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Spatiotemporal dynamics and prevention strategies of cervical cancer incidence in Addis Ababa, Ethiopia: an ecological study

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ABSTRACT

Objective This study analysed the spatial and temporal patterns of cervical cancer incidence in Addis Ababa from 2012 to 2021.

Design An ecological study was conducted from 1 September to 30 November 2023 to examine the spatiotemporal trends of cervical cancer incidence.

Setting The research was conducted in Addis Ababa, the capital city of Ethiopia.

Participants Included were all patients with clinically and/or histopathologically confirmed diagnoses of cervical cancer.

Data analysis The study employed advanced analytical tools including R programming, Quantum Geographic Information System V.3.36.0, GeoDa V.1.2.2 and System for Automated Geoscientific Analyses GIS V.9.3.2. Techniques such as Bayesian empirical testing with a block weighting matrix for hotspot identification, Global Moran's I for spatial autocorrelation, nearest neighbour imputation and universal Kriging interpolation were used to manage data gaps. Joinpoint trend analysis and direct age-standardised incidence rate (ASIR) using the Segi's World standard population was applied to compare trends across subcities. A statistical significance threshold was set at $p<0.05$.

Results Between 2012 and 2021, a total of 2435 new cervical cancer cases were recorded in the Addis Ababa City Population-based Cancer Registry, with significant spatial clustering observed in Nifas Silk Lafto, Bole, Kirkos as well as parts of Gulele and Yeka sub cities (z score>1.96) in 2018. The citywide age-standardised incidence rate varied from 19 to 26 cases per 100 000 women-years during 2013 and 2016, respectively. Subcity trends varied significantly, with increases and decreases noted in Akaki Kality and Kolfe Keraniyo over different periods while Bole subcity showed modest increase at 4.2% APC (95% CI: 0.6% to 7.9%; p=0.026).

Conclusion The study highlights substantial fluctuations in ASIR and significant geographic disparities in cervical cancer throughout Addis Ababa. To address these challenges, the implementation of school-based human papillomavirus vaccination programmes, alongside targeted interventions, active campaigns and sustained surveillance, is critical. These strategies are essential to effectively reduce the cervical cancer burden and improve health outcomes in the community.

STRENGTHS AND LIMITATIONS OF THE STUDY

⇒ This study's analysis spans a decade (2012–2021) using data from the Addis Ababa cancer registry, offering extensive insights into the spatial and temporal trends of cervical cancer.

⇒ The utilisation of sophisticated spatial and temporal analytical techniques, including Bayesian empirical testing and spatial autocorrelation, enhances the robustness of the findings.

⇒ Dependence on registry data that may suffer from under-reporting or incomplete records could potentially affect the accuracy of incidence rates.

⇒ The absence of detailed individual-level information, such as human papillomavirus status and socioeconomic factors, might limit the exploration of specific determinants of cervical cancer incidence.

INTRODUCTION

Cervical cancer continues to be a significant global health challenge, ranking as the fourth most common cancer among women, with nearly 660 000 new cases and 350 000 deaths reported in 2022, according to the WHO.[1] This burden is especially severe in low-income and middle-income countries, where access to prevention and early detection resources is critically limited.[2] Cervical cancer is primarily caused by persistent infection with high-risk human papillomavirus (HPV) types, particularly HPV 16 and 18, which are commonly transmitted sexually.[3] Preventative and clinical practices focus on reducing the incidence and enhancing early diagnosis through HPV vaccination,[4] regular screening[5 6] and timely treatment.[6] HPV vaccines, especially recommended for young adolescents before virus exposure, have proven highly effective in reducing HPV infection rates. Screening methods, such as Pap smears and HPV testing, are vital for the early detection of precancerous lesions, allowing for intervention before cancer develops. Collectively, these preventive strategies could significantly reduce cervical cancer incidence and improve patient outcomes, underscoring the need for accessible prevention programmes in high-risk populations. Prevention efforts and targeted interventions could be further optimised by using up-to-date evidence generated through rigorous methodologies, including spatial and temporal analyses.

Spatial analysis, a branch of geographic analysis employing mathematical techniques and geometry, elucidates the topological patterns of phenomena. While geographic information systems (GIS) facilitate the study and comprehension of real-world processes through manipulation, analysis criteria and modelling, spatial analysis, an integral aspect of GIS, allows modelling of both vector-based and raster data using sophisticated tools.[7] Its application in health programme monitoring and performance indicator display is well documented.[8 9] Temporal analysis, on the other hand, observes chronological event occurrences to reveal trends over time. Combining spatial and temporal metrics forms a spatiotemporal framework, an emerging field known as spatiotemporal data mining (STDM), which encompasses analysing event-based data, trajectories, time series, spatial maps and raster data. Key tasks within STDM include clustering, anomaly detection, frequent pattern mining, relationship mining, change detection and predictive learning.[10]

Globally, a variety of studies have depicted either the spatial or spatiotemporal pattern of cervical cancer, highlighting the significant role of GIS in its detection and mapping, along with other cancers.[11] According to a report on the application of spatial analysis in China, GIS can effectively display the distribution of cancer cases and employ spatial analysis methods and scanning statistical techniques to identify key areas of cancer incidence, thereby informing the development of regional public health policies and recommendations for cancer screening and resource allocation.[11] Many of these studies rely on national-level or district-level cancer registry centres, ensuring stable population data and high-quality epidemiological recording. Moreover, a spatial study in Uganda conducted by Beyer *et al* demonstrated the usefulness of population-based cancer registry data and geospatial mapping in low-resource settings, supporting cancer prevention and control efforts and enabling research into geographic factors influencing cancer outcomes.[12]

Many findings reported in the literature show an improvement in combining spatial and temporal analyses. Furthermore, several studies have incorporated multiple covariate models to assist in identifying potential factors exhibiting spatial autocorrelation.[13–15] Taking into account the specifics, Zhao *et al* demonstrated that cervical cancer incidence trends over time vary by religion, indicating disparities in sexual practices, lifestyle and culturally associated beliefs between Muslims and Buddhists. This suggests distinct risk factor profiles for these groups. For example, the elevated incidence rates (IRs) in Sadao and Hat Yai were reported to be attributed to the major road leading to Malaysia passing through these areas, facilitating frequent commercial sex trade. As such, targeting female sex workers as a vulnerable population for screening efforts is imperative to mitigate the persistent burden of cervical cancer.[13]

The incidence of cervical cancer in Ethiopia has been recorded at approximately 22.3 cases per 100 000 women per year, while the age-standardised mortality rates are estimated at 16.8 per 100 000 women-years.[16] These statistics highlight the considerable burden of the disease, positioning cervical cancer as the second most prevalent and fatal cancer among women.[17] Presently, there is a dearth of evidence concerning the spatial and temporal trends of cervical cancer, emphasising the crucial need for targeted resource allocation toward its prevention and management. This study endeavours to bridge this gap by offering a comprehensive and current understanding of the disease's IR, as well as its spatial and temporal dynamics in Addis Ababa, Ethiopia.

METHODS

Study area, design and period

The study took place in Addis Ababa, Ethiopia's capital city, strategically situated at the heart of the country with geographic coordinates of 9°2′N latitude and 38°45′E longitude. Encompassing a total area of 540 km^2 and boasting an average altitude of 2400 MASL,[18] the city is divided administratively into 10 subcities: Arada, Kirkos, Yeka, Addis Ketema, Gulele, Kolfe Keraniyo, Nifas Silk Lafto, Akaki Kality, Lideta and Bole. An additional subcity, named 'Lemi Kura', was established in 2021, which now shares a significant portion of the Bole subcity. Currently, there are 116 woredas (lower administrative units) in Addis Ababa. According to the 2007 national population and housing census,[19] Addis Ababa's population totalled 2 739 551, growing at an annual rate of 3.8%. Subsequent data from 2021 reported a population increase to 3 773 999, with Kolfe Keranyo, Yeka, Nifas Silk Lafto and Bole subcities recording the highest figures.[20] Addis Ababa serves as the economic hub of the nation, contributing approximately 29% of the urban gross domestic product (GDP) and 20% of the national urban employment.[21] Its economy is predominantly service oriented, accounting for about 75% of its GDP, followed by the industrial sector at 24.3% (Central Statistical Agency, 2021).[18] From 1 September to 30 November 2023, an ecological study design was conducted to assess the spatial and temporal trends and IRs of cervical cancer throughout Addis Ababa (online supplemental figure 1).

Populations, data sources and eligibility criteria

The source population consisted of all females residing in Addis Ababa during the specified review period. The study population encompassed all newly diagnosed cases from 1 January 2012 to 31 December 2021. Data regarding these cases were sourced from the Addis Ababa cancer registry, while estimates of age-grouped and woreda-level female populations for the same period were obtained from the Ethiopian Statistical Service. Exclusions from the incident cases comprised individuals for whom subcity-level or district-level data were unavailable, those with source codes indicating locations outside Addis Ababa and cases involving cancer sites other than the cervix.

Data extraction and processing

Spatial and temporal data, encompassing patient age, date of confirmed diagnosis, test method, cancer stage, treatment history, subcity, woreda/kebele and report date, were extracted from the cancer registry using a structured format. To facilitate external comparison, age data was segmented into 5-year age groups (that is, 0–4, 5–9, …, ≥80+) for the period spanning from 1 January 2012 to 30 December 2021 and standardised to the world standard population proposed by Segi.[22] Initially, age-group-specific crude rates were computed for each subcity. Subsequently, specific crude IRs calculated for each subcity were weighted by standardised proportions. Ultimately, age-adjusted cumulative IRs were estimated by aggregating the weighted rates for each subcity and for the entirety of Addis Ababa. Microsoft Excel V.10 was used for all calculations.

Data analysis

Following data processing in MS Excel, additional manipulation and analysis were conducted using a combination of R programming packages and the Quantum Geographic Information System (QGIS) V.3.36.0 software.[23] Descriptive statistics were performed to describe the cohort. Direct age standardisation was performed using the Segi's World standard population.[22] Age groups were estimated using a 5-year group age classification. Reverse geocoding of locations at woreda level was executed in QGIS using the OpenStreetMap provider.[24] For instances of missing geographic coordinates (n=11), nearest neighbour imputation was performed using R. Subsequently, GeoDa software V.1.2.2[25] was used to visualise the spatial distribution of cervical cancer hotspots and cold spots across 99 geographic locations. The Local Indicator of Spatial Autocorrelation was applied, employing the Bayesian Empirical Test with a significance threshold of p<0.05. Weight matrix estimation was conducted using the block method. To address locations with minimal or absent values, spatial interpolation was performed using the System for Automated Geoscientific Analyses GIS V.9.3.2 software.[26] The best fitting model, whether spherical, cubic or Gaussian, was determined based on the results of semivariogram analysis conducted for each year's data. Subsequently, the universal Kriging method was employed to interpolate and map values at unknown locations. The spatial dependence of cervical cancer across the study area was estimated using the Global Moran's I statistic and z score. Finally, temporal trends of incident cases and rates across subcities and age groups were analysed using the Joinpoint trend analysis software from the National Cancer Institute.[27] The appropriate number of joinpoints, which best describes the underlying structure of the data, was determined using the Bayesian information criterion (BIC). The results were presented as annual per cent changes (APC) in IR per 100 000 person-years. Statistical significance was considered at p<0.05.

RESULTS

Profile of cases and data preparation

From 1 January 2012 to 31 December 2021, a total of 2441 cases of cervical cancer were reported. Among these, six cases were missing information at both the subcity and woreda levels and were consequently excluded, leaving the number of eligible cases at 2435. The lowest number of new cases was reported in 2013 (n=191) while the highest number was recorded in 2021 (n=287). The majority of these cases were diagnosed by histology of primary tumour (n=2248, 92.3%), followed by those diagnosed through cytology (n=88, 3.6%), and clinical investigation or ultrasound (n=53, 2.2%). The mean (±SD) age of the cases was 51.8 (±12.4) years, ranging from 20 to 99. The 25th, 50th and 75th percentiles of age were 42.0, 51.0 and 60.0 years, respectively. The stage of cancer was unknown for the majority of cases (n=1882, 77.3%). Among the reported stages, the majority were stage IIB (n=160, 6.6%), followed by stage IIIB (n=103, 4.2%), and stage IV (n=74, 3.0%). All identified cases were malignant; no preinvasive lesions were registered (online supplemental table 1).

Local spatial clustering of new cases

Assessment of hotspots and cold spots from 2012 to 2021 reveals dynamic spatial patterns in cervical cancer incidence across subcities in the study area. In 2012, 30 high–high cluster woredas were identified primarily in Nifas Silk Lafto, Kirkos, Yeka, Gulele, Lideta, Kality and Addis Ketema subcities, while the majority of woredas (n=61) were classified as cold spots surrounded by other cold spots (low–low) (figure 1A).

The trend continued in 2013 with a similar proportion of woredas (n=26) exhibiting high–high clustering compared with the previous year, while the number of low–low clustering areas remained consistent (figure 1B). By 2014, high clusters of cases expanded to Nifas Silk Lafto, Addis Ketema, Gulele and Akaki subcities, with the majority of locations maintaining coldspot characteristics (figure 1C).

In 2015, the number of high–high spots diminished significantly (n=2), mainly localised in Nifas Silk Lafto and Kirkos subcities. Conversely, certain woredas in Nifas Silk Lafto, Akaki, Yeka and Kolfe Keraniyo subcities emerged as high cluster areas surrounded by low cluster woredas, while others were identified as low–low or non-significant spots (figure 1D). Subsequent years saw fluctuations in clustering patterns. In 2016, an increase

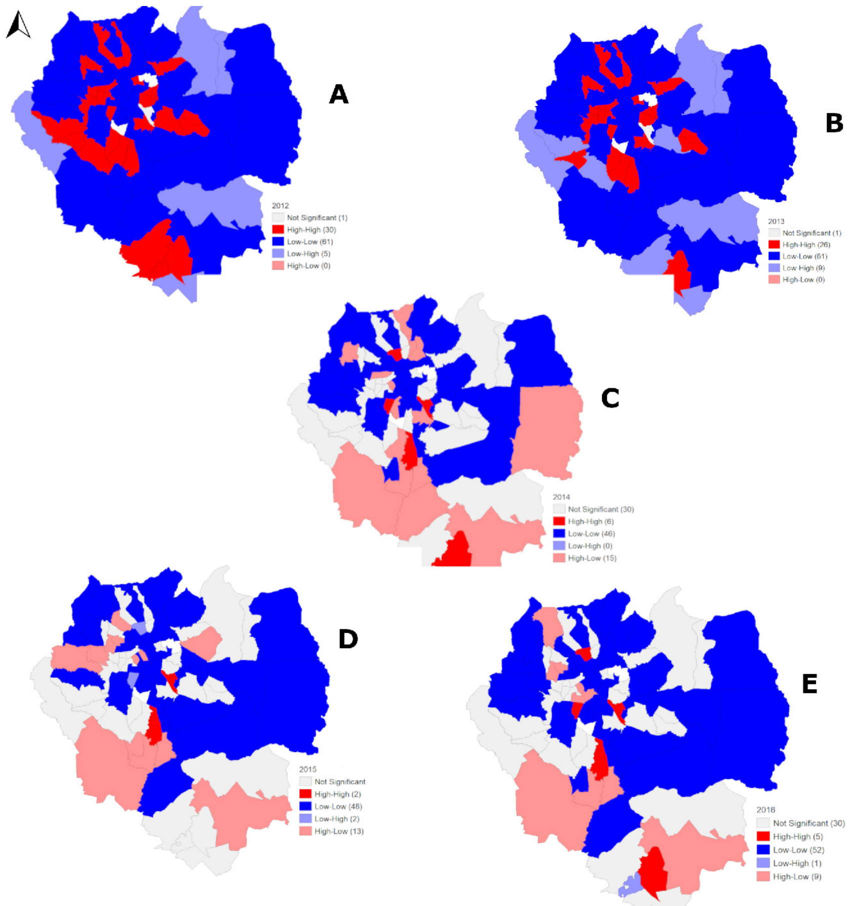

Figure 1 Clusters of reported cervical cancer cases in Addis Ababa from 2012 to 2016.

in high–high clusters was observed in various subcities, while other areas remained predominantly cold spots or non-significant (figure 1E).

This trend continued with minor variations in 2017, 2018 and 2019 (figure 2A–C). In 2020, a restabilised pattern of spatial dependence emerged, with high–high areas identified in specific subcities, while the majority of woredas exhibited low–low or non-significant spatial dependence (figure 2D). In 2021, there was a further decrease in high–high clustering, with an increase in locations exhibiting high–low clusters. However, the majority of woredas remained either non-significant or low–low clusters (figure 2E).

Global clustering and interpolation with space and time

The universal Kriging interpolation from 2012 to 2021 sheds light on the spatial distribution of new cervical cancer cases across Addis Ababa with statistically significant positive spatial autocorrelation (Moran's I range: 0.947–0.989). In 2012, hotspots with moderate elevation above the mean (z score above 0.80) were clustered in the western part of Kolfe Keraniyo and Nifas Silk Lafto subcities. Similarly, moderate numbers of cases (z score 0.64–0.80) were observed in most parts of Nifas Silk Lafto, Kirkos, Lideta, Gulele, Addis Ketema and Yeka, while the remainder of the city exhibited low clustering near the entire mean (figure 3A).

Subsequent years showed dynamic shifts in hotspot trends. In 2013, hotspots shifted to the southern parts of the city, particularly in Nifas Silk Lafto, Kolfe and Akaki Kality subcities (z score above 0.92), with moderate clusters prevalent in these areas (z score 0.80–0.92) (figure 3B). By 2014, high clusters of cases emerged in woredas of Bole, Yeka, Kolfe Keraniyo, Gulele and Nifas Silk Lafto (z score above 1.0), surrounded by moderate levels of cases (z score 0.60–1.0), while other subcities exhibited cold spots or average clustering (z score 0.0–0.60) (figure 3C).

In 2015, areas with z scores above 1.0 indicated significantly more cases, particularly in southeastern, eastern and northeastern parts of Akaki Kality, Bole and Yeka subcities. Most woredas in these areas reported moderate numbers of cases (z score 0.80–1.0), with other parts of the city showing insignificant variability from the mean (figure 3D). The trend continued in 2016, with high clusters prevalent in multiple woredas of Nifas Silk Lafto, Kolfe, Gulele, Yeka and Bole, along with moderate clustering (z score 0.6–1.0), while the rest of the city demonstrated non-significant variability (figure 3E).

Further years continued to show fluctuations in hotspot distribution. In 2017 and 2018, an increasing trend of clustering was observed in several woredas of various subcities with high clusters prevailing in certain areas, namely Bole, Nifas Silk Lafto, Kolfe Keraniyo, Yeka and Gulele (z score

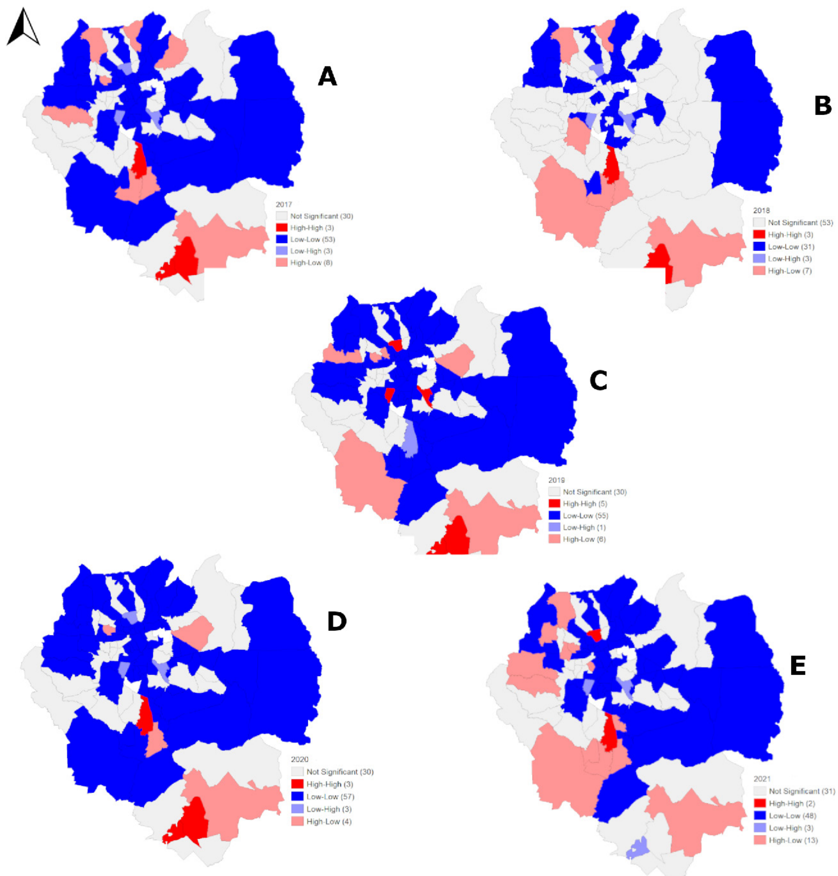

Figure 2 Clusters of reported cervical cancer cases in Addis Ababa from 2017 to 2021.

above 1.0) and moderate clustering in neighbouring woredas (figure 4A,B). Particularly, a statistically significant spatial autocorrelation (z score>1.96) was recorded in 2018 in the subcities, Nifas Silk Lafto, Bole, Kirkos and parts of Gulele and Yeka (Figure 4B). Similarly, in 2019 and 2020, hotspot patterns persisted in specific woredas, with high numbers of cases (z score above 1.0) identified in certain areas across the city (figure 4C,D). The trend continued into 2021, with specific woredas in various subcities exhibiting high numbers of cases as that of 2018/2019 (z score above 1.0), indicating the persistence of hotspot areas (figure 4E). In summary, although many woredas exhibited strong case clustering from 2012 to 2021, as indicated by high and positive Global Moran's I values, statistically significant spatial autocorrelation (i.e p<0.05) was observed only in 2018.

IR of cervical cancer in the city

The IR of cervical cancer in Addis Ababa city was assessed for the years 2012 to 2021. Analysis of age-standardised IR per 100 000 women-years revealed no significant changes across the entire city, with rates ranging from a minimum of 19 in 2013 to a maximum of 26 in 2016. When examining subcities individually for each year, Kirkos had an IR of 33 in 2012, followed by Gulele, Nifas Silk Lafto and Bole, each with an IR of 23 in 2013. In 2014, Arada recorded an IR of 26, while Yeka had an IR of 32 in 2015, and again in 2016. Gulele had an IR of 32 in 2017, Bole recorded an IR of 24 in 2018, Kolfe Keraniyo had an IR of 30 in 2019, Bole reached an IR of 33 in 2020 and Akaki Kality had the highest IR of 39 in 2021 (table 1).

Analysis of specific age groups for each year revealed a consistent increase in cervical cancer risk among individuals aged 45–74 years. The age group with the highest IR varied across the years: in 2012, it was 50–54 years (IR=5); in 2013, 60–64 years (IR=4); in 2014, both 50–54 and 60–64 years (IR=4 each); in 2015, both 45–49 and 60–64 years (IR=4 each); in 2016, 60–64 years (IR=5); in 2017, 55–59 years (IR=4); in 2018, 60–64 years (IR=4); in 2019, both 45–49 and 60–64 years (IR=4 each); in 2020, both 45–49 and 60–64 years (IR=4 each); and in 2021, 45–49 years (IR=5) (online supplemental table 2).

Trend analysis of age-specific IRs and count of cases

Figure 5 depicts the trend of age-specific counts (figure 5A) and IRs (figure 5B) of cervical cancer over the years. Consistent with the figures in table 1 and online supplemental table 2, the number of new cases among age groups 45 through 74 exhibited a steady increase, particularly noticeable from 2018 onwards (figure 5A). However, the age-standardised IR per 100 000 women per year remained relatively stable from 2017 onwards, compared with the peak estimate observed in 2016. Additionally, across the plot, age groups 45 through 74 consistently displayed the highest rates of new cases per 100 000 women per year over the years (figure 5B).

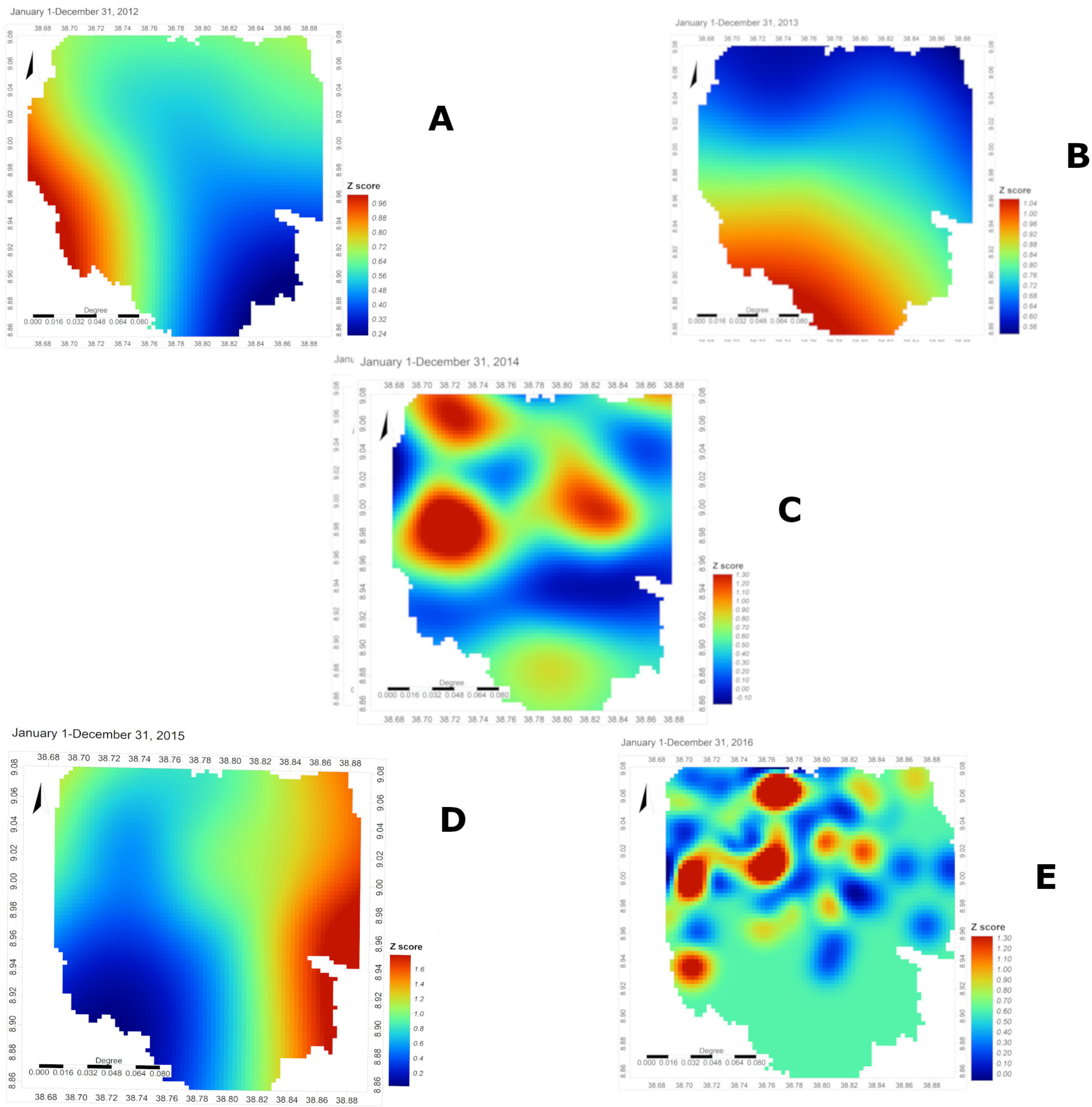

Figure 3 Global clustering of incident cervical cases in Addis Ababa from 2012 to 2016.

Time series analysis of IRs by subcity and year

The comprehensive joinpoint regression analysis revealed distinct trends in cervical cancer IRs across various subcities. Akaki Kality, Nifas Silk Lafto and Kolfe Keraniyo exhibited a single joinpoint, with Akaki Kality and Nifas Silk Lafto experiencing trend turning points in 2014, while Kolfe Keraniyo showed a trend change in 2019. Conversely, the remaining subcities were estimated to have zero joinpoints based on the BIC estimation. In Akaki Kality, there was a notable 10.6% (95% CI: –46.5% to 49.4%) APC decrease in IRs from 2012 to 2014. This, however, was not statistically significant (p=0.598) suggesting a random variation. However, from 2014 to 2021, the trend reversed, with an almost 10.0% (95% CI: 5.2% to 15.1%) significant APC increase observed (p=0.003). Similarly, Kolfe Keraniyo exhibited a statistically significant 13.5% (95% CI: 5.9% to 21.8%) APC increase in IRs from 2012 through 2019 (p=0.006). Subsequently, from 2019 to 2021, there was a decline in the trend, with an APC decrease of 18.1% (95% CI: –69.6% to 120.5%) but not statistically significant (p=0.627). And, in Bole subcity, the trend in cervical cancer IRs showed a statistically significant but modest 4.2% (95% CI: 0.6% to 7.9%; p=0.026) APC increase from 2012 through 2021 (figure 6).

DISCUSSION

This study aimed to explore the spatial and temporal patterns of cervical cancer incidence in Addis Ababa,

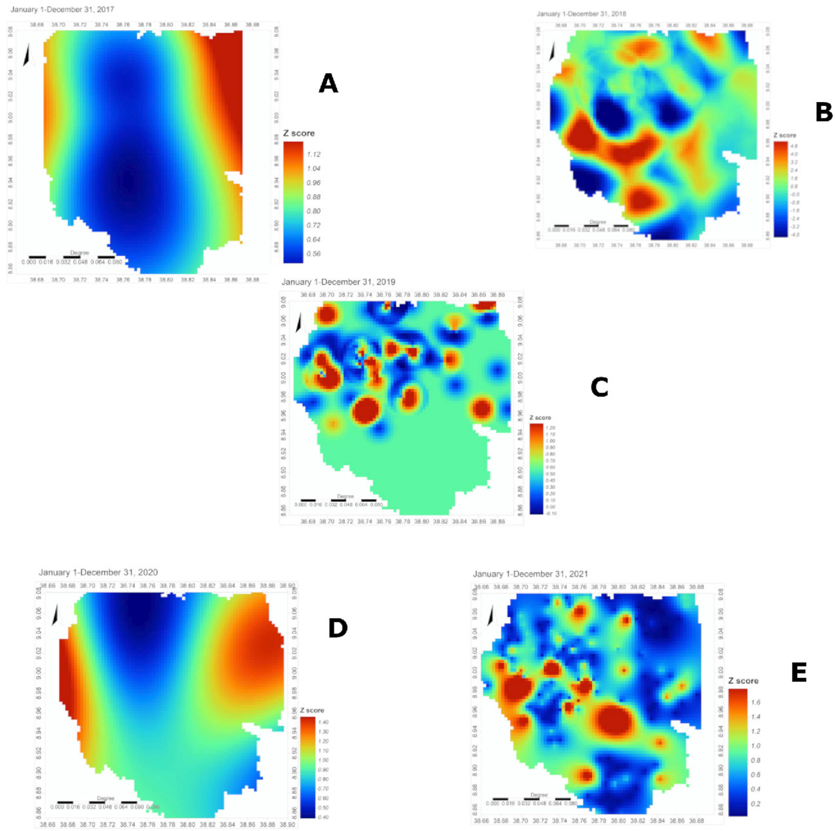

Figure 4 Global clustering of incident cervical cases in Addis Ababa from 2017 to 2021.

Ethiopia, spanning a decade from 2012 to 2021. The research sought to illuminate how cases were distributed across various subcities, age brackets and years, offering crucial insights to inform public health interventions and resource allocation. The number of newly identified cases of cervical cancer in Addis Ababa over the past decade appears to be relatively lower compared with a report for the eastern African region. In our study, the most recent data from 2021 indicates an age-standardised IR of 24 cases per 100 000 in Addis Ababa, whereas the 2022 estimate for Eastern Africa was reported to be 40.3 cases per 100 000.[28] The relatively higher figure in the latter report may be attributed to regional variations in disease burden across countries, potentially inflating the overall rate.

Understanding the spatial autocorrelation of cervical cancer within subcities and woredas was a crucial step in identifying geographic locations with elevated risk and implementing targeted interventions. The findings revealed a notable clustering of cervical cancer cases in specific subcities and woredas within Addis Ababa, with varying trends observed over the years. The spatial autocorrelation analysis for each review year indicated that

Table 1 Age-standardised incidence rate of cervical cancer per 100 000 women-years by year and subcity in Addis Ababa, Ethiopia, 2012–2021

Subcity	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Akaki Kality	26	14	16	21	21	23	22	28	24	39
Nifas Silk Lafto	27	23	21	20	28	25	23	29	24	29
Kolfe Keranyo	14	14	18	11	27	21	27	30	27	18
Gulele	26	23	16	25	19	32	22	21	18	21
Lideta	31	15	22	30	27	26	23	15	11	27
Kirkos	33	22	19	30	29	26	22	15	17	13
Arada	23	17	22	20	18	13	10	19	20	18
Addis Ketema	20	18	22	22	18	17	21	19	20	25
Yeka	29	19	20	32	32	22	21	23	25	29
Bole	17	23	19	30	26	20	24	27	33	25
Addis Ababa	24	19	20	23	26	22	22	24	23	24

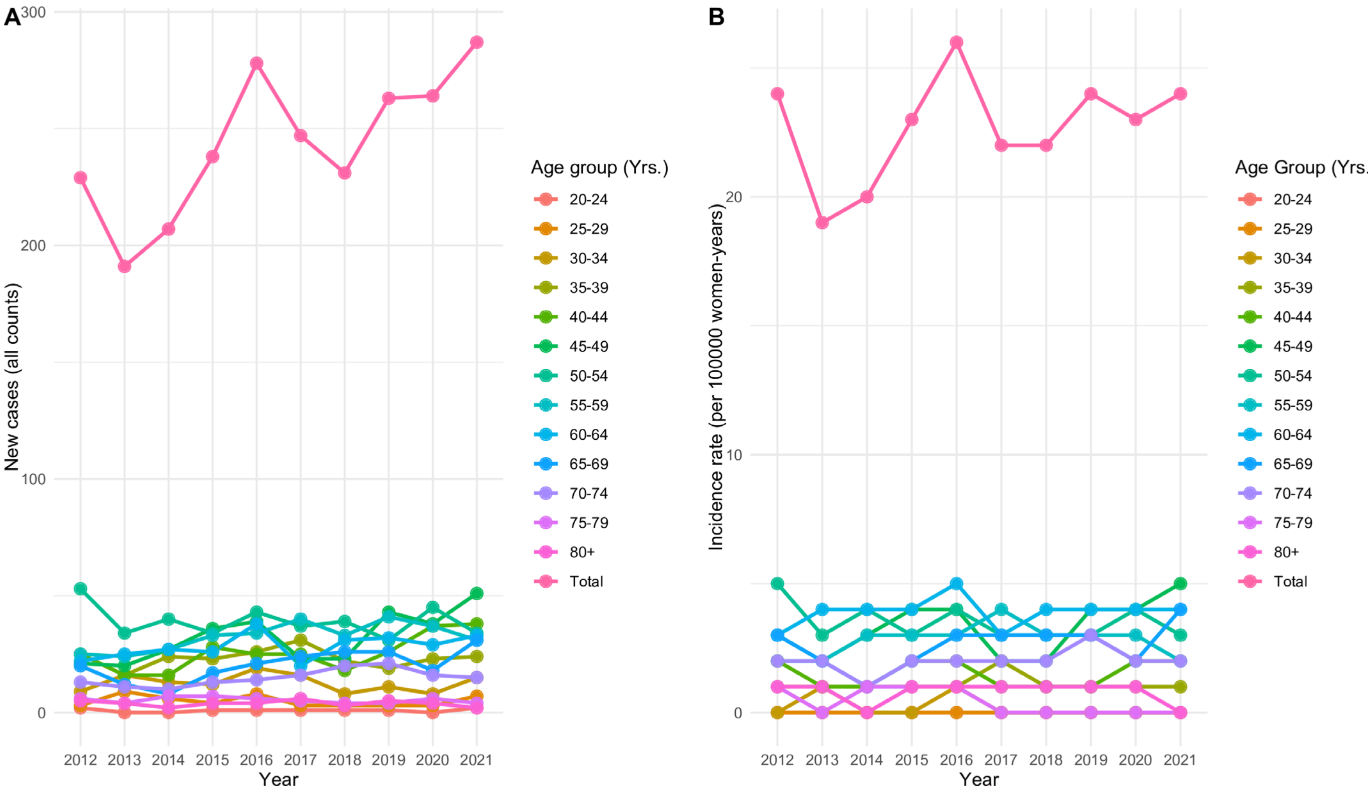

Figure 5 Trend line depicting age-specific count and age-standardised incidence rates of cervical cancer from 2012 to 2021.

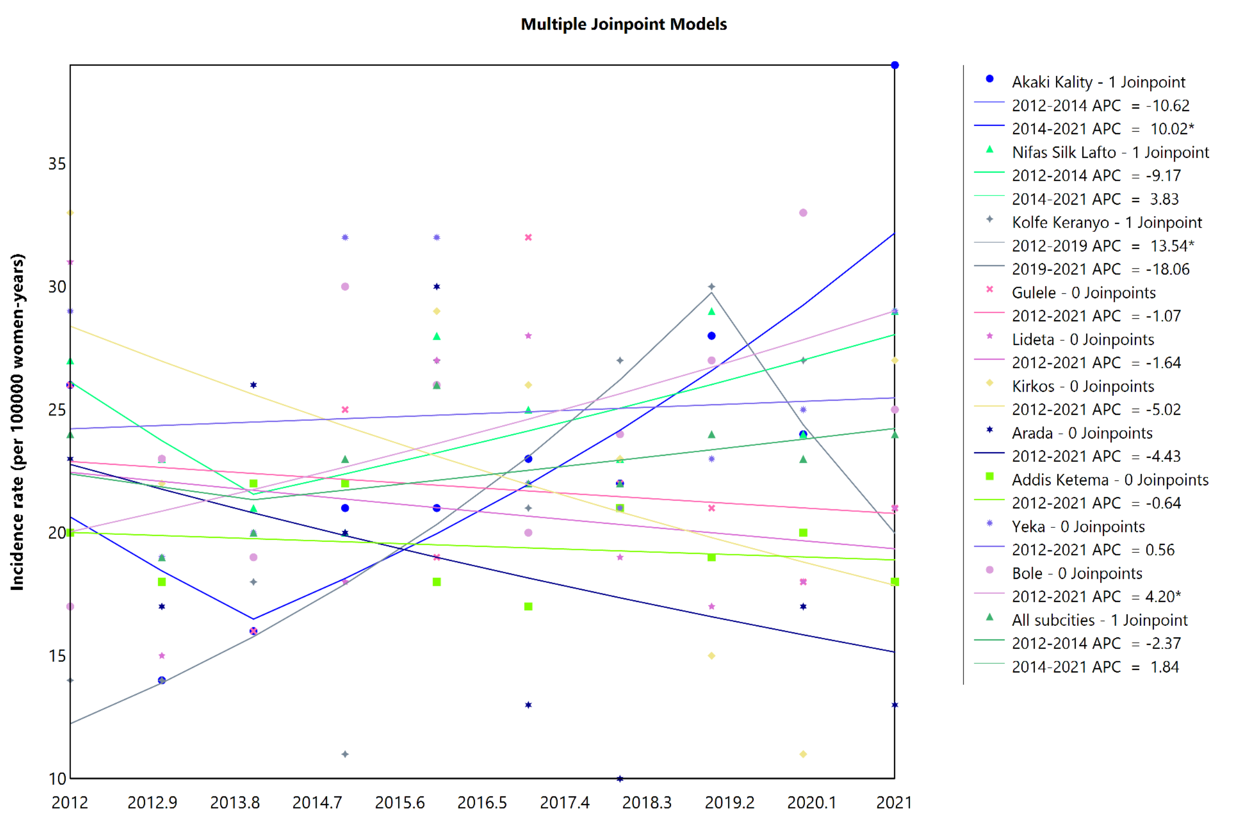

Figure 6 Joinpoint regression analysis of cervical cancer age-standardised incidence rates per 100 000 women-years by subcity in Addis Ababa spanning from 2012 to 2021. APC, annual percent change. *Statistically significant.

the distribution of cervical cancer cases was non-random and influenced by geographic factors. A similar trend of clustering in the incidence of non-cervical cancer types has been reported in Saudi Arabia.[29] The risk of cervical cancer in Thailand also demonstrated spatial and temporal dependence, revealing higher incidences in certain provinces such as Chiang Rai and Nan, while others remained cold spots. Generally, there was a decreasing trend over time observed in these areas.[30] In a nationwide study conducted in South Africa, the incidence of cervical cancer among people living with human immunodeficiency virus was found to be higher in locations with accessible health facilities compared with areas with low affluence. Specifically, the IRs were reported as 3.18 in areas with accessible health facilities, whereas in areas with lower affluence, the IRs were recorded at 1.52.[31]

The stability observed in the age-standardised IRs of cervical cancer across Addis Ababa city over the study period is notable. However, comparing the age-standardised IRs in the current study to a specific year of 2012 with a figure in Shijiazhuang city in China revealed a significant difference.[32] Specifically, there was a nearly tripled figure in Addis Ababa compared with Shijiazhuang city, with IRs of 24 vs 8.4 persons per 100 000 women, respectively. The same figure, however, was comparable to a finding in Shexian County in rural China, where the IR was reported as 25.2 per 100 000 women.[32] The higher figure in our study compared with those in China is likely linked to factors such as differences in access to screening, prevalence of HPV infection and socioeconomic conditions, all of which may contribute to the disparity in findings. Ethiopia's low-income status may hinder widespread cervical cancer prevention efforts, leading to a higher disease burden compared with more developed regions like Shijiazhuang city in China. While the stable IRs suggest a consistent level of risk, it is important to recognise that cervical cancer remains a significant cause of morbidity and mortality, particularly among women in low-resource settings.[33,34] The estimated age-standardised IRs in our study remain higher compared with a similar report in Kampala, Uganda, which documented relatively low subcounty-level IRs of cervical cancer from 2008 to 2015. However, both studies noted distinct spatial dependence in certain counties, resembling our findings.[12] The observed differences between the two studies could stem from various factors, including differences in population demographics, review years, underlying risk factors, and potential genetic variations, among other factors.

Subcity-level analysis revealed spatial disparities in cervical cancer incidence, with certain areas consistently exhibiting higher rates compared with others. Specifically, the subcities of Akaki, Bole and Kolfe Keraniyo demonstrated an increasing trend, although the latter showed a slight decline in the last 3 years. These disparities may stem from various factors, including changes in population demographics, variations in access to healthcare services, differences in screening and diagnostic practices, and the prevalence of HIV, among others. For instance, community-based screening campaigns conducted by health extension workers have been widely implemented in the city along with the expansion of many health centres and a few hospitals over the past decade, potentially contributing to the number of observed new cases in some of the subcities. The lack of staging information for most reported cases might be due to these campaigns being carried out at lower-level facilities with limited diagnostic capabilities. On the other hand, recent projections for HIV prevalence in 2022–2023 indicated that Bole and Kolfe Keraniyo were among the leading subcities with 3.5% and 3.6% burden of the infection, respectively.[35] This could also lead to the high number of cervical cancer cases in these areas. Furthermore, it is worth noting that a significant portion of Bole represents the highest socioeconomic class, whereas the remaining subcities represent among the low socioeconomic class inhabitants. This socioeconomic disparity could influence the observed rising trends in cervical cancer incidence. Factors such as access to healthcare resources, education levels, lifestyle behaviours and environmental exposures may vary significantly between these socioeconomic classes, potentially contributing to differences in cervical cancer risk and IRs. Studies have revealed that lower socioeconomic status often leads to a disproportionate utilisation of screening services, potentially contributing to disparities in cervical cancer detection and treatment.[36] According to reports, poorly managed dietary practices[37] and a sedentary lifestyle[38] have been associated with an increased risk of cervical cancer burden.

Age group analysis highlighted a consistent increase in cervical cancer risk among individuals aged 45–74 years. This figure is different from what is observed in high or upper-middle-income countries where age-standardised IRs increased up to 35 or 39 years.[39,40] However, the same reports documented that the ASIR exhibited an increasing trend during the late years, which is in agreement with our finding. The higher incidence observed in the upper age group may be attributed to the low screening practices, limited healthcare access and demographic factors specific to Ethiopia. In Ethiopia, the lack of widespread, early screening and preventive services,[41] especially among those of lower age,[42] may delay detection until later ages, while higher fertility rates and prolonged reproductive years could increase cumulative exposure to HPV and related risks. Additionally, HPV infection can persist for years or even decades before developing into cervical cancer, with the risk of progression increasing with age.[43] According to a research, the average duration from HPV infection to the diagnosis of CIN3 or more severe conditions is approximately 9.4 years, with a SD of 4.1 years. The progression from CIN3 to invasive cervical cancer typically spans 10 to 20 years and varies based on the HPV genotype.[44,45] Additionally, a modelling study by Burger *et al* indicated that the median time from HPV acquisition to the detection of cervical cancer ranges between 17.5 and 26.0 years.[46] Therefore, the higher IRs observed in older age groups may reflect the cumulative effect of HPV infection over time. Furthermore, studies have reported that cumulative exposure to HPV infection increases with age, while the clearance rate of the virus decreases with increasing age.[47] These findings are consistent with previous research demonstrating an association between increasing age and elevated cervical cancer risk.[48] While the primary aim of the current study was to estimate incidence and trends, the findings also imply the importance of robust prevention strategies. The WHO urges countries to achieve the 90-70-90 targets by 2030: 90% of girls fully vaccinated with HPV vaccine by age 15, 70% of women screened with high-performance tests by ages 35 and 45, and 90% of women with pre-cancer or invasive cancer receiving appropriate treatment, aiming to eliminate cervical cancer within the next century.[1]

Since 2015, the Ethiopian Ministry of Health has developed and expanded a national cervical cancer prevention and control programme.[49] The guidelines include three components of care: primary prevention (eg, condom use, HPV vaccination), secondary prevention (eg, screening and treatment of precancerous lesions) and tertiary care (eg, surgery, radiotherapy and palliative care). Visual inspection with acetic acid (VIA) and more recently primary HPV precision testing followed by VIA is the standard cervical cancer screening method in Ethiopia, though utilisation remains low among younger age groups.[42] While the guidelines recommend HPV vaccination for girls aged 9–14, the country introduced vaccination for 14-year-old girls in December 2018 due to vaccine supply shortage, covering over 6.3 million girls in this age group to date.[50] Additionally, the guidelines outline procedures for managing precancerous lesions, including cryotherapy, along with more advanced techniques like loop electrosurgical excision procedure and conization (cone biopsy). Advanced procedures and tertiary care are primarily accessible in urban centres with teaching hospitals, particularly in Addis Ababa. For instance, functional radiotherapy services are currently available only at Tikur Anbessa Specialized Hospital, making it the sole provider for this treatment in the country. As a result, patients referred from across Ethiopia must travel to a few hospitals in Addis Ababa for follow-up care, which places a heavy burden on these facilities and leads to catastrophic expenditure and significant delays in timely treatment.

In the current study, we employed multiple models and statistical approaches to visualise and obtain reliable estimates, enhancing the robustness of our findings. This novel approach adds significant contributions to the existing literature on cervical cancer epidemiology, particularly in the context of low-resource settings such as Ethiopia. By elucidating the spatial and temporal dynamics of cervical cancer incidence, our study offers essential information for guiding targeted interventions, resource allocation and public health policies aimed at reducing the burden of cervical cancer in the region. The study, however, is not without limitations. One limitation is that there was no detailed information about the time points of screening campaigns or specific health centre efforts to increase screening, which could easily boost the number of newly diagnosed patients during a certain time period. Additionally, the lack of individual-level data limited our ability to explore factors such as HPV infection status, socioeconomic status and lifestyle behaviours, which could have provided further insights into the determinants of cervical cancer incidence. At last, our study focused specifically on Addis Ababa, and the findings may not be generalisable to other regions or countries with different demographic, cultural and healthcare system characteristics.

In conclusion, our study identified significant spatial clustering of cervical cancer cases in specific subcities and woredas of Addis Ababa from 2012 to 2021. Concurrently, the age-standardised IRs varied over the years, with a notable increase in individuals aged 45–74. To address these trends, it is crucial to not only improve access to screening and treatment services, particularly for vulnerable populations, but also to confront socioeconomic disparities that contribute to disparate risk levels. Importantly, implementing a school-based HPV vaccination programme could serve as a foundational preventive measure, targeting young populations before exposure to HPV. Sustained surveillance, strategic prevention and control measures, including widespread HPV vaccination, are essential to reduce the impact of cervical cancer in Addis Ababa and improve health outcomes for its community.

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