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RESEARCH

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Spatiotemporal variation of under-5 children diarrhea incidence and associated meteorological factors in central Gondar zone, Northwest Ethiopia. A retrospective time series study

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Abstract
Under-5 children's diarrhea is a significant public health threat, and the World Health Organization (WHO) reported that it is the second leading cause of children's death worldwide. In this study area, little is known about the spatiotemporal distribution of under-5 children's diarrhea incidence rates. Therefore, this study was conducted to assess the spatiotemporal variation under-5 diarrhea incidence and associated meteorological factors in the Central Gondar Zone. The data for under-5 diarrhea were obtained from Central Gondar Zone Health Department diarrhea reports from January 2013 to December 2022. Climatic variables were obtained from the West Amhara Meteorological Agency. Every district was covered and given a geocode. The spatial data were created in ArcGIS 10.8.1. Global and local spatial autocorrelation were used to detect hot spots. The Poisson model, which applies the Kulldorff methods and SaTScan™9.6, was used to analyze the purely temporal, spatial, and space-time clusters. Spearman correlation and bivariate and multivariable negative binomial regressions were used to analyze the relationships between under-5 diarrhea cases and climatic factors. This study revealed spatial variation in the incidence of under-5 diarrhea, where Dembia, Gondar Zuria, and Chilga districts and Gondar Zuria, East Dembia, and Lay Armacho districts were high-rate spatial clusters between 2013 and 2018 and between 2019 and 2022, respectively. A temporal scan statistic identified 2014–2016 and 2020–2021 as risk periods across all districts. Spatiotemporal scan statistics revealed high-rate clusters in Dembia, Gondar Zuria, Chilga, Wegera, Alefa, Lay Armacho, and West Belesa between 2013 and 2018, and Gondar City, Gondar Zuria, East Dembia, Lay Armacho, and Alefa between 2019 and 2022. This study also revealed positive correlations between the number of individuals with under-5 diarrhea and the average monthly temperature at 0 and 2 lag months, with values of 1.0209 (1.0034–1.0387) and 1.0202 (1.0022–1.0385), respectively. In addition, there was a negative correlation between the number of under-5 diarrhea events and the average monthly rainfall at 0 and 2 lag months, with values of 0.999 (0.9985–0.9996) and 0.9992 (0.9987–0.9997), respectively. In conclusion, there has been spatiotemporal variability in the

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incidence of diarrhea in children under-5 years of age in the Central Gondar Zone. The mean monthly temperature and rainfall were positively and negatively related to the incidence of diarrhea in children under-5 years of age. Season-specific intervention strategies should be developed to reduce under-5 morbidity and mortality.

Keywords Cluster, Spatial, Spatiotemporal, Temporal, Under-5 diarrhea incidence

Introduction

Globally, diarrhea is the major cause of death in children under-5 years of age. It kills more children than AIDS, malaria, and measles combined [1]. Globally, it causes 8% of deaths among children under the age of five [2]. Since 2022, more than 1,300 young children have died each day, or approximately 484,000 children per year, despite the availability of a simple treatment solution [3]. Even if there has been a significant decline in childhood mortality from diarrhea, it still poses a significant issue for public health, especially in developing countries [4, 5, 6]. Among children under-5 years of age, the number of deaths caused by diarrhea is highest in South Asia and sub-Saharan Africa [3]. Ethiopia is ranked fifth worldwide in terms of total child deaths, and approximately 73,700 children die each year due to diarrhea, accounting for 20% of all child deaths [7, 8].

Diarrhea is highly prevalent in Ethiopia and is the second leading cause of death [9, 10]. It decreased from 24% in 2000 to 18% in 2005 [11], 13% in 2011 [12], and 12% in 2016 [13]. According to the recent EDHS, the prevalence of childhood diarrhea was 11.87%, which is high in the SNNP, Amhara, Addis Ababa, and Oromia regions [14]. The prevalence varied from 8.5 to 30.5% across different parts of the country. Moreover, the yearly number of childhood deaths due to diarrheal illness is estimated to be 95,000 [15]. In 2021, the mortality rate of children under-5 years of age was 46.8 per 1000 live births [16].

The incidence of diarrhea is highly heterogeneous both within and between countries, exhibiting substantial spatial and temporal variability [17]. For example, in one study conducted in Ethiopia, Azage et al. [18] found spatial and temporal variation in under-5 diarrhea events in Northwest Ethiopia, and another study in the Bench Maji Zone, Southwest Ethiopia, also identified spatiotemporal variation [19]. These variations are largely driven by meteorological factors [20], socioeconomic status and WASH infrastructure [21], poor hygiene practices and unsafe human waste disposal [22], and access to and quality of health services [23]. The interaction of these factors can lead to different pathways for diarrhea transmission, which creates a setting-specific spatial and temporal variation in diarrhea occurrence.

Diarrhea is seasonal, and all causes are associated with temperature and rainfall in all countries; these variables have changed over the past decades [24, 25]. The World Health Organization (WHO) projects an annual increase of approximately 50,000 child diarrhea deaths worldwide in 2050 attributable to climate change [26]. In sub-Saharan Africa, and Ethiopia in particular, projected climate scenarios show an increase in rainfall variability and temperature as well as prolonged droughts in the region [27]. At relatively high ambient temperatures, common bacterial infections linked to diarrhea, such as diarrheagenic *Escherichia coli*, proliferate quickly. Furthermore, high temperatures prolong infection survivability in the external environment [24, 28, 29]. Droughts and diarrheal disorders are related because of the high prevalence of malnutrition and water scarcity [30, 31]. Different studies that have been conducted in different countries such as Afghanistan [20], Bhutan [32], Iran [33], and Ethiopia [34] revealed a positive correlation between an increase in temperature and under 5 diarrhea incidence. Low ambient temperatures favor the growth of viral pathogens that cause diarrhea, such as rotavirus, and the lifespan of these bacteria is prolonged during cooler months [35].

After heavy rainfall/precipitation and associated extreme hydrologic conditions like floods and drought Excess cases of diarrhea are expected. For example, flooding and surface runoff, increase the rate of contamination of drinking water sources at the beginning of the rainy season. The finding of a study conducted in Ethiopia [36] supports this idea. The central Gondar zone is generally characterized by a subtropical climate. The temperature is hot during winter and cold during summer and reaches 40 °C.

The WHO Program for Control of Diarrheal Diseases (CDD) was launched in 1978 to reduce diarrhea-associated morbidity and mortality among infants and young children in lower- and middle-income countries [37]. To address this issue, a seven-point action plan promoting immunization, rotavirus vaccination, hygiene, breastfeeding, oral rehydration therapy, and zinc supplementation was established [38, 39]. The national rotavirus immunization coverage in 2022 was 52.3% [40]. Despite these efforts, diarrhea remains a severe health concern, accounting for more than 25% of national morbidity across the country and leading to significant geographic disparities [41].

In Ethiopian studies that assess seasonal trends, spatial, temporal, and space-time clusters of diarrhea are not widespread. Many studies have been conducted in different parts of Ethiopia, including this study area, which aims to determine the prevalence of diarrhea in children under-5 years of age, specific to a certain area, via logistic regression models; however, these studies lack the determination of space and time clusters and the distribution of diarrhea in children under-5 years of age at the district level in the central Gondar Zone. Meteorological variables have changed over the past decades, and including these variables is important but was not included in most of the previous studies that have been conducted in this area as a risk factor for under-5 years of diarrhea. Therefore, this study was conducted to fill these gaps and assess the spatiotemporal distributions of under-5 diarrhea incidence rates and associated meteorological conditions in the Central Gondar Zone.

Methods

Study design and setting

A retrospective time series cross-sectional study was conducted in the central Gondar zone from 1 January 2013 to 30 December 2022. The Central Gondar Zone is located in the Amhara Region and is geographically located at 17^0 29'32" North latitude and 42^0 38'25" East longitude. The mean annual rainfall ranges from 875 to 1025 mm, and the temperature ranges from 18 to 35 degrees centigrade [42]. It includes 15 districts and the Gondar city capital of the zone [43]. The boundaries are adjoined with the North Gondar zone in the North, the Awi zone in the West and West Gojjam zone in the South, the North Wollo zone in the East, and the South Gondar zone in the Southeast [42]. According to 2014 EC (2022 GC) zonal health department data, there is 1 referral hospital, 9 hospitals, 406 health posts, and a total of 796 health extension workers. The total population residing in all districts is estimated to be 2,896,928 [44], and according to the 2014 EC (2022 GC) zonal health department, there are 297,241 children under-5 years of age in all districts (Fig. 1).

Data collection

Data on children under-5 years of age were obtained retrospectively from the Central Gondar Zone Health Department diarrhea report on 10 April 2023, and all confirmed under-5 children diarrhea cases reported from 2013–2022 were used. Diarrhea is "the passing of three or more loose or liquid stools per day or passing more frequently than is normal for the individual according to the World Health Organization (WHO) definition [45]. Health facilities send reports of under 5 diarrhea cases to district health offices. District health offices report this case to the zonal health department. The datasets were subsequently aggregated at the district level, and information on the patients was obtained according to age category, sex category, and time of illness (month and year).

The polygon shape file provided by the Ethiopia Statistics Service contained the spatial coordinates (latitudes and longitudes) for every district. The population data for each district for each year were obtained from the Ethiopia Statistics Service. The meteorological data, such as the monthly minimum and maximum temperatures, humidity, and rainfall, of all districts were obtained from the West Amhara Meteorological Directives, Bahir Dar.

Quality control

The data were retrieved from quarterly surveillance data stored in the Central Gondar Zone Health Department from 1 January 2013 to 30 December 2022. Trained personnel who were familiar with HMIS data management collected the data. The data collectors were informed

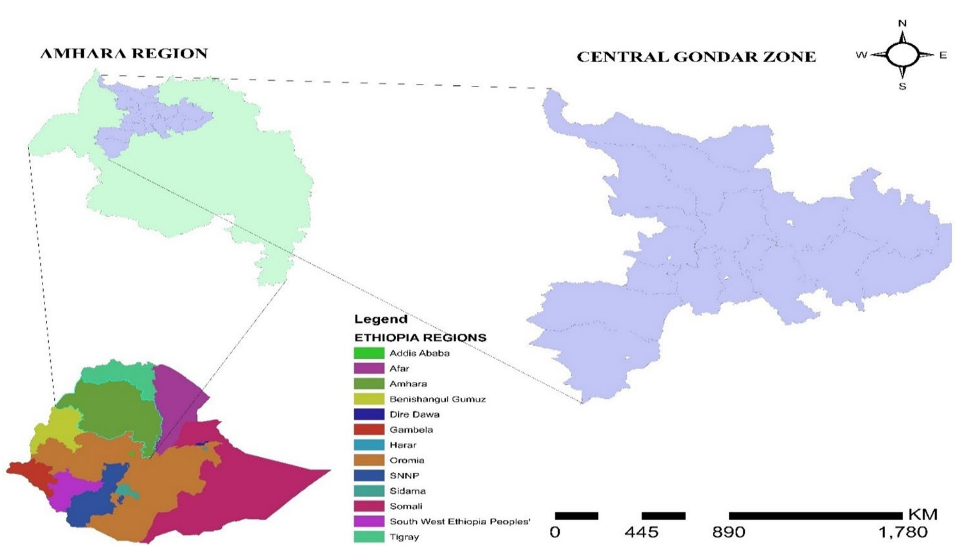

Fig. 1 Map of Central Gondar Zone, Northwest Ethiopia, Ethiopia. The study area map was plotted using ArcGIS V. 10.7 software (https://www.arcgis.com/index.html)

about the research objectives and data collection procedures. All methods were performed following the relevant guidelines and regulations. After collection, the principal investigator of the study before analysis checked the data completeness and consistency. The data were cleaned, edited, checked, and sorted via Excel. Further cleaning was performed after the data were imported into STATA 14.2 software.

Data management and analysis

All 15 districts and Gondar city in the Central Gondar zone were included and geo-coded for this study. The Central Gondar Zone, which was previously known as the North Gondar Zone, was newly formed at the end of 2018. This has led to the incorporation of some districts in the Zone, such as Kinfaz Begela, while other districts have been divided into two parts, such as Chilga to Chilga 01 and 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 parts: from 1 January 2013 to 31 December 2018 and from 1 January 2019 to 31 December 2022. The Ethiopia Statistics Service provided a shape file with district boundaries and polygon shapes both before and after classification. Each district was georeferenced to its geographic centroid. The centroids allowed us to perform the district-level study by providing details about a particular area. The coordinates were specified via the standard Cartesian coordinate system. The annual incidence of diarrhea in children under-5 years of age in each district and the average cumulative annual diarrhea incidence for 2013–2018 and 2019–2022 were calculated and connected with their respective coordinates. The data were subsequently saved in Comma Delimited (CSV).

The ArcGIS 10.8.1 version of the software was used for hotspot detection and to construct a map of the study area. The average cumulative annual diarrhea incidence of children under-5 years of age in each district was merged with the district's respective shape file and XY coordinates. The global Moran's I was calculated for the overall pattern, and hot spot analysis was conducted for mapping local clusters. The Poisson model was fitted via population data from the Ethiopia Statistics Service as a known underlying population at risk. The incidence of diarrhea in children under the age of five years was determined.

The monthly and annual cumulative incidence of diarrhea among children under-5 years of age during the required period was determined by taking the number of cases of diarrhea among under-5 children in the population at risk. The monthly and annual cumulative incidence of diarrhea among children under-5 years of age in each district and the seasonal trend were calculated via Excel. The data were subsequently plotted to determine the annual fluctuations in the incidence of diarrhea in children under-5 years of age from 1 January 2013 to 30 December 2022.

For this research, the discrete Poisson model was utilized since the data were count data [46]. The coordinates of the study areas, the number of diarrhea cases per month, and the population of under 5 children were used as input variables for the discrete Poisson model, which was based on the assumption that the number of cases in each district has a Poisson distribution with a known population of Under-5 children who are at risk for diarrhea. Next, the Poisson data were analyzed via spatial, temporal, and space-time scan statistics via SaTScan™ 9.6 software.

Cluster analysis: The scan statistics developed by Kulldorff and SaTScan™ 9.6 software were used to identify the presence of the purely spatial, temporal, and space-time under-5 child diarrhea clusters. Multiple statistical tests are limited, but SaTScan can identify a cluster at any location and of any size up to a predetermined maximum. Furthermore, compared with other approaches, it has greater power for local cluster detection [47].

The scan statistics were gradually scanned across time and/or space to identify the number of observed and expected observations inside the window at each location. The expected number of cases is the number of cases of an event that are expected to occur by chance alone within a specific risk period. The scanning window was an interval (in time), a circle (in space), or a cylinder with a circular base (in space-time) for which window sizes were determined, the window with the maximum likelihood was the most likely cluster, and a p-value was assigned to this cluster. For space and time scan statistics analysis the under-5 diarrhea case data were retrieved from quarterly surveillance data stored in the Central Gondar Zone Health Department.

Spatial scan statistical analysis: The entire study area was scanned via a circular window. The percentage of the maximum total population that is at risk inside the scanning window is specified by the maximum size. A maximum cluster size of 50% of the population at risk will be used [19]. The alternative hypothesis was that the risk inside the window differs from the risk outside, and the null hypothesis was that the disease risk is the same in space both inside and outside the scanning window. The primary cluster that was most likely to have arisen by chance was determined to be a circle with the largest likelihood ratio and more observed cases than anticipated [46]. $P < 0.05$ was used to set the number of permutations to 999, which was deemed to demonstrate statistical significance [19].

Space-time scan statistics: This method was employed to detect clusters in both space and time. It helps to detect clusters that cannot be detected by purely spatial statistics. It is assumed that the relative risk of the case was the same within the window as outside the window. To identify spatiotemporal clusters, a circular-based cylindrical window was employed. As in the purely spatial scan statistic, the base of the cylinder represents space, whereas the height indicates time. Using a p-value found through Monte Carlo simulations, districts with a sizable number of instances within the matching period were found. For each purely spatial and space-time scan statistic, secondary clusters were found via an iterative method, as outlined in Kulldorff, in addition to the primary cluster that was the most likely [18]. 50% of the population at risk was designated as the maximum cluster size.

Temporal scan statistics: A single-dimensional moving window is employed. The time dimension is represented by the height of the cylindrical window. Monte Carlo simulations were used to produce a p-value. A p-value of less than 0.05 was employed as the threshold for statistical significance. The most likely cluster was the only one indicated for temporal analysis alone. Areas with high rates (clusters) were identified after the scan.

Spatial autocorrelation analysis: Spatial autocorrelation (global Moran's *I*) was used to evaluate whether the disease patterns were dispersed, clustered, or randomly distributed in the study area [48]. This method was used to detect the spatial autocorrelation of diarrhea incidence. A calculated Moran's *I* value close to – 1 indicates disease dispersion, whereas an *I* close to +1 indicates disease clustering and a random distribution if the *I* value is zero. A statistically significant Moran's I ($p < 0.05$) leads to the rejection of the null hypothesis and indicates the presence of spatial autocorrelation [49].

Using Z scores and p values, Getis–Ord Gi statistics were utilized to locate cases with high or low values spatially to find hotspot locations for diarrhea in children under-5 years of age. When the Z score was large and positive, clusters of high values were regarded as hotspots; when the Z score was small and negative, cold spot areas were regarded [50]. The null hypothesis that is, "there is no spatial clustering of Under-5 children diarrhea" was taken into consideration when interpreting the results of the high/low clustering analysis. The null hypothesis was rejected when the absolute value of the z score was high and the p-value was extremely low. When the null hypothesis was disproved, the Z score sign w was taken into account. In the research area, a positive Z score suggested strong clustering. The 95% confidence interval's corresponding p-value was 0.05. The statistical analyses were carried out and presented via ArcGIS 10.8.1 software.

Microsoft Excel spreadsheet was used to describe the data and draw line graphs. Spatial, temporal, and spatiotemporal clusters were analyzed via the SaTScan^{TM}9.6 program. A map of the significant clusters was generated via ArcGIS 10.8.1 software.

Correlation and regression analysis

Bivariate and multivariable negative binomial regressions were performed to test the relationships between climatic factors and the incidence of diarrhea in children under the age of 5.

A negative binomial (NB) regression accounts for overdispersion by adding a dispersion (variance) parameter to the Poisson model, and this regression model can accommodate increased variability [51]. Spearman's correlation analysis was performed between the incidence of diarrhea in children under-5 years of age and climatic variables by considering 0, 1, and 2 lag months. The multicollinearity between climate variables was checked via the variance inflation factor (VIF) before the multivariable regression analysis, and it was ˂5, which is 4.3.

A bivariate negative binomial regression was performed to examine the crude associations between the climatic factors and the outcome variable. The multivariable negative binomial regression adjusted incidence rate ratio (IRR) with a 95% confidence interval was calculated to identify the independent effect of each explanatory variable concerning the outcome variable. A significance level of 0.05 was used for all the statistical tests. AIRRs with 95% CIs were used to determine statistical significance. Statistical analyses were conducted via STATA 14.2 software.

Ethics consideration

Ethical approval was obtained from the Institutional Review Board of the College of Medicine and Health Sciences, University of Gondar (reference number: IPH/2505/2023). All methods were carried out following the Helsinki Declarations and guidelines and regulations of the University of Gondar research and ethics review committee. A request letter for the required data was written to the Central Gondar Zone Health Department and West Amhara Meteorological Directive Bahir Dar from the Department of Environmental and Occupational Health and Safety, and a request letter for the Ethiopian Statistics Service was written from the Institute of Public Health, College of Medicine and Health Sciences, University of Gondar. To ensure the confidentiality of the data, they were kept secure and were not used for any other purpose.

Results

Distribution of diarrhea incidence among children under-5 years of age by type, sex, and age

Monthly diarrheal morbidity data were collected for all 15-study districts from the 10 years of Central Gondar

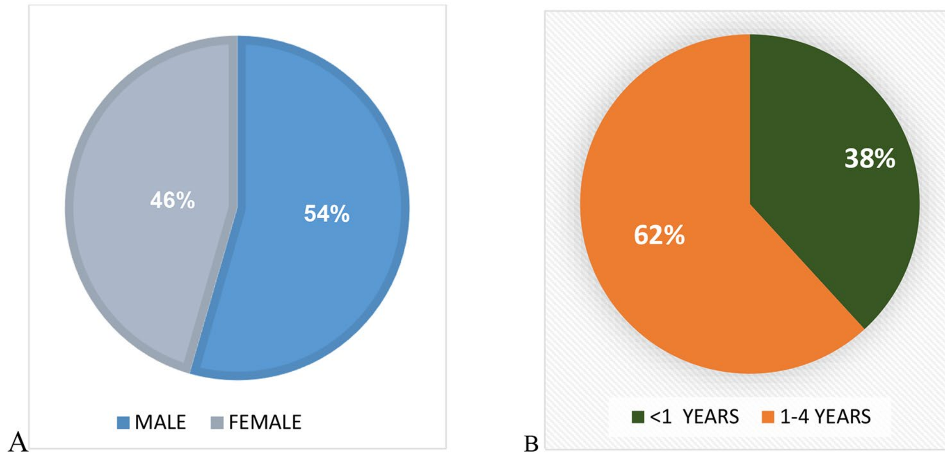

Fig. 2 **a** and **b** Proportion of under-5 diarrhea patients according to their sex and age respectively in the Central Gondar Zone, Northwest Ethiopia, 2023

Table 1a DiarrheA incidence among children under-5 years of age from 2013–2018 in districts of the central Gondar zone, Northwest Ethiopia

S.*N*	District Name	Yearly diarrhea incidence rate per 1000 under-5 children					
		2013	2014	2015	2016	2017	2018
1	Alefa	131.6	148.2	149.2	175.1	123.1	156.2
2	Chilga	126.0	175.0	154.9	190.1	180.3	190.3
3	Dembia	176.0	284.6	179.9	268.6	210.4	219.4
4	Gondar Zuria	169.8	187.5	172.8	250.9	176.6	225.3
5	Lay Armacho	121.4	175.1	159.1	165.8	154.3	135.5
6	West Belesa	155.0	119.6	173.0	161.3	124.1	136.7
7	East Belesa	104.0	126.5	148.8	120.4	119.1	118.6
8	Tach Armacho	115.2	106.4	135.6	88.7	86.5	60.5
9	Takusa	100.6	145.7	166.9	115.0	129.6	120.5
10	Tegede	98.9	82.6	112.4	98.8	88.7	90.5
11	Wogera	145.1	151.3	175.7	162.2	130.2	140.7
Average		131.2	154.76	157.1	163.3	138.4	144.9

Zone HMIS data. 527,058 patients with under-5 diarrhea cases were reported during the study period. Non-bloody diarrhea was dominant between 2013 and 2018 (75.33%: 207,717), and functional diarrhea was dominant between 2019 and 2022 (80.6%: 202,587). The highest proportion of diarrhea cases was reported among male children (286,806: 54%), and between 2019 and 2022, children aged 1–4 years accounted for the largest share (155,016: 62%) (Fig. 2a and b).

Distribution of the incidence of under-5 diarrhea at the district level each year

Incidence rates were calculated for all districts every year. The incidence rate is the number of new cases divided by the total population and multiplied by 1000. The incidence rate varies from place to place and from year to year. Between 2013 and 2018, the highest and lowest incidence rates were 284.6 per 1000 in 2014 in the Dembia district and 60.5 per 1000 in 2018 in the Tach Armacho district (Table 1a). Between 2019 and 2022, the highest and lowest incidence rates were 249.5 per 1000 in 2021 in Gondar city and 82.2 per 1000 in 2022 in the Tegede district (Table 1b).

Trends of Under-5 types of diarrhea based on the annual incidence rate

There was an overall increasing trend with a yearly fluctuating incidence of under-5 diarrhea, and there was monthly and seasonal variability. In 2013, five diarrhea events had the lowest incidence, with an annual incidence rate of 138.5 (38,079 cases), and it reached its peak in 2016 and 2021, with annual incidence rates of 180.9 (52,330 cases) and 177.5 (66,704 cases), respectively (Fig. 3).

There were three under-5 diarrhea cases in peak months for most years. Overall, Fig. 4 shows that the cases of diarrhea among children under-5 years of age in Central Gondar decreased between December and January. The highest cases were recorded in February, followed by June and October (Fig. 4).

The 10-year seasonal trend of the smoothed and deseasonalized incidence of under-5 diarrhea was

Table 1b Diarrhea incidence among children under-5 years of age from 2019–2022 in districts of the central Gondar zone, Northwest Ethiopia

S. *N*	District Name	Yearly diarrhea incidence rate per 1000 under-5 children			
		2019	2020	2021	2022
1	Alefa	161.1	173.5	166.0	156.1
2	Chilga 01	139.0	153.9	137.7	125.3
3	Nebaru Chilga	103.5	113.8	115.9	88.7
4	East Dembia	186.9	212.8	190.2	195.2
5	West Dembia	132.6	128.5	122.8	116.3
6	Gondar Zuria	224.4	236.2	246.0	208.7
7	Lay Armacho	176.0	184.0	194.2	167.2
8	West Belesa	162.7	159.9	146.7	140.1
9	East Belesa	134.5	111.3	122.7	120.2
10	Tach Armacho	99.1	110.2	137.3	112.7
11	Central Armacho	90.3	86.6	84.5	87.0
12	Takusa	141.0	135.1	161.7	141.7
13	Tegede	103.6	93.1	105.1	82.2
14	Wogera	163.9	189.7	194.3	176.0
15	Kinfaz Begela	98.0	114.2	109.9	103.0
16	Gondar City	217.6	237.1	249.5	221.7
Average		145.9	152.5	155.3	140.1

calculated first by using a 12-month moving average and then a central moving average. A centered moving average is a statistical method used to smooth out short-term fluctuations in time series data while highlighting longer-term trends or cycles. The trend component was calculated via linear regression between the deseasonalized value and the time code, which gives the type of equation $Y = ax + b$, where Y refers to the trend component of the original value of under-5 diarrhea, $a =$ slope, and $b =$ y intercept. It showed an increasing trend, with an equation of $Yt = 0.027t + 10.9$, which starts to increase in January and reaches its peak in February. The number of diarrhea cases starts to slowly decline over time, reaching their lowest peaks in November and December (Fig. 5).

The Spatial pattern of the incidence of under-5 diarrhea events

The Spatial pattern of the incidence of under-5 diarrhea events between 2013 and 2018

The global autocorrelation results indicated that the incidence of under-5 diarrhea was clustered (global Moran's $I = 0.573291$, Z score $= 2.256799$, and P value $= 0.024021$) (Fig. 6).

The districts with the highest incidence of under-5 diarrhea in the Zone are indicated in red on the map and are clustered around the southern part of the study area, whereas the second highest incidence of under-5 diarrhea is indicated in orange. The lowest proportions are located in the northern part of the zone (Fig. 7).

Hotspot detection (January 2013-December 2018)

Hotspot areas with a high cluster of under-5 diarrhea incidence were identified. A hotspot area with high-rate clusters at 95% confidence was observed in Dembia and Gondar Zuria. Dembia accounted for 21.3% (average cumulative annual $IR = 223.2$) and Gondar Zuria accounted for 13.4% (average cumulative annual $IR = 197.1$) of the diarrhea cases reported from January 2013 to December 2018 in the study area (Fig. 8).

The maximum peak, where spatial clustering was highly pronounced, was at a distance of 43786.8337 m, with a corresponding Z score of 2.256799 (p-value < 0.05). This distance band was used for the analysis of hotspot clusters.

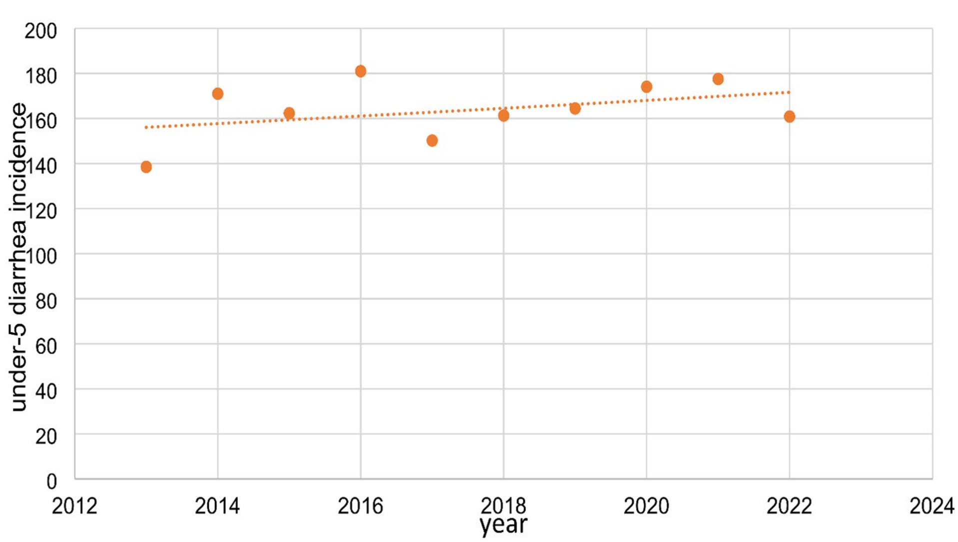

Fig. 3 Yearly trend of diarrhea incidence among children under-5 years of age from 2013–2022 in the Central Gondar Zone, Northwest Ethiopia

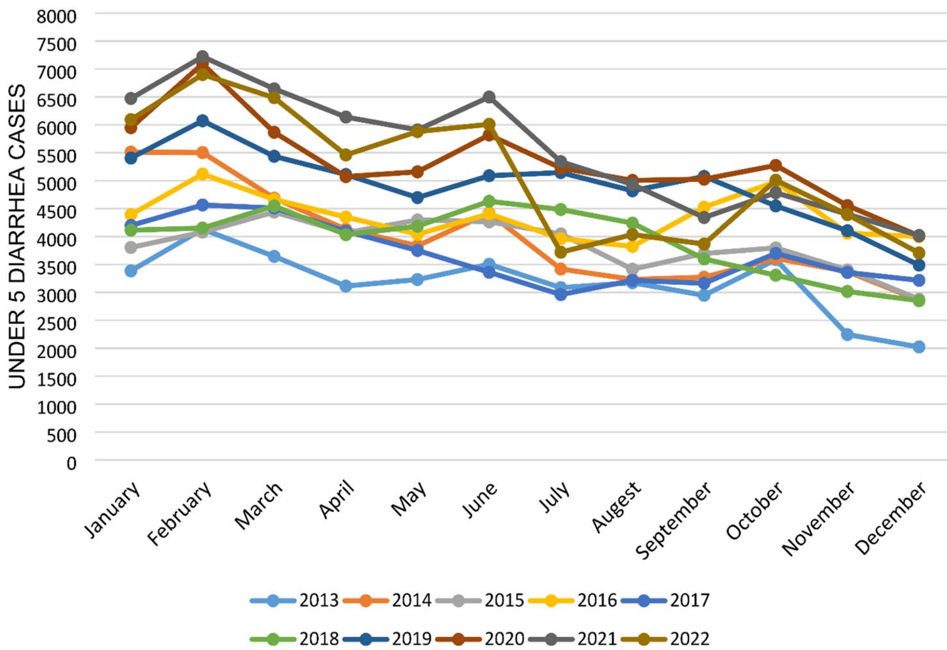

Fig. 4 Monthly and yearly variation in diarrhea cases among children under-5 years of age in the Central Gondar Zone, Northwest Ethiopia, 2023

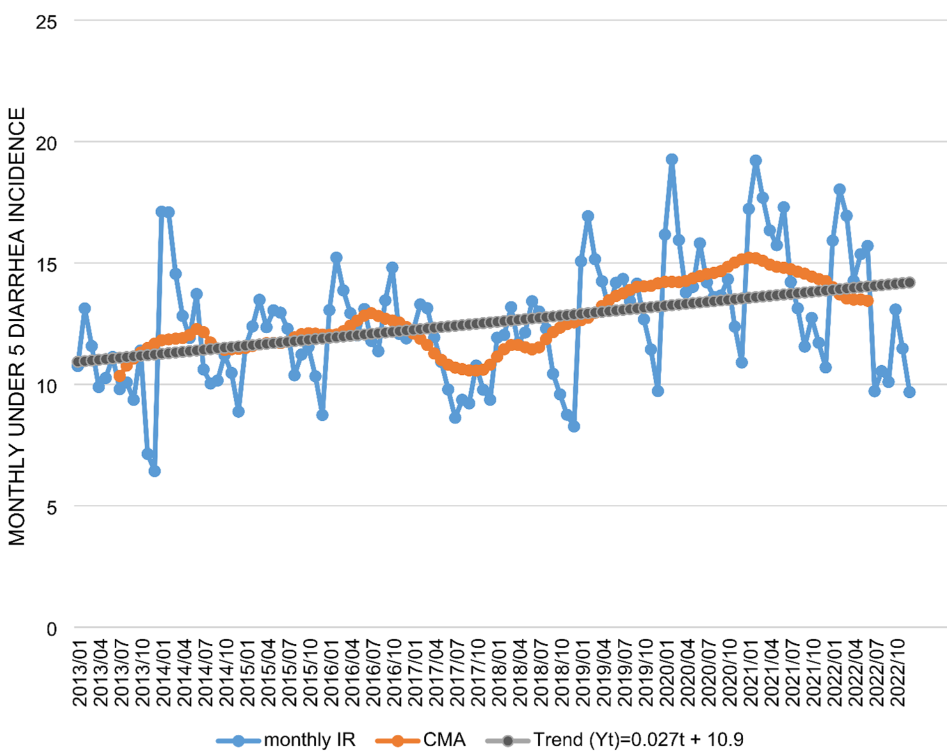

Fig. 5 Trends and seasonal variation of diarrhea incidence among children under-5 years of age in the Central Gondar Zone, Northwest Ethiopia, between January 2013 and December 2022

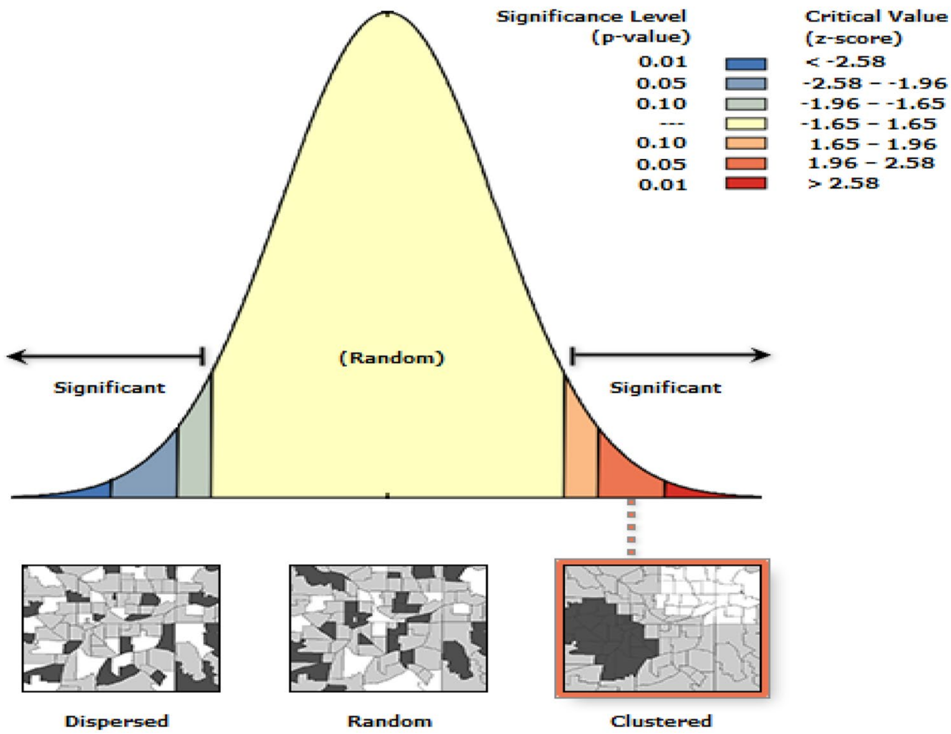

Fig. 6 Spatial autocorrelation based on feature locations and attribute values (average cumulative annual diarrhea incidence among children under-5 years of age calculated via the global Moran's I statistic across the study area in the Central Gondar Zone, Northwest Ethiopia, January 2013-December 2018

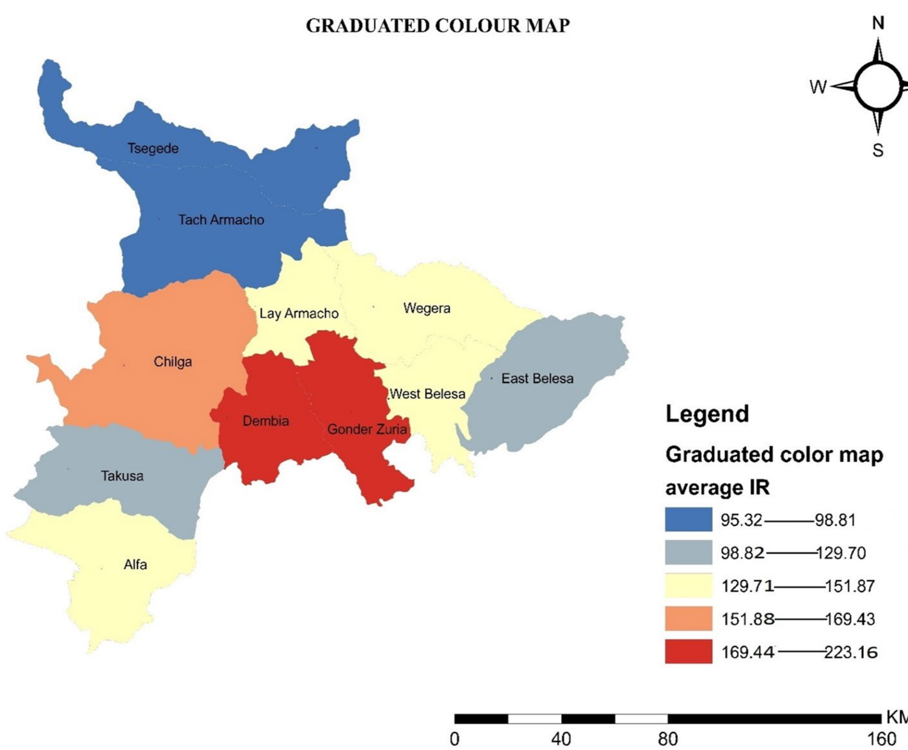

Fig. 7 Graduated color (choropleth) map that depicts the density of diarrhea incidence among children under-5 years of age in Central Gondar Zone, Northwest Ethiopia, from January 2013-December 2018

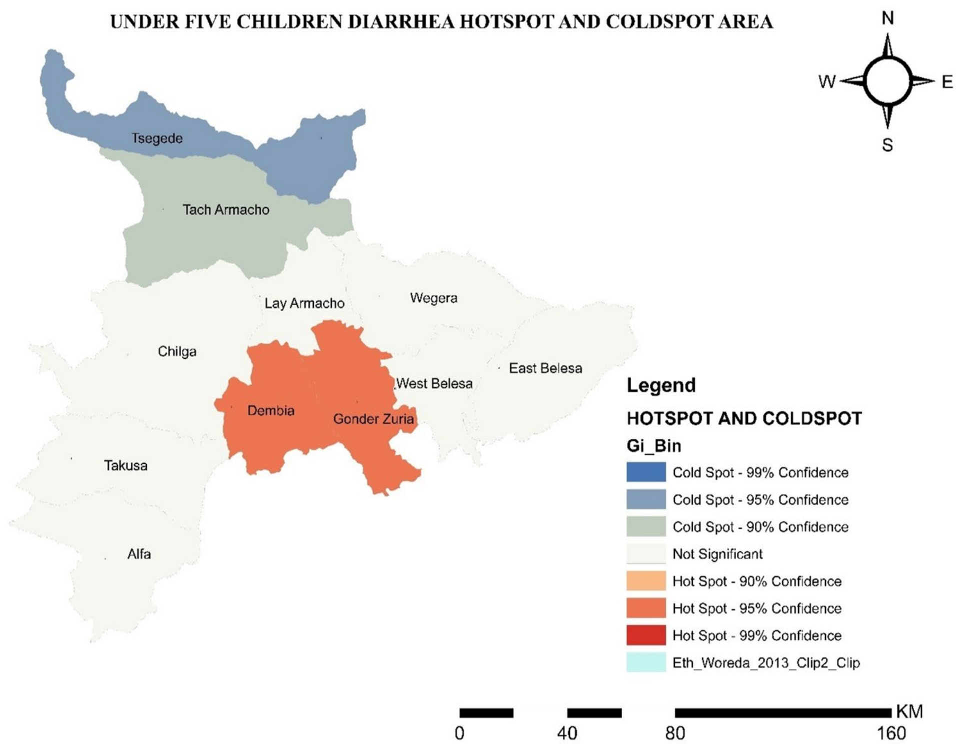

Fig. 8 Hot spot detection of diarrhea incidence among children under-5 years of age in the Central Gondar Zone, Northwest Ethiopia, January 2013-December 2018

Table 2 Significantly high-rate Spatial clusters of Under-5 diarrhea in the central Gondar zone, Northwest Ethiopia, from January 2013 to December 2018

Cluster	District	Population	Coordinates/radius	Obs.*	Exp.*	RR	LLR
1	Dembia	58,971	14.703325 N, 28.918317 E/0 km	55,349	42475.53	1.49	3451.517
2	Gondar Zuria	31,212	13.857757 N, 41.118134 E/0 km	36,997	30114.99	1.26	829.817
3	Chilga	36,076	14.415455 N, 29.107939 E/0 km	36,784	34808.66	1.07	63.138

p-value < 0.0001 for all clusters

RR, Relative Risk;

LLR, Log Likelihood Ratio

Obs.*, Number of observed cases in a cluster

Exp.*, Number of expected cases in a cluster

Table 3 Significantly high rates of Temporal clusters of Under-5 diarrhea in the central Gondar zone Northwest Ethiopia from January 2013 to December 2018

Cluster	District	Time frame	Obs.*	Exp. *	RR	LLR	*p*-value
1	All	January 2014 to December 2016	1,463,763	137324.08	1.14	594.692	0.001

RR, Relative Risk;

LLR, Log Likelihood Ratio

Obs.*, Number of observed cases in a cluster

Exp.*, Number of expected cases in a cluster

High-rate Spatial clusters

In the study area, under-5 diarrhea distributions were clustered. High-rate spatial clusters were detected throughout the study period. These clusters were observed in Chilga (LLR = 63.14, $p < 0.0001$), Gondar Zuria (LLR = 829.82, $p < 0.0001$), and Dembia (LLR = 3451.517, $p < 0.0001$). (Table 2)

High-rate Temporal cluster

Significantly high rates of individuals in the under-5 diarrhea clusters were observed. These clusters were observed across all districts from January 2014 to December 2016 (LLR = 594.692, $p = 0.001$) (Table 3).

Table 4 Significantly high-rate Spatiotemporal clusters of Under-5 diarrhea in the central Gondar zone, Northwest Ethiopia, from January 2013 to December 2018

Cluster	District	Time frame	Obs.*	Exp.*	RR	LLR	*p*-value
1	Dembia	2014/1/1 to 2016/12/30	32,019	21088.25	1.59	2678.866	< 0.001
2	Gondar Zuria	2016/1/1 to 2018/12/30	20,866	14528.28	1.38	919.320	< 0.001
3	Chilga	2016/1/1 to 2018/12/30	20,725	17829.47	1.18	239.651	< 0.001
4	Wegera	2015/1/1 to 2015/12/30	6245	5712.13	1.10	24.642	< 0.001
5	Alefa	2016/1/1 to 2016/12/30	4853	4467.00	1.09	16.492	< 0.001
6	Lay Armacho	2014/1/1 to 2014/12/30	4372	4013.43	1.09	15.797	< 0.001
7	West Belesa	2015/1/1 to 2015/12/30	3936	3656.37	1.08	10.574	< 0.001

RR, Relative risk;

LLR, Log likelihood ratio

Obs.*, Number of observed cases in a cluster

Exp.*, Number of expected cases in a cluster

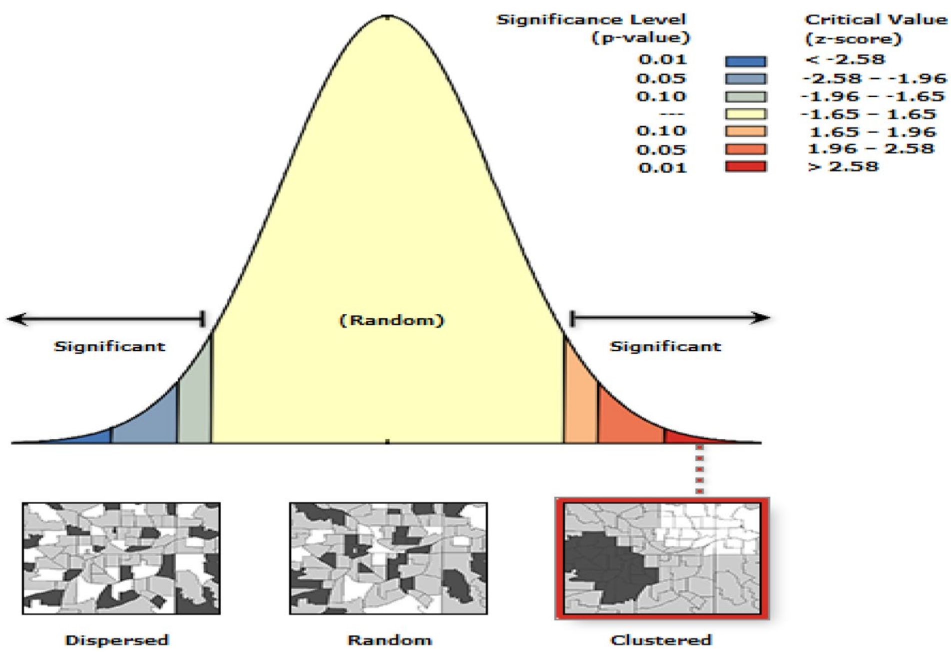

Fig. 9 Spatial autocorrelation based on feature locations and attribute values (average cumulative annual diarrhea incidence among children under-5 years of age via the global Moran's I statistic across the study area in the Central Gondar Zone, Northwest Ethiopia, from January 2019-December 2022

High-rate Spatiotemporal clusters

The spatiotemporal analysis provided further evidence that a greater number of cases than the expected number of under-5 diarrhea cases occurred within a defined place and time. Significant spatiotemporal under-5 diarrhea clusters were detected in seven districts, namely, West Belesa from 2015/1/1 to 2015/12/30, lay Armacho from 2014/1/1 to 2014/12/30, Alefa from 2016/1/1 to 2016/12/30, Wegera from 2015/1/1 to 2015/12/30, Chilga from 2016/1 to 2018/12/30, Gondar Zuria from 2016/1 to 2018/12/30 and Dembia from 2014/1 to 2016/12/30, from least to most clusters (Table 4).

The Spatial pattern of the incidence of under-5 diarrhea events between 2019 and 2022

The global autocorrelation results indicated that the incidence of under-5 diarrhea was clustered (global Moran's I = 0.733302, Z score = 2.927980, and P–value = 0.003375) (Fig. 9).

The districts with a lower incidence of the under-5 Diarrhea proportion in the Zone are indicated by the green color on the map and are clustered around the northern part of the study area, whereas the districts with the highest and second highest incidence of the under-5 Diarrhea proportion are indicated by the high dark red and orange colors, which are located in the central and southern parts of the study area (Fig. 10).

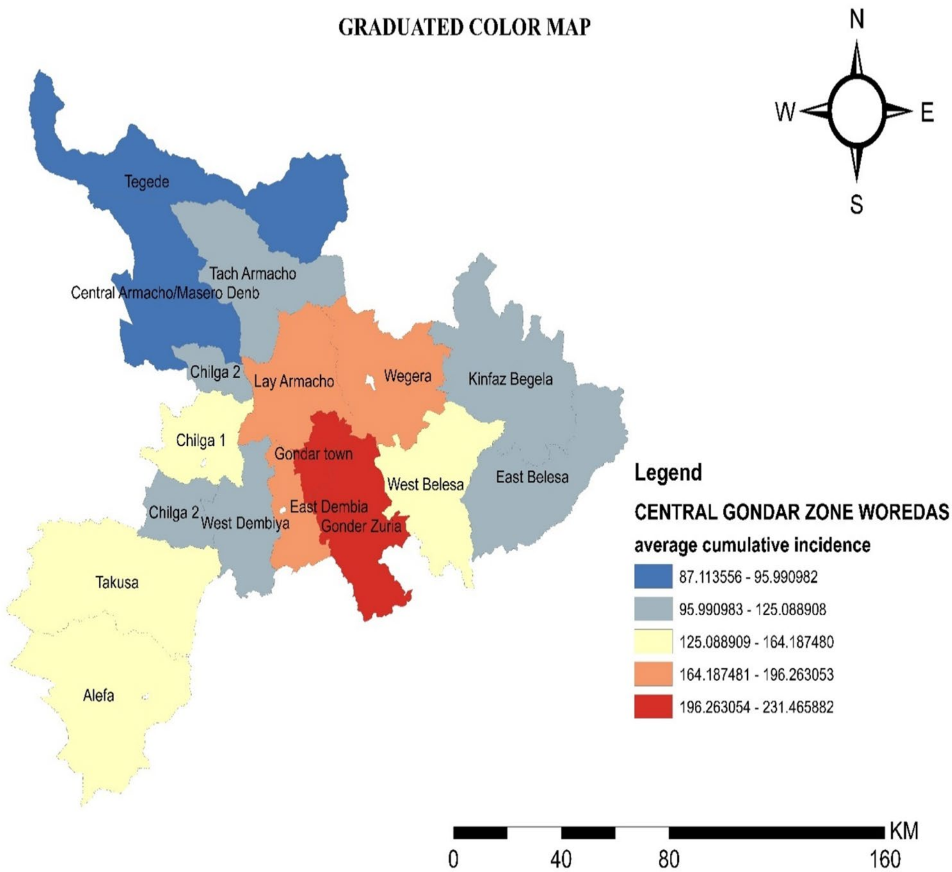

Fig. 10 Graduated color (choropleth) map that depicts the density of diarrhea incidence among children under-5 years of age in Central Gondar Zone, Northwest Ethiopia, from January 2019–to December 2022

Hotspot detection

Hotspot areas with a high cluster of under-5 diarrhea incidence were identified. A hotspot area with high-rate clusters at the 99% confidence level was observed in Gondar City and Gondar Zuria. The strains cover 22.02% (average cumulative annual IR = 231.5) and 12.18% (average cumulative annual IR = 228.8) of the total under-5 diarrhea cases reported from January 2019 to December 2022 in the Central Gondar Zone (Fig. 11).

The maximum peak, where spatial clustering was highly pronounced, was at a distance of 33750.1845 m, with a corresponding Z score of 2.931320 (p-value < 0.05). This distance band was used for the analysis of hotspot clusters.

High-rate Spatial clusters

In the study districts, individuals with under-5 diarrhea statuses were clustered. Five high-rate spatial clusters were detected throughout the study period. These clusters were detected hierarchically at Tach Armacho (LLR = 30.533, $p < 0.0001$), Wegera (LLR = 60.776, $p < 0.0001$), East Dembia (LLR = 261.297, $p < 0.0001$), Gondar Zuria (LLR = 1401.652, $p < 0.0001$), and Gondar city (LLR = 3001.019, $p < 0.0001$) (Table 5).

Color identification of the clusters was arranged in accordance with high-rate clusters based on the likelihood ratio test statistic value (Fig. 12).

High-rate Temporal cluster

Significantly, high percentages of individuals in the temporal under-5 diarrhea clusters were observed. These clusters were observed across all districts from January 2019 to December 2022 (LLR = 200.304, $p < 0.001$) (Table 6).

High-rate Spatiotemporal clusters

The spatiotemporal analysis yielded additional evidence that a greater number of cases than the expected number of under-5 diarrhea cases occurred within a defined place and time. Significant spatiotemporal under-5 diarrhea clusters were detected in Gondar City, Gondar Zuria, East Dembia, Wegera, Lay Armacho, and Alefa between 1 January 2020 and 30 December 2021 (Table 7).

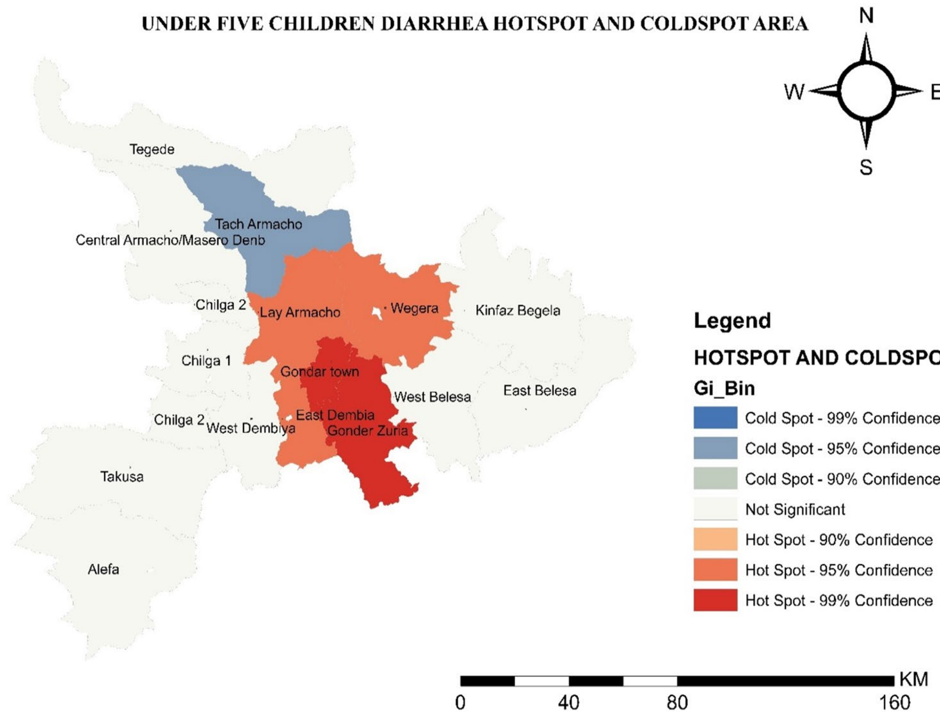

Fig. 11 Hotspot detection of diarrhea incidence among children under-5 years of age in the Central Gondar Zone, Northwest Ethiopia, January 2019-December 2022

Table 5 Significantly high-rate Spatial clusters of Under-5 diarrhea in the central Gondar zone, Northwest Ethiopia, January 2019-December 2022

Cluster	District	Population	Coordinates/radius	Obs.*	Exp.*	RR	LLR
1	Gondar city	59,751	12.575528 N, 37.450339 E/0 km	55,349	40441.17	1.47	3001.019
2	Gondar Zuria	33,462	12.385233 N, 37.590973 E/0 km	30,616	22648.07	1.40	1401.652
3	East Dembia	29,078	12.781798 N, 37.675980 E/0 km	22,832	19680.98	1.18	261.297
4	Wegera	34,008	12.781798 N, 37.675980 E/0 km	24,628	23017.36	1.08	60.776
5	Lay Armacho	20,202	12.765897 N 37.369456 E/0 km	14,571	13673.43	1.07	30.533

p-value < 0.0001 for all clusters

RR, Relative Risk;

LLR, Log Likelihood Ratio

Obs.*, Number of observed cases in a cluster

Exp.*, Number of expected cases in a cluster

The pattern of climate variability

Ten years of monthly averages of climatic variables at the study sites revealed that the monthly minimum temperature was 8.73 °C, and the maximum temperature was 31.89 °C, with an average mean temperature of 21.59 °C and ± 4.91 °C standard deviation (± SD). The mean monthly rainfall was 122.17 mm ± 172.9 mm (± SD), with a range of 0 to 1175.7 mm, whereas the mean relative humidity (± SD) was 48.2% (± 19.37%), with a maximum of 89% and a minimum of 14.1%. The relationships between the incidence of under-5 diarrhea events and the average temperature, average rainfall and average humidity are shown below (Fig. 13).

Effect of climate variability on Under-5 diarrhea

Spearman's correlation analysis

Correlation analysis was conducted to quantify the relationships between the monthly incidence of under-5 diarrhea and climatic variables during the study period, with 0-, 1- and 2-month lags. Lag correlation occurs when the first metric increases or decreases in sync with the second but with a lag between the first and second metrics.

A significant positive correlation was found between the incidence of under-5 diarrhea and the monthly average temperature at 0-, 1- and 2-month lags. The correlation coefficient decreased as the number of lags increased from 0 to 2 months. The monthly mean rainfall and incidence of under-5 diarrhea were negatively correlated at all lags (0, 1, and 2 months). All lag months were

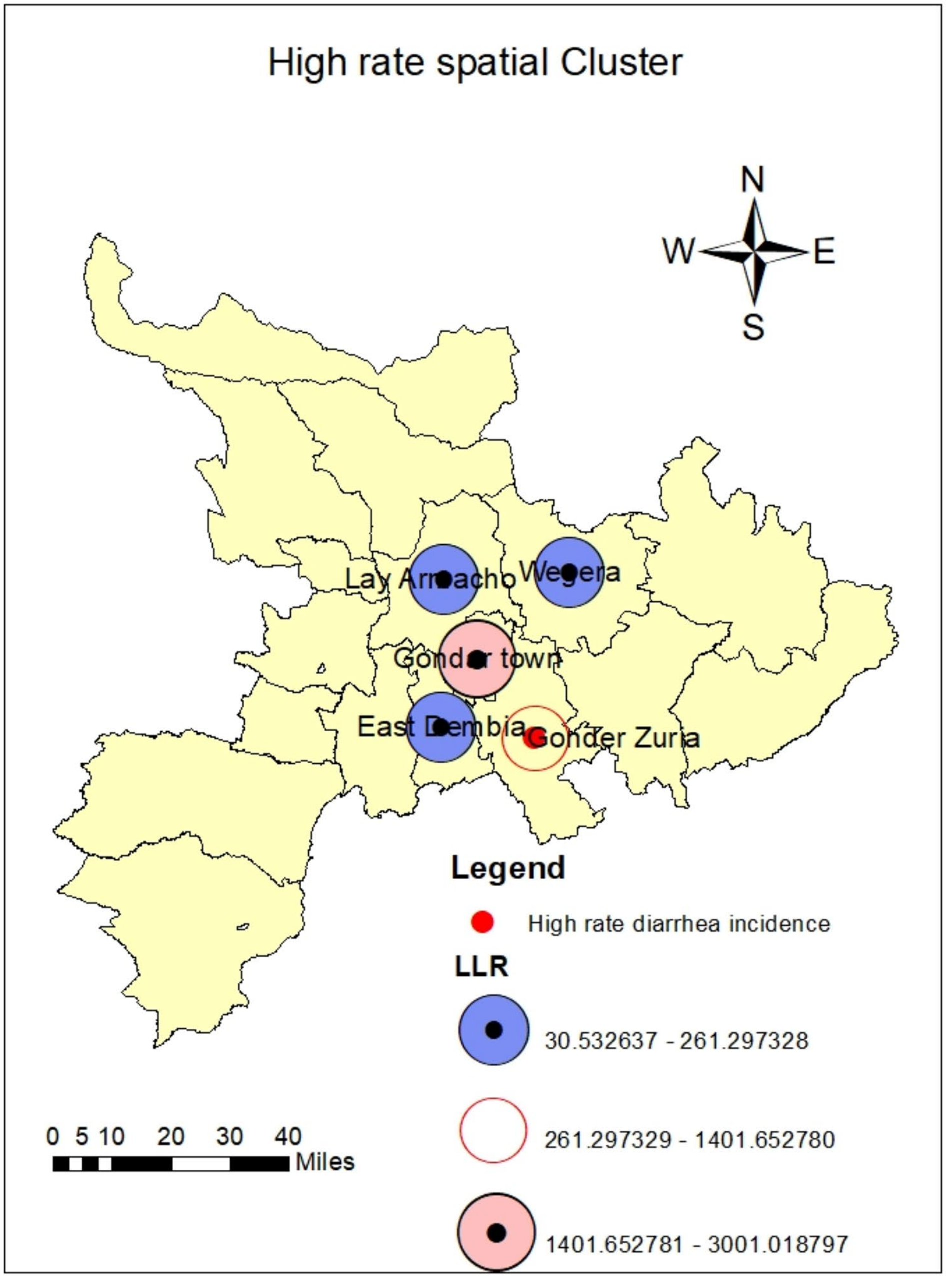

Fig. 12 Spatial clustering of Under-5 Diarrhea in the Central Gondar Zone, Northwest Ethiopia, January 2019-December 2022

Table 6 Significantly high rates of Temporal clusters of Under-5 diarrhea in the central Gondar zone, Northwest Ethiopia, from January 2019 to December 2022

Cluster	District	Time frame	Obs.*	Exp. *	RR	LLR	*p*-value
1	All	January 2020 to December 2021	130,773	125895.91	1.08	189.329	0.001

RR, Relative Risk;

LLR, Log Likelihood Ratio

Obs.*, Number of observed cases in a cluster

Exp.*, Number of expected cases in a cluster

Table 7 Significantly high-rate Spatiotemporal clusters of under-5 diarrhea events in the central Gondar zone, Northwest Ethiopia, from January 2019 to December 2022

Cluster	District	Time frame	Obs.*	Exp.*	RR	LLR	*p*-value
1	Gondar City	2020/1/1 to 2021/12/30	29,068	20222.94	1.49	1872.856	< 0.001
2	Gondar Zuria	2020/1/1 to 2021/12/30	16,131	11329.96	1.45	946.262	< 0.001
3	East Dembia	2020/1/1 to 2021/12/30	11,746	9867.34	1.20	175.789	< 0.001
4	Wegera	2020/1/1 to 2021/12/30	13,063	11519.57	1.14	104.042	< 0.001
5	Lay Armacho	2020/1/1 to 2021/12/30	7640	6840.05	1.12	46.363	< 0.001
6	Alefa	2020/1/1 to 2021/12/30	5567	5438.77	1.02	1.533	< 0.001

RR, Relative risk;

LLR, Log likelihood ratio

Obs.*, Number of observed cases in a cluster

Exp.*, Number of expected cases in a cluster

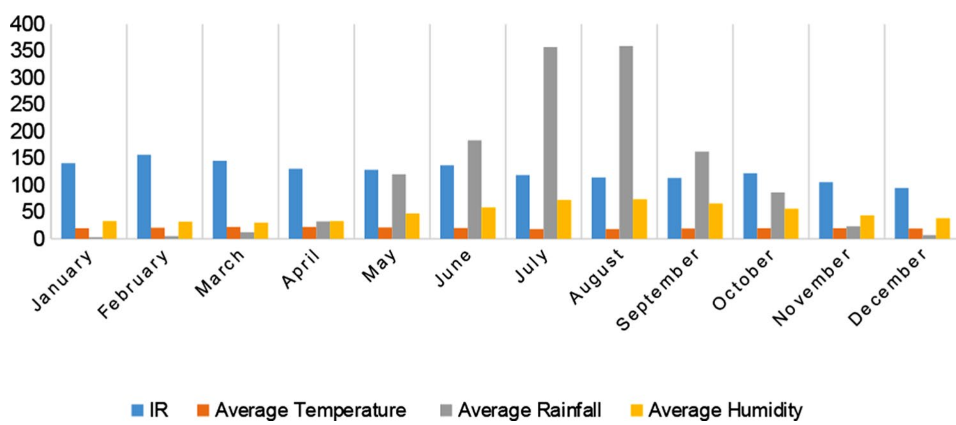

Fig. 13 Relationships between the 10-year incidence of under-5 diarrhea by month and the 10-year average temperature, average rainfall, and relative humidity in the Central Gondar Zone, 2013–2022

Table 8 Correlations between the monthly incidence of under-5 diarrhea events and the mean monthly Climatic variables in the central Gondar zone from 1 January 2013 to 30 December 2022

Monthly mean climatic variables	Lag-months	Spearman's *r*	*p*-value
Temperature (^{O}C)	0 months	0.2954	< 0.001
	1 month	0.2693	< 0.001
	2 months	0.2410	< 0.001
Rainfall (mm)	0 months	-0.1023	0.0019
	1 month	-0.1606	< 0.001
	2 months	-0.1753	< 0.001
Relative humidity (%)	0 months	0.0946	0.0518
	1 month	0.0774	0.1126
	2 months	0.0681	0.1647

significant, and the correlation increased as the number of lags increased. The monthly mean relative humidity and all lag month humidity were positively correlated (Table 8).

Regression analysis

The multivariable regression results revealed that the monthly average temperature and monthly average rainfall were significantly associated with the incidence of under-5 diarrhea. There was a significant positive association between the monthly average temperature and the incidence of under-5 diarrhea for 0 and 2 lag months. Monthly average rainfall and under-5 diarrhea incidence were negatively associated with 0 and 2 lag months.

There was a significant positive association between the monthly average temperature (IRR = 1.0209; 95% CI (1.0034–1.0387)) and the incidence of under-5 diarrhea events at 0 lag months. Again, there was a significant positive association between the monthly average temperature (IRR = 1.0202; 95% CI (1.0022–1.0385)) and the incidence of under-5 diarrhea at 2 lag months.

The monthly average rainfall (IRR = 0.999; 95% CI (0.9985–0.9996)) and (IRR = 0.9992; 95% CI (0.9987–0.9997)) were negatively associated with the incidence of under-5 diarrhea at 0 lag and 2 lag months, respectively (Table 9).

Discussion

A retrospective time series cross-sectional study conducted from 1 January 2013 to 30 December 2022 revealed the spatiotemporal distribution of under-5 diarrhea in the Central Gondar Zone. There was interannual heterogeneity in the incidence of diarrhea in children

Table 9 Negative binomial regression analysis of the effects of climate variability on Under-5 diarrhea in the central Gondar zone from January 2013 to December 2022

Monthly mean climate variables	Lag-months	Crude IRR (95% CI)	Adjusted IRR (95% CI)
Monthly average temperature (°C)	0 months lag	**1.0505 (1.0405–1.0606) *** **	**1.0209 (1.0034–1.0387) ***
	1-month lag	1.0473 (1.0371–1.0576) ***	0.9983(0.9765–1.0206)
	2-month lag	**1.0422 (1.0318–1.0527) *** **	**1.0202 (1.0022–1.0385) ***
Monthly average rainfall (mm)	0 months lag	**0.9988 (0.9986–0.9991) *** **	**0.999 (0.9985–0.9996) *** **
	1-month lag	0.9987 (0.9985–0.9989) ***	0.9999 (0.9994–1.0006)
	2-month lag	**0.9987 (0.9985–0.9989) *** **	**0.9992 (0.9987–0.9997) ***

***, p-value < 0.0001

**, p-value < 0.001

*, p-value < 0.05

IRR = Incidence Rate Ratio, 95% Confidence Interval, Adjusted IRR 95%CI indicates all the climate variables entered in the final model to investigate the independent effect of each climate variable by controlling the confounding effect between explanatory variables and the outcome variable

under-5 years of age across survey years and districts. This finding is supported by a study conducted in southern Ethiopia [52], northwest Ethiopia [36], resource-limited areas of Ethiopia [19], and Nepal [17], which revealed spatiotemporal variations in the incidence of under-5 diarrhea events. This variation could be due to geographical differences, meteorological factors, WASH infrastructure, and socioeconomic and environmental factors.

The incidence of under-5 diarrhea was greater among males than females in this study, with 54.4% (286,806) and 45.6% (240,252), respectively. This finding is supported by a study conducted on childhood diarrhea in Ethiopia [53] and North West Ethiopia [36] and a study conducted on the health impact of climate change [54], which revealed that males were more at risk for diarrhea than females. The likely explanation is that boys in Ethiopia are permitted to play outside of the house, and when they are 4 or 5 years old, they start working with their elders to engage in economic chores such as caring for domestic animals in the field [55]. This distinction may have played a role in boys' increased propensity to stray into unhygienic areas relative to girls, which could ultimately result in diarrheal morbidity.

In terms of age, children aged less than I years accounted for 38% of the sample. These findings are supported by a study conducted in the North Gondar Zone, which revealed that individuals aged 0–2 months were at risk for diarrhea [56]. This is the time when children start to crawl, walk, and play outside their homes where they come in contact with contaminants from the environment, and they also start complementary feeding where poor hygiene during food preparation can increase their probability of diarrhea.

In this study area, the total average annual cumulative incidence rates of diarrhea in children under-5 years of age from 2013 to 2018 and 2019–2022 were 14.83% and 14.85%, respectively. The overall average annual cumulative incidence of Under-5 Diarrhea during the study period was 14.84%. These findings were greater than those of studies conducted in the higher and lower parts of the Amhara region, which were 13.5% (95% CI 12.2–14.8%) [57], and in the 2016 EDHS study, which was 12% (95% CI: 11.39, 12.63) [14]. The dissimilarity may result from variations in study designs. For example, the EDHS employs a cross-sectional household survey at the national level, focusing on children who experienced diarrhea two weeks before the survey. On the other hand, children who experienced diarrhea went to public health facilities and received treatment were included in this retrospective analysis. The variances were caused by changes in the population characteristics throughout the previous years, as well as discrepancies in the data source and setting.

The highest rates of purely spatial clusters between 2013 and 2018 were detected in Dembia, Gondar Zuria, and Chilga. These districts contribute to the largest proportion of children under-5 years of age in the zone, so there is a high possibility of having a high incidence of diarrhea. Between 2019 and 2022, clusters were detected in Gondar city, Gondar Zuria, Wegera, and East Dembia districts. Population density plays a great role [58], and compared with other districts, Gondar City has the largest population. The displacement of people from surrounding districts to the city increases the crowding and expansion of slum areas in the city. This increases the scarcity of water supply and contact among the population in the city, which increases the transmission and incidence of diarrhea. Moreover, healthcare utilization for diarrhea patients might be greater in cities because of the strong healthcare-seeking behaviors of mothers, improved access to healthcare facilities, and increased number of health facilities, which can result in high case reporting [59]. In contrast, diarrhea in rural districts might be underreported, which contributes to having fewer cases in these areas. Dembia is known for being a hot area where the temperature is rising throughout the year [60]. This increasing temperature trend has a paramount impact on water, land, and food production, the multiplication of pathogens, hygiene, and sanitation through worsening negative consequences on human health and the productive capacities of the community.

These four identified clusters are closer to one another, and one of the important steps of cluster analysis is to detect the aggregation of disease cases and to identify risk factor evidence so that preventative and control efforts can be concentrated there.

This finding revealed temporal variation in the overall risk of under-5 diarrhea, which indicated that under-5 diarrhea was not randomly distributed over time. Between 2013 and 2018, a high-rate temporal cluster was found between 2014 and 2016. This might be due to the influence of socioeconomic, environmental, and climate-related factors. In 2014–2016, especially strong ENSO events from 2015 to 2016 generated excess rainfall and flooding, drought, and temperature extremes that created ecological conditions potentially favoring disease transmission worldwide [61]. The northern part of Ethiopia battled from 2015/2016 El Nino-induced drought, which caused a widespread shortage of food and water stocks and increased disease transmission [62]. The other high-rate cluster was 2020–2021. This is the year when COVID-19 was an alarming issue in society, and everyone's focus, including health professionals and governmental and nongovernmental bodies who previously worked on diarrhea, shifted their focus to COVID-19 prevention and reduction. This contributes to the increase in diarrhea this year. These findings are supported by a study conducted on diarrhea during COVID-19 infection, which revealed an increasing number of diarrhea cases ranging from 2 to 50% during the pandemic [63] because diarrhea is one sign and symptom of COVID-19. The other reason is that there has been political instability in most parts of the Amhara region, which has created distractions in infrastructure and displaced people, increasing the transmission of diarrhea in this study area [64, 65].

The spatiotemporal analysis provided further evidence for a greater-than-expected number of under-5 diarrhea cases arising within a defined place and time. Significant spatiotemporal under-5 diarrhea clusters were detected between 2013 and 2018. A primary cluster was detected in Dembia from 2014/1/1 to 2016/12/30, and the next clusters were 46 from 2016/1/1 to 2018/12/30, Wegera from 2015/1/1 to 2015/12/30, Alefa from 2016/1/1 to 2016/12/30 and lay Armacho from 2014/1/1 to 2014/12/30. West Belesa from 2015/1/1 to 2015/12/30. Between 2019 and 2022, there was one primary hotspot and three secondary hotspots of under-5 diarrhea. Primary clusters were detected in Gondar City between 1 January 2021 and 30 December 2022, and second, third, and fourth statistically significant clusters were identified in Gondar Zuria, Wegera, and East Dembia, respectively, between 1 January 2020 and 30 December 2021.

This study revealed the existence of long-standing and emerging high-rate spatial clusters associated with the incidence of under-5 diarrhea. Gondar Zuria, Dembia, and Wegera were long-standing clusters that were found during both the 2013–2018 and 2019–2022 study periods. This finding indicates that risk factors such as population density play a substantial role [58], and water infrastructure and accessibility to healthcare, which contribute to under-5 diarrhea cases, are still issues in these districts. East Dembia and Lay Armacho are emerging high-rate spatial clusters that were observed between 2019 and 2022.

There was also an increasing trend annually during the study period from 2013 to 2018 (131.2, 154.76, 157.1,163.3, 138.4,144.9) and 2019–2022 (145.9, 152.5,155.3,140.1) (Table 1a and 1b). These findings are similar to those of previous studies in southern Ethiopia on childhood diarrhea, where diarrhea incidence increased [52], and studies conducted in resource-limited areas of Ethiopia [19]. This finding contradicts the findings of a study conducted in northwestern Ethiopia, which reported a decreasing trend in the incidence of under-5 diarrhea [76]. Potential rebound increases in diarrhea-associated mortality and morbidity are due to increasing urbanization and climate change [24, 66, 67]. Resource constraints, particularly concerning program utilization and availability; in particular, inadequate primary health care unit implementation [19] and reduced exclusive breastfeeding during the first six months of life, a critical child survival intervention [68], an overall increasing number of population and under-5 populations in each district and improvements in the reporting system both from existing and newly built health facilities, especially in recent years, civil war and cost inflation contributed to the overall incremental trend of Under-5 Diarrhea.

A trend toward seasonality shows a seasonal variation in the incidence of diarrhea among children under-5 years of age. It starts to increase in January and reaches its peak in February. This occurred because it was the beginning of the dry season, and the average temperature was the highest. Similar studies have shown that an increase in temperature is positively associated with diarrhea incidence [20, 32]. A shortage of water in the dry season has been associated with an increased incidence of diarrhea [69]. This may be due to the lower availability of fresh water or longer water storage and worsened personal hygiene because of the lower availability of water [70]. The transmission of diarrhea by flies increases as they breed intensively during the pre-rainy season [71].

Another peak incidence was observed in June. The beginning of the rainy season creates a suitable environment for contaminating water sources [72]. Other environmental factors, such as surface runoff and floods, accelerate the rate at which drinking water sources become contaminated during the start of the rainy season because the first rainfalls following the dry season carry [30, 73]. In addition, according to the Zonal Health Department, June is the yearly budget closest to the month, and all unreported cases might be reported in this month.

The incidence rate starts to slowly decline over time to reach its lowest level from July to September, which is referred to as the main rainy season. This finding is similar to that of a study conducted in the northwestern part of Ethiopia on the effect of climate on childhood diarrhea [36]. This could be due to the effects of geography, seasonality, and reporting factors where population activities wind down and communications are interrupted, particularly in rural districts [20]. This study identified a slight peak in October. This peak is related mainly to the end of the rainy season and the start of the warm season, which favors the growth and survival of bacterial pathogens that cause diarrhea [20]. Excess cases of diarrhea have been reported after heavy rainfall and associated extreme hydrologic conditions such as floods and drought [74]. Again, a month follows September when there are many holidays and celebrities. This month, there was a change in the method of food consumption; most people tended to consume animal products, especially raw meat, which has a high chance of being contaminated by microorganisms that may cause diarrhea. Considering the incubation period from the time of exposure, signs and symptoms are likely to be visible in October, which contributes to the increased number of cases in this month.

Temperature is known to influence transmission intensity through its effects on the growth of pathogens [20]. Temperature was statistically significant and positively associated with the incidence of under-5 diarrhea events in this study. The findings of this study are supported by previous studies in southwestern Ethiopia [34], Bhutan [32], and Iran [33], which revealed a positive connection between temperature and diarrhea. The first reason for the increased risk of childhood diarrhea associated with high temperature could be the rapid multiplication and survival of causative agents of diarrhea for longer periods, which occur in warmer months [75]. The second reason may be due to temporal changes in human behavior during hot weather conditions, such as higher water consumption, the use of unimproved drinking water sources, and less hygienic practices due to the scarcity of water since most improved drinking water sources are out of commission during dry seasons [30]. The other is that increased temperatures could lead to food poisoning because food spoils easily in warmer weather [75].

The findings of this study indicate a negative relationship between rainfall and the incidence of diarrhea in children under-5 years of age. This finding is supported by a study conducted in northwestern parts of Ethiopia [36]. The possible reason is that during rainy months, there is an increased quantity of rainwater available for other household needs, such as hand washing, cleaning, or bathing, which reduces exposure to diarrheal pathogens [76]. The other reason is that in the main rainy season, there is less movement and contact among people, especially in rural areas, and the probability of visiting health facilities is lower [20]. In the cold season, people, especially children, tend to stay at home under the care of their parents, which reduces transmission.

Conclusion

This study revealed spatiotemporal variations in the incidence of Under-5 diarrhea events in the Central Gondar Zone. An increasing trend with a seasonal variation in the incidence of Under-5 diarrhea, which peaks in February, June, and October, was observed. To decrease and avoid the morbidity and mortality caused by diarrhea, priority intervention should be given to areas that are identified as hotspot areas of under-5 diarrhea. Moreover, precautionary measures, such as early warnings, should be taken since the incidence of under-5 diarrhea has shown seasonality, with three peak points in February, June, and October. The mean monthly temperature at 0- and 2-month lags was positively related to under-5 diarrhea, whereas the mean monthly rainfall at 0- and 2-month lags was negatively related to under-5 diarrhea incidence. Further studies to investigate the underlying causes of increased risk in the identified hotspot areas, including individual factors, household factors, and environmental factors, are recommended to obtain a more inclusive view of under-5 diarrhea risk.

Strengths of the study

This "spatial, temporal and spatiotemporal variation in the incidence of diarrhea in under-5 children and associated meteorological factors in the central Gondar zone" represents the first attempt in the Central Gondar Zone. Therefore, this study will serve as a baseline for evaluating the progression of under-5 diarrhea incidence interventions in upcoming research projects.

This study is methodologically rigorous and provides a comprehensive understanding of the spatiotemporal distributions of diarrhea incidence among children under-5 years of age. It also serves as a starting point to explore what makes hot spot districts hot spot areas and cold spot districts cold spot areas so that we can work on these risk factors.

Limitations of the study

The information came from a system of passive surveillance. This finding indicates that the total number of individuals with Under-5 diarrhea in the districts was not fully captured by the clinical records since some individuals may not have reported to official government health facilities, choosing instead to employ conventional medicine or buy medications independently. Therefore, this study might not accurately represent the morbidity of diarrhea among children under-5 years of age in the study area.

This study was performed by incorporating host (individual-level), household, socioeconomic, other environmental, and organizational factors. Unfortunately, information regarding these variables was not obtained.

Abbreviations

WHO	World Health Organization
CDD	Control of Diarrheal Diseases
EDHS	Ethiopian Demographic Health Survey
IRR	Incidence Rate Ratio
AIRR	Adjusted Incidence Rate Ratio
LLR	Likelihood Ratio
HMIS	Health Management Information System
ESS	Ethiopia Statistics Service
WASH	Water, Sanitation, and Hygiene

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Author contributions
This study was designed by G.Y. L.D and K.A participated in data management. G.Y, H.F, Z.A and Z.G participated in the data analysis. G.Y prepared the manuscript and all the figures in the manuscript. All authors read the manuscript and approve for submission.

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Data availability
The data sets generated during and/or analysed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethical approval and consent to participate
Ethical approval was obtained from the Institutional Review Board of the College of Medicine and Health Sciences, University of Gondar (reference number: IPH/2505/2023). Informed consent to participate was waived by the Institutional Review Board of the College of Medicine and Health Sciences, University of Gondar (Reference Number: IPH/2505/2023), as the study utilized secondary data on under-five children's diarrhea records from the zonal health department. All methods were carried out following the Helsinki Declarations and guidelines and regulations of the University of Gondar research and ethics review committee. A retrospective study was conducted by taking diarrhea reports from children under-5 years of age from the Central Gondar Zone Health Department. Central Gondar Zone Health Department were contacted and permission was obtained. There were no individual participant identifiers such as name to maintain the privacy and confidentiality of the participants in the study. All the collected records were kept confidential.

Consent for publication
This manuscript does not contain any personal data.

Competing interests
The authors declare no competing interests.

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