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Spatial and temporal variation of pneumonia incidence among under-five children in central gondar zone, Northwest Ethiopia, 2013- 2022

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Abstract

Pneumonia is one of the major causes of morbidity and mortality among under-five years old children's worldwide, with Ethiopia having the highest rates among Sub-Saharan African nations. Effective control and preventative measures will be made clear by comprehending the spatial, temporal, and spatiotemporal variation of pneumonia incidence among under-five children. A time series cross-sectional study design was conducted from 1 January 2013 to 31 December 2022 using pneumonia reports obtained from the Central Gondar Zone health department and Gondar administrative health department. Fifteen districts and one administrative city were included and geo-coded in the study.

Spatial, temporal, and space-time scan spatial statistics were employed to identify clusters of pneumonia incidence among under-five children and were performed by using Excel and the SaTScan program, and the map was plotted using ArcGIS. Pneumonia incidence among under-five children reveals a general trend of rise and seasonal variation in the study area. During this study period, 147,294 under-five cases of pneumonia were reported and males made up most cases accounting for 54.94%. The average cumulative incidence proportion was 9.1. Purely high-rate spatial clusters were detected in Dembiya, Chilga, Wogera, and Gondar Zuria between 2013 and 2018. Gondar City, Wogera, and Gondar Zuria were high-rate spatial clusters detected between 2019 and 2022. The purely temporal cluster was observed from 2017 to 2018 and 2021 to 2022. Spatiotemporal clusters were detected in Dembia, Chilga, Gondar Zuria, and Wogera from 2013 - 2018 and in Gondar City, Wogera, and Gondar Zuria from 2019 - 2022. During this period pneumonia showed seasonal variation with two major peak months namely in April and October. Under five children pneumonia was found to have spatial, temporal, spatiotemporal clustering, and seasonal patterns. Also, the incidence increased over time. Interventional and preventive strategies should be developed and given priority to the areas that have been detected as hot spots in this study to reduce the mortality and morbidity of under 5 children caused by pneumonia.

Keywords Under-five children, Pneumonia, Spatial, Temporal, Spatiotemporal

Introduction

Pneumonia is known as the world's deadliest infectious killer of children, killing more than 800,000 children under five in 2019 and almost 1 million in 2022 [1, 2]. It was ranked as the 4th most common cause of death in 2017 and could rise to the 3rd spot by 2040 [3]. Pneumonia represents 14% of the worldwide illness burden in 2019 [4] and 15% of all child deaths in 2022 [2].

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According to the World Health Organization (WHO), pneumonia accounts for 20% of deaths among children under the age of five, resulting in 3 million fatalities annually [2]. The death rate of under-five children worldwide reduced by almost 50% between 2000 and 2019. However, improvement is still slower, in 65 (32%) of 204 nations [5]. Africa loses thousands of children due to pneumonia each year which causes around 750,000 child deaths per year in sub-Saharan African (SSA) countries [2].

The majority (50%) of the burden of the worldwide pneumonia mortality rate among children under five was in Sub-Saharan African nations (SSA) [6]. Yet the majority share occurs in the African continent, which has the largest burden of child mortality globally. Pneumonia claimed the lives of more than 490,000 children under-five in SSA in 2016 [6]. Nigeria, India, Pakistan, the Democratic Republic of the Congo, and Ethiopia accounted for more than half of all child deaths under the age of five in 2019 [7]. This makes Ethiopia one of the fifteen nations with the highest global mortality rate for children under five from clinical pneumonia.

Ethiopia is one of the SSA countries with the highest rates of pneumonia, with an estimated 3,370,000 children encountering pneumonia annually, which contributes to 18% of all causes of death of more than 40,000 under-five children every year [8]. The under-five pneumonia mortality rate was recorded as 9 per 1,000 live births in 2018 [9] and 15 per 1000 live births in 2019 [10]. According to the 2016 Ethiopian Demographic Health Survey (EDHS), 18% of Ethiopians have acute respiratory infections (ARI) [11]. Pneumonia accounts for 8.0% of all ARI among children under-five in the Amhara region, one of the worst-affected areas; while the national rate is 7.0% [12]. Although, the Ethiopian government is working to improve the survival of children under-five by training healthcare workers, formulating case management guidelines, strengthening communities with health insurance services and adequate health information, and extending healthcare facilities and infrastructures for implementing integrated community case management [13]. Despite interventions and persistent efforts by different stakeholders, it continues to be the major cause of under-five morbidity and mortality [14].

Pneumonia among under-five children varied geographically and within the time [15]. A study conducted in Nigeria used optimized hotspot analysis to identify regions with a significantly high prevalence of pneumonia symptoms. In addition, studies conducted in Ethiopia found that Acute Respiratory infection prevalence varied across regions, with higher rates in highland areas, influenced by the pathogen's survival, reproduction, and spread, as well as host and environmental factors [16, 17]. Pneumonia in children under five is strongly associated with poverty-related factors including socioeconomic status, malnutrition, environmental exposures, and limited healthcare access [18, 19].

Spatial, temporal, and spatiotemporal methods using Poisson distribution are suitable for modeling count data, such as the number of pneumonia incidents. Its parameters allow for capturing variations in incidence rates across space and time. By applying this distribution to spatial, temporal, and spatiotemporal analyses, researchers can effectively identify patterns, hotspots, and trends in pneumonia occurrence, informing targeted prevention and control measures.

No studies have examined the spatial, temporal, and spatiotemporal patterns of pneumonia among under-five children in Ethiopia. Understanding these spatial and temporal variations is crucial for developing effective control and prevention strategies to reduce the pneumonia burden in this population. Additionally, this study will provide crucial evidence to inform policymakers and program planners at various levels in Ethiopia, enabling them to develop, implement, and evaluate effective health promotion policies and strategies to address the issue. Therefore, this study aimed to determine the spatial and temporal variation of Pneumonia incidence among under-five children in Central Gondar Zone, Northwest Ethiopia by using a discrete poission model which uses for count data and SATScan which has a high capacity of determining purely high rate spatial, temporal and spatiotemporal clusters.

Methods and materials

Study area

The study was carried out in the Amhara region's Central Gondar Zone, which is in North Ethiopia. Ethiopia is located at approximately 9° North latitude and 40° East longitude. Gondar, the capital of the Central Gondar Zone, is located 175 kilometers from Bahir Dar, the capital of the Amhara Region, and 725 kilometers from Addis Ababa, the nation's capital. The population of the Central Gondar Zone is expected to be 382,786 as per the 2007 census (93). The Zone was divided into 15 districts, including Alefa, Central Armachiho, Cheilga 01, East Belesa, East Dembiya, Gondar Zuria, Lay Armachiho, Cheilga (Arogew), Tach Armachiho, Takusa, Tsegede, West Belesa, West Dembiya, Wogera, and Kinfaz Begela, and 1 administrative city which is Gondar city (Figure 1).

Study design and period

The time series cross-sectional study design was conducted from 1 January 2013 to December 31, 2022, using a year's pneumonia report obtained from the Central Gondar Zone health department and Gondar City.

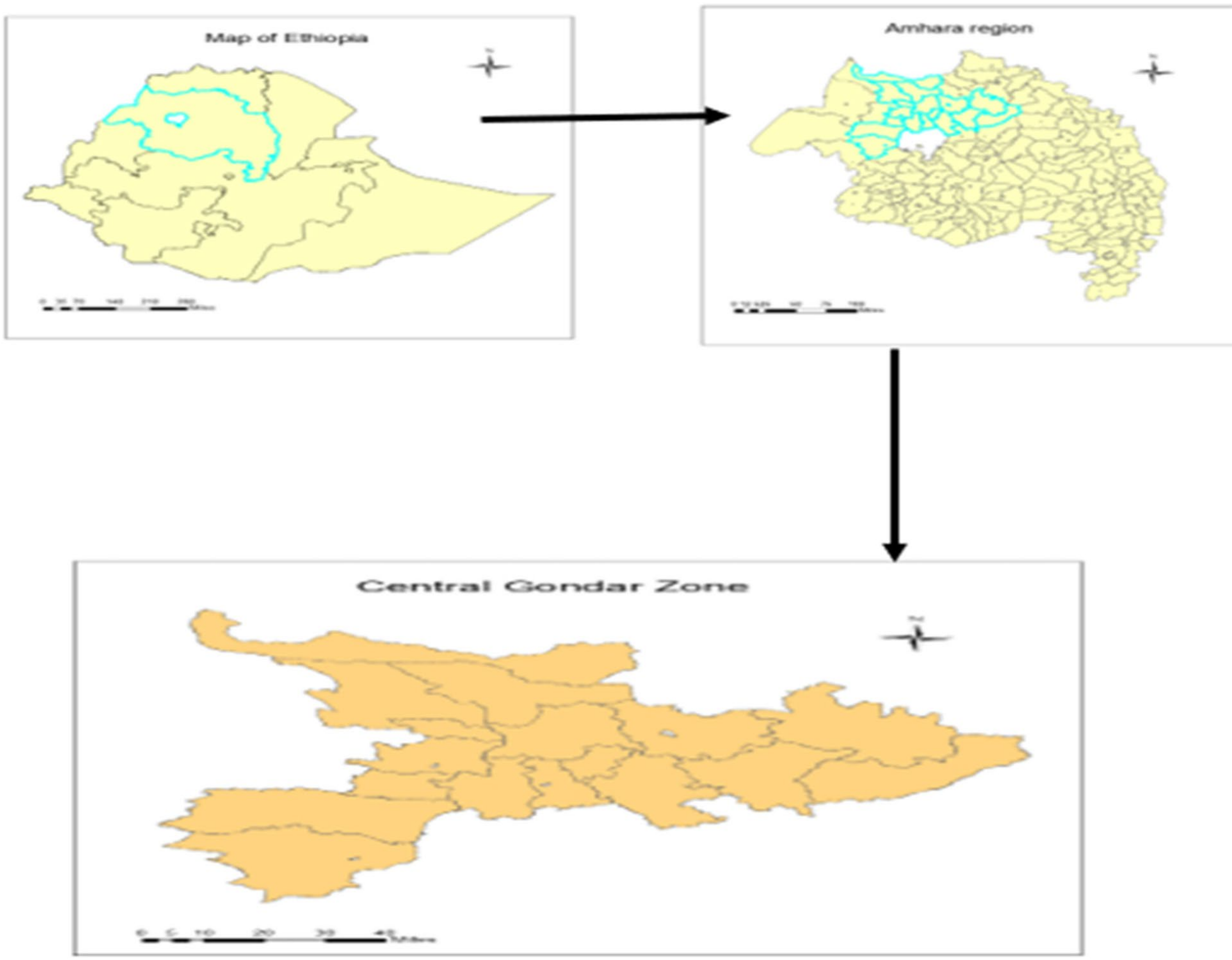

Fig 1 Map of the study area. The study area map was created by running ArcGIS software version 10.7 (https://www.arcgis.com/index.html)

Population

All Under 5 children who lived in Central Gondar Zone, from 1 January 2013 to 31 December 2022 were the source population for this study.

All Under 5 children who had confirmed cases of pneumonia from 1 January 2013 to 31 December 2022 were our study population.

Sample size determination and sampling technique

All confirmed pneumonia cases for the under-five age group from 1 January 2013 to 31 December 2022 were used. Rather than using a predetermined sample size, all cases (147,294) reported in each district of Central Gondar Zone from January 1, 2013, to December 31, 2022, were included as the sample for the spatial, temporal, and spatiotemporal analysis of under-five pneumonia incidence. Therefore, there is no pre-determined sample size and sampling technique to select from the cases reported.

Data collection procedure and quality assurance

Data on pneumonia among under-five children incidence cases among under-five from 1 January 2013 to 31 December 2022 was obtained from monthly reports from the Central Gondar Zone health department and Gondar city administration health department. The data was aggregated from health facilities to the district health department in a monthly surveillance form. The district health department reports directly to the Zone health department. The spatial coordination (the latitude and longitude) for each district was obtained from the Ethiopia Statistics Service in a polygon shape file.

Data was retrieved from monthly surveillance data stored in the Central Gondar Zone health department with the approval of the department for the period January 1, 2013, to December 31, 2022. The data collectors were informed about the research's objectives and data collection procedures. All methods were performed following the relevant guidelines and regulations. After collection, the principal investigator of the study checked the completeness and consistency of the data before analysis. The data were cleaned, edited, checked, and sorted using Excel. Further cleaning was done after importing to STATA software using cross-tabulation.

Data management

Central Gondar Zone which was previously known as North Gondar Zone, was newly formed at the end of 2018. This has made some districts be incorporated into the Zone like Kinfaz Begela, while some districts were divided into two like Chilga to Chilga 01and Nebaru Chilga, Tach Armachiho to Central Armachiho and Tach Armachiho, Dembiya to West Dembiya and East Dembiya. Therefore, to manage this difference the study period was divided into two from 1 January 2013 to 31 December 2018 and 1 January 2019 to 31 December 2022.

Data obtained from the Central Gondar Zone health department don't include Gondar city data as the Gondar city administrative health department independently reports data to the region office (S1 File and S2 File). Although the data was reported in different departments, the geographic area shows Gondar city in the center of the Zone. Therefore, this study incorporates Gondar City in the study area.

Gondar City was excluded from the study period from 2013 to 2018 because there was no report of under-five pneumonia cases in Gondar City from the health center level in this specific period. The number of confirmed pneumonia cases remained unchanged at 147,294 following data cleaning and management.

Statistical analysis

For this study, all 15 districts in the Central Gondar Zone and Gondar City were included and geo-coded. Each district was geo-referenced to its geographic centroid using a shape file containing district boundaries and polygon shapes that were obtained from the Ethiopia Statistics Service. Each district's spatial data was produced using ArcGIS 10.8.2 software.

To examine the yearly variations of pneumonia among under-five children's incidences from January 1, 2013, to December 31, 2022, the monthly and yearly cumulative incidences of pneumonia among under-five children for each district were calculated and plotted. It was included by dividing the number of pneumonia among children incidence cases by the population at risk.

The discrete Poisson model: Because the number of incidences in each place is Poisson distributed, the data was counted, and the population's aggregate number of person-years lived was utilized to fit the Poisson model. For this reason, the discrete poison model was employed [20, 21]. The Poisson model is versatile in analyzing spatial, temporal, and spatiotemporal data. In spatial statistics, it models point patterns, estimating intensity and accounting for clustering or inhibition [22]. For temporal data, it counts events within intervals, estimating rates and accommodating time-varying trends [23]. In spatiotemporal settings, it extends to modeling events in both space and time, capturing varying intensities and dependencies [24]. All assumptions of the discrete Poisson model (to name some like independent occurrence of cases, nature of the data count data, distribution), have been verified as met by the data. Therefore, we proceed with further analysis.

Cluster analysis: ArcGIS10.8.2 was used to combine data on pneumonia among under-five children with the shape file, test the pneumonia among under-five children distribution pattern hypothesis using Global Moran's I, and perform hot spot analysis using the Getis-Ord Gi* statistic.

The presence of merely spatial, temporal, and space-time pneumonia among under-five children clusters was determined using the scanned statistics created by Kulldorff utilizing SaTScan TM 10.1 software. To determine the number of observed and expected cases inside the window at each point, the scan statistics were gradually scanned through time and/or space. The window with the highest likelihood is the most likely cluster, and a *p*-value was given to this cluster. The scanning window is an interval (in time), a circle (in space), or a cylinder with a circular base (in space-time) to which window sizes are determined.

Purely spatial clusters: This technique for spatial statistical analysis uses a circular window to scan the entire study area. The circle's radius fluctuates continually between zero and a predetermined maximum size. The percentage of the population at risk inside the scanning window was set by the maximum size. Which was 50% of the population at risk. The alternative theory is that the risk of disease inside and outside the scanning window in space is not the same. The most probable (main) cluster that is least likely to have happened by chance was determined as the circle with the highest likelihood ratio and more incidence than predicted. The greatest likelihood ratio test statistic is represented by the likelihood ratio for this window. By comparing the rank of the maximum likelihood from the real dataset with the maximum likelihoods from the random datasets, Monte Carlo simulations were used to estimate the p-value. The significance of the cluster was determined using an alpha level of 0.05.

Spatiotemporal clusters: The Kulldorff utilizing SaTScan TM 10.1 software was used to find spatiotemporal clusters. This was to make it easier to find clusters that the simple spatial statistic may miss. Spatiotemporal clusters were identified using a cylindrical window.

Similar to the purely spatial scan statistic, the cylinder's base represents the spatial component, while its height represents the temporal dimension. The time window was limited to the annual for this study, and the spatial window was limited to 1 kilometer. Using a p-value that is calculated using Monte Carlo simulations, districts with a substantial number of incidences within the corresponding time were discovered. For each solely spatial and space-time scan data, secondary clusters in addition to the most likely cluster (primary) were found using an iterative approach as stated in Kulldorff. After that, this process was repeated until no clusters with p-values less than 0.05 were left. As with the spatiotemporal clusters, a *p*-value was produced using Monte Carlo simulations. A significant cluster was recognized at an alpha level of 0.05 or lower.

Purely temporal clusters; the height of the cylindrical window was used as the time dimension for a window that moved solely in one dimension. Using Monte Carlo simulations, such as spatiotemporal clusters, a p-value was produced. A significant risk period was determined using a significance level of alpha 0.05, just like spatial and spatiotemporal clusters. Just the most probable cluster was presented for solely temporal analyses. The scan was used to look for regions, districts, and instances that have large concentrations of clusters of pneumonia among children incidence cases.

Ethics approval and consent to participate

All methods were carried out following the relevant guidelines and regulations of the Declaration of Helsinki. Ethical clearance was obtained from the research and ethical review committee of the Institution of Public Health, College of Medicine and Health Sciences, University of Gondar on April 06, 2023 (Ref No/IPH/2707/2023). A support letter was obtained from the Department of Environmental and Occupational Health and Safety for the required data to the Central Gondar Zone health department and Ethiopia Statistical Service. To ensure the confidentiality of data, it was kept secure and the data was not used for other purposes. There were no individual participants and no need for informed consent in this study because it was secondary data/count of under 5 pneumonia which has no personal identifiers.

Result

Distribution of pneumonia among under-five children

In the Central Gondar Zone, a monthly incidence of pneumonia among under-five children was gathered from January 1, 2013, to December 31, 2022. Between January 1, 2013, and December 31, 2022, 147,294 cases of pneumonia in children under-five were reported in Gondar city and 15 districts of the Central Gondar Zone. In Gondar city and Tsegede, there were the greatest and lowest yearly incidences of pneumonia among under-five children in the years 2022 and 2013, respectively (Fig. 2a and b).

Pneumonia incidence varies from time to time as well as from district to district this variation has been shown in the figure below (Fig. 3a and b).

The proportion of pneumonia among under-five children varies by sex. Males made up most cases of pneumonia among under-five children (54.94%) (Figure 4), while females made up the remaining 44.06% (Figure 5).

The incidence rate varies from place to place and through the years, a higher incidence rate was observed in 2020 to 2022 and had lower incidence rate in 2013 and 2014. The highest incidence rate was observed in Gondar city in the year 2022, While the lowest incidence rate was observed in Tsegede in 2013 (S3 File).

Trends of Pneumonia among under-five children incidence

The incidence of pneumonia among under-five children was increasing progressively each year. Maximum and minimum number of incidences were documented during 2022 and 2013 respectively (Figure 6).

Pneumonia among children is generally on the rise, with seasonal variations quickly extending between January and April and September and November. Each year, there were two peaks under 5 seasons of pneumonia incidence: the first peak was seen in April, and the second peak was seen in October (Figure 7).

The 10-year seasonal trend of the smoothed and deseasonalized incidence rate of pneumonia among under-five children shows an increase trend with an equation of (Yt)=4.74t +3457.91 (Figure 8).

Spatial variation of pneumonia among under-five children incidence

Global spatial autocorrelation

The global spatial autocorrelation results indicate that pneumonia incidence among under-five children pneumonia was clustered with global Moran's I = 0.48, p-value =0.043 from January 2013 to December 2018 (Figure 9a) and from 2019 2022 the global Moran's was I =0.45 with p-value = 0,045) (Figure 9b).

The maximum peak, where spatial clustering is highly pronounced is at a distance of 45692.65 meters with the corresponding Z score of 2.467394 (p-value < 0.05). This distance band is used for the analysis of hot spot clusters (Figure 10).

Hot spot detection

Hot spot areas with a high cluster of incidence of pneumonia among under-five children were identified. A hotspot area with a high-rate cluster at 90% confidence

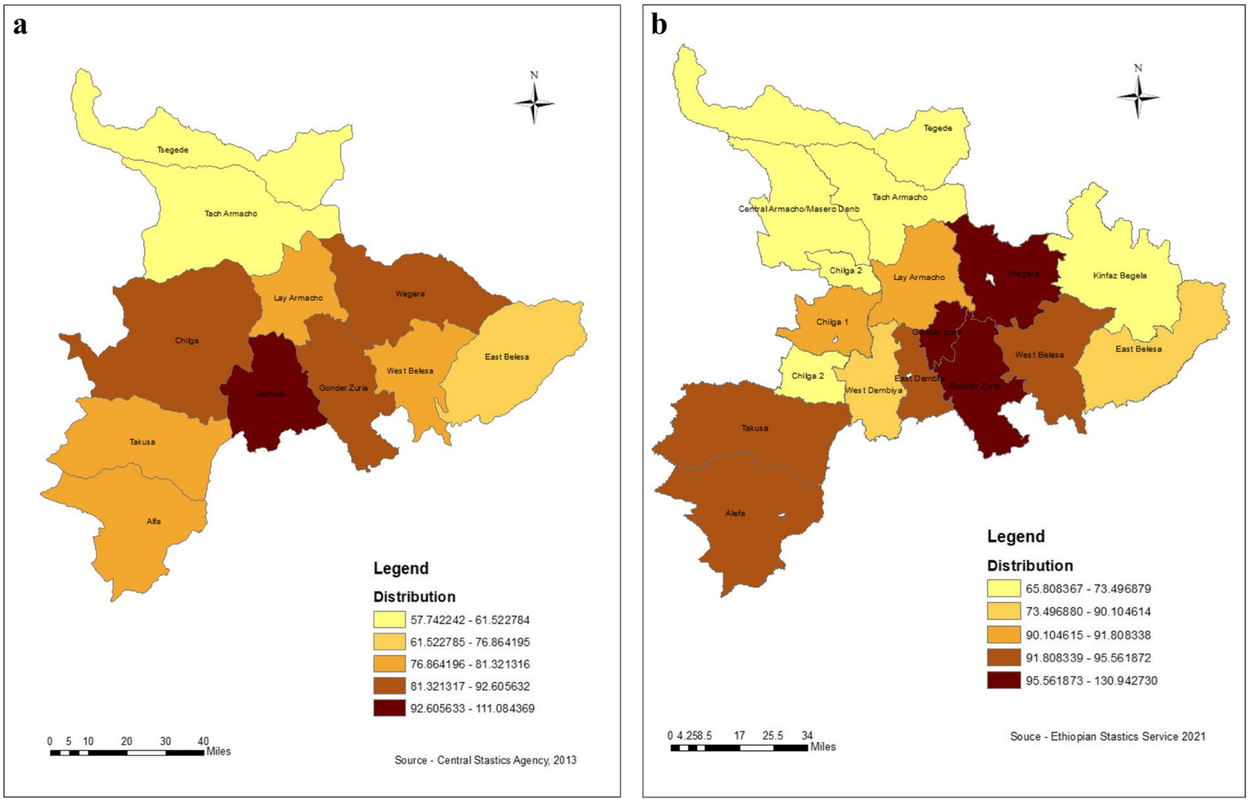

Fig 2 Graduated color (choropleth) map that depicts density based on average cumulative annual childhood incidence per 1000 population at risk in Central Gondar Zone **a**) Between 1 January 2013 – 31 December 2018 **b**) Between 1 January 2019 – 31 December 2022.

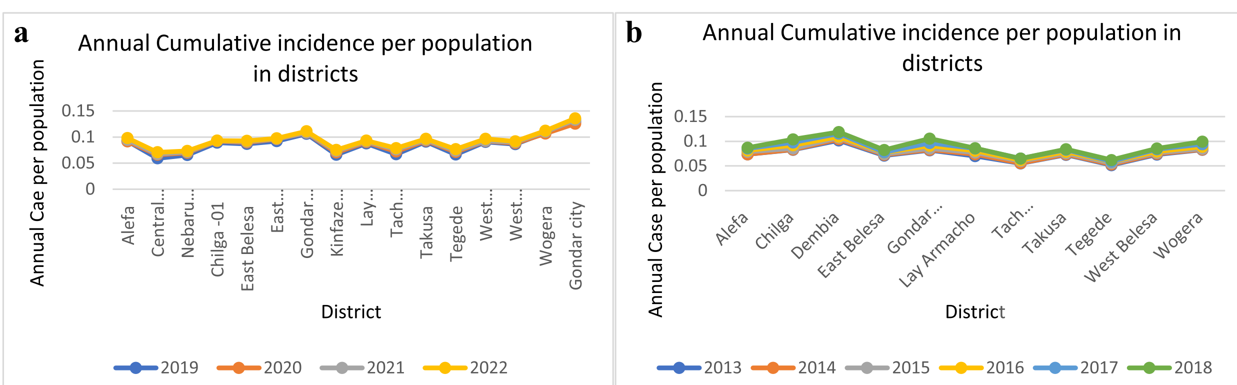

Fig 3 District-level Annual cumulative pneumonia among under-five children incidence in Central Gondar Zone, **a**) Between 2013 – 2018 **b**) Between 2019-2022

was observed in Dembiya and Gondar Zuria districts, Dembiya covered 19.7% of the total pneumonia incidence among under-five children from 1 January 2013 to 31 December 2018 in Central Gondar Zone. On the other hand, a 99% confidence cold spot was observed in Tsegede and Tach Armacho districts, those districts cover 2.5% and 3.6% of the total pneumonia incidence among under-five children from 1 January 2013 to 31 December 2018 in Central Gondar Zone (Figure 11a).

For the study period 1 January 2019 to 31 December 2022, a hot spot area with a high-rate cluster at 95% confidence was observed in Gondar City, Wogera, Gondar Zuria, East Belesa, and Lay Armacho. Those districts cover 21.3%, 10.1%, 9.9%, 4.9%, and 4.9% of the total

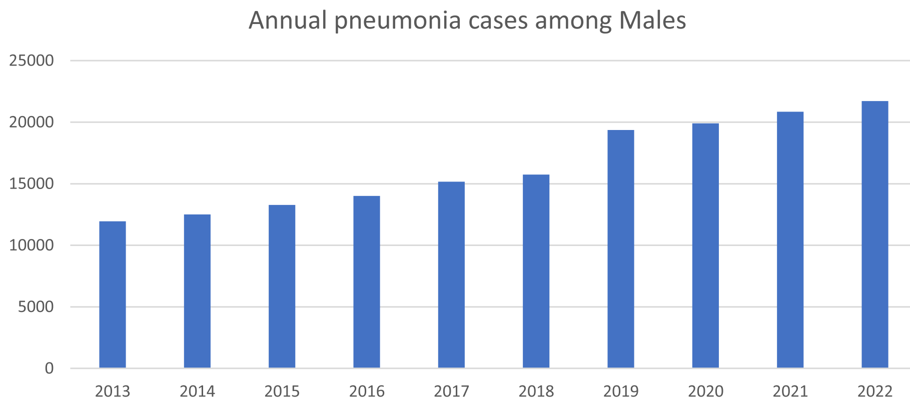

Fig 4 Distribution of annual cumulative incidence by male in Central Gondar Zone, 2013 – 2022.

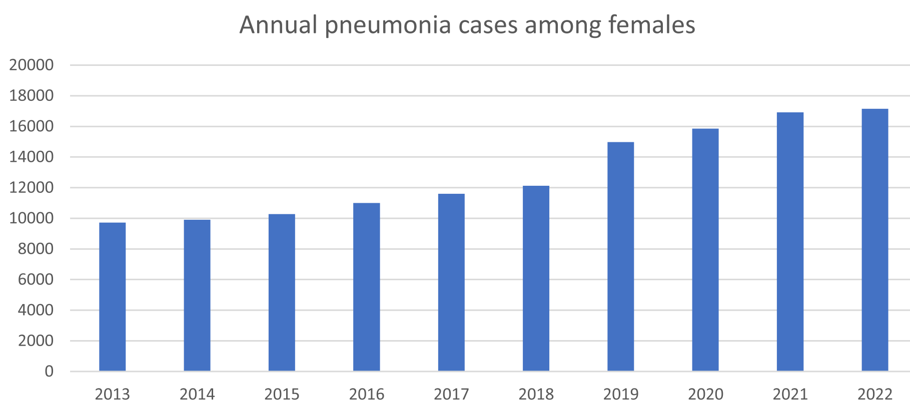

Fig 5 Distribution of annual cumulative incidence by females in Central Gondar Zone, 2013 – 2022.

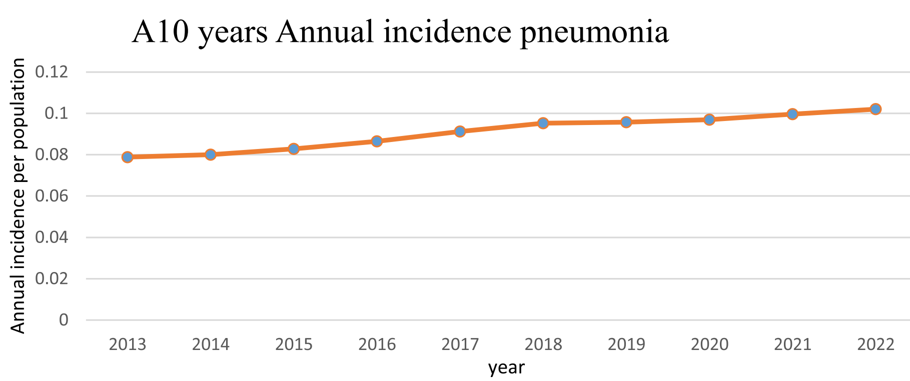

Fig 6 Annual cumulative pneumonia among under-five children incidence in Central Gondar Zone Northwest Ethiopia from 2013 to 2022.

pneumonia incidence among under-five children from 1 January 2019 to 31 December 2022 in Central Gondar Zone respectively. 90% and 95% cold spots were observed in Central Armacho and Tach Armacho, Central Armacho covered 1.1% and Tach Armacho covered 3.1% of the total pneumonia incidence among under-five children from 1 January 2019 to 31 December 2022 in Central Gondar Zone respectively (Figure 11b).

Purely spatial cluster

High-rate spatial clusters

The purely spatial cluster analysis result shows the non-random distribution of Pneumonia incidence

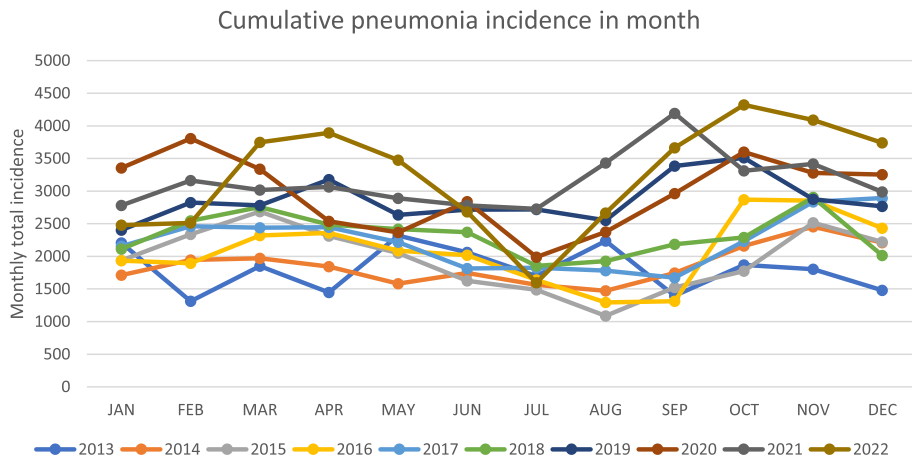

Fig 7 Cumulative incidence of pneumonia among under-five children in 2013 – 2022, Central Gondar Zone, Northwest Ethiopia

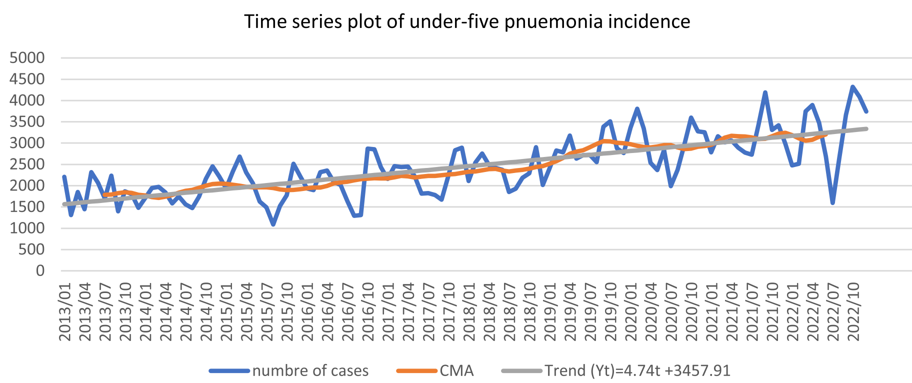

Fig 8 Trend and seasonal variability rate of pneumonia among under-five children in Central Gondar Zone, between January 2013 and December 2022

among under-five children in the Central Gondar Zone from January 2013 – December 2022, and it was found to be clustered having significantly higher cases than the expected (log-likelihood ratio greater than 1) using the maximum spatial cluster size of ≤ 50% of the total population. Four high-rate spatial clusters were detected for the study period between January 2013 to December 2018, the primary cluster was detected in Dembiya while a secondary cluster was detected in Chilga, Wogera,, and Gondar Zuria. Three high-rate spatial clusters were detected during the study period of January 2019 to December 2022. Primary clusters were identified in Gondar City, while secondary clusters were found in Wogera and Gondar Zuria (Table 1).

The distribution of District with a High rate pneumonia incidence have been shown in the figure below (Figure 12)

Purely temporal clusters

High-rate Temporal clusters

A significantly high rate of purely temporal pneumonia incidence was observed among under-five children clusters during the study periods of 2017-2018 and 2021-2022, with Log Likelihood Ratios of 283.27 and 45.11, respectively (Table 2).

Spatiotemporal clusters

Additional evidence for a higher-than-expected incidence of pneumonia among under-five children within the specified period and location is provided by the spatiotemporal analysis. The space-time cluster analysis of pneumonia among under-five children cases between January 2013 and December 2022 in the Central Gondar zone revealed that the disease was not distributed randomly. Significant spatiotemporal clusters

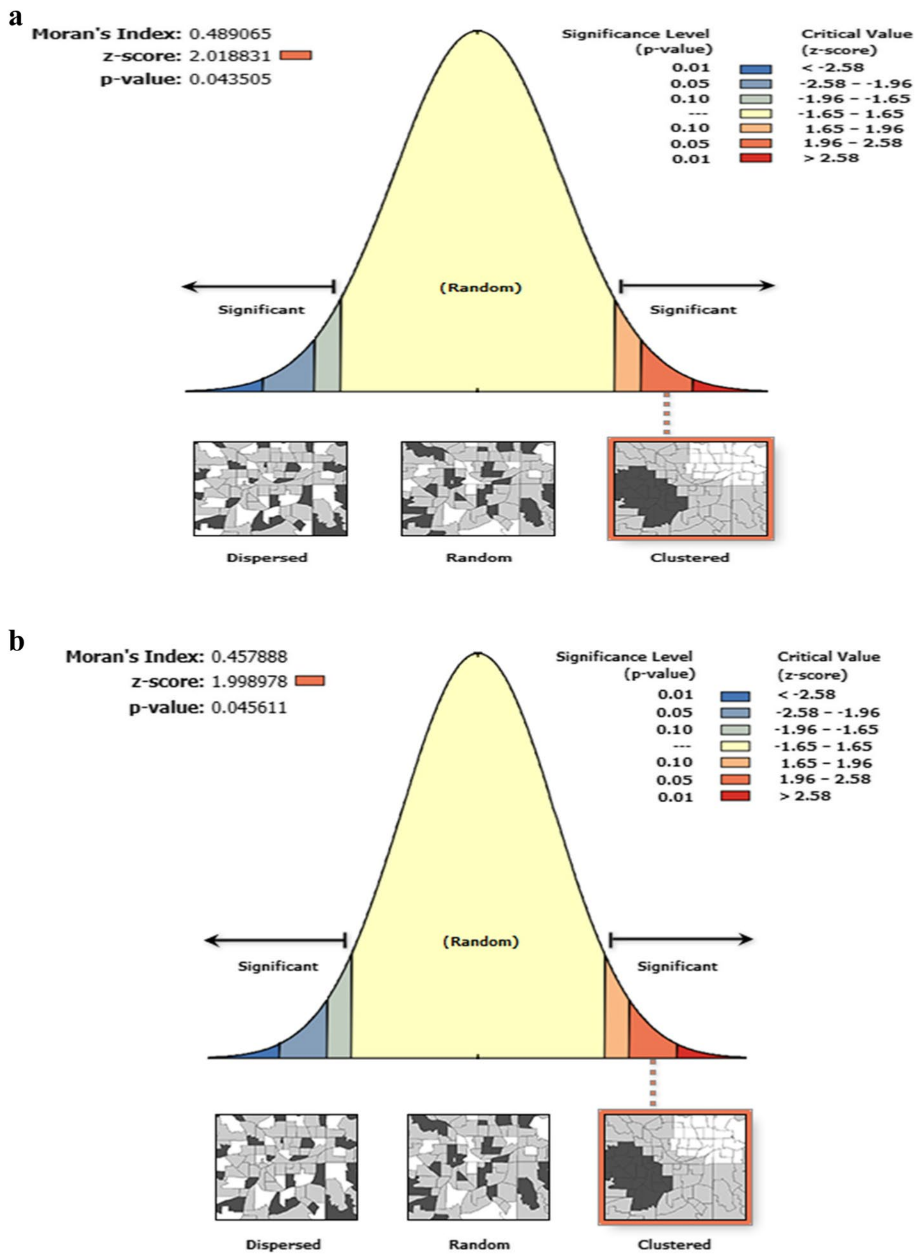

Fig 9 **a** Spatial autocorrelation based on feature locations and attribute values (average cumulative annual pneumonia incidence among under-5 children) calculated using the Global Moran's I statistic across the study area in the Central Gondar Zone, Northwest Ethiopia, January 2013-December 2018. **b** Spatial autocorrelation based on feature locations and attribute values (average cumulative annual pneumonia incidence among children) calculated using the Global Moran's I statistic across the study area in the Central Gondar Zone, Northwest Ethiopia, January 2019-December 2022.

of pneumonia among under-five children were found using a maximum spatial cluster size of 50% of the total population (Table 3).

Discussion

The 10-year monthly report on pneumonia incidence among under-five children reveals a general pattern of

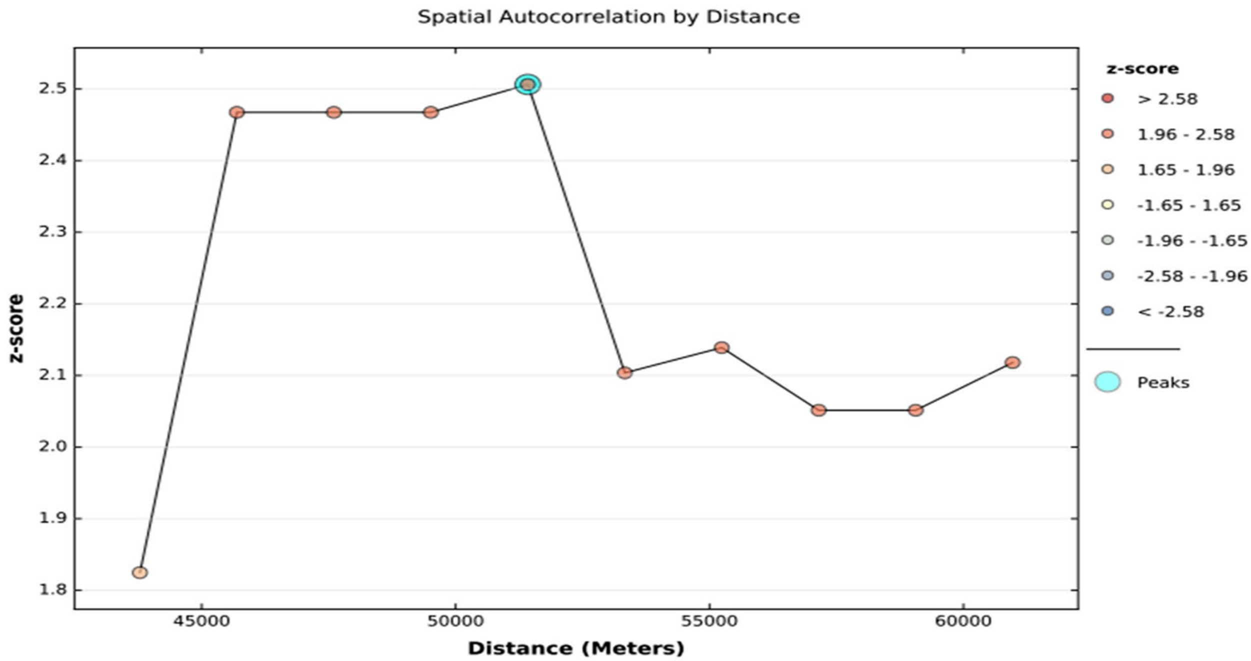

Fig 10 Incremental Spatial autocorrelation by distance in Central Gondar Zone from 2013 to 2022.

rise and seasonal variation in the study area. The lowest incidence rate was recorded in Tsegede in 2013, while the highest incidence rate peak was recorded in Gondar City in 2022. It was also noted that pneumonia incidence among under-five children has been rising over time.

During the research period, the annual cumulative incidence rate of pneumonia among under-five children showed an upward trend (74.3858, 75.5759, 78.3464, 81.8214, 85.93779, 89.03563, 86.54282, 89.00797, 91.11628 and 93.22216). 9.1% was the average cumulative incidence proportion for pneumonia among under-five children. Consequently, the outcome was higher than the EDHS of 2016, which was found to be 6.6% [25], but lower in studies conducted in Jimma Zone (12%) [26], Northwest Ethiopia (28.1%) [27], peri-urban kebeles of Dessie City (17.1%) [28], Wondo Genet District (South Nation and Nationality People Region, Ethiopia) (16.1%) [29], Gamo Zone (southern Ethiopia) (30%) [30], Este town and surrounding rural kebeles (Northwest Ethiopia) (33.3%) [31], and also in a study conducted in Dibrugarh town (India) (16.34%) [32], and West Nusa Tenggara (Indonesia) (33.3%) [33]. This heterogeneity may result from a variety of reasons, including a different technique of data collecting, study setting, study term, evaluation method, accumulation of risk factors, and environmental factors.

Although Ethiopia implemented integrated management of childhood illness (IMCI) in the middle of the 1990s, integrated management of newborn and childhood illness (IMNCI) in 2003 [34], the fourth Millennium Development Goal in 1990 and 2015 [35], integrated Community Case Management (ICCM) in 2004 [36], community-based treatment for pneumonia among under-five children through the use of health extension workers in 2010 and pneumococcal conjugate vaccine added to its expanded immunization campaign in 2011 [37], pneumonia among under-five children continued to have a big burden.

Despite this study's incidence is lower than other study findings, it is highlighted that the incidence each year is rising quickly. This could occur as a result of increased climatic variability, differences in and a lack of concern for lower respiratory tract infections, as well as poor levels of knowledge, attitude, and practice about the disease's transmission, prevention, and treatment.

The percentage of males with pneumonia among under-five children was found to be 55.94%, compared to the percentage of females at 44.06%. On the other hand, a study conducted in Brazil found that a boy was less likely than a girl to have pneumonia [38]. This result does, however, some studies line up with this study where males were more likely to experience pneumonia episodes [39]. This may be because female lungs typically have a lower volume and smaller airways than men's lungs of equal height and age, which affects the contact surface area in the lung for particular causative microorganisms, resulting in a lower rate of pneumonia in females than males [40].

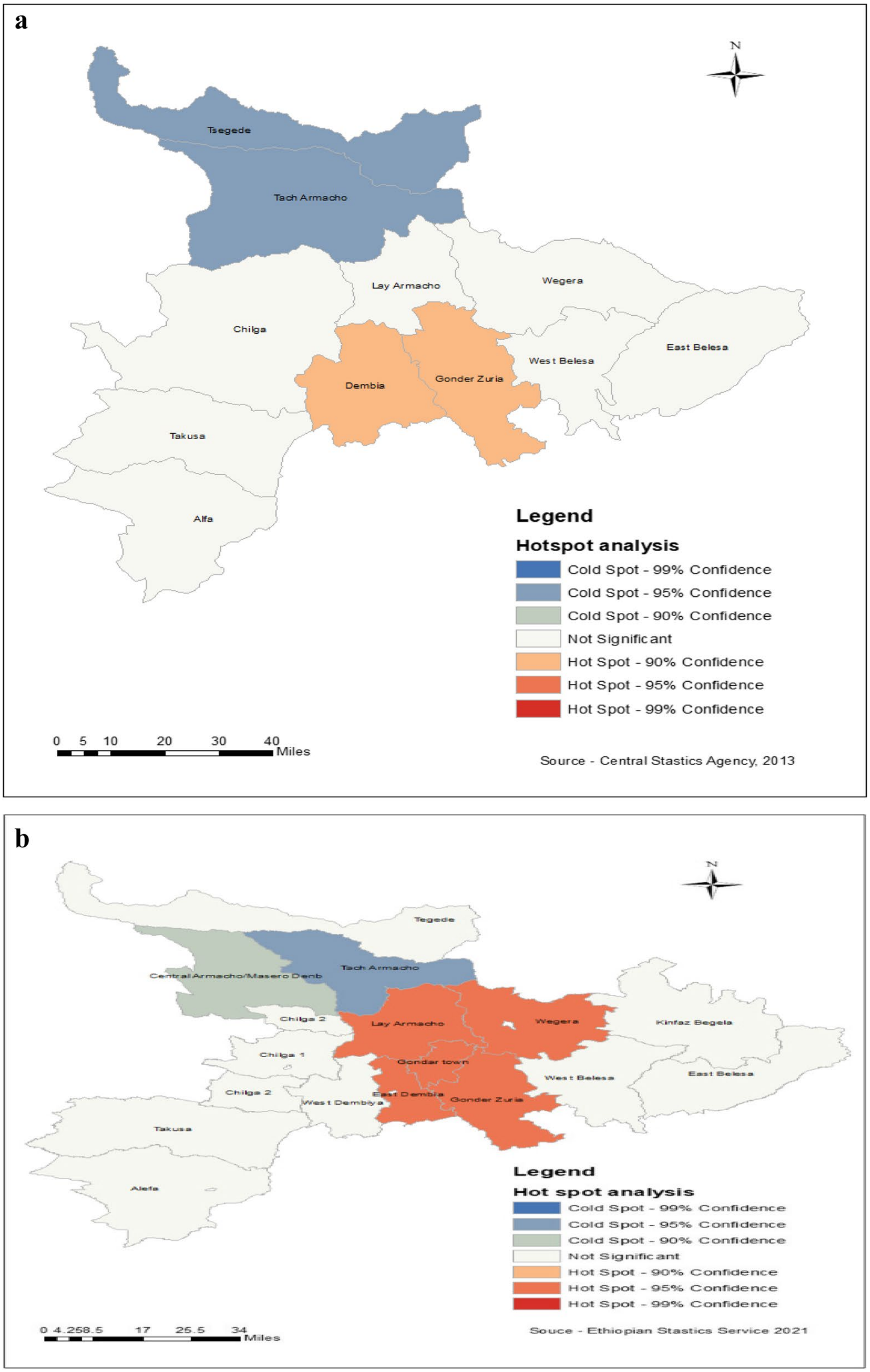

Fig 11 **a** Hotspot detection based on average cumulative annual pneumonia incidence among under-5 children in the Central Gondar Zone, Northwest Ethiopia, January 2013-December 2018. **b** Hotspot detection based on average cumulative annual pneumonia incidence among under-5 children in the Central Gondar Zone, Northwest Ethiopia, January 2019-December 2022.

Table 1 Significant high-rate spatial clusters of pneumonia incidence among under-five children in Central Gondar Zone

Cluster	District	Population	Coordinate/radius	Obs.*	Exp.*	RR	LLR
For the study period from January 2013 to December 2018							
1	Dembia	44022	(13.715384 N, 31.120175 E) / 0 km	28978	22691.35	1.34	961.339695
2	Chilga	36076	(13.932453 N, 27.243625 E) / 0 km	36076	18595.54	1.07	40.309833
3	Gondar Zuria	31212	(13.739707 N, 34.287107 E) / 0 km	17005	16088.08	1.06	28.858068
4	Wogera	35798	(14.123745 N, 36.732072 E) / 0 km	19148	18451.95	1.04	14.849891
For the study period from January 2019 to December 2022							
1	Gondar city	59751	(12.575528 N, 37.450339 E) / 0 km	31330	23580.29	1.42	1402.669479
2	Wogera	34008	(12.781798 N, 37.675980 E) / 0 km	14859	13420.88	1.12	82.233266
3	Gondar Zuria	33462	(12.385233 N, 37.590973 E) / 0 km	14533	13205.55	1.11	71.218483

p-value <0.001 for all clusters

RR Relative Risk

LLR Log Likelihood Ratio

Obs.*Number of observed cases in the cluster

Exp.*Number of expected cases in the cluster

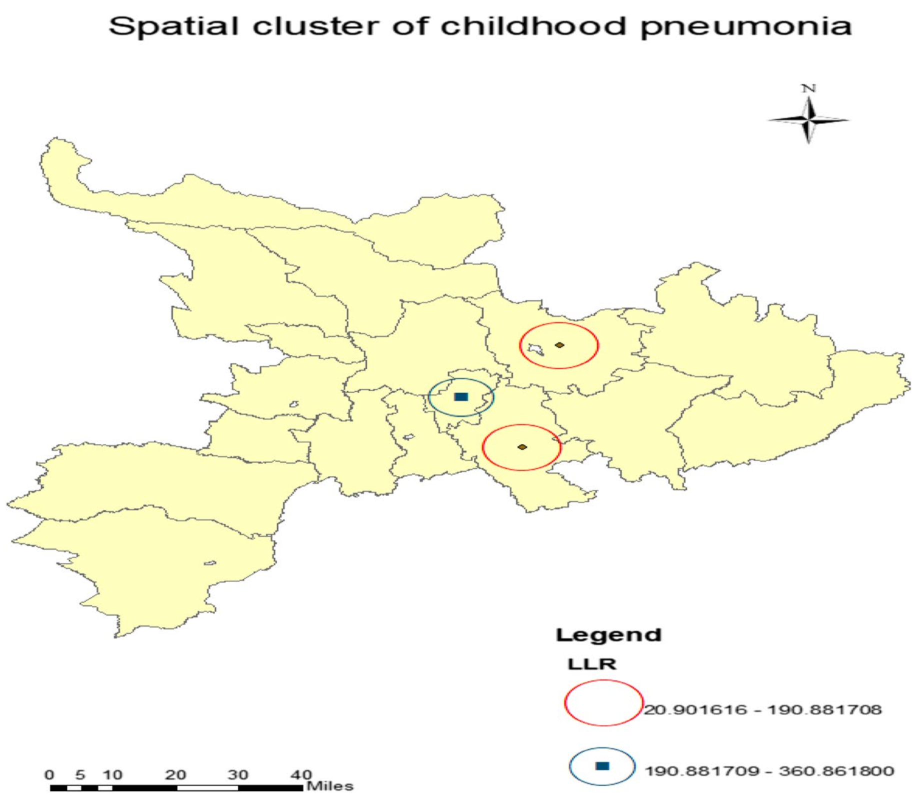

Fig 12 spatial distribution of significant high-rate pneumonia incidence among under-five children cluster at district level in Central Gondar Zone, 1 January 2013 – 31 December 2022.

This study also discovered that 43% of all pneumonia cases in children under the age of five were in newborns or children under the age of 12 months. According to a cross-sectional study conducted in the SNNPR district of Wondo Genet, children under the age of two months have a four times higher chance of developing pneumonia than children between the ages of twelve and sixty-nine months [29], similarly studies conducted in urban areas of Oromia region and Ethiopian Demographic Health Survey, 2016 show that children in the

Table 2 Significant temporal clusters of pneumonia incidence among under-five children in Central Gondar Zone.

Cluster	District	Time frame	Obs.*	Exp.*	RR	LLR	*P*-value
1	All	2017 to 2018	54632	50272.13	1.14	283.276612	0.001
2	All	2021 to 2022	76508	74690.59	1.05	45.111803	0.001

RR Relative Risk

LLR Log Likelihood Ratio

Obs.*Number of observed cases in the cluster

Exp.*Number of expected cases in the cluster

Table 3 Significant high-rate spatiotemporal cluster of pneumonia incidence among under-five children in Central Gondar Zone, January 2013 - December 2018 and January 2019 – December 2022.

For study period January 2013 to December 2018							
Cluster	District	Time frame	Obs.*	Exp.*	RR	LLR	p-value
1	Dembia	2016/1/1 to 2018/12/31	15506	11615.64	1.37	645.245303	< 0.001
2	Chilga	2017/1/1 to 2018/12/31	7521	6391.19	1.19	98.989553	< 0.001
3	Gondar Zuria	2017/1/1 to 2018/12/31	6521	5530.84	1.19	87.236847	< 0.001
4	Wogera	2017/1/1 to 2018/12/31	7143	6335.45	1.13	51.727876	< 0.001
For study period January 2019 to December 2022							
1	Gondar City	2021/1/1 to 2022/12/31	16847	12335.49	1.41	816.256475	< 0.001
2	Wogera	2021/1/1 to 2022/12/31	7685	6824.94	1.13	54.700681	< 0.001
3	Gondar Zuria	2021/1/1 to 2022/12/31	7408	6650.58	1.12	43.634542	< 0.001

RR Relative Risk

LLR Log Likelihood Ratio

Obs.*Number of observed cases in the cluster

Exp.*Number of expected cases in the cluster

age range of 2–11 months had higher chance of having ARI compared to older age ones [25, 41]. Another study conducted in Bangladesh found that infants were the most affected group [42]. Infants may spend more time indoors and come into touch with more germs, fungi, or viruses since they are indoors for longer periods [43]. The majority of households in the study area used charcoal as a source of fuel indoors [44].

Geographical location affects the likelihood of contracting an infectious disease, however epidemics or hot spots have rarely been found. Spatial and space-time analysis has been frequently employed in cluster identification. It is a dynamic technique that indicates where and how much an incidence is present, making it a useful tool for examining the spatial distribution of a disease.

Many studies conducted in different geographic areas show pneumonia among under-five children had strong clustering with seasonality and it was in an assorted manner [43, 45, 46]. Purely spatial high-rate clusters, which are statistically significant were observed in Dembiya, Chilga, Wogera, and Gondar Zuria for the study period between January 2013 to December 2018 and three high-rate spatial clusters were detected for the study period January 2019 to December 2022 in Gondar City, Wogera and Gondar Zuria. These clusters except Dembiya were located in highland areas with cooler and medium temperatures than other areas because many residents there cook their meals inside the house using biomass fuel, which pollutes indoor air [44]. Another factor could be that residents in colder climates prefer to stay inside their homes, which reduces airflow and increases crowding, increasing the likelihood that respiratory illnesses will propagate [47]. In addition, the majority of people spend their nights in the same house as their domestic animals [48]. Although it is thought that 90% of rural households in Ethiopia possess farm animals [49], sharing a dwelling with livestock is relatively common and is associated with congested living conditions and sickness [50].

Pneumonia among under-five children's temporal dynamics have a clear seasonal pattern, with wintertime peaks and summertime troughs [45, 51]. The first period, which ran from 2017 to 2018, and the second, which ran from 2021 to 2022, both showed noticeably high rates of temporal clusters. This demonstrates that the incidence of pneumonia among under-five children during the relevant study period has been steadily rising in the studied area. Therefore, the last year was set to be the highest. This may be due to a lack of concern by the government and the community, low awareness towards the communicability of the disease, and also COVID-19 may have an impact on this [52].

The spatiotemporal analysis provides than expected number of pneumonia incidences among children in both a defined place and time. Significant spatiotemporal childhood incidence clusters were detected for the study period between January 2013 to December 2018 in Dembia in the time frame between 2016/1/1 to 2018/12/31 and Chilga, Gondar Zuria, Wogera in the time frame between 2017/1/1 to 2018/12/31. For the study period January 2019 to December 2022, significant spatiotemporal childhood incidence clusters were detected in Gondar City, Wogera, and Gondar Zuria between 2021/1/1 to 2022/12/31. Even though numerous international and national organizations implemented various strategies and programs. Several factors made it difficult for those strategies to be used effectively [53], which suggests that these strategies need to be revised and that new, effective interventions are needed.

The incidence of pneumonia among under-five children first rises in August and peaks around the beginning of November, and then it rises again in March and peaks in May. The monthly average minimum temperature reaches its lowest during the first interval, which is also when the monthly average relative humidity and rainfall reach their highest values and start to decline. However, the second interval (March to May) marks the shift from the driest to the rainiest season, which occasionally rains, as relative humidity starts to rise along with monthly average maximum and lowest temperatures. When the temperature drops during this season, microorganisms are more likely to remain stable in the air and persist in the form of respiratory droplets. Normally, bacteria on our skin are not harmful, but during the cold and flu season, immunity declines, weakening the body and even causing damage to the airways, which gives bacteria the chance to infect us and cause diseases, most notably pneumonia [54].

According to this study, a drop in temperature was linked to a rise in the incidence of pneumonia among under-five children. This outcome is consistent with other studies conducted in Taiwan that discovered a link between pneumonia and a low temperature [55]. Similar findings were found in a different Chinese investigation [56]. According to certain studies, the connection differed depending on the disease agents and geographical areas. For instance, one study discovered that the relationship between temperature and pneumonia among under-five children differed between tropical and subtropical regions [57]. Other research, in contrast to this one, discovered a positive correlation between temperature and pneumonia among under-five children. A study done in Indonesia [58] and Papua New Guinea found that hospitalizations for respiratory tract infections were positively correlated with temperature [59].

Additionally, several studies have discovered a strong connection between child pneumonia and relative humidity. For instance, a study done in Japan revealed a link between pneumonia and humidity [60]. A study from the Philippines likewise discovered a positive association [61]. Another study, this one from China, looked at two pneumonia-causing pathogens and found no correlation between Respiratory Syncytial Virus (RSV) and Mycoplasma pneumonia; however, a negative correlation between RSV and relative humidity was found. The relative humidity, however, was not linked to pneumonia among under-five children in this study's findings. This result provides information for all concerned stakeholders and governmental bodies who are interested in the reduction and prevention of morbidity and mortality of under 5 children to provide an intervention and give priorities for the areas that are identified as hot-spot areas and increase the health and well-being of the community.

Conclusion

The incidence of pneumonia among under-five children was found to have spatial, temporal, spatiotemporal clustering, and seasonal patterns. Additionally, pneumonia incidence among under-five children increased over time. To reduce morbidity and mortality from pneumonia, prioritizing interventions in the high-rate pneumonia incidence cluster areas identified in this study is recommended. Given the seasonal pattern of pneumonia, with peaks in October and September, precautionary measures should be implemented. This result provides information for all concerned stakeholders, governmental bodies, and district health department officers who are interested in the reduction and prevention of morbidity and mortality of under 5 children to provide an intervention and give priorities for the areas that are identified as hot spot area and increase the health and wellbeing of the community. Again it provides baseline data for policymakers by providing information about high-rate spatial cluster areas this will give clues for priority interventions like vaccination, early warnings in months that pneumonia showed a high peak, identification of environmental factors in high-rate spatial cluster areas, and collaboration with different stakeholders. Further research is needed to investigate the underlying causes of increased risk in these hotspot areas, including individual, household, and environmental factors, to develop a comprehensive understanding of pneumonia risk.

Limitation

First off, the spatial, temporal, and spatiotemporal variation of pneumonia incidence among under-five children in the Central Gondar Zone is scarce. Therefore, it will serve as a basis for evaluating the progression of pneumonia interventions with upcoming research projects. The fact that complete monthly morbidity data were obtained from all districts except Gondar city throughout the study period was a strength.

As the data only includes individuals who sought treatment at the healthcare system level, there is a constraint in the underreporting of pneumonia among under-five children. As a result, the study may not accurately reflect the morbidity of pneumonia among under-five children in the study area. This restriction, though, might not be very significant given that the issue is thought to be consistent across all districts for the duration of the study. Second, the symptoms and signs advised by the WHO pneumonia guidelines were mostly used to diagnose the reported confirmed cases. Laboratory tests did not confirm these reported cases. Consequently, there is a potential for selection bias in this study.

Unfortunately, host (an individual level), household, environmental, and organizational aspects were not included in the study. The information came from a system of passive surveillance. This indicates that because some people may not report to the official governmental health facilities but instead use either private clinics and traditional therapists or purchase drugs on their own, all clinical records may not have accurately captured the level of pneumonia in the districts. Some districts that were a part of the Zone were omitted while some districts were added when it was reformed at the end of 2018 to become the Central Gondar Zone, and this may have an impact on the outcome of the study.

Abbreviations

WHO	World Health Organization
SSA	Sub Saharan Africa
EDHS	Ethiopian Demographic Health Survey
ARI	Acute Respiratory Infections
ICCM	Integrated Community Case Management
IMCI	Integrated Management of Childhood Illness
IMNCI	Integrated Management of Neonatal and Childhood Illness

Supplementary Information

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Supplementary Material 1. S1 File: Excell file for ArcGIS.

Supplementary Material 2. S2 File: Excell file for SaTScan.

Supplementary Material 3. S3 File: Annual pneumonia incidence rate.

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Authors' contributions

The study was designed by K.A. M.G, G.T and G.Y All the authors participated in the data collection, data processing and analysis and interpretation of findings. K.A prepared the manuscript and L.D prepared figures. All the authors read and approved the final manuscript.

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Data availability

Data is provided within the manuscript or supplementary information files

Declarations

Ethics approval and consent to participate

Ethical clearance was obtained from the Research and Ethical Review Committee of the Institute of Public Health, College of Medicine and Health Sciences, University of Gondar. There were no individual participants in the study because it was secondary data/count of under-5 Pneumonia which has no personal identifiers.

Consent for publication

This manuscript does not contain any person's data.

Competing interests

The authors declare no competing interests.

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