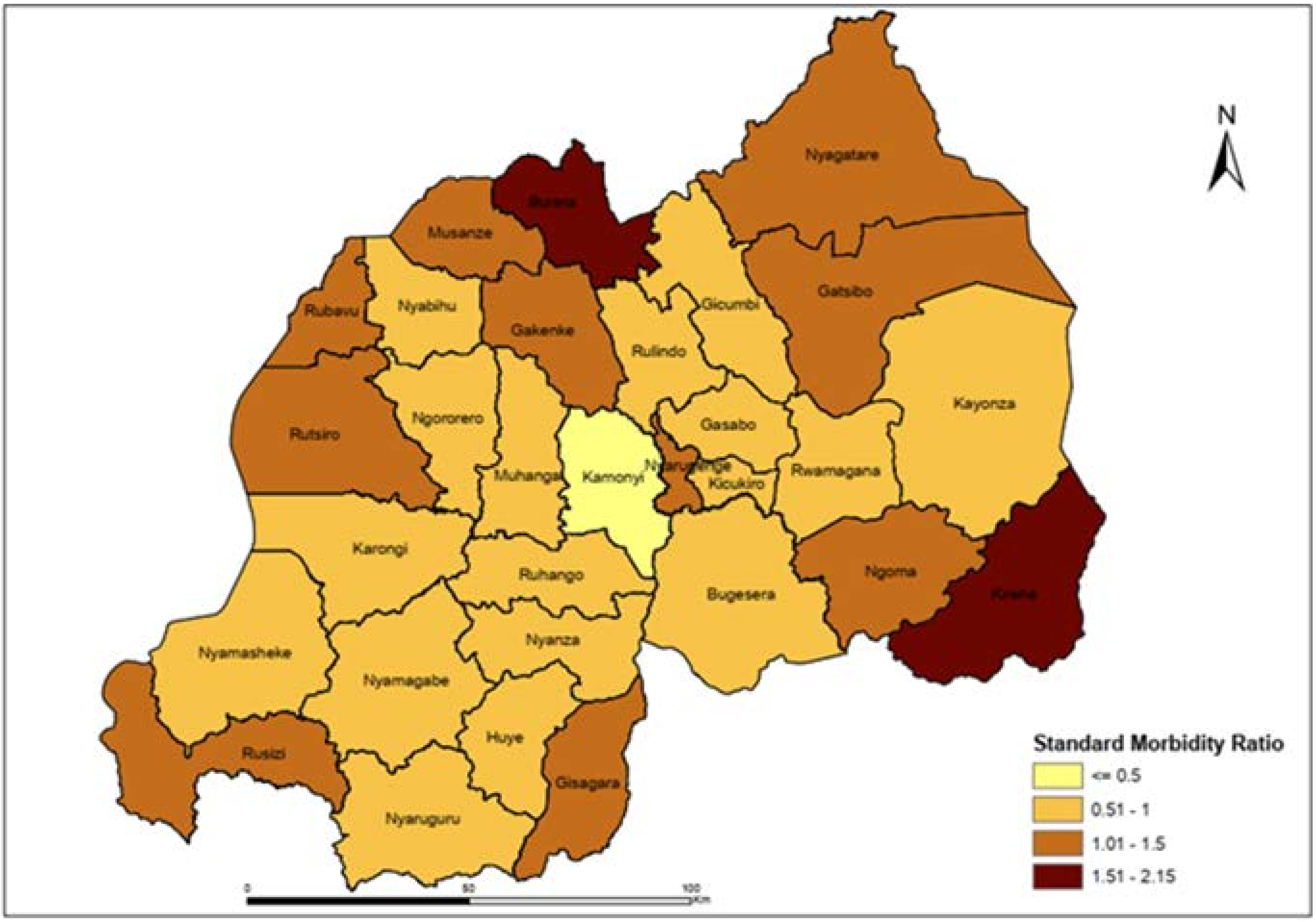

Figure 2. Map of Rwanda showing excess hazard (Standard Morbidity Ratio) of diarrhoeal diseases among children under five years from each district, January 2014 to December 2018

Purely spatial clusters were identified without considering time. The clusters occurred in all provinces and the City of Kigali, seven clusters from nine locations were identified countrywide. The most likely cluster occurred in Kirehe district of the eastern provinces, with RR=2.24 (p<0.001) and secondary cluster observed in three out of the five districts of the northern province, Burera, Musanze and Gakenke, Log-Likelihood Ratio (LLR)=9802.70 (p<0.001). Least clusters occurred in southern province, in only one out of eight (1/8) districts making up the province **(Table 2).**

Table 2. Distribution of spatial clusters of diarrhea diseases in children under five years in rwanda between January 1, 2014 and December 31, 2018

Cluster	District	Population	Coordinates/Radius	Obs.*	Exp.**	Annual case/100000	Obs./Exp.	RR	LLR	P value
1	Kirehe	51757	2.275026 S, 30.674212 E / 0 km	70560	32781.93	27269	2.15	2.24	17049.9	<0.001
2	Burera, Gakenke, Musanze	158613	1.493932 S, 29.833803 E / 22.29 km	140272	100462.64	17689.4	1.4	1.46	7894.5	<0.001
3	Nyarugenge	43271	1.952494 S, 30.062399 E / 0 km	37442	27407.05	17307.8	1.37	1.38	1697.95	<0.001
4	Rutsiro	49367	1.959969 S, 29.385713 E / 0 km	37028	31268.45	15002.7	1.18	1.19	517.51	<0.001
5	Gatsibo	65846	1.617858 S, 30.382178 E / 0 km	48207	41705.42	14644.1	1.16	1.16	504.13	<0.001
6	Gisagara	49041	2.598280 S, 29.838574 E / 0 km	35581	31061.58	14512.4	1.15	1.15	324.32	<0.001
7	Rusizi	60955	2.483495 S, 28.904454 E / 0 km	41202	38608.04	13520.3	1.07	1.07	88.71	<0.001

RR: Relative Risk; **LLR:** Log-Likelihood Ratio; **Obs.:** number of observed cases within a cluster; **Exp.:** number of expected cases in a cluster

Purely temporal cluster

Purely temporal clusters were identified taking into account the time only, with the unit of aggregation taken as a month, without considering space, referred to the district as the unit and scanning for clusters with high rates. These exhibited only one significant cluster in all districts (RR=1.23, p=0.001), from June 2017 to September 2018.

Spatiotemporal cluster

Clusters of diarrhoeal diseases were identified considering space and time distribution (district, month and the year). In total four spatiotemporal clusters of diarrhoeal diseases in children under five years occurred between January 1, 2014 and December 31, 2018. The most likely primary cluster occurred in Kirehe district, located in eastern province (LLR=12340.98, p<0.001) from June 1, 2016 to October 30, 2018. The second cluster occurred in three out of the five districts constituting the northern province, namely Burera, Gakenke and Musanze (LLR=7413.99, p<0.001) from May 1, 2016 to October 31, 2018. The fourth cluster was observed in several districts of western and southern provinces making up 11 locations (LLR=889.25, p<0.001) from July 1, to September 30, 2018. The cluster involved districts composing western province (5 out 7 districts) and south province (6 out of 8 districts) **(Table 3).**

Table 3. Spatiotemporal distribution of diarrhoeal diseases clusters in children under five years in Rwanda from January 2014 and December 2018

Cluster	District	Timeframe	Population	Obs.*	Exp.**	Obs./Exp.	RR	LLR	P value
1	Kirehe	2016/6/1 to 2018/11/30	51757	40419	16665.90	2.43	2.48	12340.98	<0.001
2	Burera, Gakenke, Musanze	2016/5/1 to 2018/10/31	158613	80000	51073.20	1.57	1.61	7413.99	<0.001
3	Nyarugenge	2015/5/1 to 2017/10/31	43271	20341	13725.91	1.48	1.49	1408.06	<0.001
4	Rusizi, Nyamasheke, Karongi, Nyamagabe, Nyaruguru, Rutsiro, Huye, Nyanza, Ru-bavu, Ruhango, Gisagara	2018/7/1 to 2018/9/30	573748	24900	18881.40	1.32	1.33	889.25	<0.001

Seasonal patterns of diarrhoeal diseases in children under five years in Rwanda

A time bound consisting of 12 months of the year was considered to illustrate results taking into account variability within months. Climate variables (rainfall and temperature) were also included, to elucidate their relationship with diarrhoeal diseases, and to determine its status during rainy and dry seasons.

A bimodal rainfall was identified, increasing from February and reaching a peak in April. A decline took place in the months of May, June, July and August, reaching the lowest in July. It started to increase again from September to November, reaching a peak in November; then it started to decline again. The mean monthly temperature showed fluctuation over 12 months, with a peak in August and a secondary peak in March, reaching the lowest levels in April and November. The incidence of diarrhoeal diseases increased inversely with the rainfall, with high increases observed during the period post-rainy season (dry season) and decline with the increase of rainfall **(Figure 3).**

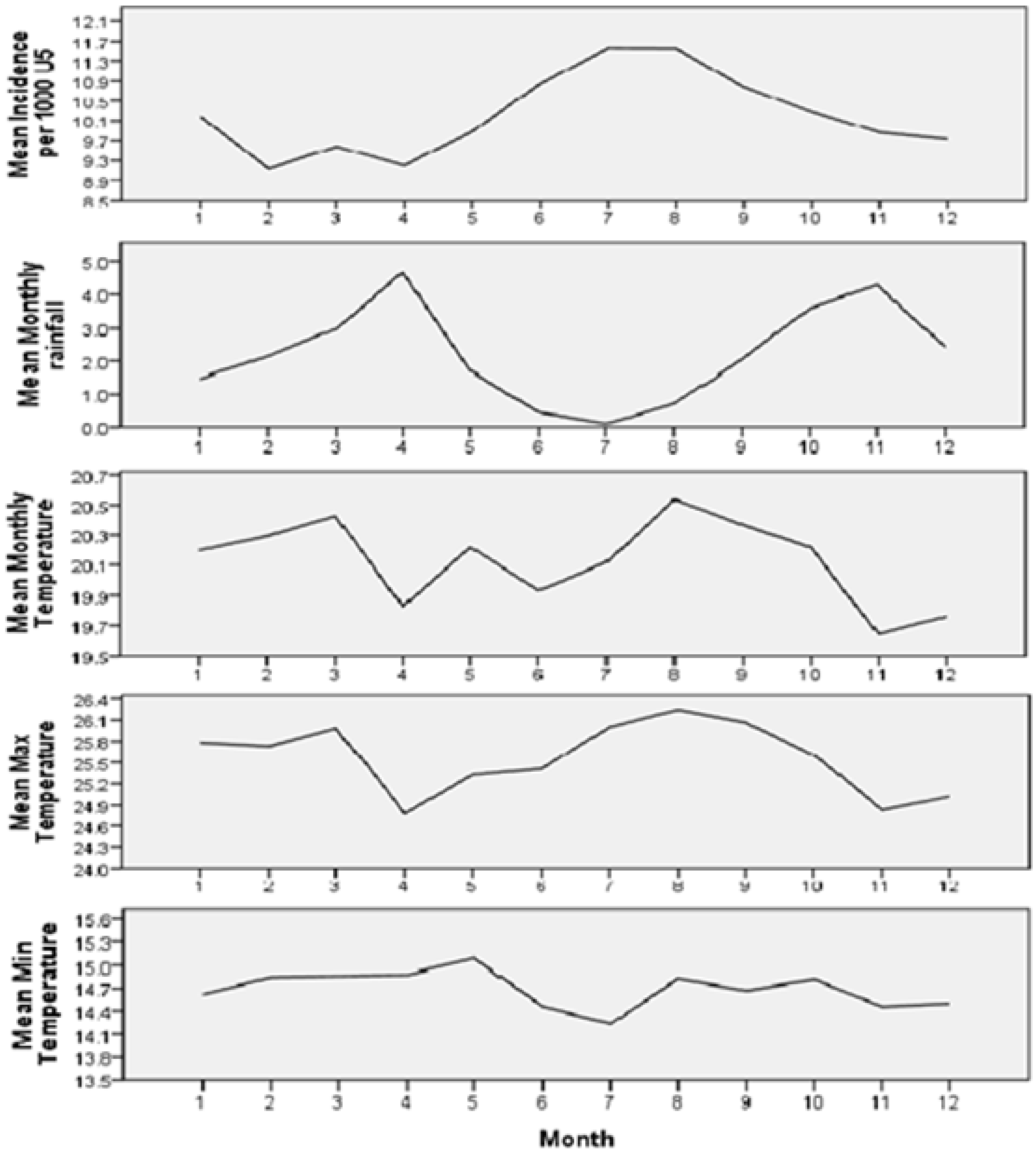

Figure 3. Four years' period of monthly data decomposition on diarrhoeal disease incidence rate, temperature, and rainfall between January 1, 2014 and December 31, 2017.

The results of the linear regression analysis showed a statistically significant impact of monthly average temperature and mean monthly rainfall on diarrhoeal disease cases. The findings revealed a positive relationship with monthly average temperature, whereby the increase in one degree Celsius ($1^{o}C$) was associated with an increase of 17 diarrhoea cases (95%

CI, 9 – 20, p<0.001). Furthermore, a negative association with mean monthly rainfall was elucidated, an increase in one millimeter (1mm) of rainfall was observed to be associated with a decrease of 14 diarrhoeal cases (95% CI, -20, -8, p<0.001) **(Table 4).**

Table 4. Relationship between diarrhoea, rainfall and temperature from January 1, 2014 to December 31, 2017

Model	Predictors	Unstandardized Coefficient B	95% CI	Std. Error	Standardized Coefficients Beta	t	p value
1	Min. Temp	-71.50	-248.44; 105.43	90.20	-0.48	-0.79	0.428
	Max. Temperature	-58.97	-235.47; 117.53	89.98	-0.54	-0.66	0.512
	Monthly Average Temperature	145.56	-207.03; 498.16	179.75	1.07	0.81	0.418
	Total rainfall	1.28	-3.86; 6.43	2.62	0.34	0.49	0.625
	Average monthly rainfall	-52.54	-208.27; 103.19	79.39	-0.46	-0.66	0.508
2	Min. temperature	-71.38	-248.27; 105.50	90.17	-0.48	-0.79	0.429
	Max. temperature	-58.99	-235.44; 117.47	89.95	-0.54	-0.66	0.512
	Monthly average temperature	145.46	-207.04; 497.96	179.70	1.06	0.81	0.418
	Average monthly rainfall	-13.71	-19.64; -7.78	3.03	-0.12	-4.53	**0.000**
3	Min. temperature	-12.51	-29.00; 3.98	8.41	-0.08	-1.49	0.137
	Monthly average temperature	27.74	12.36; 43.11	7.84	0.20	3.54	**0.000**
	Average monthly rainfall	-13.73	-19.66; -7.79	3.02	-0.12	-4.54	**0.000**
4	Monthly average temperature	17.37	10.33; 24.42	3.59	0.13	4.84	**0.000**
	Average monthly rainfall	-14.52	-20.36; -8.67	2.98	-0.13	-4.87	**0.000**

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Discussion

The present study explored space and time along with climatic patterns of childhood diarrhoea in Rwanda at national level. The findings of this study illuminated an increase tendency of diarrhoeal diseases among children under five years in Rwanda over a period of 5 years. The highest incidence rate was reported in 2018. Previous studies conducted in similar setting like in Rwanda contradict with the findings [20,21] whereby they reported a decrease tendency. However another study conducted in Ethiopia found similar findings [16]. Rwanda has made effort to decrease morbidity and mortality of diarrhoeal diseases; in the same context, much have been done to and strengthen the health system. The increase in reported diarrhoeal episodes might be explained by the institutionalization of new health facilities at the lowest community level (health posts) and improvement made in health services being provided by CHWs. By increasing access to health services might have increased the uptake of modern health services, which might have resulted in the increasing trend of diarrhoea children under five years.

Spatial Clusters with nonrandom distribution were observed across the country, this may be explained by a disparity of risk factors which may contribute to the disease incidence. The highest excess hazard of diarrhoeal diseases was detected in Kirehe district. This might be explained by the fact that the area experiences long-term drier season and low access to improved drinking water. The recent Integrated Household Living Conditions Survey (EICV) 2016/2017 reported that 8.1% use surface water in Kirehe, 15.7% of households use non improved water source. The eastern province where Kirehe district is located was reported as the least fifty in using improved water source (82.6%) compared to 87.4% national. The eastern province reported a high proportion of household with low access to improved drinking water (27.7= 72.3 less than 200m, 53.3= 46.7 less than 500m) in the EICV5 [22].

A temporal cluster was reported between 2017/6 to 2018/9 from all district. This might be due to the facts that new lowest level health facilities (health posts) were initiated increasingly during the past 2 years and might resulted in increased uptake of services.

The finding on seasonality variation considering the 5 years period, diarrhoeal diseases incidence was revealed to begin increasing in May and reaching its peak in July and August. According to the climate variability, this is a drier season observed in Rwanda continuing up to early September prior to rainy season. In addition to that a positively association was observed between increase of monthly average temperature and increase of diarrhea cases. Similar findings have been elucidated in different studies [14,16,17,20,23–25]. The increase cases observed during months with highest temperature justified by plausible explanations; higher temperature promotes the development of and growth of bacteria even though some evidences suggest that the survival and transmission of enteric viruses are increased during low temperature [26]. In addition, during drier season people experiences increased scarcity of improved drinking water which might result in consumption of contaminated water from runoff and sewage overflow happened during rainy season [27].

The decline of diarrhoea incidence rate was observed toward the end on drier season earlier to maximum rainfall. Similar findings have been reported by other researchers showing negative association between rainfall and diarrhoeal diseases [14,28]. Another study from Ghana reported a negative relationship between diarrhoeal diseases and rainfall by analyzing routine data reported on childhood diarrhoea [29]. The findings of the research that employed secondary data of DHS in Rwanda found that higher runoff was protective of diarrhoea in children living household with unimproved toilet facilities [30]. The DHS 2014/2015 elucidated that only 11.6% of household used surface water and more than a half of households used improved latrines [31]. This might have reduced the behavior of open defecation and prevented from using surface water during rainy seasons.

Conclusion

The incidence of diarrhoea in children under five years was found increasing and disproportionally distributed across districts composing Rwanda. Findings revealed statistically significant association with climate dynamics. This call for the public attention to climate changes which affect health especially children under five years. In addition, areas with high risk of diarrhoeal diseases were identified and require more attention for prevention and control measures. The finding from this study showed the importance of scan statistics to improve spatiotemporal prediction of climatic changes and associated variation in infectious diseases over space and time scales. This would contribute to the early warning signs for health effects depending on predicted climate changes. Thus, information for this scan statistics proven useful information for planners and decision makers to determine less served area for appropriate allocation of resources in public health interventions targeting diarrhoeal diseases.

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