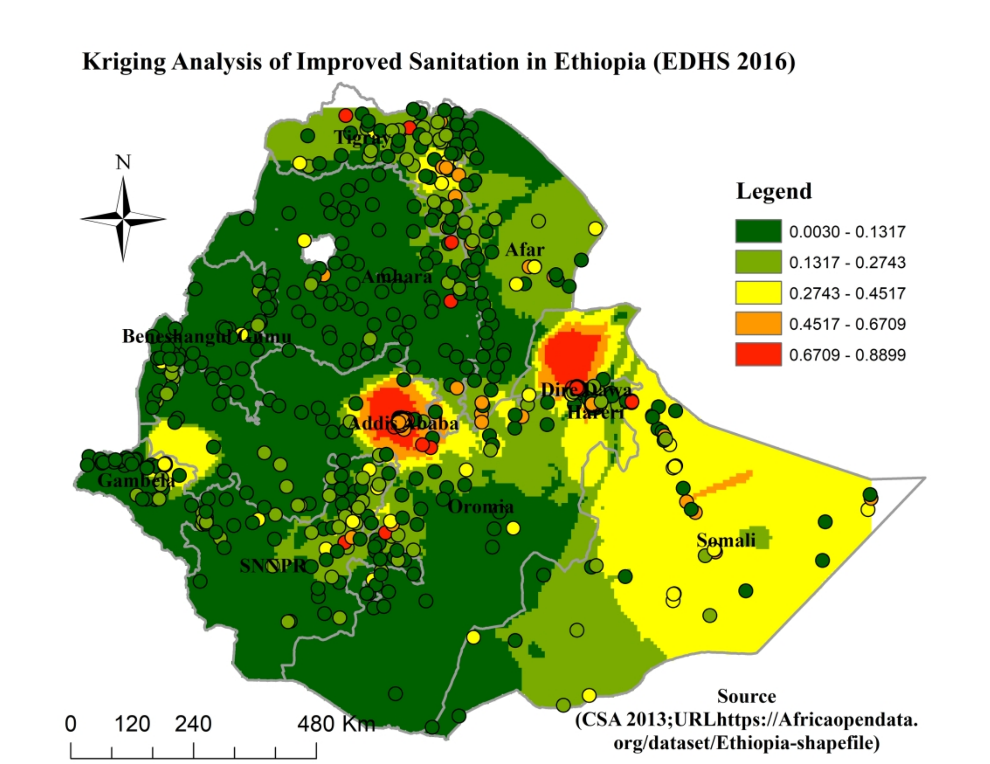


Figure 4C

279x215mm (300 x 300 DPI)

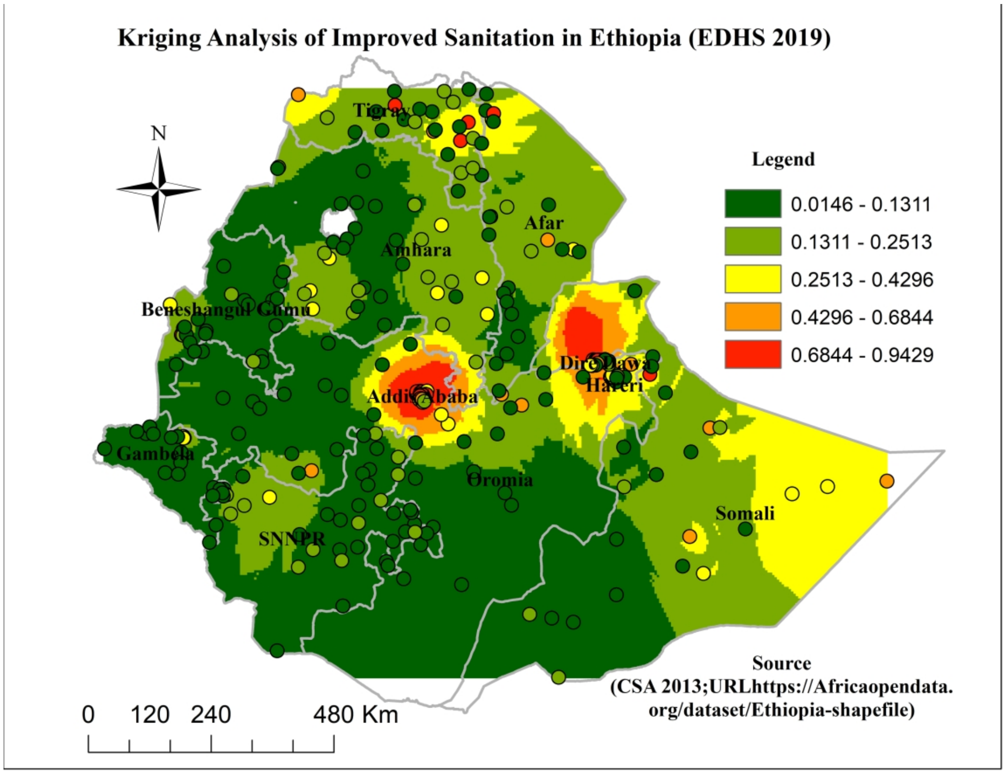


Figure 4D

279x215mm (300 x 300 DPI)

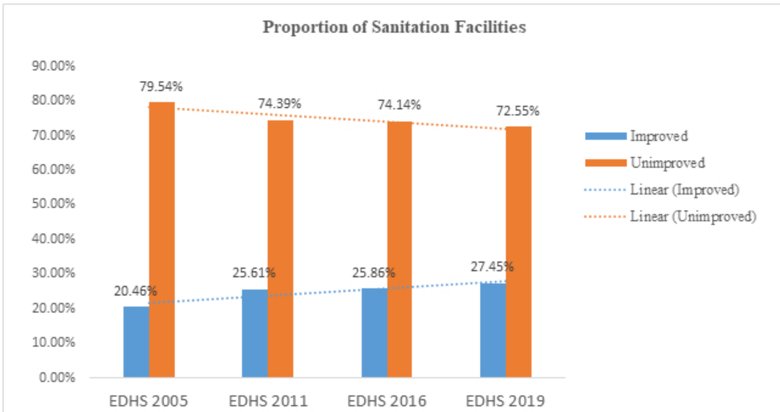


Figure 1

216x121mm (96 x 96 DPI)

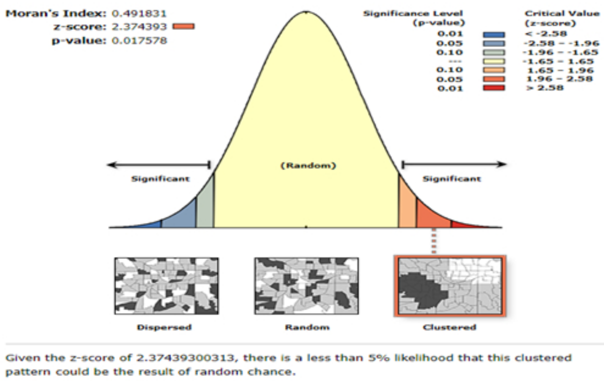


Figure 2A

216x121mm (96 x 96 DPI)

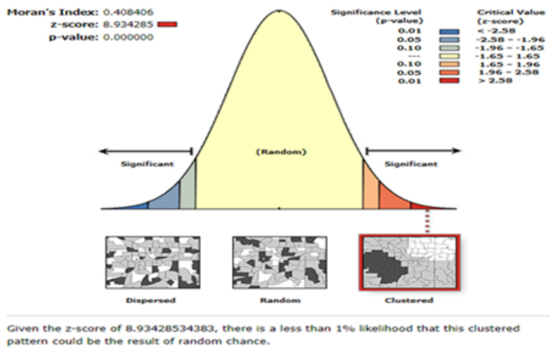


Figure 2B

216x121mm (96 x 96 DPI)

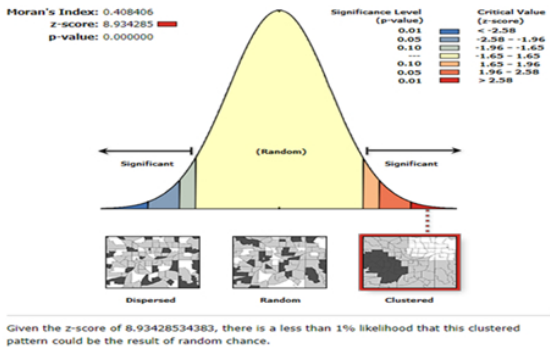


Figure 2C

216x121mm (96 x 96 DPI)

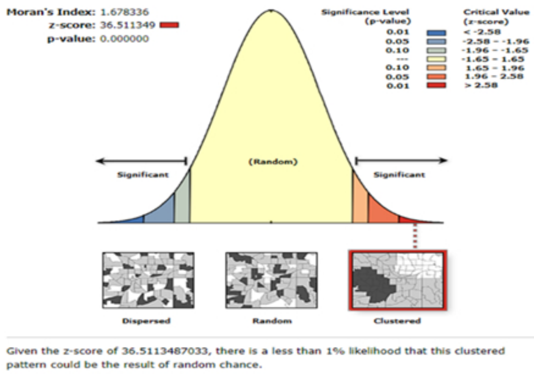


Figure 2D

216x121mm (96 x 96 DPI)

BMJ Open

Temporal trends and spatial heterogeneity of sanitation facilities in Ethiopia: evidence from the 2005-2019 Demographic and Health Surveys

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2024-088211.R2
Article Type:	Original research
Date Submitted by the Author:	22-Oct-2024
Complete List of Authors:	Azanaw, Jember; University of Gondar, Department of Environmental and Occupational Health and Safety, Institute of Public Health, College of Medicine and Health Sciences Tsegaye, Mesenbet; Department of General Surgery College of Medicine and Health Sciences, University of Gondar, Gondar, Ethiopia Mesele, Wodaje; Department of Orthopaedic and Trauma Surgeon,Department of General Surgery College of Medicine and Health Sciences, University of Gondar, Gondar, Ethiopia
Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Public health, Global health
Keywords:	Infectious diseases & infestations < DERMATOLOGY, International health services < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, Public health < INFECTIOUS DISEASES, Climate Change, Health Services, Health Education

I, the Submitting Author has the right to grant and does grant on behalf of all authors of the Work (as defined in the below author licence), an exclusive licence and/or a non-exclusive licence for contributions from authors who are: i) UK Crown employees; ii) where BMJ has agreed a CC-BY licence shall apply, and/or iii) in accordance with the terms applicable for US Federal Government officers or employees acting as part of their official duties; on a worldwide, perpetual, irrevocable, royalty-free basis to BMJ Publishing Group Ltd ("BMJ") its licensees and where the relevant Journal is co-owned by BMJ to the co-owners of the Journal, to publish the Work in this journal and any other BMJ products and to exploit all rights, as set out in our licence.

The Submitting Author accepts and understands that any supply made under these terms is made by BMJ to the Submitting Author unless you are acting as an employee on behalf of your employer or a postgraduate student of an affiliated institution which is paying any applicable article publishing charge ("APC") for Open Access articles. Where the Submitting Author wishes to make the Work available on an Open Access basis (and intends to pay the relevant APC), the terms of reuse of such Open Access shall be governed by a Creative Commons licence – details of these licences and which Creative Commons licence will apply to this Work are set out in our licence referred to above.

Other than as permitted in any relevant BMJ Author's Self Archiving Policies, I confirm this Work has not been accepted for publication elsewhere, is not being considered for publication elsewhere and does not duplicate material already published. I confirm all authors consent to publication of this Work and authorise the granting of this licence.

Temporal trends and spatial heterogeneity of sanitation facilities in Ethiopia: evidence from the 2005-2019 Demographic and Health Surveys

Jember Azanaw[1]*, Mesenbet Tsegaye[2], Wodaje Mesele[3]

[1]Department of Environmental and Occupational Health and Safety, Institute of Public Health, College of Medicine and Health Sciences, University of Gondar, Gondar, Ethiopia

[2]Department of General Surgery, School of Medicine, College of Medicine and Health Sciences, University of Gondar, Gondar, Ethiopia

[3]Department of Orthopaedic and Trauma Surgeon, School of Medicine, College of Medicine and Health Sciences, University of Gondar, Gondar, Ethiopia

***=Corresponding**

jemberazanaw21@gmail.com

Abstract

Background: The main aim of sanitation is to prevent human contact with fecal pathogens to decrease occurrences of diseases. However, no region in the world is on the right track to accomplish Sustainable development goal (SDG) 6.2 for universal access to sanitation. Sub-Sahara Africa, Ethiopia included, is significantly behind in meeting the 2030 SDG 6.2 targets. Hence, this study focused on the spatial and temporal analysis of sanitation in Ethiopia based on four demographic health surveys.

Method: This research was undertaken among households in Ethiopia based on a weighted sample size. Variables with a p-value below 0.2 in bivariable analysis were incorporated into the multivariable analysis. Subsequently, a 95% CI and a p-value < 0.05 were utilized to assess the statistical significance of the final model. Global and local indicators of spatial correlation were done. Statistical analyses were performed using STATA 17, and ArcGIS 10.7 software.

Results: This study includes 13,721 in 2005 EDHS, 16,702 in 2011 EDHS, 16,650 in 2016 EDHS, and in 2019 EDHS 8,663 households. The prevalence of improved sanitation facilities in Ethiopia was 20.46%, 25.61%, 25.86%, and 27.45% based on EDHS 2005, 2011, 2016, and 2019, respectively. Global Moran's I spatial autocorrelations, hotspots, and spatial interpolation analysis indicated the inequality of improved sanitation facilities. Educational status of primary (AOR = 2.43, 95% CI : 2.00, 2.95), secondary (AOR = 2.02, 95% CI : 1.61, 2.54), and higher (AOR = 4.12, 95% CI :3.35, 7.54), watching television (AOR= 5.49, 95% CI: 4.37, 6.89), urban areas (AOR= 9.08, 95% CI: 6.69, 12.33), and region were factors statistically associated with sanitation facilities.

Conclusion: The overall finding of this study concludes a very slow increment in sanitation facilities over time and presence of geographical heterogeneity in Ethiopia. Educational status, watching television, wealth index, community-level education, type of residence, and region were factors statistically associated with sanitation facilities.

Keywords: EDHS, Ethiopia, Improved Sanitation, Spatiotemporal variation

Background

Sanitation refers to the endowment of services and facilities for the safe and clean controlling of human excreta, from the toilet to handling and containment to the final end-use or removal [1]. Sanitation is an integral component of basic human rights comparable to food, shelter, and water and is vital for healthy life [2].

According to the United Nations (UN-2018) report, in the world, around 4.5 billion people had no safe sanitation sand 892 million continue to practice Open Defecation (OD) [3, 4]. Inadequate access to sanitation is a principal reason for poverty in unindustrialized nations because it causes early mortality [5, 6]. The World Health Organization (WHO) estimated in 2019 that over 800,000 people die each year from diarrhea brought on by inadequate water, sanitation, and hygiene (WASH), and that two billion people's drinking water sources were tainted with excrement. Climate change, shifting precipitation patterns, increasing urbanization, and a dearth of practical, context-specific guidance on adaption strategies for sanitation service providers are all predicted to have an influence on the sanitation sector globally [7-9]. Over 70% of the population in Eastern and Southern Africa—340 million people—do not have access to basic sanitation services, while 19% defecate in the open, 179 million use unimproved facilities, and 63 million utilize shared sanitation facilities [10].

The Sustainable Development Goals (SDGs 6.2) aim to guarantee universal access to fair sanitation by 2030 as a result of these issues [11]. SDG 6.2 of the United Nations, which emanated in 2015 from the Millennium Development Goals, aims at equitable access to safe and affordable sanitation for all by 2030 (10). The main aim of this SDG is to prevent human contact with fecal pathogens to decrease occurrences of diseases [12, 13]. However, urban sewer connections are growing at an embarrassingly slow rate of 0.14% per year, and no place in the world is on track to achieve SDG 6.2 for universal access to sanitation [14]. Sub-Saharan African (SSA) nations, in particular, are well behind schedule in achieving SDG 6.2 of the 2030 agenda because of their fast population expansion and inadequate investment in sanitary infrastructure [15, 16]. At the same time, disparities in sub-Saharan African nations' access to sanitary facilities were more noticeable [17]. There are differences between nations, primarily in terms of urban and rural housing, which showed that people in rural areas had far worse access to sanitation than people in urban areas [18]. Low and middle-income nations exhibit this subnational variance in access to improved sanitation facilities, which is defined as the range of values from the unit with the highest level of access to the unit with the lowest level of access or no access at all [19] . Like other developing countries [20] access to sanitation is a challenge across Ethiopia [21], as well as there are disparities among the regions of the country. However, countries have the power to either advance or impede the development of fair access to better sanitary facilities.

Previous studies in Ethiopia were based on a single EDHS or only multilevel analysis or spatial analysis in order to investigate improved sanitation facilities [22]. These researches are unable to demonstrate the trend of better sanitary facilities over time. As in earlier research, the enhanced sanitation source is linked to residence, educational achievement, television viewing, household size, region, and wealth index [23-25]. In order to better understand the progress and geographic variance within Ethiopia, this study concentrated on the spatial and temporal analysis of sanitation facilities based on a combination of different demographic health surveys conducted in 2005, 2010, 2016, and 2019.

Methods

Study area and Data source

The study was carried out in Ethiopia, which consists of two administrative cities (Addis Ababa and Dire-Dawa) and nine geographical regions (Tigray, Afar, Amhara, Oromia, Somali, Benishangul-Gumuz, Southern Nations Nationalities and Peoples Region (SNNPR), Gambella, and Harari). The nation is situated in the Horn of Africa, with coordinates of 40.4897° East longitude and 9.145° North latitude [26]. The four consecutive Ethiopian Demographic and Health Surveys (EDHS 2005, 2011, 2016, and 2019) database survey were used in this investigation. These are therefore population-based surveys that are nationally representative and have sizable sample sizes at various points in time.

The DHS website, https://www.dhsprogram.com/data/dataset_admin/login_main.cfm , provides access to open source EDHS data.

All EDHS samples were a two-stage stratified cluster sample [27], sampling weights were calculated based on sampling probabilities separately for each sampling stage and each cluster. In 2005 surveys, 540 enumeration areas (EAs) (139 urban and 401 rural areas) [28], 2011 EDHS, 624 EAs (187 urban and 437 rural areas) [29], 2016 EDHS 645 EAs (202 in urban areas and 443 in rural areas) [30], and 2019 EDHS 305 EAs (93 in urban areas and 212 in rural areas) [31]were selected using systematic sampling with likelihood proportional to size.

In the second stage of selection, a fixed number of 30 households per cluster were selected with an equal probability of systematic selection from the newly created household listing. The field practice was conducted in Adama in clusters that were not part of the survey sample. Ethiopian public health institute investigators, an ICF technical specialist, an advisor, and representatives from other organizations, including central statistics agency, the Federal Ministry of Health, the World Bank, and USAID, supported the data collection in this EDHS data collection [28].

Among included households, 13,721, 16,702, 16, 650, and 8,663 were successfully interviewed in EDHS 2005, 2011, 2016, and 2019, respectively [28, 30]. Weighted by sampling weight was done to do a reliable statistical analysis. The geographical location data were taken from selected respective Enumeration Areas (EAs).

Study Variables

Outcome variables

The dependent variable was the sanitation facilities. The sanitation type designated as '1' represents 'improved sanitation', which can be accessed through flush/pour flush to piped sewer systems, septic tanks, or pit latrines; ventilated improved pit latrines, composting toilets, or pit latrines with slabs; and '0' represents 'unimproved sanitation' since it includes pit latrines without a platform or slab, hanging latrines or bucket latrines, and open defecation [32-34].

Predictor variables

Individual level variables: sex of household head (male or female), wealth index (poor, middle, and rich), educational status (no education, primary education, secondary education, and higher education), having a television (yes or no) and radio (yes or no) were individual-level predictor variables.

Community level variables: Community level education (lower/higher), the place of residence (urban/rural), community level media exposure (exposed/unexposed), region (Benishangul-Gumuz, Somali, Gambella, Afar, Oromia, SNNPR, Amhara, Tigray, and Harari) and City administration (Addis Ababa, and Dire Dawa).

Data management and analysis

The first step in data handling was downloading the raw datasets from the DHS website. These contained pertinent demographic and socioeconomic factors as well as household-level data on sanitation facilities. Pretests comprising in-class instruction, biomarker training, and field exercises were conducted for ensuring the quality of the data. The field exercise was conducted in clusters, which were not included in the EDHS sample. A debriefing session was held with the pretest field staff, and adjustments to the questionnaires were done based on lessons drawn from the field practice.

Data cleaning techniques included re-coding, removing duplicates, and resolving missing values to get the data ready for analysis. The datasets underwent further processing after data cleaning in order to extract significant predictors and analytic findings. The management approach also ensured that sample weights from the DHS data were appropriately applied to all analyses, taking into account the complex survey design, to ensure nationally representative results. In order to prepare the spatial data, shapefiles of the Ethiopian regions were accessed, and sanitation data was superimposed on them.

Stata Version 17 was utilized to do regression analysis and descriptive statistics. Logistic regression analysis was used to evaluate the relationships between outcome variables and predictor variables because the outcome variables were dichotomous. Multivariable binary logistic regression analysis was performed using bivariate analysis variables that had a p-value of less than 0.2. In the final model, statistical significance was determined by a p-value of less than 0.05 and a 95% confidence interval (CI) [35].

Multilevel Analysis

Model 1 included dependent and individual-level predictors, Model 2 included dependent and community-level predictors, Model 3 included all variables from Models 1 and 2, and Model 0 was a null model with no predictor variables. Random effects were measured using cluster variance (Vc), a proportional change in variance ((PCV $((Vc - Vn)/Vc)$) the intraclass correlation coefficient (ICC$(Vc/(Vc + 3.29)$)), and the median odds ratio (MOR (exp $[(0.95)\sqrt{Vc}]$)) [36, 37]. The goodness-of-fit for all models was evaluated using AIC, BIC, and Deviance. Then the model with the lower value of deviance, AIC, and BIC, was demonstrating the best-fit model [38]. As well as Multicollinearity, the effect of independent variables was measured using the variance inflation factor (VIF).

Spatial and temporal analysis

Spatial Autocorrelation

In order to examine geographical variability, a geospatial study of the distribution of sanitary facilities was carried out using ArcGIS version 17. The best essential instruments for access to improved sanitation facilities within the designated term are both global and local indicators of spatial correlation, which may be used to investigate the geographical distribution.

Global autocorrelations

Global autocorrelations analysis was performed in order to identify geographical variations in access to improved sanitation facilities. To determine whether the discrepancy is the result of non-random/dispersion or the clustering effect, global spatial autocorrelation (Moran's I index) was employed [39, 40]. Additionally, a basic exploratory spatial analysis was conducted to determine the country's geographic reliance distribution and the existence of better sanitary facilities. Places with similar access to sanitation tended to cluster together when Moran's I value was positive, while places with varying levels of sanitation were near one another when it was negative.

Local statistical analysis

Since global autocorrelations show a clustering effect (positive spatial autocorrelation) on the availability of sanitary facilities nationwide, more research utilizing figures and maps is required. In order to highlight the previously mentioned use of global autocorrelations (cluster effect) on access to sanitary facilities and to find patterns of geographical variation, hotspot analysis (Gettis-Ord Gi*) was carried out. The spatial patterns of the dependent variables (access to sanitary facilities) were described using cluster and outlier analysis (Anselin local Moran is I). Since this cluster and outlier analysis allows for the identification of groups and regions where the discrepancies occur, it was utilized to confirm and accompany the display of extremes (the hotspot and cold spot) [41].

Additionally, Kriging interpolation techniques were employed to visualize and forecast sanitary availability in locations that were not specifically studied. Kriging provided a continuous surface

198 of sanitation access across Ethiopia and generated more precise spatial projections by taking into
199 account both the distance between survey points and the degree of spatial autocorrelation. This
200 allowed us to pinpoint the regions that have experienced the greatest improvements in cleanliness
201 over time as well as those with the lowest coverage.

202 The authors used graphical presentation to do temporal trend analysis in order to examine the
203 evolution of sanitation access through time. The combination of trend and spatial studies allowed
204 for a thorough understanding of the regional heterogeneity and temporal evolution of sanitation
205 access in Ethiopia between 2005 and 2019.

206 Results

207 Socio-demographic characteristics of the study population

208 This study include 13,721 in 2005 EDHS, 16,702 in 2011 EDHS, 16,650 in 2016 EDHS, and in
209 2019 EDHS 8,663 participants. The higher percentage of study participants in all EDHS data sets
210 had no education (63.59%, 55.74%, 52.06%, and 47.65%, respectively). According to Table 1,
211 the majority of participants in the 2005 EDHS, the 2011 EDHS, the 2016 EDHS, and the 2019
212 EDHS—88.30%, 81.68%, 76.98%, and 77.10%, respectively did not own a television (Table 1).

213 Table 1. Socio-demographic characteristics of study Participants in Ethiopia

Variables	EDHS 2005 (N= 13,721) Frequency (%)	EDHS 2011 (N=16,702) Frequency (%)	EDHS 2016 (N= 16,650) Frequency (%)	EDHS 2019 (N= 8,663) Frequency (%)
Sex of HHH				
Male	10,243(74.65)	11,906(71.28)	11,413(68.55)	6,291(72.62)
Female	3,478(25.35)	4,796 (28.72)	5,237(31.45)	2,372(27.38)
Age of HHH				
<30	3,428(24.98)	4,823(28.88)	4,257(25.57)	2,520(29.09)
30-40	3,501(25.52)	4,116(24.64)	4,132(24.82)	2,287(26.40)
41-54	3,756(27.37)	4,047(24.23)	4,230(25.41)	1,717(19.82)
>54	3,036(22.13)	3,716(22.25)	4,031(24.21)	2,139(24.69)
Educational status of HHH				
No education	8,725(63.59)	9,309(55.74)	8,668(52.06)	4,128(47.65)
Primary	2,705(19.71)	5,020(30.06)	4,658(27.98)	2,715(31.34)
Second	1,754(12.78)	1,189(7.12)	1,686(10.12)	963(11.12)
Higher	495(3.61)	1,140(6.83)	1,580(9.49)	857(9.89)
Wealth index				
Poor	5,393(39.30)	6,506(38.95)	7,024(42.19)	3,498(40.38)

Middle	2,055(14.98)	2,364(14.15)	2,057(12.35)	1,285(14.83)
Rich	6,273(45.72)	7,832(46.89)	7,569(45.46)	3,880(44.79)
Share toilet with other households				
Yes	2,712(45.72)	4,467(46.12)	4,727(43.83)	2,222 (38.18)
No	3,204(54.01)	5,204(53.73)	6,059(56.17)	3,598(61.82)
Having radio				
No	8,157(59.45)	9,658(57.83)	11,680(70.15)	6,170 (71.22)
Yes	5,560(40.52)	7,040(42.15)	4,970(29.85)	2,493(28.78)
Having Television				
No	12,116(88.30)	13,643(81.68)	12,818(76.98)	6,679 (77.10)
Yes	1,601(11.67)	3,051(18.27)	3,832(23.02)	1,984(22.90)
Community-level media exposure				
Unexposed	8,105(59.07)	8,973(53.72)	10,024(60.20)	5,195(59.97)
Exposed	5,616(40.93)	7,729(46.28)	6,626(39.80)	3,468(40.03)
Community-level educational status				
Lower	8,730(63.63)	9,309(55.74)	8,726(52.41)	4,308(49.73)
Higher	4,991(36.37)	7,393(44.26)	7,924(47.59)	4,355(50.27)
Residence				
Urban	3,666(26.72)	5,112(30.61)	5,232(31.42)	2,645(30.53)
Rural	10,055(73.28)	11,590(69.39)	11,418(68.58)	6,018(69.47)
Region				
Tigray	1,282(9.34)	1,730(10.36)	1,734(10.41)	714(8.24
Afar	806(5.87)	1,267(7.59)	1,220(7.33)	664 (7.66)
Amhara	2,066(15.06)	2,071(12.40)	1,902(11.42)	1,007(11.62)
Oromia	2,155(15.71)	2,165(12.96)	1,988(11.94)	1,018(11.75)
Somali	796(5.80)	975(5.84)	1,564(9.39)	657(7.58)
Benishangul-Gumuz	869(6.33)	1,323(7.92)	1,280(7.69)	734(8.47)
SNNPR	1,933(14.09)	2,045(12.24)	1,897(11.39)	1,017(11.74)
Gambella	820(5.98)	1,215(7.27)	1,280(7.69)	693(8.00)
Harari	904(6.59)	1,201(7.19)	1,135(6.82)	719(8.30)
Addis Ababa	1,333(9.72)	1,524(9.12)	1,489(8.94)	702(8.10)
Dire Dawa	757(5.52)	1,186(7.10)	1,161(6.97)	738(8.52)
Key: EDHS= Ethiopian demographic health survey, HHH=Household head, SNNPR= South nation Nationalities Republic				

Trends of Sanitation facilities in Ethiopia

Figure 1 below presented that the trend of improved sanitation facilities in Ethiopia was 20.46%, 25.61%, 25.86%, and 27.45% based on EDHS 2005, 2011, 2016, and 2019, respectively (figure 1).

Factors Associated with Sanitation Facilities Accessibility

The odds of accessibility to improved sanitation facilities among participants with educational status of primary, secondary, and higher were 2.43 (AOR = 2.43, 95% CI :(2.00, 2.95)), 2.02 (AOR = 2.02, 95% CI :(1.61, 2.54)), and 4.12 (AOR = 4.12, 95% CI :(3.35, 7.54) times more likely respectively, compared to those with no education.

Study participants with wealth status of the middle, and rich were 1.49 (AOR = 1.49, 95% CI :(1.21, 1.83)), and 3.15 (AOR = 3.15, 95% CI :(2.55, 3.89)) times more likely in the odds of accessing improved sanitation facilities respectively, compared to those counterparts poor.

The odds of accessing improved sanitation facilities among study participants watched television were 5.49 (AOR= 5.49, 95% CI: (4.37, 6.89)) more likely compared to counterparts who did no watching television.

Community-level education was a statistically significant predictor variable. The odds of accessing improved sanitation facilities among Communities with higher educational levels were 3.90 (AOR= 3.90, 95% CI: (3.15, 4.82) times more likely compared to the community with lower education.

The chance of accessing improved sanitation facilities among communities exposed to media was 5.61 (AOR= 5.61, 95% CI: (3.84, 10.09)) times more likely than in the community unexposed to the media.

The odds of accessibility-improved sanitation facilities among the study population living in urban areas were 9.08 (AOR= 9.08, 95% CI: (6.69, 12.33) times more likely compared to the o study population living in rural areas.

Communities across various regions, including Tigray (54% less likely, AOR=0.46; 95% CI: 0.37, 0.57), Afar (33% less likely, AOR=0.67; 95% CI: 0.51, 0.86), Somali (77% less likely, AOR=0.23; 95% CI: 0.18, 0.29), Amhara (60% less likely, AOR=0.40; 95% CI: 0.32, 0.49), Benishangul Gumuz (37% less likely, AOR=0.63; 95% CI: 0.49, 0.80), Gambella (55% less likely, AOR=0.45; 95% CI: 0.35, 0.57), Harari (36% less likely, AOR=0.64; 95% CI: 0.52, 0.80), SNNRP (72% less likely, AOR=0.28; 95% CI: 0.22, 0.34), and Dire Dawa (72% less likely, AOR=0.28; 95% CI:

0.22, 0.35), exhibit decreased access to improved sanitation facilities compared to communities in Addis Ababa.

The median odds ratio (MOR), proportion change in variance (PCV), and intra-cluster correlation coefficient (ICC) were used to illustrate the random changes in cleanliness. According to the null model's ICC, variations through cluster regions accounted for 67.65% of the overall variability in access to improved sanitation services. According to Models 1 and 2, individual and community-level characteristics accounted for 59.74% and 26.35% of the Proportion Change in Variance (PCV) of the variation in the communities' access to better sanitation, respectively. If two areas were chosen at random, the MOR between the area with the greatest access to improved sanitary facilities and the region with the least access was 7.07.

Using the lowest AIC, DIC, and Deviance values, the model statistics showed a fair fit. Consequently, the best-fit model was validated by the final model's lowest AIC; DIC, and Deviance, which were 11,151.08, 11,282.33, and 11,117.0824, respectively (Table 2 and Table 3)

Table 2. Multilevel binary logistic regression analysis of predictors towards accessibility of sanitation facilities in Ethiopia, EDHS 2011

Variables	Model 0 (Null model)	Model 1 AOR (95% CI)	Model 2 AOR (95% CI)	Model 3 AOR (95% CI)
Individual level Factors				
Sex of HHH				
Male		0.97(0.82,1.04)		1.01(0.84,1.11)
Female		1	1	1
Age of HHH				
<30		0.97(0.94,1.01)		0.96 (0.20,2.34)
30-40		0.57(0.35,2.02)		1.49(0.13,2.41)
41-54		0.43(0.22,0.61)		1.17(0.86,1.59)
>54		1	1	1
Educational status				
No education		1		1
Primary		3.23 (2.63,3.96)**		2.43(2.00,2.95)**
Secondary		6.36(5.26,7.67)**		2.02(1.61,2.54)**
Higher		8.11 (7.16,9.19)*		4.12(3.35,7.54)**
Wealth index				
Poor		1		1
Middle		2.96 (2.34,4.24)**		1.49 (1.21,1.83)**

Rich		5.48 (3.45,5.89)**		3.15(2.55,3.89)**
Having television				
No		1		1
Yes		4.81(4.16,5.56)**		5.49(4.37,6.89)**
Community level factors				
Community level education				
Higher			6.50(5.82,7.27)**	3.90(3.15,4.82)**
Lower			1	1
Community-level media exposure				
Exposed			6.07(5.42,6.81)**	5.61(3.84,10.09)**
Unexposed			1	1
Type of residence				
Urban			16.74(11.85, 23.65)**	9.08(6.69,12.33)**
Rural			1	1
Region				
Tigray			0.50(0.41,0.62)**	0.46(0.37,0.57)**
Afar			0.86(0.67,1.09)	0.67(0.51,0.86)*
Amhara			0.43(0.35,0.53)**	0.40(0.32,0.49)**
Oromia			0.89 (0.72,1.09)	0.90(0.73,1.12)
SNNRP			0.25(0.20,0.31)*	0.28(0.22,0.34)**
Somali			0.33(0.26,0.41)**	0.23(0.18,0.29)**
Benishangul Gumuz			0.74(0.59,0.94)*	0.63(0.49,0.80)**
Gambella			0.51(0.41,0.64)**	0.45(0.35,0.57)**
Harari				0.64(0.52.0.80)**
Addis Ababa			1	1
Dire Dawa			0.25(0.21,0.31)**	0.28(0.22,0.35)**
VIF		2.35	2.27	2.05

1= reference, **P-value < 0.001(Adjusted OR), *P-value < 0.05(Adjusted OR), AIC=Akaike's information criteria, BIC=Bayesian information criteria, HHH =household head, HH=household, Model 0 (Null model) was fitted without predictor variables. ; Model 1 is adjusted for individual-level variables. Model 2 is adjusted for community-level variables; Model 3 is the final model adjusted for both individual- and community-level predictors.

Table 3: Measures variation metrics and the model fitness test statistics used for included models

Metrics	Model 0 (Null model)	Model 1	Variables	Model 0 (Null model)
Variance	6.88(5.84,8.10)	2.77(2.30,3.32)	2.04(1.71,2.44)	1.97(1.65,2.35)
MOR	7.07	4.35	3.82	3.78
PCV	Reference	59.74%	26.35%	3.43 %
ICC	0.6765	0.4571	0.3827	0.3745
Model fitness test statistics				
AIC	12204.07	11338.86	11610.79	11151.08
BIC	12219.51	11454.67	11734.32	11282.33
Deviance	12,200.0736	11,323.6174	11611.497	11,117.0824

Analysis of spatial heterogeneity

Spatial autocorrelation (Moran's I)

All EDHS were clustered in obtaining better sanitation facilities through Ethiopia, according to global Moran's I spatial autocorrelations positive z-scores (with the z-scores of 2005 EDHS 2.374393, 2011 EDHS 7.067996, 2016 EDHS 8.9374285, and 2019 EDHS 36.511348) (Figure 2).

Hot and cold spot analysis (Getis-Ord Gi*)

All EDHS in Ethiopia showed the same trend in the spatial distribution of improved sanitation facilities, according to hot and cold spot analysis. The percentage of EDHS that had access to improved sanitation was much lower in the majority of the country, according to the numbers below, and it was higher only in Addis Ababa and Dire Dawa (Figure 3).

Spatial interpolation

The study used spatial Kriging interpolation analysis to determine which parts of the country had less improved sanitation accessibility. As illustrated in the figures below, the red color denotes areas of the country (Addis Ababa and Dire Dawa) with greater access to improved sanitation facilities, while the green color (the majority of the country) indicates areas with lower access (figure 4).

Discussion

Using multilevel and geographical analysis techniques on Ethiopia's 2005-2019 EDHS datasets, the studies are unique in their thorough investigation of geographic variances and temporal changes in sanitation facilities. Their thorough investigation into the ways in which access to sanitation infrastructure has changed over time and differed among Ethiopia's many regions has produced a fresh contribution by illuminating hitherto unseen trends and inequalities. In order to reduce inequities and enhance overall sanitation access in Ethiopia, this research highlights locations for focused interventions and offers insightful information about the dynamic nature of sanitation service.

To hygienically isolate human excreta from human touch, which causes many infectious diseases, improved sanitation facilities must be accessible in a sustainable and fair manner [42]. This study's primary goal was to examine, using four consecutive EDHS datasets, the spatiotemporal variation and factors linked to improved sanitation facilities that are accessible in Ethiopia. According to these findings, the percentage of households with access to improved sanitation facilities was 20.46% in EDHS 2005, 25.61% in EDHS 2011, 25.86% in EDHS 2016, and 27.45% in EDHS 2019. The rise from 2011 to 2016 was only 0.25%, but the increase from 2005 to 2011 was 5.15%. These results indicate that, between 2005 and 2019, Ethiopia's access to better sanitation facilities improved at relatively modest steady rates. This outcome is consistent with other research showing that certain nations have made significant strides toward SDG 6, while others look to be stuck at low levels of sanitation coverage with little or no development [43]. Such setback with little or no development levels of access to improved sanitation facilities is the experience of developing countries including Ethiopia [44]. The construction of sanitation facilities may receive less attention from the government and non-governmental organizations because of international environmental change, poverty, and the nation's instability brought on by the trauma of the civil war. This result is in line with previously conducted research conducted global [33, 45-49].

Based on four EDHS datasets, the geographical analysis's results for Global Moran's autocorrelation, hotspot, cluster, and Kriging revealed significant differences in Ethiopia's access to better sanitation services. Among other regions of the nation, Addis Ababa and Dire Dawa were identified as high hot spots for improved sanitation facilities based on the findings of the Kriging analysis and hot spot analysis conducted in all EDHS. This result demonstrated that access to better sanitation facilities varies significantly by region across the nation. It ran counter to aim 6.2 of the

2030 Sustainable Development Goals, which is to "end open defecation and provide access to adequate and equitable sanitation for all"[50]. This variation could be the difference in economic growth, overpopulation growth, unplanned urbanization, and inaccessibility of infrastructure, government overload towards other burning daily tasks, socio-political instability, awareness, and adaptability towards sanitation facilities.

The household head's educational level, television ownership, and wealth index were individual-level predictors linked to access to better sanitation facilities, while community-level predictor variables included education, media exposure, residence type, and region.

Household heads with higher levels of education were more likely to have access to better sanitary facilities than heads with lower levels of education. Ethiopia, Kenya, West and Central Africa, Bangladesh, Benin, and Vietnam have all conducted research that corroborate this conclusion [51-54]. The community with higher education accessed improved sanitation facilities than part of the community with lower education. This finding was in line with other previous studies conducted in different parts of the world [23, 55, 56]. Other possible explanation for this discrepancy is that more people that are educated may be aware of the link between better sanitary facilities and health. If so, compared to household heads with lower educational background, they are excited to have these sanitation services.

Access to better sanitary facilities was correlated with wealth status in a proportionate manner. Compared to the poorest homes, wealthy and middle-class households were more likely to have access to better sanitary facilities. The research conducted in Ghana, Benin, Vietnam, and Eswatini supports this conclusion [52, 57-59]. This discrepancy may result from the development of better sanitation facilities like septic tanks and pour-flush toilets; the impoverished may find it difficult to afford slab pit latrines and composting toilets.

When all other factors were held constant, families with television had a higher chance of having access to better sanitary facilities than those without. This may be because residents spent a lot of time watching television, which serves as a visual information source about topics like how better cleanliness can prevent the spread of disease. The other statistically significant predictor of access to better sanitation facilities at the community level was media exposure. In Ethiopia, householders who were exposed to community-level media—whether it was radio, television, or both—were more likely to have access to better sanitation. This result was consistent with earlier research carried out in Ethiopia [22, 23], and sub-Saharan Africa [60].

Compared to households in rural areas, urban households are more likely to have access to better sanitation services. A prior Ethiopian study that showed Ethiopia's rural communities are severely trailing behind in the battle to achieve SDGs supported this issue 6.2 [43] and the other study done in Vietnam [57]. Different amounts of improved sanitation facilities were available to households located in different parts of Ethiopia. Addis Ababa, the capital, was better to the other parts of the country. This finding is aligns with the studies done in Kenya [61], Nepal [62] and WHO, UNICEF, 2019 report [63] which indicated that persist disparities in access to WASH services in rural versus urban settings. This discrepancy could be explained by the fact that Addis Ababa serves as both the nation's capital and the headquarters of the Africa Union, providing access to better infrastructure, including sanitary facilities. Low socioeconomic position, regional sociopolitical instability, ignorance, and a lack of ability to adjust to sanitary facilities could all be contributing factors[64].

The self-report nature of data collection, which leads to interviewer bias, social acceptability bias, recall bias and incompleteness of the recent mini demographic health survey (EDHS 2019), could be potential sources of errors and the limitations of this study.

Conclusion

According to the study's general findings, Ethiopia's access to sanitary facilities has gradually increased over time. Additionally, there was geographical variation in the country's accessibility of improved sanitation facilities that was statistically significant. To achieve the suggested goal, the rate of advancement in universal access to sanitary facilities (SDG 6.2) in 2030 should be accelerated. The following parameters were statistically linked to the accessibility of sanitation facilities in Ethiopia: region, type of habitation, wealth index, community-level education, community-level media exposure, educational status, and television viewing. This study recommended that local and international organizations focus on solutions that allow for the advancement of universal access to sanitary facilities, particularly in developing nations.

Strengths and Limitations of this study

The first strength is the use of multi-EDHS data, which allows trend analysis of Ethiopia's sanitation situation.

The second strength is that a large, nationally representative sample is ensured by using data from numerous Demographic and Health Surveys, increasing the generalizability of findings throughout Ethiopia.

The third strength, DHS surveys provide detailed information on the types of sanitation facilities, from basic to improved, which allows for a significance understanding of the sanitation countryside in Ethiopia.

The first limitation, there could be social desirable bias since the data were collected through face-to-face interview.

The second limitation, while the quantitative analysis identifies trends and spatial disparities, it may not provide insights into the behavioral, and cultural level factors influencing sanitation adoption and usage.

Abbreviations

AIC: Akaike's Information Criterion, AOR: Adjusted Odds Ratio, CI: Confidence Interval, DHS: Demographic and Health Survey, EAs: Enumeration Areas, EDHS: Ethiopian Demographic and Health Survey, ICC: Intra Class Correlation, MOR: Median Odd Ratio, PCV: Proportional Change in Variance

Declarations

Ethics approval and consent to participate

This study was based on secondary data from the Ethiopian Demographic and Health Survey and secured the permission letter from the main Demographic Health and Survey. Permission for data access was obtained from a major Demographic and Health Survey through an online request at (https://www.dhsprogram.com/data/dataset_admin/login_main.cfm.). Participant consent was not directly obtained since authors used secondary data.

Patient and Public Involvement

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

This research was done using a publicly available dataset found at https://www.dhsprogram.com/data/dataset_admin/login_main.cfm after approval from Data Archivist of the Demographic and Health Surveys (DHS) Program.

Competing interests

There is no any competing interest.

Funding

The authors have not received any specific grant for this research from public, commercial, or not-for-profit funding agencies

Authors' contributions

JA Engaged in data curation**.** JA Conducted the statistical analysis. JA**,** MT, and WM involved in investigation of the study. JA and WM had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. JA, MT, and WM done validation and visualization. JA and WM conducted the write-up and drafted the manuscript. All authors involved in review & editing. JA is responsible for the overall content as guarantors.

Acknowledgments

The author acknowledges the Ethiopian Central Statistical Agency for providing them with the data and shape files for this study.

References

1. Organization, W.H., World health statistics overview 2019: monitoring health for the SDGs, sustainable development goals. 2019, World Health Organization.
2. Erridge, M., Human Right to Sanitation. Clean Water and Sanitation, 2020: p. 1-11.
3. Water, U., Sustainable Development Goal 6 Synthesis Report on Water and Sanitation. United Nations. 2018.
4. Carvalho, D.M., Tripartite organizational partnerships and the wickedness of the water and sanitation sector in Brazil: an institutional analysis. 2019.

5. Kumwenda, S., Challenges to hygiene improvement in developing countries. Vol. 1. 2019: IntechOpen London, UK.

6. Peter, A.K. and U. Umar, Combating diarrhoea in Nigeria: the way forward. J Microbiol Exp, 2018. **6**(4): p. 191-197.

7. Oates, N., et al., Adaptation to climate change in water, sanitation and hygiene. London: Overseas Development Institute.[Google Scholar], 2014.

8. Clemenz, N., R. Boakye, and A. Parker, Rapid Climate Adaption Assessment (RCAA) of water supply and sanitation services in two coastal urban poor communities in Accra, Ghana. Journal of Water and Climate Change, 2020. **11**(4): p. 1645-1660.

9. Hyde-Smith, L., et al., Climate change impacts on urban sanitation: a systematic review and failure mode analysis. Environmental science & technology, 2022. **56**(9): p. 5306-5321.

10. Morgan, C., et al., Water, sanitation, and hygiene in schools: Status and implications of low coverage in Ethiopia, Kenya, Mozambique, Rwanda, Uganda, and Zambia. International journal of hygiene and environmental health, 2017. **220**(6): p. 950-959.

11. Dickin, S., et al., Sustainable sanitation and gaps in global climate policy and financing. NPJ Clean Water, 2020. **3**(1): p. 24.

12. Obani, P., SDG 6.2 and the right to sanitation: exploring the complementarities and incoherence. UNIPORT Journal of International and Comparative Law 1, 2020: p. 1-17.

13. Mattos, K.J., et al., Household water, sanitation, and hygiene practices impact pathogen exposure in remote, rural, unpiped communities. Environmental Engineering Science, 2021. **38**(5): p. 355-366.

14. Corburn, J., Water and sanitation for all: Citizen science, health equity, and urban climate justice. Environment and Planning B: Urban Analytics and City Science, 2022. **49**(8): p. 2044-2053.

15. Tykhomyrova, T., V. Sebko, and V. Babenko, Sustainable development. 2022.

16. Hutton, G. and M. Varughese, The costs of meeting the 2030 sustainable development goal targets on drinking water, sanitation, and hygiene. 2016.

17. Organization, W.H., Progress on household drinking water, sanitation and hygiene 2000-2020: five years into the SDGs. 2021.

18. Walsh, P.P., E. Murphy, and D. Horan, The role of science, technology and innovation in the UN 2030 agenda. Technological Forecasting and Social Change, 2020. **154**: p. 119957.

19. Campos Nonato, I., Mapping geographical inequalities in access to drinking water and sanitation facilities in low-income and middle-income countries, 2000–17. 2020.

20. Prüss-Ustün, A., et al., Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: an updated analysis with a focus on low-and middle-income countries. International journal of hygiene and environmental health, 2019. **222**(5): p. 765-777.

21. Baye, D., Sustainable development goals (SDG) target 6.2 in Ethiopia: challenges and opportunities. Open Access Library Journal, 2021. **8**(5): p. 1-28.

22. Demsash, A.W., et al., Spatial and multilevel analysis of sanitation service access and related factors among households in Ethiopia: using 2019 Ethiopian national dataset. PLOS Global Public Health, 2023. **3**(4): p. e0001752.

23. Azanaw, J., et al., A multilevel analysis of improved drinking water sources and sanitation facilities in Ethiopia: Using 2019 Ethiopia mini demographic and health survey. Frontiers in Public Health, 2023. **11**.

24. Gebremichael, S.G., et al., Determinants of water source use, quality of water, sanitation and hygiene perceptions among urban households in North-West Ethiopia: A cross-sectional study. Plos one, 2021. **16**(4): p. e0239502.

25. Adil, S., M. Nadeem, and I. Malik, Exploring the important determinants of access to safe drinking water and improved sanitation in Punjab, Pakistan. Water Policy, 2021. **23**(4): p. 970-984.

26. Dwivedi, R., K. Sreenivas, and K. Ramana, Cover: Land-use/land-cover change analysis in part of Ethiopia using Landsat Thematic Mapper data. International Journal of Remote Sensing, 2005. **26**(7): p. 1285-1287.

27. Anteneh, Z.A. and J.-P. Van Geertruyden, Spatial variations and determinants of anemia among under-five children in Ethiopia, EDHS 2005–2016. Plos one, 2021. **16**(4): p. e0249412.

28. Central Statistical Agency Addis Ababa, E., Ethiopia Demographic and Health Survey 2005. 2005.

29. Central Statistical Agency Addis Ababa, E.I.I.C., Maryland, USA, Ethiopia Demographic and Health Survey. 2011.

30. Central Statistical Agency Addis Ababa, E., ETHIOPIA Demographic and Health Survey. 2016.

31. Ethiopian Public Health Institute Addis Ababa Federal Ministry of Health Addis Ababa The DHS Program ICF Rockville, M., USA, ETHIOPIA Mini Demographic and Health Survey 2019.

32. Armah, F.A., et al., Access to improved water and sanitation in sub-Saharan Africa in a quarter century. Heliyon, 2018. **4**(11): p. e00931.

33. Wang, C., et al., Geographic inequalities in accessing improved water and sanitation facilities in Nepal. International journal of environmental research and public health, 2019. **16**(7): p. 1269.

34. Davis, J., et al., Improving access to water supply and sanitation in urban India: microfinance for water and sanitation infrastructure development. Water Science and Technology, 2008. **58**(4): p. 887-891.

35. Sun, G.-W., T.L. Shook, and G.L. Kay, Inappropriate use of bivariable analysis to screen risk factors for use in multivariable analysis. Journal of clinical epidemiology, 1996. **49**(8): p. 907-916.

36. Goicolea, I. and M. San Sebastian, Unintended pregnancy in the amazon basin of Ecuador: a multilevel analysis. International journal for equity in health, 2010. **9**: p. 1-11.

37. Schootman, M., et al., Geographic clustering of adequate diagnostic follow-up after abnormal screening results for breast cancer among low-income women in Missouri. Annals of epidemiology, 2007. **17**(9): p. 704-712.

38. Li, F., et al., Model selection methods for mixture dichotomous IRT models. Applied Psychological Measurement, 2009. **33**(5): p. 353-373.

39. Roll, U., et al., Onset of a pandemic: characterizing the initial phase of the swine flu (H1N1) epidemic in Israel. BMC infectious diseases, 2011. **11**(1): p. 1-13.

40. Blake, S.B., Exploring Spatial Relationships Among Dairy Farms, Drinking Water Quality, and Maternal-Child Health Outcomes in the San Joaquin Valley. 2014: University of California, Davis.

41. Sánchez-Martín, J.-M., J.-I. Rengifo-Gallego, and R. Blas-Morato, Hot spot analysis versus cluster and outlier analysis: An enquiry into the grouping of rural accommodation in Extremadura (Spain). ISPRS International Journal of Geo-Information, 2019. **8**(4): p. 176.

42. Ritchie, H. and M. Roser, Clean water and sanitation. Our world in data, 2021.

43. Bankole, A.O., et al., Factors affecting sanitation coverage in three income levels and potential toward achieving SDG 6.2. Water Policy, 2023. **25**(2): p. 146-176.

44. Organization, W.H., National systems to support drinking-water: sanitation and hygiene: global status report 2019: UN-Water global analysis and assessment of sanitation and drinking-water: GLAAS 2019 report. 2019.

45. Azage, M., A. Motbainor, and D. Nigatu, Exploring geographical variations and inequalities in access to improved water and sanitation in Ethiopia: mapping and spatial analysis. Heliyon, 2020. **6**(4).

46. Pullan, R.L., et al., Geographical inequalities in use of improved drinking water supply and sanitation across sub-Saharan Africa: mapping and spatial analysis of cross-sectional survey data. PLoS medicine, 2014. **11**(4): p. e1001626.

47. Armah, F.A., et al., Access to improved water and sanitation in sub-Saharan Africa in a quarter century. Heliyon, 2018. **4**(11).

48. Yu, W., et al., A global perspective on drinking-water and sanitation classification: an evaluation of census content. PLoS One, 2016. **11**(3): p. e0151645.

49. Ghosh, P., M. Hossain, and A. Alam, Water, sanitation, and hygiene (WASH) poverty in India: a district-level geospatial assessment. Regional Science Policy & Practice, 2022. **14**(2): p. 396-417.

50. Hueso, A., Is 'access to adequate and equitable sanitation' for all by 2030 achievable? Perspectives from sector experts on what needs to change to realise the Sustainable Development Goal. Journal of Water, Sanitation and Hygiene for Development, 2016. **6**(4): p. 650-657.
51. Koskei, E.C., et al., Effect of socio-economic factors on access to improved water sources and basic sanitation in Bomet Municipality, Kenya. Research Journal of Environmental and Earth Sciences, 2013. **5**(12): p. 714-719.
52. Gaffan, N., et al., Household access to basic drinking water, sanitation and hygiene facilities: secondary analysis of data from the demographic and health survey V, 2017–2018. BMC Public Health, 2022. **22**(1): p. 1-16.
53. Andualem, Z., et al., Households access to improved drinking water sources and toilet facilities in Ethiopia: a multilevel analysis based on 2016 Ethiopian Demographic and Health Survey. BMJ open, 2021. **11**(3): p. e042071.
54. Simen-Kapeu, A., et al., Prevalence of diarrhoea, acute respiratory infections, and malaria over time (1995-2017): A regional analysis of 23 countries in West and Central Africa. Journal of global Health, 2021. **11**.
55. Agbadi, P., E. Darkwah, and P.L. Kenney, A multilevel analysis of regressors of access to improved drinking water and sanitation facilities in Ghana. Journal of environmental and public health, 2019. **2019**.
56. Kong, Y.-L., et al., Socio-economic factors related to drinking water source and sanitation in Malaysia. International Journal of Environmental Research and Public Health, 2020. **17**(21): p. 7933.
57. Tuyet-Hanh, T.T., et al., Household trends in access to improved water sources and sanitation facilities in Vietnam and associated factors: findings from the Multiple Indicator Cluster Surveys, 2000–2011. Global Health Action, 2016. **9**(1): p. 29434.
58. Simelane, M.S., et al., Determinants of households' access to improved drinking water sources: a secondary analysis of eswatini 2010 and 2014 multiple indicator cluster surveys. Advances in Public Health, 2020. **2020**: p. 1-9.
59. Akpakli, D.E., et al., Determinants of access to improved sanitation facilities in rural districts of southern Ghana: evidence from Dodowa Health and Demographic Surveillance Site. BMC research notes, 2018. **11**(1): p. 1-7.
60. Seidu, A.-A., et al., A multilevel analysis of individual and contextual factors associated with the practice of safe disposal of children's faeces in sub-Saharan Africa. Plos one, 2021. **16**(8): p. e0254774.
61. Health, M.o., Kenya environmental sanitation and hygiene strategic framework 2016–2020. 2015.

62. Dhital, S.R., et al., Prevalence and Correlates of Water, Sanitation, and Hygiene (WASH) and Spatial Distribution of Unimproved WASH in Nepal. International journal of environmental research and public health, 2022. **19**(6): p. 3507.

63. Organization, W.H., Progress on household drinking water, sanitation and hygiene 2000-2017: special focus on inequalities. 2019: World Health Organization.

64. Deshpande, A., et al., Mapping geographical inequalities in access to drinking water and sanitation facilities in low-income and middle-income countries, 2000–17. The Lancet Global Health, 2020. **8**(9): p. e1162-e1185.

Figure 1: The proportion of sanitation facilities accessibility in Ethiopia using the four EDHS.

Figure 2A: Global Spatial autocorrelation analysis of accessibility of improved sanitation facilities in Ethiopia, EDHS 2005.

Figure 2B: Global Spatial autocorrelation analysis of accessibility of improved sanitation facilities in Ethiopia, EDHS 2011

Figure 2C: Global Spatial autocorrelation analysis of accessibility of improved sanitation facilities in Ethiopia, EDHS 2016

Figure 2D: Global Spatial autocorrelation analysis of accessibility of improved sanitation facilities in Ethiopia, EDHS 2019

Figure 3A: Hot and cold spot analysis of accessibility of improved sanitation facilities in Ethiopia based on the dataset of EDHS 2005

Figure 3B: Hot and cold spot analysis of accessibility of improved sanitation facilities in Ethiopia based on the dataset of EDHS 2011

Figure 3C: Hot and cold spot analysis of accessibility of improved sanitation facilities in Ethiopia based on the dataset of EDHS 2016

Figure 3D: Hot and cold spot analysis of accessibility of improved sanitation facilities in Ethiopia based on the dataset of EDHS 2019

Figure 4A: Kriging interpolation analysis result of improved sanitation facilities accessibility in Ethiopia based on EDHS 2005

Figure 4B: Kriging interpolation analysis result of improved sanitation facilities accessibility in Ethiopia based on EDHS 2011

Figure 4C: Kriging interpolation analysis result of improved sanitation facilities accessibility in Ethiopia based on EDHS 2016

Figure 4D: Kriging interpolation analysis result of improved sanitation facilities accessibility in Ethiopia based on EDHS 2019

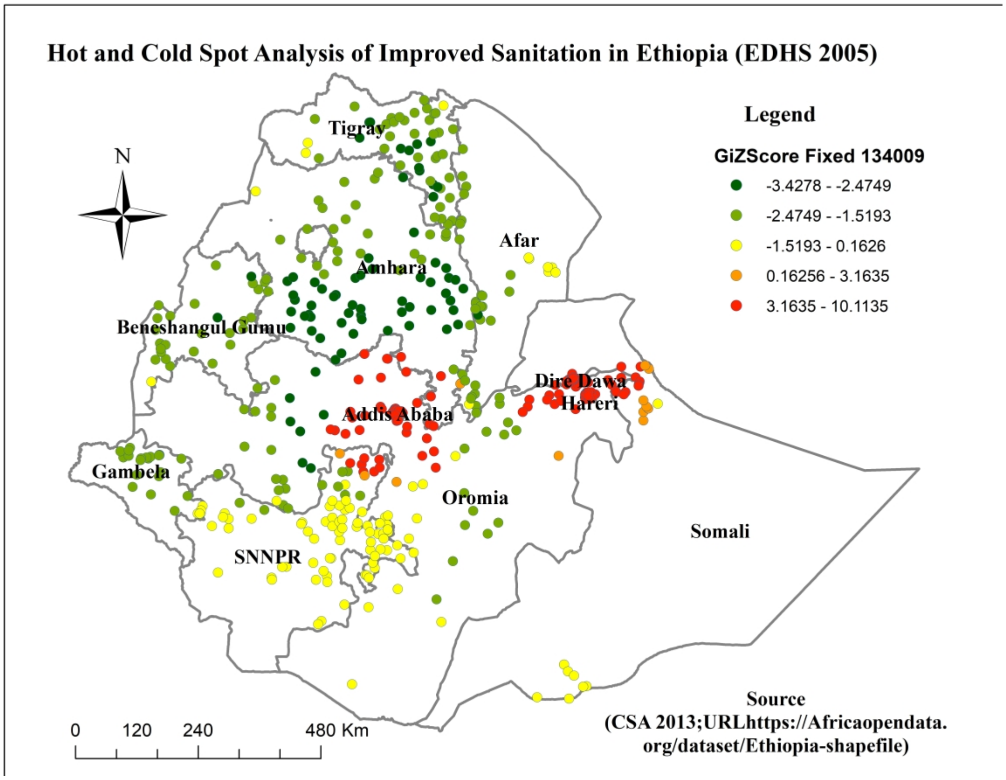


Figure 3A

279x215mm (600 x 600 DPI)

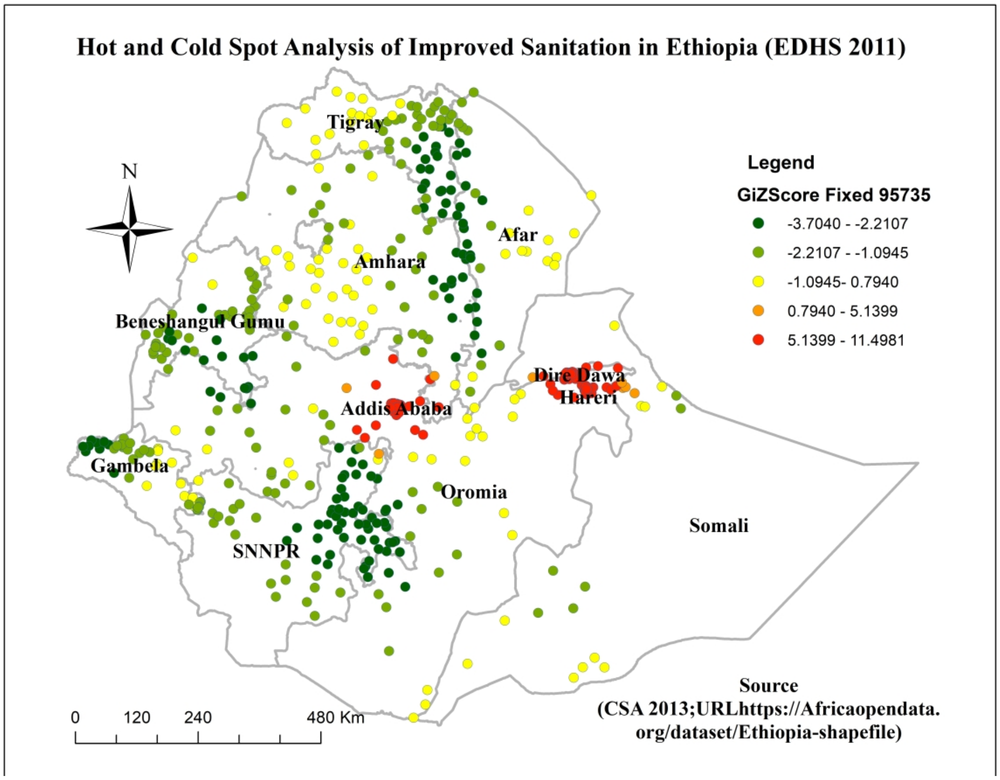


Figure 3B

279x215mm (600 x 600 DPI)

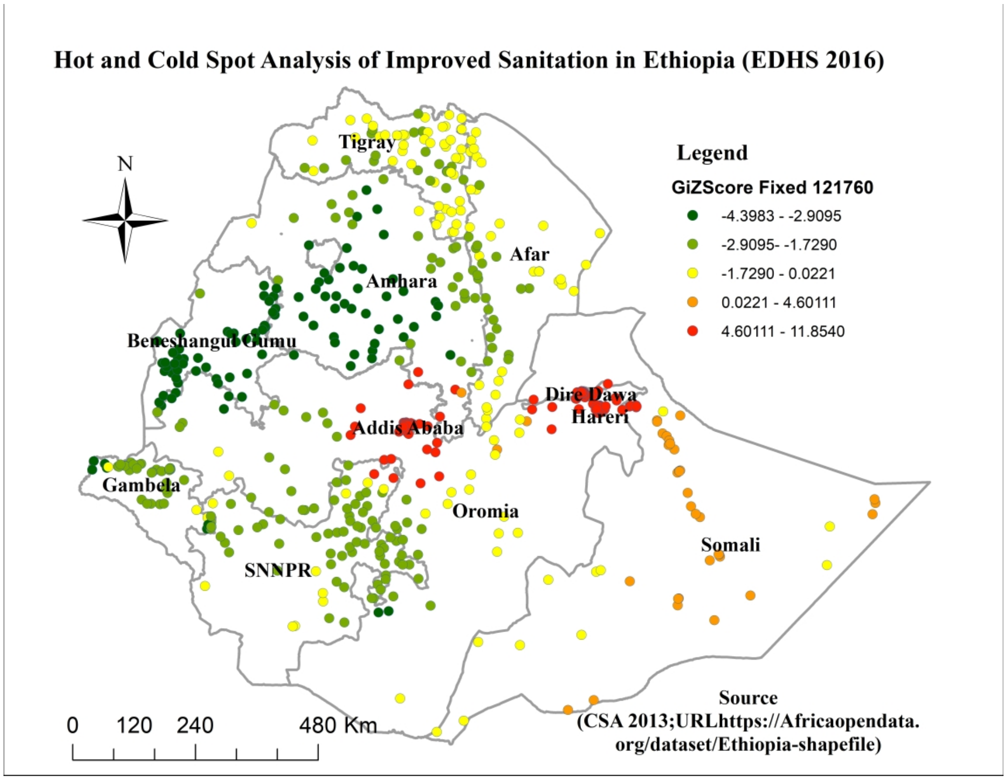


Figure 3C

279x215mm (600 x 600 DPI)

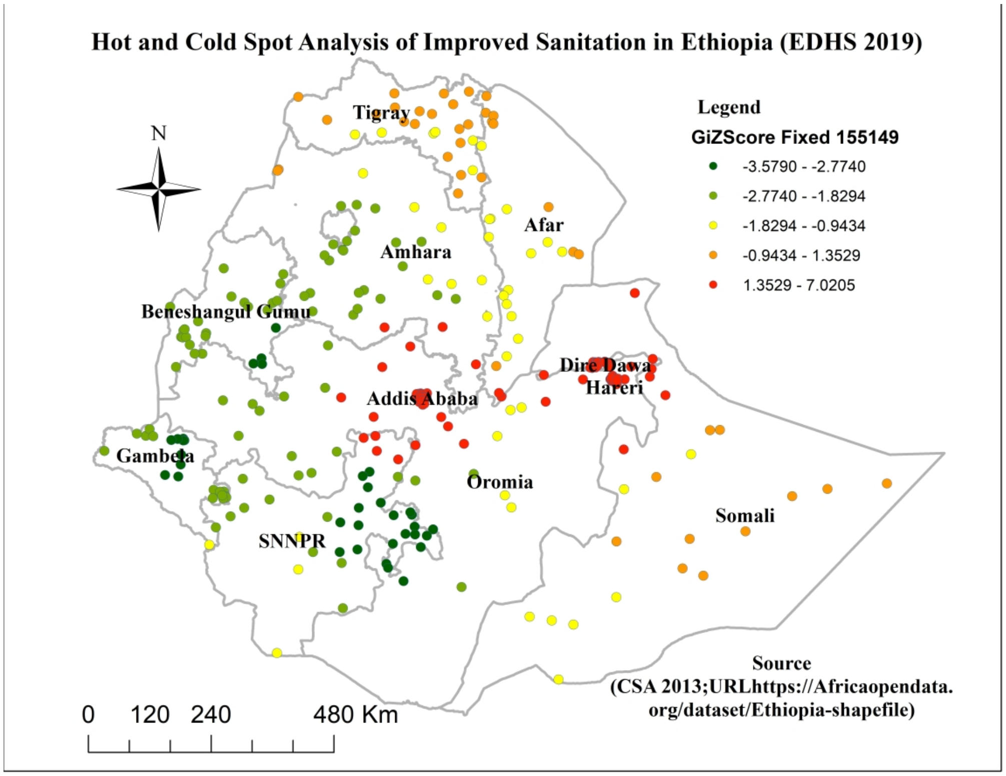


Figure 3D

279x215mm (600 x 600 DPI)

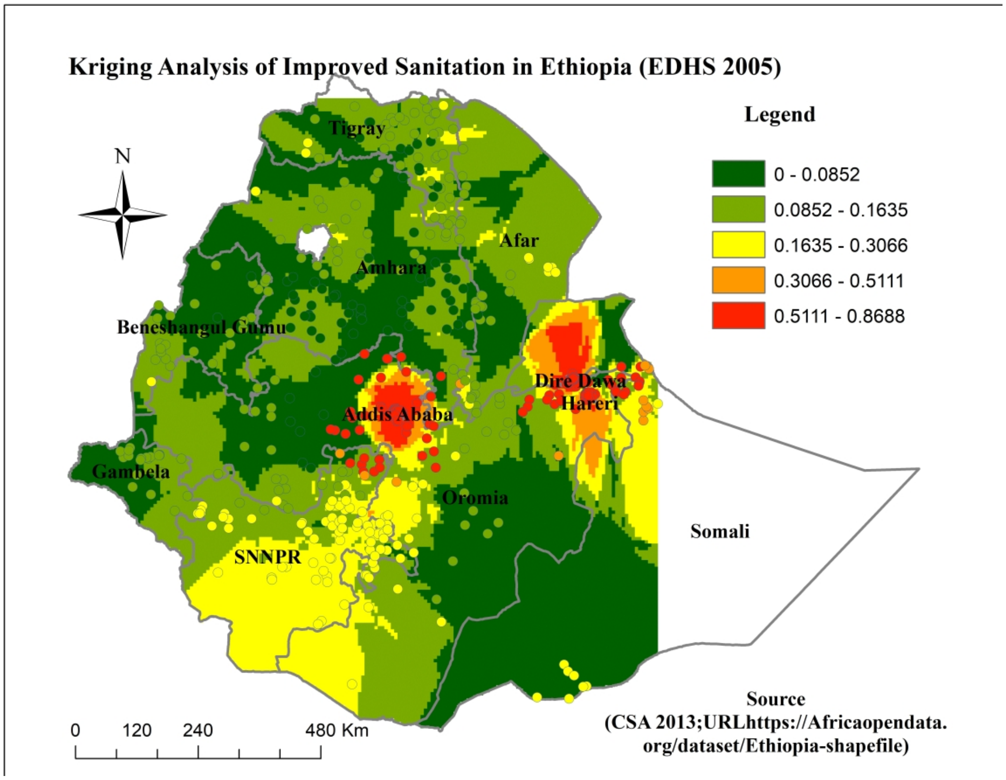


Figure 4A

279x215mm (600 x 600 DPI)

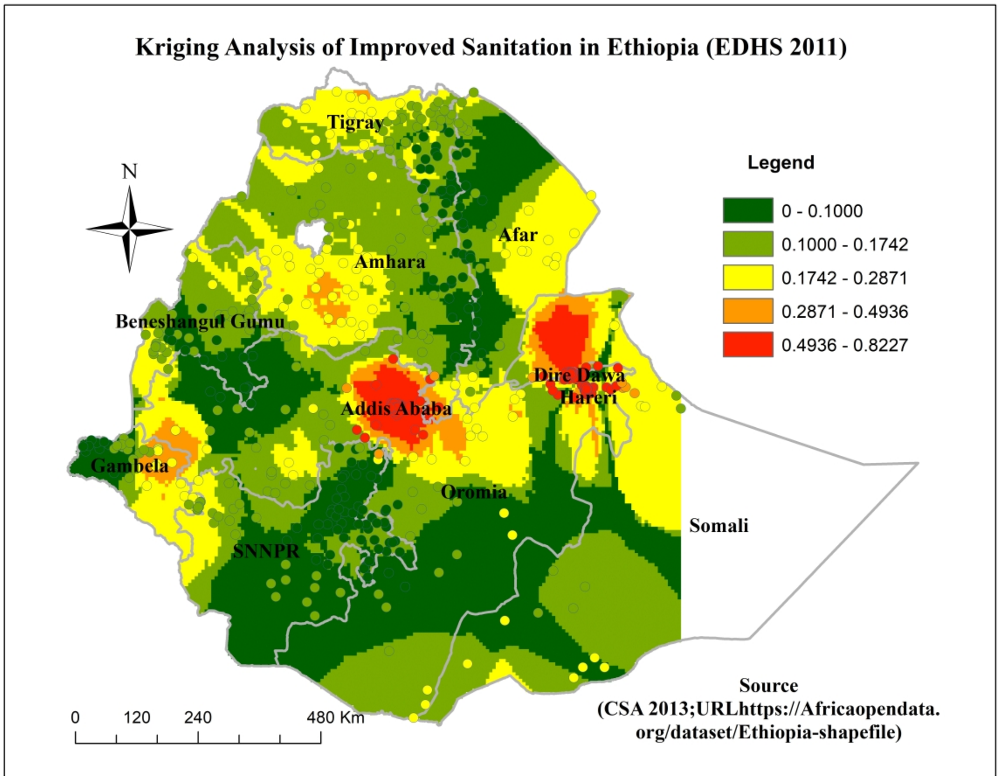


Figure 4B

279x215mm (600 x 600 DPI)

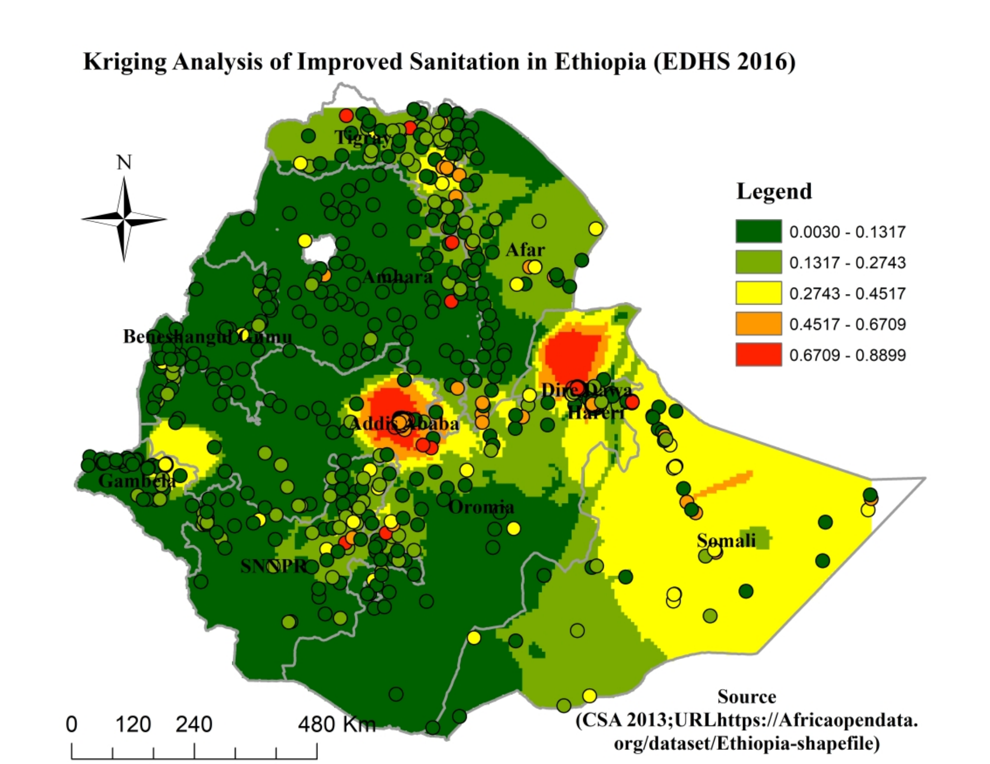


Figure 4C

279x215mm (600 x 600 DPI)

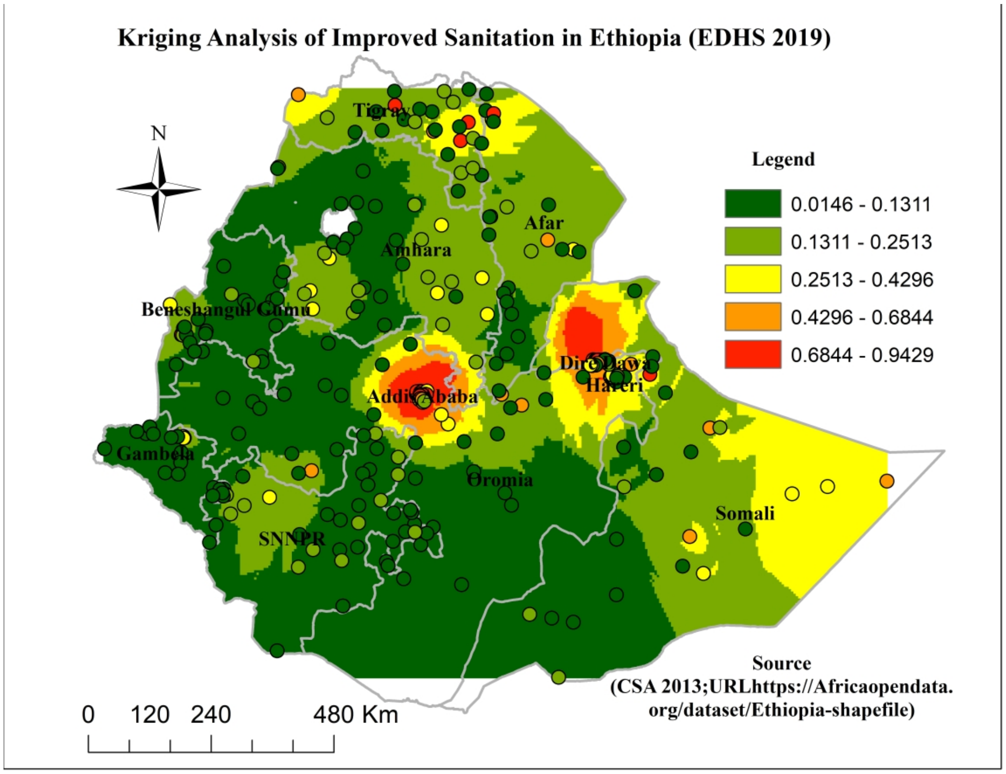


Figure 4D

279x215mm (600 x 600 DPI)

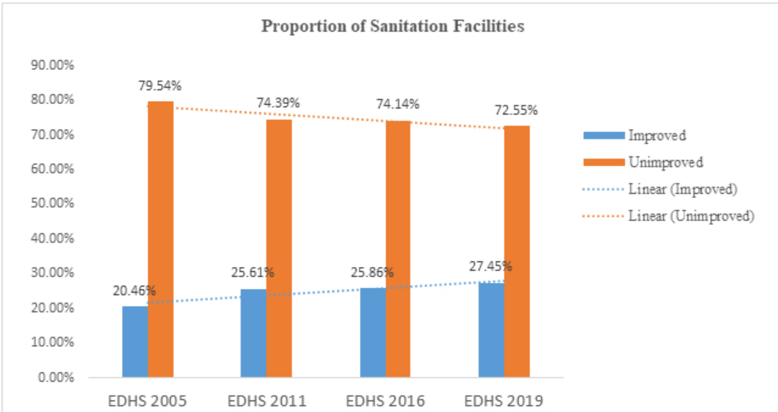


Figure 1

216x121mm (96 x 96 DPI)

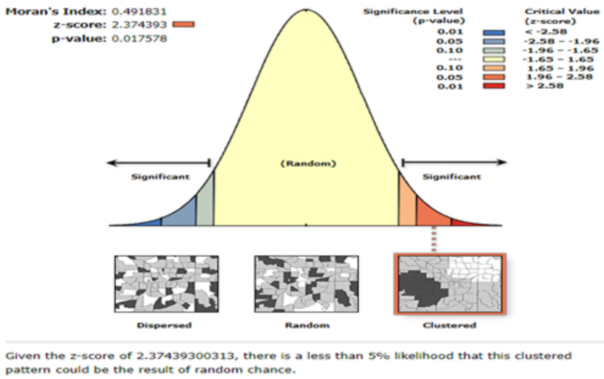


Figure 2A

216x121mm (96 x 96 DPI)

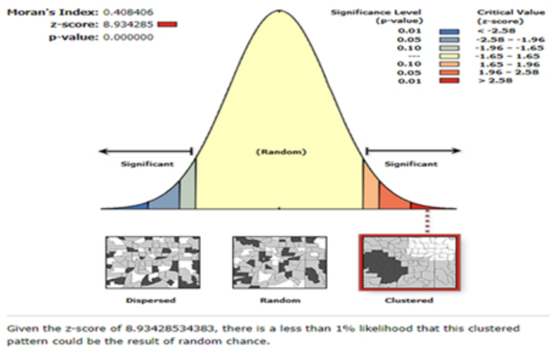


Figure 2B

216x121mm (96 x 96 DPI)

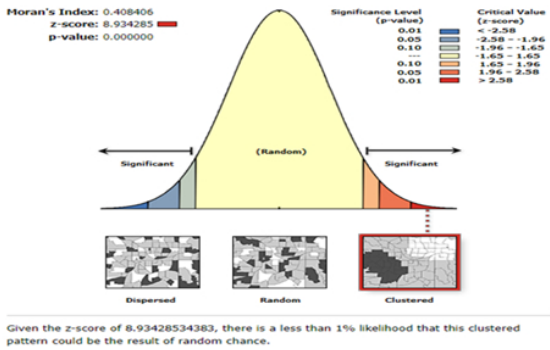


Figure 2C

216x121mm (96 x 96 DPI)

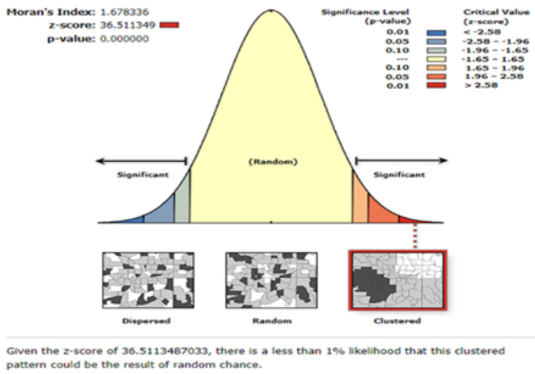


Figure 2D

216x121mm (96 x 96 DPI)

BMJ Open

Temporal trends and spatial heterogeneity of sanitation facilities in Ethiopia: evidence from the 2005-2019 Demographic and Health Surveys

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2024-088211.R3
Article Type:	Original research
Date Submitted by the Author:	29-Oct-2024
Complete List of Authors:	Azanaw, Jember; University of Gondar, Department of Environmental and Occupational Health and Safety, Institute of Public Health, College of Medicine and Health Sciences Tsegaye, Mesenbet; Department of General Surgery, School of Medicine, College of Medicine and Health Sciences, University of Gondar, Gondar, Ethiopia Mesele, Wodaje; Department of Orthopaedic and Trauma Surgeon, School of Medicine, College of Medicine and Health Sciences, University of Gondar, Gondar, Ethiopia
Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Public health, Global health
Keywords:	Infectious diseases & infestations < DERMATOLOGY, International health services < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, Public health < INFECTIOUS DISEASES, Climate Change, Health Services, Health Education

SCHOLARONE™ Manuscripts

I, the Submitting Author has the right to grant and does grant on behalf of all authors of the Work (as defined in the below author licence), an exclusive licence and/or a non-exclusive licence for contributions from authors who are: i) UK Crown employees; ii) where BMJ has agreed a CC-BY licence shall apply, and/or iii) in accordance with the terms applicable for US Federal Government officers or employees acting as part of their official duties; on a worldwide, perpetual, irrevocable, royalty-free basis to BMJ Publishing Group Ltd ("BMJ") its licensees and where the relevant Journal is co-owned by BMJ to the co-owners of the Journal, to publish the Work in this journal and any other BMJ products and to exploit all rights, as set out in our licence.

The Submitting Author accepts and understands that any supply made under these terms is made by BMJ to the Submitting Author unless you are acting as an employee on behalf of your employer or a postgraduate student of an affiliated institution which is paying any applicable article publishing charge ("APC") for Open Access articles. Where the Submitting Author wishes to make the Work available on an Open Access basis (and intends to pay the relevant APC), the terms of reuse of such Open Access shall be governed by a Creative Commons licence – details of these licences and which Creative Commons licence will apply to this Work are set out in our licence referred to above.

Other than as permitted in any relevant BMJ Author's Self Archiving Policies, I confirm this Work has not been accepted for publication elsewhere, is not being considered for publication elsewhere and does not duplicate material already published. I confirm all authors consent to publication of this Work and authorise the granting of this licence.

Temporal trends and spatial heterogeneity of sanitation facilities in Ethiopia: evidence from the 2005-2019 Demographic and Health Surveys

Jember Azanaw[1]*, Mesenbet Tsegaye[2], Wodage Mesele[3]

[1]Department of Environmental and Occupational Health and Safety, Institute of Public Health, College of Medicine and Health Sciences, University of Gondar, Gondar, Ethiopia

[2]Department of General Surgery, School of Medicine, College of Medicine and Health Sciences, University of Gondar, Gondar, Ethiopia

[3]Department of Orthopaedic and Trauma Surgeon, School of Medicine, College of Medicine and Health Sciences, University of Gondar, Gondar, Ethiopia

***=Corresponding**

jemberazanaw21@gmail.com

Abstract

Background: The main aim of sanitation is to prevent human contact with fecal pathogens to decrease occurrences of diseases. However, no region in the world is on the right track to accomplish Sustainable development goal (SDG) 6.2 for universal access to sanitation. Sub-Sahara Africa, Ethiopia included, is significantly behind in meeting the 2030 SDG 6.2 targets. Hence, this study focused on the spatial and temporal analysis of sanitation in Ethiopia based on four demographic health surveys.

Design: This research was undertaken among households in Ethiopia based on a weighted sample size. Variables with a p-value below 0.2 in bivariable analysis were incorporated into the multivariable analysis. Subsequently, a 95% CI and a p-value < 0.05 were utilized to assess the statistical significance of the final model. Global and local indicators of spatial correlation were done. Statistical analyses were performed using STATA 17, and ArcGIS 10.7 software.

Results: This study includes 13,721 in 2005 EDHS, 16,702 in 2011 EDHS, 16,650 in 2016 EDHS, and in 2019 EDHS 8,663 households. The prevalence of improved sanitation facilities in Ethiopia was 20.46%, 25.61%, 25.86%, and 27.45% based on EDHS 2005, 2011, 2016, and 2019, respectively. Global Moran's I spatial autocorrelations, hotspots, and spatial interpolation analysis indicated the inequality of improved sanitation facilities. Educational status of primary (AOR = 2.43, 95% CI : 2.00, 2.95), secondary (AOR = 2.02, 95% CI : 1.61, 2.54), and higher (AOR = 4.12, 95% CI :3.35, 7.54), watching television (AOR= 5.49, 95% CI: 4.37, 6.89), urban areas (AOR= 9.08, 95% CI: 6.69, 12.33), and region were factors statistically associated with sanitation facilities.

Conclusion: The overall finding of this study concludes a very slow increment in sanitation facilities over time and presence of geographical heterogeneity in Ethiopia. Educational status, watching television, wealth index, community-level education, type of residence, and region were factors statistically associated with sanitation facilities.

Keywords: EDHS, Ethiopia, Improved Sanitation, Spatiotemporal variation

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ✓ The first strength is using multi EDHS data, which enable to show trend analysis of sanitation status in Ethiopia.
- ✓ The second strength is using data from multiple Demographic and Health Surveys ensures a large, nationally representative sample, which increases the generalizability of findings across Ethiopia.
- ✓ The third strength, DHS surveys provide detailed information on the types of sanitation facilities, from basic to improved, which allows for a significance understanding of the sanitation countryside in Ethiopia.
- ✓ The first limitation, there could be social desirable bias since the data were collected through face-to-face interview.
- ✓ The second limitation, while the quantitative analysis identifies trends and spatial disparities, it may not provide insights into the behavioral, and cultural level factors influencing sanitation adoption and usage.

Background

Sanitation refers to the endowment of services and facilities for the safe and clean controlling of human excreta, from the toilet to handling and containment to the final end-use or removal [1]. Sanitation is an integral component of basic human rights comparable to food, shelter, and water and is vital for healthy life [2].

According to the United Nations (UN-2018) report, in the world, around 4.5 billion people had no safe sanitation sand 892 million continue to practice Open Defecation (OD) [3, 4]. Inadequate access to sanitation is a principal reason for poverty in unindustrialized nations because it causes early mortality [5, 6]. The World Health Organization (WHO) estimated in 2019 that over 800,000 people die each year from diarrhea brought on by inadequate water, sanitation, and hygiene (WASH), and that two billion people's drinking water sources were tainted with excrement. Climate change, shifting precipitation patterns, increasing urbanization, and a dearth of practical, context-specific guidance on adaption strategies for sanitation service providers are all predicted to have an influence on the sanitation sector globally [7-9]. Over 70% of the population in Eastern and Southern Africa—340 million people—do not have access to basic sanitation services, while

19% defecate in the open, 179 million use unimproved facilities, and 63 million utilize shared sanitation facilities [10].

The Sustainable Development Goals (SDGs 6.2) aim to guarantee universal access to fair sanitation by 2030 as a result of these issues [11]. SDG 6.2 of the United Nations, which emanated in 2015 from the Millennium Development Goals, aims at equitable access to safe and affordable sanitation for all by 2030 (10). The main aim of this SDG is to prevent human contact with fecal pathogens to decrease occurrences of diseases [12, 13]. However, urban sewer connections are growing at an embarrassingly slow rate of 0.14% per year, and no place in the world is on track to achieve SDG 6.2 for universal access to sanitation [14]. Sub-Saharan African (SSA) nations, in particular, are well behind schedule in achieving SDG 6.2 of the 2030 agenda because of their fast population expansion and inadequate investment in sanitary infrastructure [15, 16]. At the same time, disparities in sub-Saharan African nations' access to sanitary facilities were more noticeable [17]. There are differences between nations, primarily in terms of urban and rural housing, which showed that people in rural areas had far worse access to sanitation than people in urban areas [18]. Low and middle-income nations exhibit this subnational variance in access to improved sanitation facilities, which is defined as the range of values from the unit with the highest level of access to the unit with the lowest level of access or no access at all [19] . Like other developing countries [20] access to sanitation is a challenge across Ethiopia [21], as well as there are disparities among the regions of the country. However, countries have the power to either advance or impede the development of fair access to better sanitary facilities.

Previous studies in Ethiopia were based on a single EDHS or only multilevel analysis or spatial analysis in order to investigate improved sanitation facilities [22]. These researches are unable to demonstrate the trend of better sanitary facilities over time. As in earlier research, the enhanced sanitation source is linked to residence, educational achievement, television viewing, household size, region, and wealth index [23-25]. In order to better understand the progress and geographic variance within Ethiopia, this study concentrated on the spatial and temporal analysis of sanitation facilities based on a combination of different demographic health surveys conducted in 2005, 2010, 2016, and 2019.

Methods

Study area and Data source

The study was carried out in Ethiopia, which consists of two administrative cities (Addis Ababa and Dire-Dawa) and nine geographical regions (Tigray, Afar, Amhara, Oromia, Somali, Benishangul-Gumuz, Southern Nations Nationalities and Peoples Region (SNNPR), Gambella, and Harari). The nation is situated in the Horn of Africa, with coordinates of 40.4897° East longitude and 9.145° North latitude [26]. The four consecutive Ethiopian Demographic and Health Surveys (EDHS 2005, 2011, 2016, and 2019) database survey were used in this investigation. These are therefore population-based surveys that are nationally representative and have sizable sample sizes at various points in time.

The DHS website, https://www.dhsprogram.com/data/dataset_admin/login_main.cfm , provides access to open source EDHS data.

All EDHS samples were a two-stage stratified cluster sample [27], sampling weights were calculated based on sampling probabilities separately for each sampling stage and each cluster. In 2005 surveys, 540 enumeration areas (EAs) (139 urban and 401 rural areas) [28], 2011 EDHS, 624 EAs (187 urban and 437 rural areas) [29], 2016 EDHS 645 EAs (202 in urban areas and 443 in rural areas) [30], and 2019 EDHS 305 EAs (93 in urban areas and 212 in rural areas) [31]were selected using systematic sampling with likelihood proportional to size.

In the second stage of selection, a fixed number of 30 households per cluster were selected with an equal probability of systematic selection from the newly created household listing. The field practice was conducted in Adama in clusters that were not part of the survey sample. Ethiopian public health institute investigators, an ICF technical specialist, an advisor, and representatives from other organizations, including central statistics agency, the Federal Ministry of Health, the World Bank, and USAID, supported the data collection in this EDHS data collection [28].

Among included households, 13,721, 16,702, 16, 650, and 8,663 were successfully interviewed in EDHS 2005, 2011, 2016, and 2019, respectively [28, 30]. Weighted by sampling weight was done to do a reliable statistical analysis. The geographical location data were taken from selected respective Enumeration Areas (EAs).

Study Variables

Outcome variables

The dependent variable was the sanitation facilities. The sanitation type designated as '1' represents 'improved sanitation', which can be accessed through flush/pour flush to piped sewer systems, septic tanks, or pit latrines; ventilated improved pit latrines, composting toilets, or pit latrines with slabs; and '0' represents 'unimproved sanitation' since it includes pit latrines without a platform or slab, hanging latrines or bucket latrines, and open defecation [32-34].

Predictor variables

Individual level variables: sex of household head (male or female), wealth index (poor, middle, and rich), educational status (no education, primary education, secondary education, and higher education), having a television (yes or no) and radio (yes or no) were individual-level predictor variables.

Community level variables: Community level education (lower/higher), the place of residence (urban/rural), community level media exposure (exposed/unexposed), region (Benishangul-Gumuz, Somali, Gambella, Afar, Oromia, SNNPR, Amhara, Tigray, and Harari) and City administration (Addis Ababa, and Dire Dawa).

Data management and analysis

The first step in data handling was downloading the raw datasets from the DHS website. These contained pertinent demographic and socioeconomic factors as well as household-level data on sanitation facilities. Pretests comprising in-class instruction, biomarker training, and field exercises were conducted for ensuring the quality of the data. The field exercise was conducted in clusters, which were not included in the EDHS sample. A debriefing session was held with the pretest field staff, and adjustments to the questionnaires were done based on lessons drawn from the field practice.

Data cleaning techniques included re-coding, removing duplicates, and resolving missing values to get the data ready for analysis. The datasets underwent further processing after data cleaning in order to extract significant predictors and analytic findings. The management approach also ensured that sample weights from the DHS data were appropriately applied to all analyses, taking into account the complex survey design, to ensure nationally representative results. In order to prepare the spatial data, shapefiles of the Ethiopian regions were accessed, and sanitation data was superimposed on them.

Stata Version 17 was utilized to do regression analysis and descriptive statistics. Logistic regression analysis was used to evaluate the relationships between outcome variables and predictor variables because the outcome variables were dichotomous. Multivariable binary logistic regression analysis was performed using bivariate analysis variables that had a p-value of less than 0.2. In the final model, statistical significance was determined by a p-value of less than 0.05 and a 95% confidence interval (CI) [35].

Multilevel Analysis

Model 1 included dependent and individual-level predictors, Model 2 included dependent and community-level predictors, Model 3 included all variables from Models 1 and 2, and Model 0 was a null model with no predictor variables. Random effects were measured using cluster variance (Vc), a proportional change in variance ((PCV $((Vc - Vn)/Vc)$) the intraclass correlation coefficient (ICC$(Vc/(Vc + 3.29)$)), and the median odds ratio (MOR (exp $[(0.95)\sqrt{Vc}]$)) [36, 37]. The goodness-of-fit for all models was evaluated using AIC, BIC, and Deviance. Then the model with the lower value of deviance, AIC, and BIC, was demonstrating the best-fit model [38]. As well as Multicollinearity, the effect of independent variables was measured using the variance inflation factor (VIF).

Spatial and temporal analysis

Spatial Autocorrelation

In order to examine geographical variability, a geospatial study of the distribution of sanitary facilities was carried out using ArcGIS version 17. The best essential instruments for access to improved sanitation facilities within the designated term are both global and local indicators of spatial correlation, which may be used to investigate the geographical distribution.

Global autocorrelations

Global autocorrelations analysis was performed in order to identify geographical variations in access to improved sanitation facilities. To determine whether the discrepancy is the result of non-random/dispersion or the clustering effect, global spatial autocorrelation (Moran's I index) was employed [39, 40]. Additionally, a basic exploratory spatial analysis was conducted to determine the country's geographic reliance distribution and the existence of better sanitary facilities. Places with similar access to sanitation tended to cluster together when Moran's I value was positive, while places with varying levels of sanitation were near one another when it was negative.

Local statistical analysis

Since global autocorrelations show a clustering effect (positive spatial autocorrelation) on the availability of sanitary facilities nationwide, more research utilizing figures and maps is required. In order to highlight the previously mentioned use of global autocorrelations (cluster effect) on access to sanitary facilities and to find patterns of geographical variation, hotspot analysis (Gettis-Ord Gi*) was carried out. The spatial patterns of the dependent variables (access to sanitary facilities) were described using cluster and outlier analysis (Anselin local Moran is I). Since this cluster and outlier analysis allows for the identification of groups and regions where the discrepancies occur, it was utilized to confirm and accompany the display of extremes (the hotspot and cold spot) [41].

Additionally, Kriging interpolation techniques were employed to visualize and forecast sanitary availability in locations that were not specifically studied. Kriging provided a continuous surface of sanitation access across Ethiopia and generated more precise spatial projections by taking into account both the distance between survey points and the degree of spatial autocorrelation. This allowed us to pinpoint the regions that have experienced the greatest improvements in cleanliness over time as well as those with the lowest coverage.

The authors used graphical presentation to do temporal trend analysis in order to examine the evolution of sanitation access through time. The combination of trend and spatial studies allowed for a thorough understanding of the regional heterogeneity and temporal evolution of sanitation access in Ethiopia between 2005 and 2019.

Results

Socio-demographic characteristics of the study population

This study include 13,721 in 2005 EDHS, 16,702 in 2011 EDHS, 16,650 in 2016 EDHS, and in 2019 EDHS 8,663 participants. The higher percentage of study participants in all EDHS data sets had no education (63.59%, 55.74%, 52.06%, and 47.65%, respectively). According to Table 1, the majority of participants in the 2005 EDHS, the 2011 EDHS, the 2016 EDHS, and the 2019 EDHS—88.30%, 81.68%, 76.98%, and 77.10%, respectively did not own a television (Table 1).

Table 1. Socio-demographic characteristics of study Participants in Ethiopia

Variables	EDHS 2005 (N= 13,721) Frequency (%)	EDHS 2011 (N=16,702) Frequency (%)	EDHS 2016 (N= 16,650) Frequency (%)	EDHS 2019 (N= 8,663) Frequency (%)
Sex of HHH				
Male	10,243(74.65)	11,906(71.28)	11,413(68.55)	6,291(72.62)
Female	3,478(25.35)	4,796 (28.72)	5,237(31.45)	2,372(27.38)
Age of HHH				
<30	3,428(24.98)	4,823(28.88)	4,257(25.57)	2,520(29.09)
30-40	3,501(25.52)	4,116(24.64)	4,132(24.82)	2,287(26.40)
41-54	3,756(27.37)	4,047(24.23)	4,230(25.41)	1,717(19.82)
>54	3,036(22.13)	3,716(22.25)	4,031(24.21)	2,139(24.69)
Educational status of HHH				
No education	8,725(63.59)	9,309(55.74)	8,668(52.06)	4,128(47.65)
Primary	2,705(19.71)	5,020(30.06)	4,658(27.98)	2,715(31.34)
Second	1,754(12.78)	1,189(7.12)	1,686(10.12)	963(11.12)
Higher	495(3.61)	1,140(6.83)	1,580(9.49)	857(9.89)
Wealth index				
Poor	5,393(39.30)	6,506(38.95)	7,024(42.19)	3,498(40.38)
Middle	2,055(14.98)	2,364(14.15)	2,057(12.35)	1,285(14.83)
Rich	6,273(45.72)	7,832(46.89)	7,569(45.46)	3,880(44.79)
Share toilet with other households				
Yes	2,712(45.72)	4,467(46.12)	4,727(43.83)	2,222 (38.18)
No	3,204(54.01)	5,204(53.73)	6,059(56.17)	3,598(61.82)
Having radio				
No	8,157(59.45)	9,658(57.83)	11,680(70.15)	6,170 (71.22)
Yes	5,560(40.52)	7,040(42.15)	4,970(29.85)	2,493(28.78)
Having Television				
No	12,116(88.30)	13,643(81.68)	12,818(76.98)	6,679 (77.10)
Yes	1,601(11.67)	3,051(18.27)	3,832(23.02)	1,984(22.90)
Community-level media exposure				
Unexposed	8,105(59.07)	8,973(53.72)	10,024(60.20)	5,195(59.97)

Exposed	5,616(40.93)	7,729(46.28)	6,626(39.80)	3,468(40.03)
Community-level educational status				
Lower	8,730(63.63)	9,309(55.74)	8,726(52.41)	4,308(49.73)
Higher	4,991(36.37)	7,393(44.26)	7,924(47.59)	4,355(50.27)
Residence				
Urban	3,666(26.72)	5,112(30.61)	5,232(31.42)	2,645(30.53)
Rural	10,055(73.28)	11,590(69.39)	11,418(68.58)	6,018(69.47)
Region				
Tigray	1,282(9.34)	1,730(10.36)	1,734(10.41)	714(8.24
Afar	806(5.87)	1,267(7.59)	1,220(7.33)	664 (7.66)
Amhara	2,066(15.06)	2,071(12.40)	1,902(11.42)	1,007(11.62)
Oromia	2,155(15.71)	2,165(12.96)	1,988(11.94)	1,018(11.75)
Somali	796(5.80)	975(5.84)	1,564(9.39)	657(7.58)
Benishangul-Gumuz	869(6.33)	1,323(7.92)	1,280(7.69)	734(8.47)
SNNPR	1,933(14.09)	2,045(12.24)	1,897(11.39)	1,017(11.74)
Gambella	820(5.98)	1,215(7.27)	1,280(7.69)	693(8.00)
Harari	904(6.59)	1,201(7.19)	1,135(6.82)	719(8.30)
Addis Ababa	1,333(9.72)	1,524(9.12)	1,489(8.94)	702(8.10)
Dire Dawa	757(5.52)	1,186(7.10)	1,161(6.97)	738(8.52)
Key: EDHS= Ethiopian demographic health survey, HHH=Household head, SNNPR= South nation Nationalities Republic				

Trends of Sanitation facilities in Ethiopia

Figure 1 below presented that the trend of improved sanitation facilities in Ethiopia was 20.46%, 25.61%, 25.86%, and 27.45% based on EDHS 2005, 2011, 2016, and 2019, respectively (figure 1).

Factors Associated with Sanitation Facilities Accessibility

The odds of accessibility to improved sanitation facilities among participants with educational status of primary, secondary, and higher were 2.43 (AOR = 2.43, 95% CI :(2.00, 2.95)), 2.02 (AOR = 2.02, 95% CI :(1.61, 2.54)), and 4.12 (AOR = 4.12, 95% CI :(3.35, 7.54) times more likely respectively, compared to those with no education.

Study participants with wealth status of the middle, and rich were 1.49 (AOR = 1.49, 95% CI :(1.21, 1.83)), and 3.15 (AOR = 3.15, 95% CI :(2.55, 3.89)) times more likely in the odds of accessing improved sanitation facilities respectively, compared to those counterparts poor.

The odds of accessing improved sanitation facilities among study participants watched television were 5.49 (AOR= 5.49, 95% CI: (4.37, 6.89)) more likely compared to counterparts who did no watching television.

Community-level education was a statistically significant predictor variable. The odds of accessing improved sanitation facilities among Communities with higher educational levels were 3.90 (AOR= 3.90, 95% CI: (3.15, 4.82) times more likely compared to the community with lower education.

The chance of accessing improved sanitation facilities among communities exposed to media was 5.61 (AOR= 5.61, 95% CI: (3.84, 10.09)) times more likely than in the community unexposed to the media.

The odds of accessibility-improved sanitation facilities among the study population living in urban areas were 9.08 (AOR= 9.08, 95% CI: (6.69, 12.33) times more likely compared to the o study population living in rural areas.

Communities across various regions, including Tigray (54% less likely, AOR=0.46; 95% CI: 0.37, 0.57), Afar (33% less likely, AOR=0.67; 95% CI: 0.51, 0.86), Somali (77% less likely, AOR=0.23; 95% CI: 0.18, 0.29), Amhara (60% less likely, AOR=0.40; 95% CI: 0.32, 0.49), Benishangul Gumuz (37% less likely, AOR=0.63; 95% CI: 0.49, 0.80), Gambella (55% less likely, AOR=0.45; 95% CI: 0.35, 0.57), Harari (36% less likely, AOR=0.64; 95% CI: 0.52, 0.80), SNNRP (72% less likely, AOR=0.28; 95% CI: 0.22, 0.34), and Dire Dawa (72% less likely, AOR=0.28; 95% CI: 0.22, 0.35), exhibit decreased access to improved sanitation facilities compared to communities in Addis Ababa.

The median odds ratio (MOR), proportion change in variance (PCV), and intra-cluster correlation coefficient (ICC) were used to illustrate the random changes in cleanliness. According to the null model's ICC, variations through cluster regions accounted for 67.65% of the overall variability in access to improved sanitation services. According to Models 1 and 2, individual and community-level characteristics accounted for 59.74% and 26.35% of the Proportion Change in Variance (PCV) of the variation in the communities' access to better sanitation, respectively. If two areas were chosen at random, the MOR between the area with the greatest access to improved sanitary facilities and the region with the least access was 7.07.

Using the lowest AIC, DIC, and Deviance values, the model statistics showed a fair fit. Consequently, the best-fit model was validated by the final model's lowest AIC; DIC, and Deviance, which were 11,151.08, 11,282.33, and 11,117.0824, respectively (Table 2 and Table 3)

Table 2. Multilevel binary logistic regression analysis of predictors towards accessibility of sanitation facilities in Ethiopia, EDHS 2011

Variables	Model 0 (Null model)	Model 1 AOR (95% CI)	Model 2 AOR (95% CI)	Model 3 AOR (95% CI)
Individual level Factors				
Sex of HHH				
Male		0.97(0.82,1.04)		1.01(0.84,1.11)
Female		1	1	1
Age of HHH				
<30		0.97(0.94,1.01)		0.96 (0.20,2.34)
30-40		0.57(0.35,2.02)		1.49(0.13,2.41)
41-54		0.43(0.22,0.61)		1.17(0.86,1.59)
>54		1	1	1
Educational status				
No education		1		1
Primary		3.23 (2.63,3.96)**		2.43(2.00,2.95)**
Secondary		6.36(5.26,7.67)**		2.02(1.61,2.54)**
Higher		8.11 (7.16,9.19)*		4.12(3.35,7.54)**
Wealth index				
Poor		1		1
Middle		2.96 (2.34,4.24)**		1.49 (1.21,1.83)**
Rich		5.48 (3.45,5.89)**		3.15(2.55,3.89)**
Having television				
No		1		1
Yes		4.81(4.16,5.56)**		5.49(4.37,6.89)**
Community level factors				
Community level education				
Higher			6.50(5.82,7.27)**	3.90(3.15,4.82)**
Lower			1	1
Community-level media exposure				
Exposed			6.07(5.42,6.81)**	5.61(3.84,10.09)**
Unexposed			1	1
Type of residence				
Urban			16.74(11.85, 23.65)**	9.08(6.69,12.33)**
Rural			1	1
Region				

Tigray			0.50(0.41,0.62)**	0.46(0.37,0.57)**
Afar			0.86(0.67,1.09)	0.67(0.51,0.86)*
Amhara			0.43(0.35,0.53)**	0.40(0.32,0.49)**
Oromia			0.89 (0.72,1.09)	0.90(0.73,1.12)
SNNRP			0.25(0.20,0.31)*	0.28(0.22,0.34)**
Somali			0.33(0.26,0.41)**	0.23(0.18,0.29)**
Benishangul Gumuz			0.74(0.59,0.94)*	0.63(0.49,0.80)**
Gambella			0.51(0.41,0.64)**	0.45(0.35,0.57)**
Harari				0.64(0.52.0.80)**
Addis Ababa			1	1
Dire Dawa			0.25(0.21,0.31)**	0.28(0.22,0.35)**
VIF		2.35	2.27	2.05

1= reference, **P-value < 0.001(Adjusted OR), *P-value < 0.05(Adjusted OR), AIC=Akaike's information criteria, BIC=Bayesian information criteria, HHH =household head, HH=household, Model 0 (Null model) was fitted without predictor variables. ; Model 1 is adjusted for individual-level variables. Model 2 is adjusted for community-level variables; Model 3 is the final model adjusted for both individual- and community-level predictors.

Table 3: Measures variation metrics and the model fitness test statistics used for included models

Metrics	**Model 0 (Null model)**	**Model 1**	**Variables**	**Model 0 (Null model)**
Variance	6.88(5.84,8.10)	2.77(2.30,3.32)	2.04(1.71,2.44)	1.97(1.65,2.35)
MOR	7.07	4.35	3.82	3.78
PCV	Reference	59.74%	26.35%	3.43 %
ICC	0.6765	0.4571	0.3827	0.3745
Model fitness test statistics				
AIC	12204.07	11338.86	11610.79	11151.08
BIC	12219.51	11454.67	11734.32	11282.33
Deviance	12,200.0736	11,323.6174	11611.497	11,117.0824

Analysis of spatial heterogeneity

Spatial autocorrelation (Moran's I)

All EDHS were clustered in obtaining better sanitation facilities through Ethiopia, according to global Moran's I spatial autocorrelations positive z-scores (with the z-scores of 2005 EDHS

2.374393, 2011 EDHS 7.067996, 2016 EDHS 8.9374285, and 2019 EDHS 36.511348) (Figures 2,3,4,5).

Hot and cold spot analysis (Getis-Ord Gi*)

All EDHS in Ethiopia showed the same trend in the spatial distribution of improved sanitation facilities, according to hot and cold spot analysis. The percentage of EDHS that had access to improved sanitation was much lower in the majority of the country, according to the numbers below, and it was higher only in Addis Ababa and Dire Dawa (Figures 6, 7, 8, 9).

Spatial interpolation

The study used spatial Kriging interpolation analysis to determine which parts of the country had less improved sanitation accessibility. As illustrated in the figures below, the red color denotes areas of the country (Addis Ababa and Dire Dawa) with greater access to improved sanitation facilities, while the green color (the majority of the country) indicates areas with lower access (figures 10, 11, 12, 13).

Discussion

Using multilevel and geographical analysis techniques on Ethiopia's 2005-2019 EDHS datasets, the studies are unique in their thorough investigation of geographic variances and temporal changes in sanitation facilities. Their thorough investigation into the ways in which access to sanitation infrastructure has changed over time and differed among Ethiopia's many regions has produced a fresh contribution by illuminating hitherto unseen trends and inequalities. In order to reduce inequities and enhance overall sanitation access in Ethiopia, this research highlights locations for focused interventions and offers insightful information about the dynamic nature of sanitation service.

To hygienically isolate human excreta from human touch, which causes many infectious diseases, improved sanitation facilities must be accessible in a sustainable and fair manner [42]. This study's primary goal was to examine, using four consecutive EDHS datasets, the spatiotemporal variation and factors linked to improved sanitation facilities that are accessible in Ethiopia. According to these findings, the percentage of households with access to improved sanitation facilities was 20.46% in EDHS 2005, 25.61% in EDHS 2011, 25.86% in EDHS 2016, and 27.45% in EDHS 2019. The rise from 2011 to 2016 was only 0.25%, but the increase from 2005 to 2011 was 5.15%.

These results indicate that, between 2005 and 2019, Ethiopia's access to better sanitation facilities improved at relatively modest steady rates. This outcome is consistent with other research showing that certain nations have made significant strides toward SDG 6, while others look to be stuck at low levels of sanitation coverage with little or no development [43]. Such setback with little or no development levels of access to improved sanitation facilities is the experience of developing countries including Ethiopia [44]. The construction of sanitation facilities may receive less attention from the government and non-governmental organizations because of international environmental change, poverty, and the nation's instability brought on by the trauma of the civil war. This result is in line with previously conducted research conducted global [33, 45-49].

Based on four EDHS datasets, the geographical analysis's results for Global Moran's autocorrelation, hotspot, cluster, and Kriging revealed significant differences in Ethiopia's access to better sanitation services. Among other regions of the nation, Addis Ababa and Dire Dawa were identified as high hot spots for improved sanitation facilities based on the findings of the Kriging analysis and hot spot analysis conducted in all EDHS. This result demonstrated that access to better sanitation facilities varies significantly by region across the nation. It ran counter to aim 6.2 of the 2030 Sustainable Development Goals, which is to "end open defecation and provide access to adequate and equitable sanitation for all"[50]. This variation could be the difference in economic growth, overpopulation growth, unplanned urbanization, and inaccessibility of infrastructure, government overload towards other burning daily tasks, socio-political instability, awareness, and adaptability towards sanitation facilities.

The household head's educational level, television ownership, and wealth index were individual-level predictors linked to access to better sanitation facilities, while community-level predictor variables included education, media exposure, residence type, and region.

Household heads with higher levels of education were more likely to have access to better sanitary facilities than heads with lower levels of education. Ethiopia, Kenya, West and Central Africa, Bangladesh, Benin, and Vietnam have all conducted research that corroborate this conclusion [51-54]. The community with higher education accessed improved sanitation facilities than part of the community with lower education. This finding was in line with other previous studies conducted in different parts of the world [23, 55, 56]. Other possible explanation for this discrepancy is that more people that are educated may be aware of the link between better sanitary facilities and health. If so, compared to household heads with lower educational background, they are excited to have these sanitation services.

Access to better sanitary facilities was correlated with wealth status in a proportionate manner. Compared to the poorest homes, wealthy and middle-class households were more likely to have access to better sanitary facilities. The research conducted in Ghana, Benin, Vietnam, and Eswatini supports this conclusion [52, 57-59]. This discrepancy may result from the development of better sanitation facilities like septic tanks and pour-flush toilets; the impoverished may find it difficult to afford slab pit latrines and composting toilets.

When all other factors were held constant, families with television had a higher chance of having access to better sanitary facilities than those without. This may be because residents spent a lot of time watching television, which serves as a visual information source about topics like how better cleanliness can prevent the spread of disease. The other statistically significant predictor of access to better sanitation facilities at the community level was media exposure. In Ethiopia, householders who were exposed to community-level media—whether it was radio, television, or both—were more likely to have access to better sanitation. This result was consistent with earlier research carried out in Ethiopia [22, 23], and sub-Saharan Africa [60].

Compared to households in rural areas, urban households are more likely to have access to better sanitation services. A prior Ethiopian study that showed Ethiopia's rural communities are severely trailing behind in the battle to achieve SDGs supported this issue 6.2 [43] and the other study done in Vietnam [57]. Different amounts of improved sanitation facilities were available to households located in different parts of Ethiopia. Addis Ababa, the capital, was better to the other parts of the country. This finding is aligns with the studies done in Kenya [61], Nepal [62] and WHO, UNICEF, 2019 report [63] which indicated that persist disparities in access to WASH services in rural versus urban settings. This discrepancy could be explained by the fact that Addis Ababa serves as both the nation's capital and the headquarters of the Africa Union, providing access to better infrastructure, including sanitary facilities. Low socioeconomic position, regional sociopolitical instability, ignorance, and a lack of ability to adjust to sanitary facilities could all be contributing factors[64].

The self-report nature of data collection, which leads to interviewer bias, social acceptability bias, recall bias and incompleteness of the recent mini demographic health survey (EDHS 2019), could be potential sources of errors and the limitations of this study.

Conclusion

According to the study's general findings, Ethiopia's access to sanitary facilities has gradually increased over time. Additionally, there was geographical variation in the country's accessibility of improved sanitation facilities that was statistically significant. To achieve the suggested goal, the rate of advancement in universal access to sanitary facilities (SDG 6.2) in 2030 should be accelerated. The following parameters were statistically linked to the accessibility of sanitation facilities in Ethiopia: region, type of habitation, wealth index, community-level education, community-level media exposure, educational status, and television viewing. This study recommended that local and international organizations focus on solutions that allow for the advancement of universal access to sanitary facilities, particularly in developing nations.

Abbreviations

AIC: Akaike's Information Criterion, AOR: Adjusted Odds Ratio, CI: Confidence Interval, DHS: Demographic and Health Survey, EAs: Enumeration Areas, EDHS: Ethiopian Demographic and Health Survey, ICC: Intra Class Correlation, MOR: Median Odd Ratio, PCV: Proportional Change in Variance

Declarations

Ethics approval and consent to participate

This study was based on secondary data from the Ethiopian Demographic and Health Survey and secured the permission letter from the main Demographic Health and Survey. Permission for data access was obtained from a major Demographic and Health Survey through an online request at (https://www.dhsprogram.com/data/dataset_admin/login_main.cfm.). Participant consent was not directly obtained since authors used secondary data.

Patient and Public Involvement

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

This research was done using a publicly available dataset found at https://www.dhsprogram.com/data/dataset_admin/login_main.cfm after approval from Data Archivist of the Demographic and Health Surveys (DHS) Program.

Competing interests

There is no any competing interest.

Funding

The authors have not received any specific grant for this research from public, commercial, or not-for-profit funding agencies

Authors' contributions

JA Engaged in data curation**.** JA Conducted the statistical analysis. JA**,** MT, and WM involved in investigation of the study. JA and WM had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. JA, MT, and WM done validation and visualization. JA and WM conducted the write-up and drafted the manuscript. All authors involved in review & editing. JA is responsible for the overall content as guarantors.

Acknowledgments

The author acknowledges the Ethiopian Central Statistical Agency for providing them with the data and shape files for this study.

References

1. Organization, W.H., World health statistics overview 2019: monitoring health for the SDGs, sustainable development goals. 2019, World Health Organization.
2. Erridge, M., Human Right to Sanitation. Clean Water and Sanitation, 2020: p. 1-11.
3. Water, U., Sustainable Development Goal 6 Synthesis Report on Water and Sanitation. United Nations. 2018.
4. Carvalho, D.M., Tripartite organizational partnerships and the wickedness of the water and sanitation sector in Brazil: an institutional analysis. 2019.

5. Kumwenda, S., Challenges to hygiene improvement in developing countries. Vol. 1. 2019: IntechOpen London, UK.

6. Peter, A.K. and U. Umar, Combating diarrhoea in Nigeria: the way forward. J Microbiol Exp, 2018. **6**(4): p. 191-197.

7. Oates, N., et al., Adaptation to climate change in water, sanitation and hygiene. London: Overseas Development Institute.[Google Scholar], 2014.

8. Clemenz, N., R. Boakye, and A. Parker, Rapid Climate Adaption Assessment (RCAA) of water supply and sanitation services in two coastal urban poor communities in Accra, Ghana. Journal of Water and Climate Change, 2020. **11**(4): p. 1645-1660.

9. Hyde-Smith, L., et al., Climate change impacts on urban sanitation: a systematic review and failure mode analysis. Environmental science & technology, 2022. **56**(9): p. 5306-5321.

10. Morgan, C., et al., Water, sanitation, and hygiene in schools: Status and implications of low coverage in Ethiopia, Kenya, Mozambique, Rwanda, Uganda, and Zambia. International journal of hygiene and environmental health, 2017. **220**(6): p. 950-959.

11. Dickin, S., et al., Sustainable sanitation and gaps in global climate policy and financing. NPJ Clean Water, 2020. **3**(1): p. 24.

12. Obani, P., SDG 6.2 and the right to sanitation: exploring the complementarities and incoherence. UNIPORT Journal of International and Comparative Law 1, 2020: p. 1-17.

13. Mattos, K.J., et al., Household water, sanitation, and hygiene practices impact pathogen exposure in remote, rural, unpiped communities. Environmental Engineering Science, 2021. **38**(5): p. 355-366.

14. Corburn, J., Water and sanitation for all: Citizen science, health equity, and urban climate justice. Environment and Planning B: Urban Analytics and City Science, 2022. **49**(8): p. 2044-2053.

15. Tykhomyrova, T., V. Sebko, and V. Babenko, Sustainable development. 2022.

16. Hutton, G. and M. Varughese, The costs of meeting the 2030 sustainable development goal targets on drinking water, sanitation, and hygiene. 2016.

17. Organization, W.H., Progress on household drinking water, sanitation and hygiene 2000-2020: five years into the SDGs. 2021.

18. Walsh, P.P., E. Murphy, and D. Horan, The role of science, technology and innovation in the UN 2030 agenda. Technological Forecasting and Social Change, 2020. **154**: p. 119957.

19. Campos Nonato, I., Mapping geographical inequalities in access to drinking water and sanitation facilities in low-income and middle-income countries, 2000–17. 2020.

20. Prüss-Ustün, A., et al., Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: an updated analysis with a focus on low-and middle-income countries. International journal of hygiene and environmental health, 2019. **222**(5): p. 765-777.
21. Baye, D., Sustainable development goals (SDG) target 6.2 in Ethiopia: challenges and opportunities. Open Access Library Journal, 2021. **8**(5): p. 1-28.
22. Demsash, A.W., et al., Spatial and multilevel analysis of sanitation service access and related factors among households in Ethiopia: using 2019 Ethiopian national dataset. PLOS Global Public Health, 2023. **3**(4): p. e0001752.
23. Azanaw, J., et al., A multilevel analysis of improved drinking water sources and sanitation facilities in Ethiopia: Using 2019 Ethiopia mini demographic and health survey. Frontiers in Public Health, 2023. **11**.
24. Gebremichael, S.G., et al., Determinants of water source use, quality of water, sanitation and hygiene perceptions among urban households in North-West Ethiopia: A cross-sectional study. Plos one, 2021. **16**(4): p. e0239502.
25. Adil, S., M. Nadeem, and I. Malik, Exploring the important determinants of access to safe drinking water and improved sanitation in Punjab, Pakistan. Water Policy, 2021. **23**(4): p. 970-984.
26. Dwivedi, R., K. Sreenivas, and K. Ramana, Cover: Land-use/land-cover change analysis in part of Ethiopia using Landsat Thematic Mapper data. International Journal of Remote Sensing, 2005. **26**(7): p. 1285-1287.
27. Anteneh, Z.A. and J.-P. Van Geertruyden, Spatial variations and determinants of anemia among under-five children in Ethiopia, EDHS 2005–2016. Plos one, 2021. **16**(4): p. e0249412.
28. Central Statistical Agency Addis Ababa, E., Ethiopia Demographic and Health Survey 2005. 2005.
29. Central Statistical Agency Addis Ababa, E.I.I.C., Maryland, USA, Ethiopia Demographic and Health Survey. 2011.
30. Central Statistical Agency Addis Ababa, E., ETHIOPIA Demographic and Health Survey. 2016.
31. Ethiopian Public Health Institute Addis Ababa Federal Ministry of Health Addis Ababa The DHS Program ICF Rockville, M., USA, ETHIOPIA Mini Demographic and Health Survey 2019.
32. Armah, F.A., et al., Access to improved water and sanitation in sub-Saharan Africa in a quarter century. Heliyon, 2018. **4**(11): p. e00931.
33. Wang, C., et al., Geographic inequalities in accessing improved water and sanitation facilities in Nepal. International journal of environmental research and public health, 2019. **16**(7): p. 1269.
34. Davis, J., et al., Improving access to water supply and sanitation in urban India: microfinance for water and sanitation infrastructure development. Water Science and Technology, 2008. **58**(4): p. 887-891.

35. Sun, G.-W., T.L. Shook, and G.L. Kay, Inappropriate use of bivariable analysis to screen risk factors for use in multivariable analysis. Journal of clinical epidemiology, 1996. **49**(8): p. 907-916.

36. Goicolea, I. and M. San Sebastian, Unintended pregnancy in the amazon basin of Ecuador: a multilevel analysis. International journal for equity in health, 2010. **9**: p. 1-11.

37. Schootman, M., et al., Geographic clustering of adequate diagnostic follow-up after abnormal screening results for breast cancer among low-income women in Missouri. Annals of epidemiology, 2007. **17**(9): p. 704-712.

38. Li, F., et al., Model selection methods for mixture dichotomous IRT models. Applied Psychological Measurement, 2009. **33**(5): p. 353-373.

39. Roll, U., et al., Onset of a pandemic: characterizing the initial phase of the swine flu (H1N1) epidemic in Israel. BMC infectious diseases, 2011. **11**(1): p. 1-13.

40. Blake, S.B., Exploring Spatial Relationships Among Dairy Farms, Drinking Water Quality, and Maternal-Child Health Outcomes in the San Joaquin Valley. 2014: University of California, Davis.

41. Sánchez-Martín, J.-M., J.-I. Rengifo-Gallego, and R. Blas-Morato, Hot spot analysis versus cluster and outlier analysis: An enquiry into the grouping of rural accommodation in Extremadura (Spain). ISPRS International Journal of Geo-Information, 2019. **8**(4): p. 176.

42. Ritchie, H. and M. Roser, Clean water and sanitation. Our world in data, 2021.

43. Bankole, A.O., et al., Factors affecting sanitation coverage in three income levels and potential toward achieving SDG 6.2. Water Policy, 2023. **25**(2): p. 146-176.

44. Organization, W.H., National systems to support drinking-water: sanitation and hygiene: global status report 2019: UN-Water global analysis and assessment of sanitation and drinking-water: GLAAS 2019 report. 2019.

45. Azage, M., A. Motbainor, and D. Nigatu, Exploring geographical variations and inequalities in access to improved water and sanitation in Ethiopia: mapping and spatial analysis. Heliyon, 2020. **6**(4).

46. Pullan, R.L., et al., Geographical inequalities in use of improved drinking water supply and sanitation across sub-Saharan Africa: mapping and spatial analysis of cross-sectional survey data. PLoS medicine, 2014. **11**(4): p. e1001626.

47. Armah, F.A., et al., Access to improved water and sanitation in sub-Saharan Africa in a quarter century. Heliyon, 2018. **4**(11).

48. Yu, W., et al., A global perspective on drinking-water and sanitation classification: an evaluation of census content. PLoS One, 2016. **11**(3): p. e0151645.

49. Ghosh, P., M. Hossain, and A. Alam, Water, sanitation, and hygiene (WASH) poverty in India: a district-level geospatial assessment. Regional Science Policy & Practice, 2022. **14**(2): p. 396-417.

50. Hueso, A., Is 'access to adequate and equitable sanitation' for all by 2030 achievable? Perspectives from sector experts on what needs to change to realise the Sustainable Development Goal. Journal of Water, Sanitation and Hygiene for Development, 2016. **6**(4): p. 650-657.

51. Koskei, E.C., et al., Effect of socio-economic factors on access to improved water sources and basic sanitation in Bomet Municipality, Kenya. Research Journal of Environmental and Earth Sciences, 2013. **5**(12): p. 714-719.

52. Gaffan, N., et al., Household access to basic drinking water, sanitation and hygiene facilities: secondary analysis of data from the demographic and health survey V, 2017–2018. BMC Public Health, 2022. **22**(1): p. 1-16.

53. Andualem, Z., et al., Households access to improved drinking water sources and toilet facilities in Ethiopia: a multilevel analysis based on 2016 Ethiopian Demographic and Health Survey. BMJ open, 2021. **11**(3): p. e042071.

54. Simen-Kapeu, A., et al., Prevalence of diarrhoea, acute respiratory infections, and malaria over time (1995-2017): A regional analysis of 23 countries in West and Central Africa. Journal of global Health, 2021. **11**.

55. Agbadi, P., E. Darkwah, and P.L. Kenney, A multilevel analysis of regressors of access to improved drinking water and sanitation facilities in Ghana. Journal of environmental and public health, 2019. **2019**.

56. Kong, Y.-L., et al., Socio-economic factors related to drinking water source and sanitation in Malaysia. International Journal of Environmental Research and Public Health, 2020. **17**(21): p. 7933.

57. Tuyet-Hanh, T.T., et al., Household trends in access to improved water sources and sanitation facilities in Vietnam and associated factors: findings from the Multiple Indicator Cluster Surveys, 2000–2011. Global Health Action, 2016. **9**(1): p. 29434.

58. Simelane, M.S., et al., Determinants of households' access to improved drinking water sources: a secondary analysis of eswatini 2010 and 2014 multiple indicator cluster surveys. Advances in Public Health, 2020. **2020**: p. 1-9.

59. Akpakli, D.E., et al., Determinants of access to improved sanitation facilities in rural districts of southern Ghana: evidence from Dodowa Health and Demographic Surveillance Site. BMC research notes, 2018. **11**(1): p. 1-7.

60. Seidu, A.-A., et al., A multilevel analysis of individual and contextual factors associated with the practice of safe disposal of children's faeces in sub-Saharan Africa. Plos one, 2021. **16**(8): p. e0254774.

61. Health, M.o., Kenya environmental sanitation and hygiene strategic framework 2016–2020. 2015.

62. Dhital, S.R., et al., Prevalence and Correlates of Water, Sanitation, and Hygiene (WASH) and Spatial Distribution of Unimproved WASH in Nepal. International journal of environmental research and public health, 2022. **19**(6): p. 3507.

63. Organization, W.H., Progress on household drinking water, sanitation and hygiene 2000-2017: special focus on inequalities. 2019: World Health Organization.

64. Deshpande, A., et al., Mapping geographical inequalities in access to drinking water and sanitation facilities in low-income and middle-income countries, 2000–17. The Lancet Global Health, 2020. **8**(9): p. e1162-e1185.

Figure 1: The proportion of sanitation facilities accessibility in Ethiopia using the four EDHS.

Figure 2: Global Spatial autocorrelation analysis of accessibility of improved sanitation facilities in Ethiopia, EDHS 2005.

Figure 3: Global Spatial autocorrelation analysis of accessibility of improved sanitation facilities in Ethiopia, EDHS 2011

Figure 4: Global Spatial autocorrelation analysis of accessibility of improved sanitation facilities in Ethiopia, EDHS 2016

Figure 5: Global Spatial autocorrelation analysis of accessibility of improved sanitation facilities in Ethiopia, EDHS 2019

Figure 6: Hot and cold spot analysis of accessibility of improved sanitation facilities in Ethiopia based on the dataset of EDHS 2005

Figure 7: Hot and cold spot analysis of accessibility of improved sanitation facilities in Ethiopia based on the dataset of EDHS 2011

Figure 8: Hot and cold spot analysis of accessibility of improved sanitation facilities in Ethiopia based on the dataset of EDHS 2016

Figure 9: Hot and cold spot analysis of accessibility of improved sanitation facilities in Ethiopia based on the dataset of EDHS 2019

Figure 10: Kriging interpolation analysis result of improved sanitation facilities accessibility in Ethiopia based on EDHS 2005

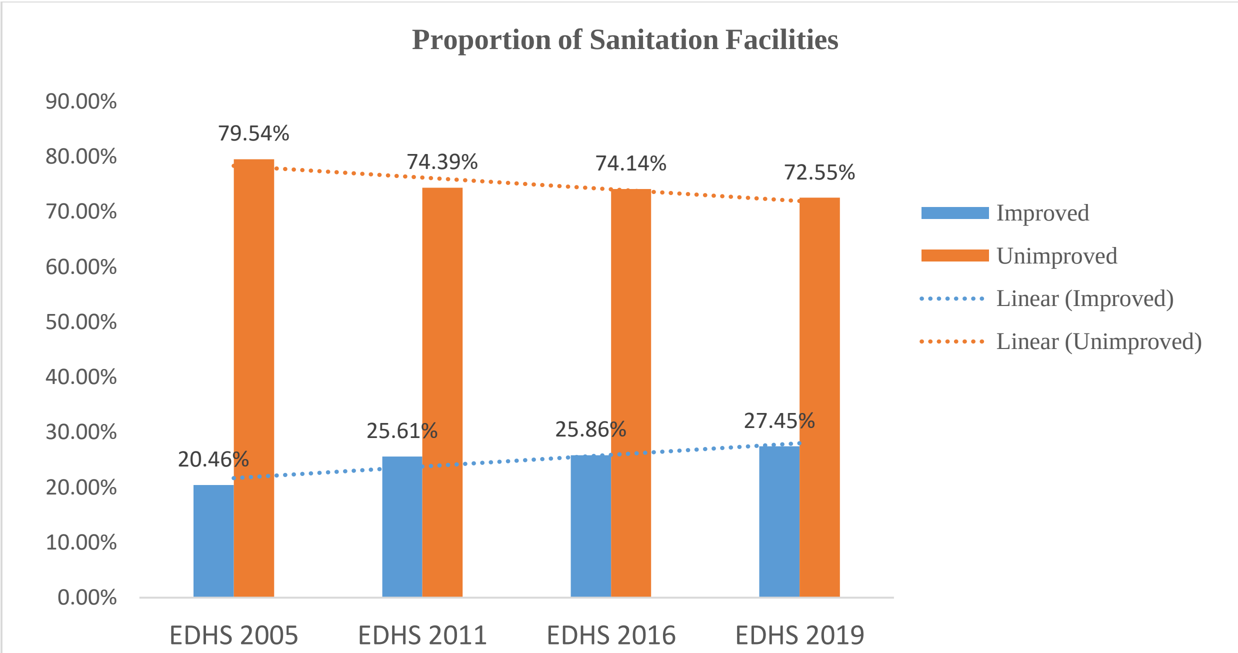
592 Figure 11: Kriging interpolation analysis result of improved sanitation facilities accessibility in
593 Ethiopia based on EDHS 2011

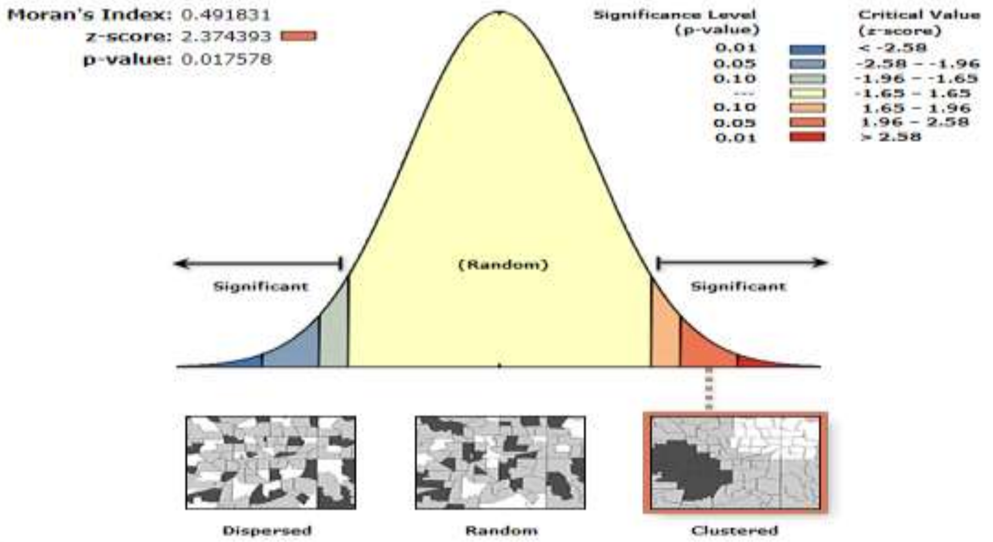
594 Figure 12: Kriging interpolation analysis result of improved sanitation facilities accessibility in
595 Ethiopia based on EDHS 2016

596 Figure 13: Kriging interpolation analysis result of improved sanitation facilities accessibility in
597 Ethiopia based on EDHS 2019

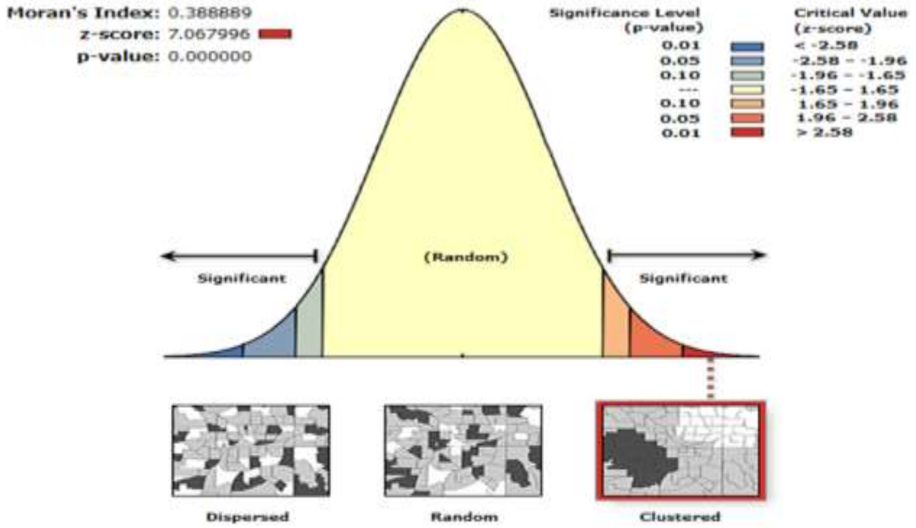
598

599

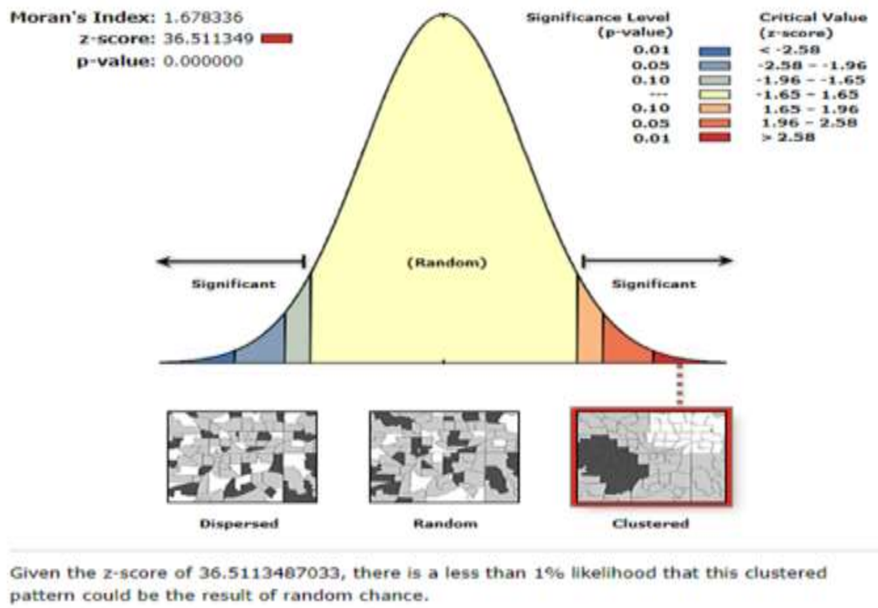

Proportion of Sanitation Facilities
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
79.54%
74.39%
74.14%
72.55%
20.46%
25.61%
25.86%
27.45%
EDHS 2005
EDHS 2011
EDHS 2016
EDHS 2019
Improved
Unimproved
Linear (Improved)
Linear (Unimproved)



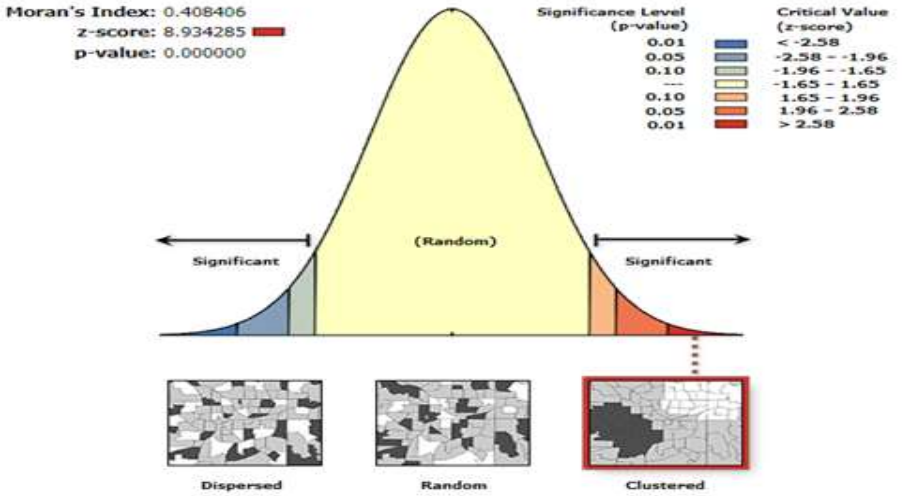
Given the z-score of 2.37439300313, there is a less than 5% likelihood that this clustered pattern could be the result of random chance.



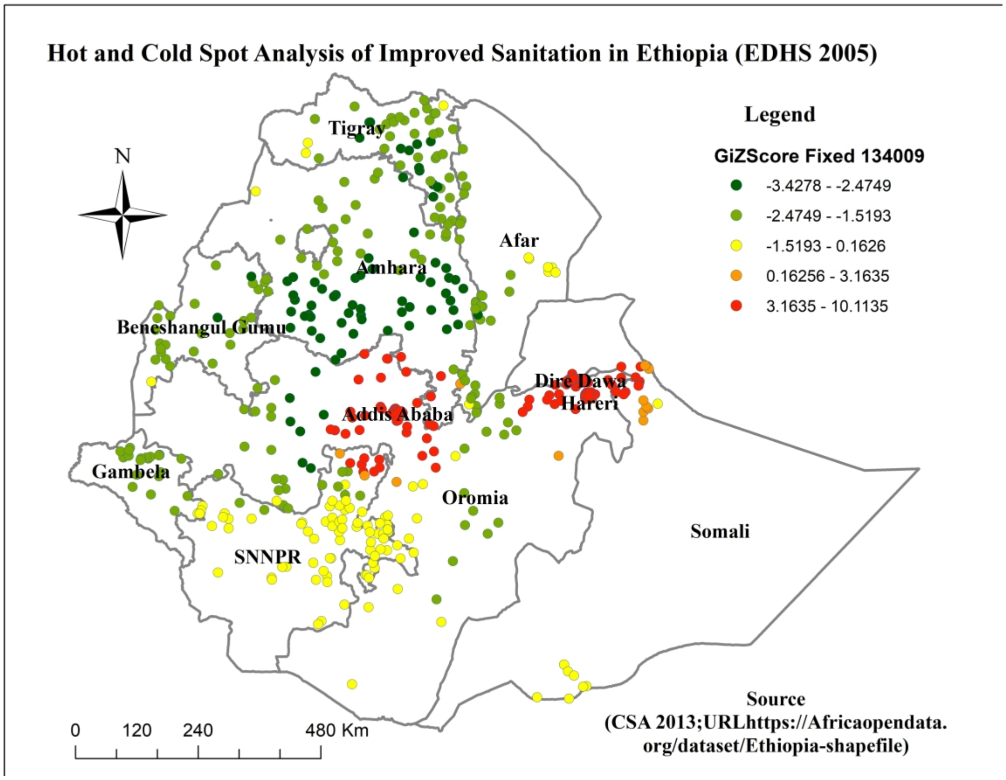
Given the z-score of 7.06799640417, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.


Moran's Index: 1.678336
z-score: 36.511349
p-value: 0.000000
Significance Level (p-value)
Critical Value (z-score)
0.01
0.05
0.10

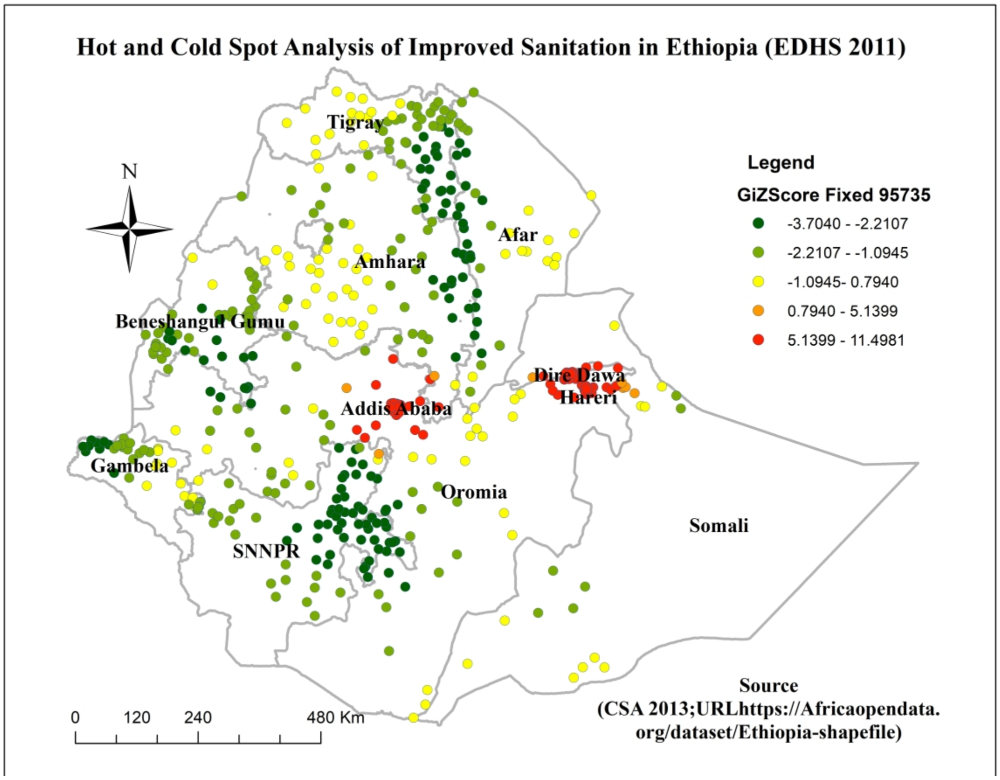
0.10
0.05
0.01
< -2.58
-2.58 - -1.96
-1.96 - -1.65
-1.65 - 1.65
1.65 - 1.96
1.96 - 2.58
> 2.58
Significant
(Random)
Significant
Dispersed
Random
Clustered
Given the z-score of 36.5113487033, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.



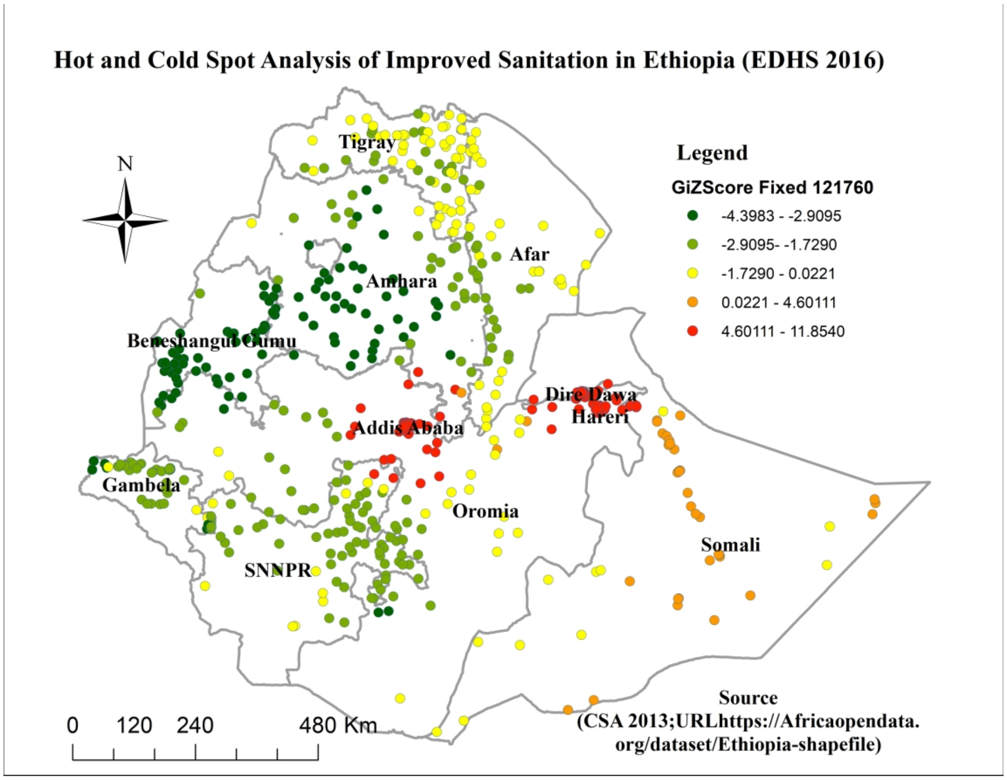
Given the z-score of 8.93428534383, there is a less than 1% likelihood that this clustered pattern could be the result of random chance.



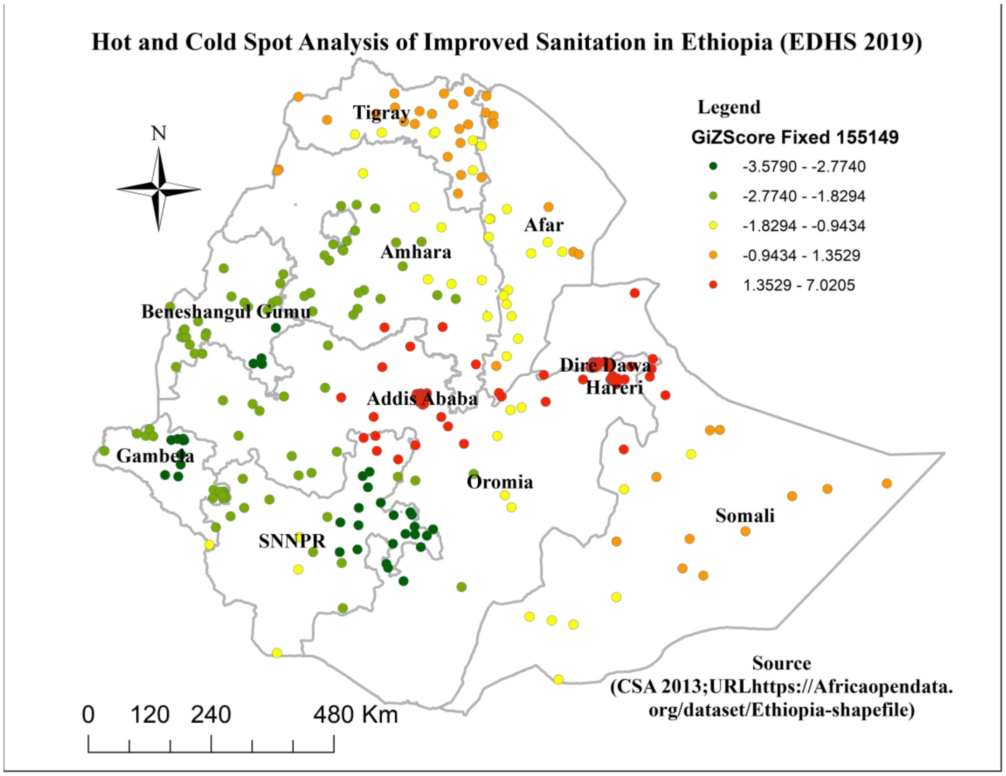
279x215mm (300 x 300 DPI)



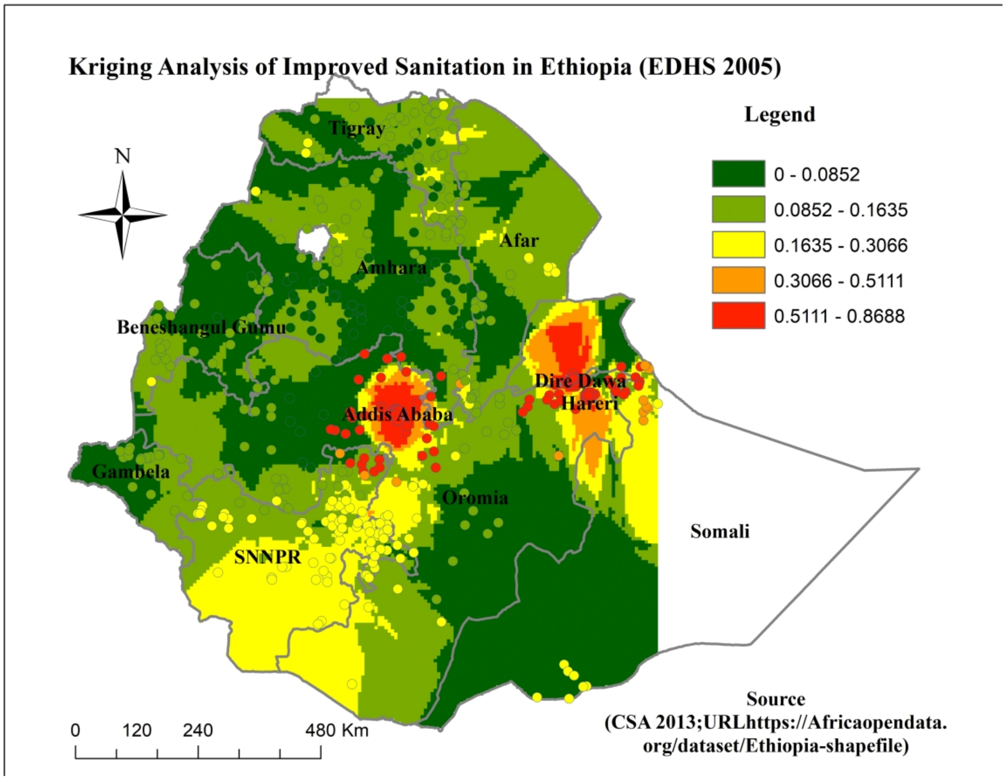
279x215mm (300 x 300 DPI)



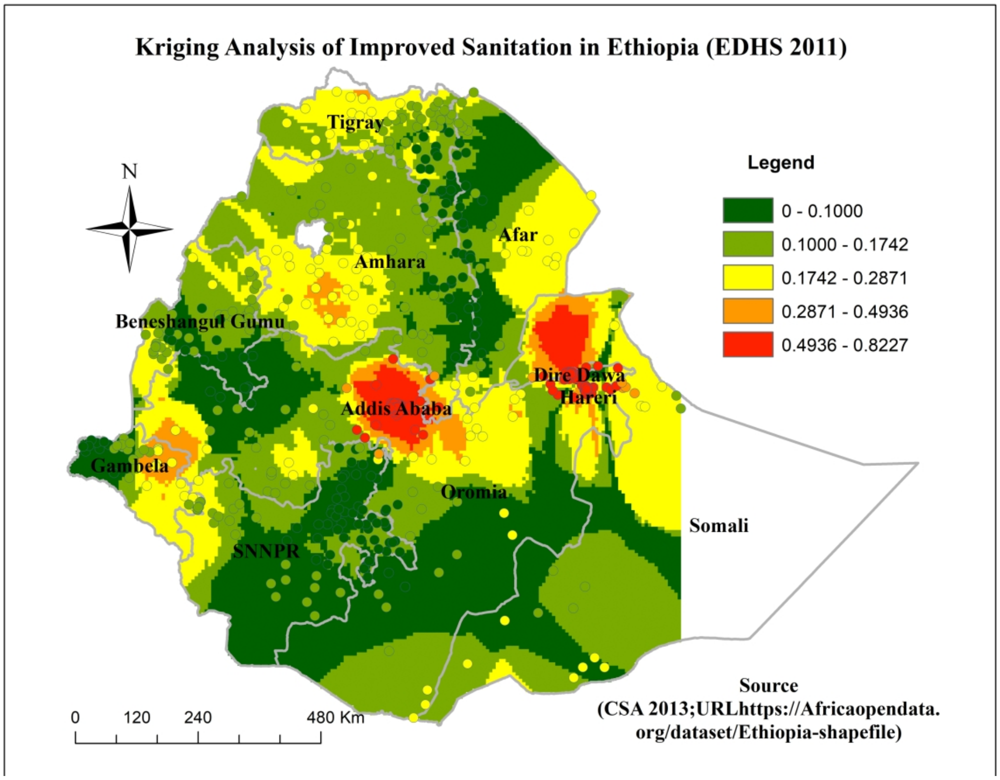
279x215mm (300 x 300 DPI)



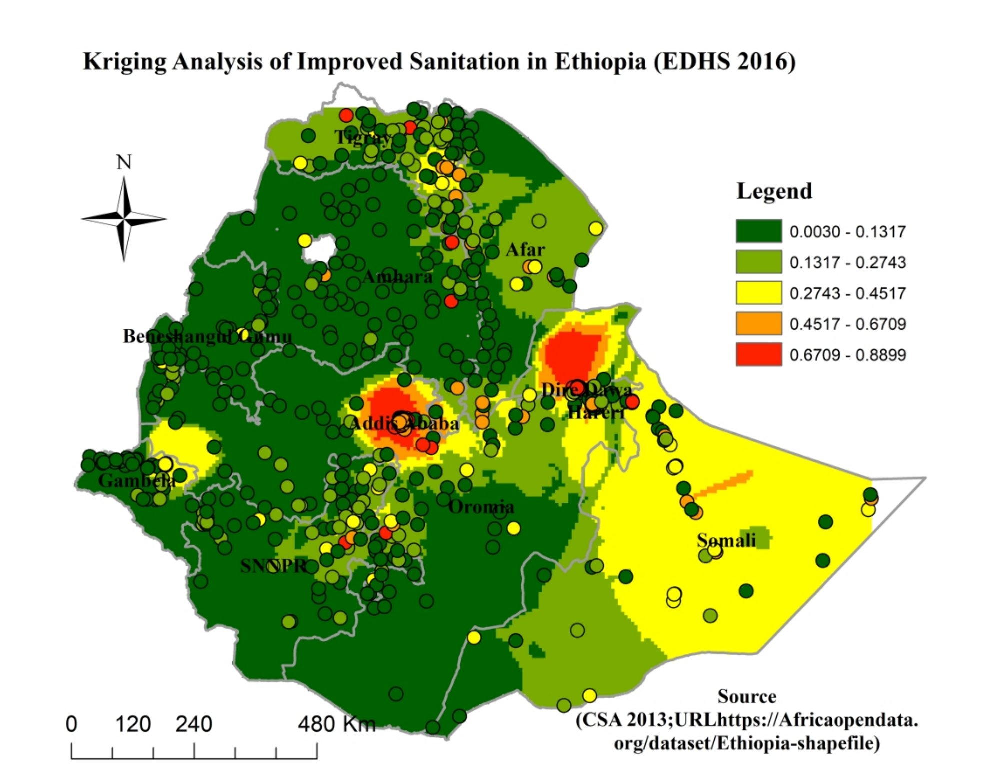
279x215mm (300 x 300 DPI)



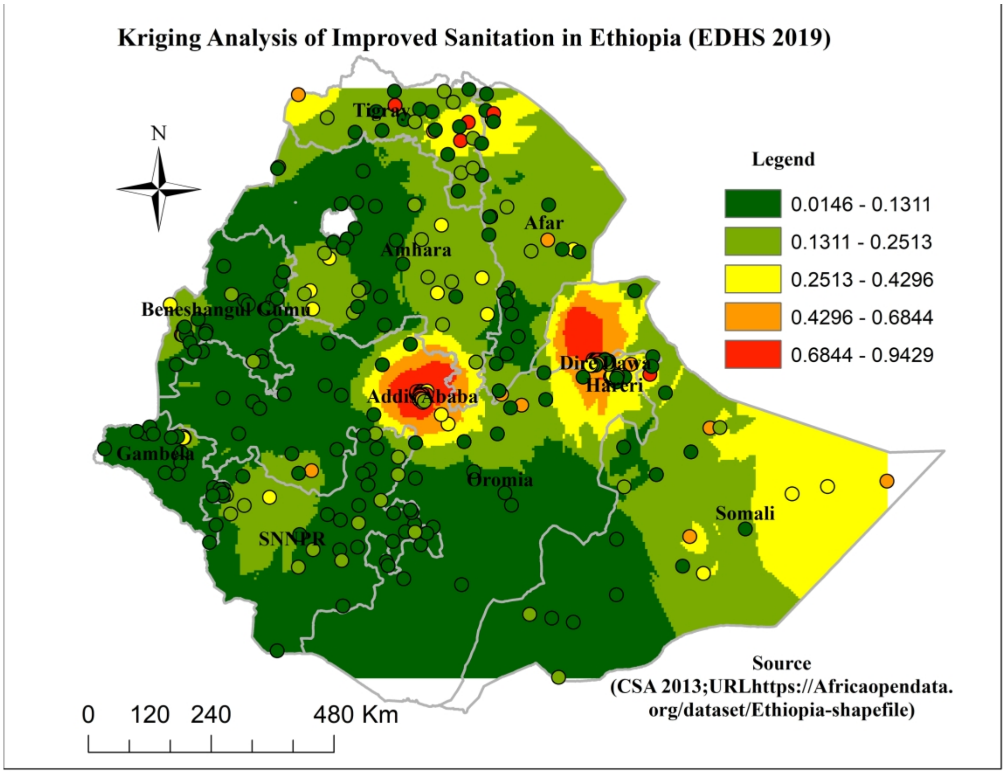
279x215mm (300 x 300 DPI)



279x215mm (300 x 300 DPI)



279x215mm (300 x 300 DPI)



279x215mm (300 x 300 DPI)