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Impacts of air pollution on pediatric respiratory infections under a changing climate in Kenyan urban cities

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Abstract

Atmospheric pollutants appear to contribute much in respiratory infections, where they have an effect on spreading viruses and bacteria, while affecting children partly due to their small nature and still undeveloped respiratory systems. This study aimed to assess the impacts of air pollution on pediatric respiratory infections under a changing climate in Mombasa, Nakuru, and Nairobi cities. Air pollutants and climate data used for this study were obtained from Modern-Era Retrospective analysis for Research and Applications, version 2 (MERRA-2), ranging from 1990 to 2020. Pediatric lower respiratory data was obtained from the Institute of Health Metrics and Evaluation (IHME) ranging from 0 to 14 years for periods of 1990 to 2019 for the three towns. Mann-Kendall test and multiple regression analysis were applied to find the relationship between air pollutants and respiratory infections. The study found out that air pollutants: $PM_{2.5,}$ carbon monoxide, sulfur dioxide and tropospheric ozone were increasing in all three cities. Minimum temperature was also found to be increasing, while precipitation increased in all cities except Mombasa where it shown a steady decline. Morbidity and mortality cases showed a decline from 2010 onwards for children below 4 years, while the numbers increased for children above 5 years. $PM_{2.5,}$ carbon monoxide, sulfur dioxide had a direct impact on lower pediatric respiratory infections in all towns. As such, these respiratory infections are then expected to rise under which the influence of climate change through enhancing its spread and dispersion in various areas. Seasonal variation of climate variables will also have an impact on lower pediatric respiratory infections, increasing and decreasing their cases annually. These findings are important for strengthening policies in health, transport, and industrial sectors, and further contributing to the reduction of pollution effects on children who are the most vulnerable in the population.

Keywords: *air pollution; climate change; greenhouse gas; minimum temperature; pediatrics, respiratory infections*

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Introduction

In a special report of the Intergovernmental Panel on Climate Change (2018), it was observed that temperature had risen by 1°C above pre-industrial levels, and that eight of the ten hottest years on record occurred in the past decade, mainly driven by the combustion of fossil fuels.

The IPCC's fourth and fifth assessment report noted that anthropogenic causes of climate change were one of the biggest social, environmental, and public health challenges the earth faced in this century (IPCC 2007, 2014). The impacts of climate change on health will vary mainly due to differences in the underlying health status of people across the globe, and the distribution of social, economic, and cultural factors that affect exposure and their capacity to respond and adapt to environmental hazards (Bennett and Friel, 2014).

Children are highly vulnerable to the effects of climate change as their bodies are developing and sensitive to environmental hazards, such as heatwaves, and harm on them can result in life-long impacts (UNICEF, 2009). A child born today will experience a world that is more than four degrees warmer than the pre-industrial levels, with climate change impacting health from infancy to old age (Lancet, 2019).

Acute Respiratory Infections (ARI) are the most common causes of morbidity and mortality in the world (Dagne *et al.*, 2020). Infants, children, and the elderly are most affected especially in countries with low and middle income per capita due to differences in specific etiologies and risk factors, making it one of the leading causes of outpatient and hospitalization in healthcare facilities, more so in childcare. Simoes *et al.,* (2006) found out that the proportion of mild to severe cases of Acute Respiratory Infections (ARI) varies between high and low-income countries in children under five, with the severity of Lower Respiratory Tract Infections (LRIs) worsening in developing countries leading to higher fatality rates. Kamath *et al.,* (1969) identified that children under five experience an average of three to six episodes of ARI no matter where they live or how their economic situation was.

Although global approaches are required to mitigate increasing global temperatures, climate change as a result of anthropogenic factors, in particular fossil fuel combustion and greenhouse gas (GHG) emissions, will act as an amplifier of these effects on the health and wellbeing of children across the globe, affecting most of the world's poorest and socially disadvantaged children, despite an improvement in healthcare, nutrition, and immunization (Bennett and Friel, 2014; UNICEF, 2007). A study by Landrigan, Sheffield and John (2010) found out that climate change increased morbidities and mortalities of respiratory diseases on children, mainly brought about by extreme weather events.

Air pollution is considered as the greatest environmental health risk worldwide, with most parts of the world recording higher levels of pollution. Exposure to fine particles polluted in the air penetrates deep into the lungs and cardiovascular system causing heart diseases, stroke, cancer, and respiratory infections including pneumonia, from both indoor and outdoor pollution, while affecting most low- and middle-income countries (WHO, 2018). In Kenya, rapid urbanization, fast rising population and increasing motorization is paving way for air pollution problems, more-so in cities such as Nairobi and Mombasa (NCC, 2018).

A special report on the state of global air (2020) found out that air pollution contributed to 27,700 deaths in Kenya, where 30% were associated with lower respiratory infections. This high number mainly came from children, brought about by ambient $PM_{2.5}$, household air pollution and ambient ozone which were the largest contributors to mortality (Health Effects Institute, 2020). The Nairobi City County Air Quality Action Plan (2019-2023) observed that respiratory infections are the leading illnesses of health among children, accounting for over 60% of hospital visits (NCC, 2019).

According to the World Health Organization guidelines, Kenya's air quality is moderately unsafe (IAMAT, 2020). In Kenya, pollution comes from vehicle emissions, cement manufacturing, power plants, and burning waste for outdoor pollution; and the use of unclean solid fuel for cooking, quality of house materials, and presence of smokers for indoor pollution. As an effect of weather variations, the highest levels of air pollution occur during cold and dry seasons, i.e., June to October (IAMAT, 2020).

The objective of this study was to assess the impacts of air pollution on pediatric respiratory infections under the changing climate in Mombasa, Nairobi, and Nakuru cities, for children below 14 years.

Considering the knowledge gaps in studies on air pollution and pediatric respiratory infections in the country, the results of this study will be useful in strengthening policies in health, transport and industrial sectors, further contributing to the reduction of air pollution effects on children.

Materials and methods

Study Area

This study focused on three major cities, i.e., Mombasa, Nakuru, and Nairobi, which are the most populous compared to other cities in the country.

Mombasa is a coastal town in Kenya that lies in Mombasa County at 4°03′S, 39°40′E, at an elevation of 54 meters. The region's climate is classified as tropical savanna under Köppen Classification, experiencing average temperatures of 26.1 degrees centigrade and a cumulative rainfall of about 1000 millimeters annually (Climate-data, 2021). It covers an area of 219.9 km², with a population density of 5,495/ km². From a population of 1.2 million people, 32.6% (393,313) is composed of children below 14 years (Brinkhoff T. , 2020).

Nairobi city lies in Nairobi County, at 1°17′S, 36°49′E, at an elevation of 1623 meters. It is classified a marine West Coast Climate under Köppen Climate Classification, where temperatures in winter happen to be mild and moderate in summer (Climate-data, 2021). It covers an area of 703.9 km², with a population density of 6,247/ km². The 2019 census showed that it holds 4.3 million people, with 30.4% (1.34 million) being children below 14 years (Brinkhoff T. , 2020).

Nakuru town lies in Nakuru County, at 0°18′S, 36°4′E, at an elevation of 1850 meters. It is classified as Mediterranean warm/cool summer climate under the Köppen-Geiger climate classification, with a mild, warm and temperate climate. Rainfall occurs mostly during winter, with relatively little rain in summer (Climate-data, 2021). It covers an area of 7462 km², with a population density of 289.7/ km². The 2019 census showed that it holds 2.16 million people, with 37.7% (815,315) being children below 14 years (Brinkhoff T. , 2020).

Study design

To achieve the set objective of this study, a quasi-experimental research design was utilized to understand the impacts of air pollution on pediatric respiratory infections. This was through having atmospheric pollutants as the independent variables, and morbidities and mortalities as the dependent variables.

Data Collection Methods

This study used point historical secondary air pollution data, climate data and lower pediatric respiratory data from various sources ranging from 1990 to 2020. The data obtained was temporal and averaged monthly from the sources.

Climate data comprising of minimum temperature (^{0}C), precipitation (mm); and air pollution data comprising of particulate matter ($PM_{2.5}$), Sulphur dioxide (SO_2), carbon monoxide (CO) and ozone (O_3); needed for this study were obtained from the Modern-Era Retrospective analysis for Research and Applications, version 2 (MERRA-2), for periods of 1990 to 2020, at resolutions of 0.5^0 x 0.67^0. MERRA-2 is widely used for studies due to its high data quality, continuous spatial and temporal resolutions and finally its diverse aerosol species (Buchard *et al.*, 2017).

For this study, five types of aerosols were simulated. These include dust, sea salt (SS), sulfate (SO4), black carbon (BC) an organic carbon (OC).

$PM_{2.5}$ concentrations were calculated by the equation 1 below:

$$PM_{2.5} = 1.375 * SO_4 + 1.6 * OC + BC + Dust + SS \ldots\ldots \textit{Equation 1}$$

Equation 1 above lacks nitrate particulate matter which is mostly emitted from vehicles and industrial emissions, where it is assumed to be absorbed by NH_4 in the form of ammonium sulfate (Malm *et al.,* 1994).

Pediatric respiratory data was obtained from the Institute of Health Metrics and Evaluation (IHME) from the University of Washington, ranging from 0 to 14 years for periods of 1990 to 2019, constituting of the number of morbidities and mortality cases for the three towns under study (IHME, 2020). The data was open source, grouped as: below 1, 1-4, 5-9 and 11-14 years, for all lower respiratory infections put together, accumulating to the total number required for the study. IHME obtains its data from a variety of sources, ranging from censuses to disease registries. Kenya supplies its data to IHME through the Kenya National Bureau of Statistics (KNBS), the Ministry of Health and through the Kenya Medical Research Institute, where it then undergoes evaluation before publication (IHME, 2018).

Data Analysis

Air pollutants, climate and pediatric data were normalized and analyzed using R statistical software version 4.0.3, by conducting the non-parametric Mann-Kendall test which is widely used to detect trends in variables in meteorology and hydrology (Wang *et al*, 2019). This is shown in *equation 1* and 2 below.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \quad \text{.........Equation 2}$$

$$sgn(x_j - x_k) = \begin{cases} +1, if(x_j - x_k) > 0 \\ 0, if(x_j - x_k) = 0 \\ -1, if(x_j - x_k) < 0 \end{cases} \quad \text{.....................Equation 3}$$

Where n is the length of the sample, x_k and x_j are from k=1, 2…, n-1, and j = k+1, n. if n is bigger than 8, S approximated to a normal distribution.

The study utilized multinomial logistical regression analysis to understand the relationship between respiratory infections and the atmospheric pollutants.

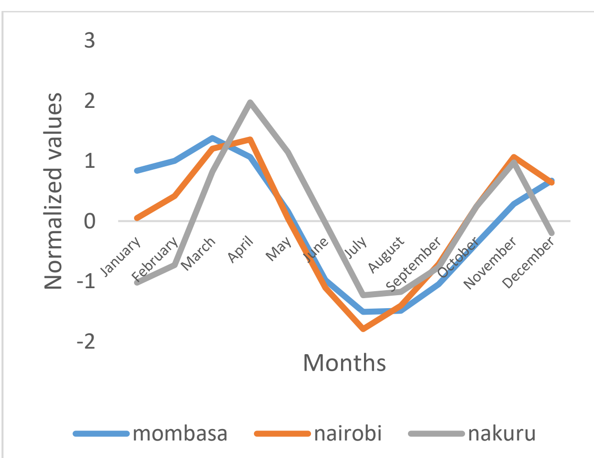
Results

Temporal analysis of climatic factors and atmospheric pollutants

Climatic factors

Minimum temperatures across all three cities were seen to have a bimodal structure for monthly averages, with peak seasons being March-April-May (MAM) and October-November-December (OND). Nakuru had the highest values of minimum temperature for the MAM season, while Nairobi was observed to have higher figures for OND season, as shown in Figure 1.

The study also found out a bimodal pattern for rainfall across the three cities, with high values observed during MAM and OND rainfall seasons. During the MAM rainy season, Nairobi and Nakuru showed higher peaks in April, while Mombasa peaked in May; in the OND season, Nairobi peaked highest in November, followed by Nakuru and Mombasa respectively, as shown in Figure 1.



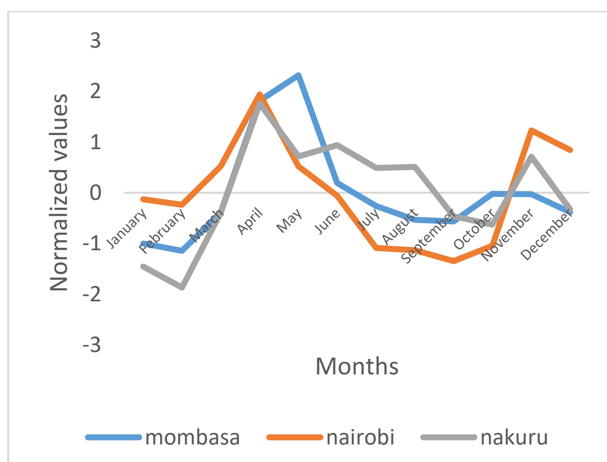


Figure 1. Normalized monthly minimum temperatures (left), Normalized monthly precipitation (right)

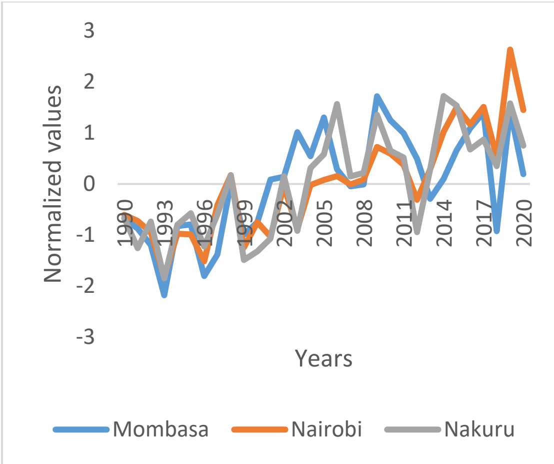


Figure 2. Normalized annual minimum temperature

Within the 30-year study period, minimum temperature, as shown in *figure 2,* was observed to have increased by 7.4% for Mombasa, 9.5% in Nairobi and 8.3% in Nakuru.

Precipitation was observed to have increased by 7.7% in Nairobi and 9.3% in Nakuru, while Mombasa showed a decreased amount by 2.8%, as seen in Figure 3.

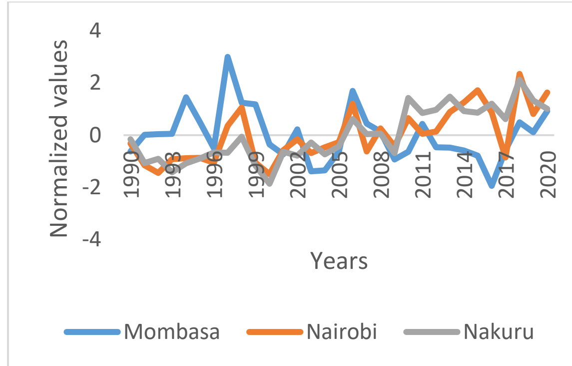


Figure 3. Normalized annual precipitation

Particulate Matter ($PM_{2.5}$)

Particulate matter (2.5) ($PM_{2.5}$) pollutants were observed to have risen in all three cities, with Mombasa leading at 9.4% increase since 1990, followed by Nairobi at 7.8% and Nakuru at 6.3%, as seen in Figure 4. Mombasa had the highest $PM_{2.5}$ which came from the presence of sea salt, from the Indian Ocean. Nairobi and Nakuru also had small amounts of sea salt, which contributed to the number of particulate matters in the atmosphere (Figure 4).

Monthly variations of $PM_{2.5}$ was observed to have three peaks for Mombasa, i.e., January, may and December; two peaks for Nairobi in February and December; and two peaks for Nakuru, in February and July. MAM and OND seasons were observed to have lower values for all three towns as shown in *figure 5*. Mombasa led on particulate matter (2.5) annually, with higher figures of up to 60 µg/m3 in January, followed by Nairobi with up to 25 µg/m3, and lastly Nakuru with around 15 µg/m3.

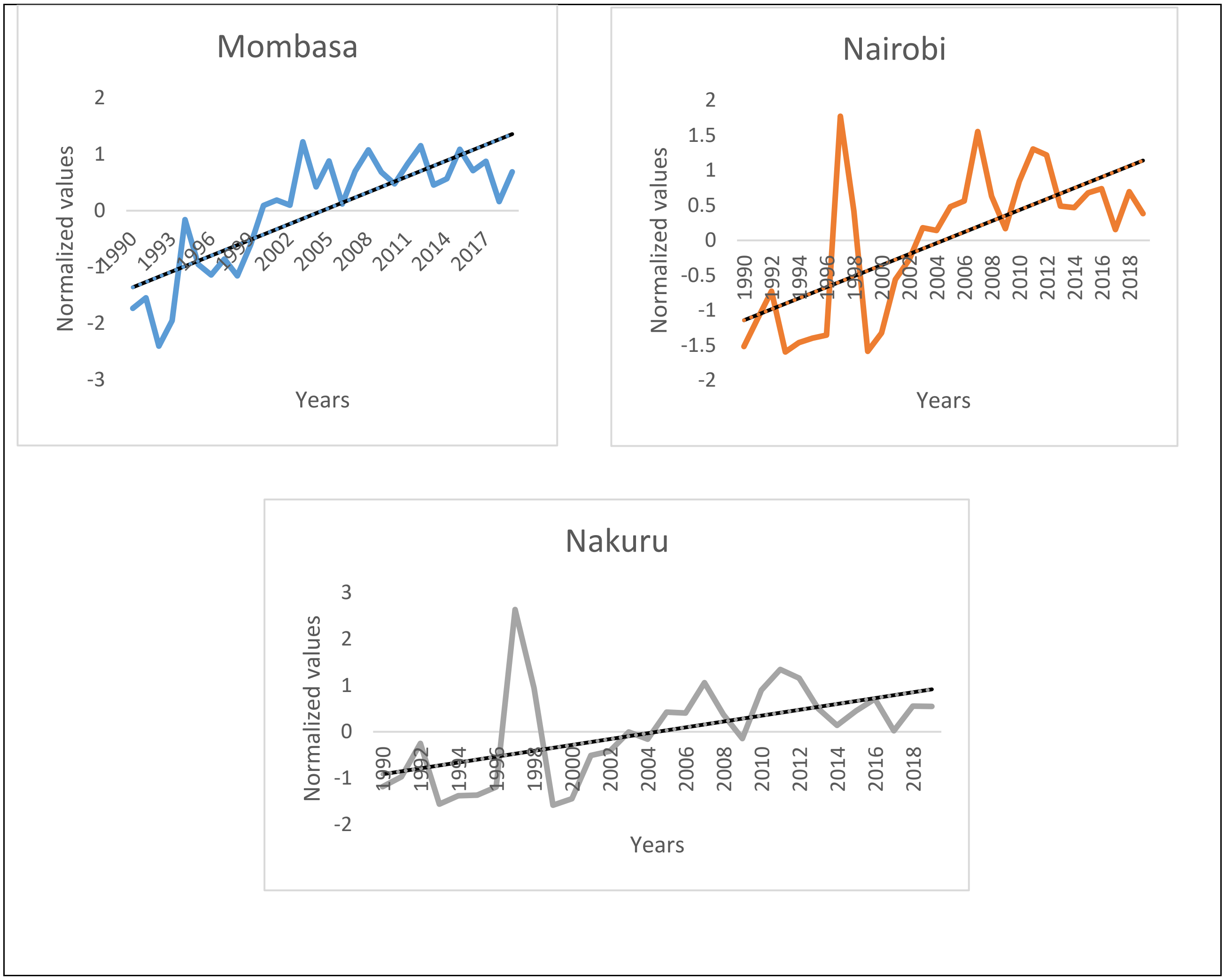


Figure 4. Normalized annual $PM_{2.5}$ values

The higher values in January follow short rain seasons of OND experienced throughout the country, which through the cool air it brings, carries this pollutant along with it. However, as most parts experience a cooler season, stagnant air conditions are created which are witnessed during night time, causing these pollutants to be suspended closer to their emission sources in a phenomenon known as radiative inversion (Asian Institute of Technology, 2019).

Sulphur Dioxide (SO_2)

Results from analysis of this study showed that Sulphur dioxide has been increasing in all three towns over the study period, as shown in *figure 6*. Mombasa and Nairobi SO_2 emissions increased highest by 10.4%, while Nakuru had an 8.4% increase over the 30-year period. Monthly values were observed to have a bimodal structure, peaking at the start of MAM and mid OND seasons for Mombasa; in February and August for Nakuru, and peaking only in February for Nairobi city, as shown in Figure 7.

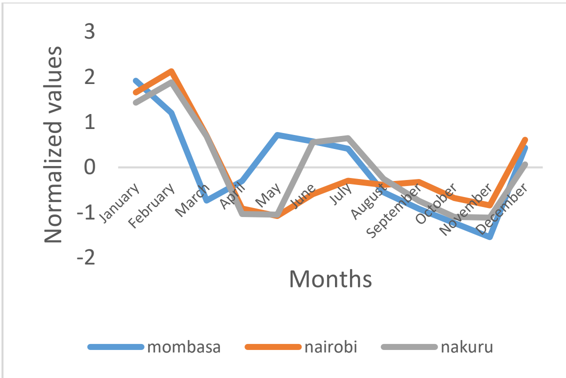


Figure 5. Normalized monthly PM2.5 values

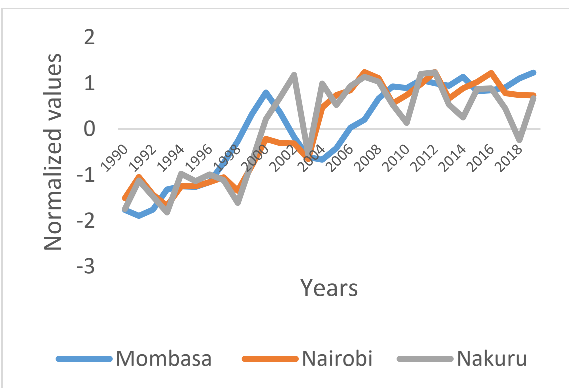


Figure 6. Normalized annual SO2 values

In comparison to the climate factors observed, SO_2 emissions were lowest during periods of higher precipitation and minimum temperature observed on MAM season, but OND season did not have much impact on SO_2 values observed in Mombasa.

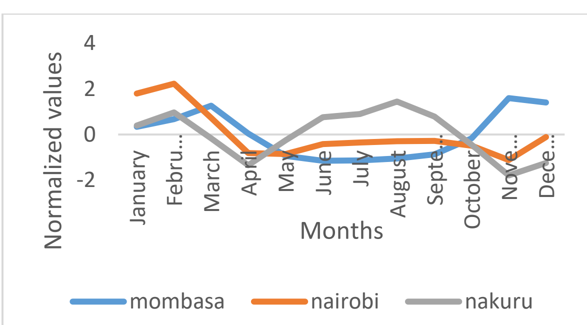


Figure 7. Normalized monthly SO_2 values

Carbon Monoxide

As seen in *figure 8*, it was observed that CO was highest in Mombasa at the start of the study period until 2007 where Nairobi and Nakuru had the highest values afterwards. Mombasa had the least increment of carbon monoxide emissions over the study period, having risen by only 3.4% since 1990. Nairobi CO emissions increased highest, by 7.8% while Nakuru by 6.3% over the study period.

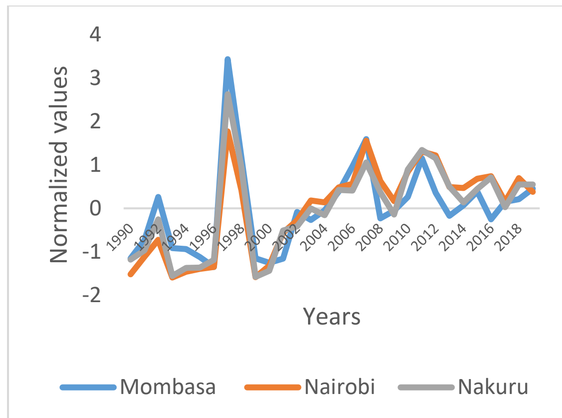


Figure 8. Normalized annual CO values

Monthly variations of carbon monoxide were seen to be reducing during MAM long rains season and increasing all the way towards the end of the year, with high values observed between June and August for Nakuru (*figure 9*). All three towns portrayed a bimodal structure with at least two peaks in a year, recording lower values during the OND rainfall season as compared to January and February.

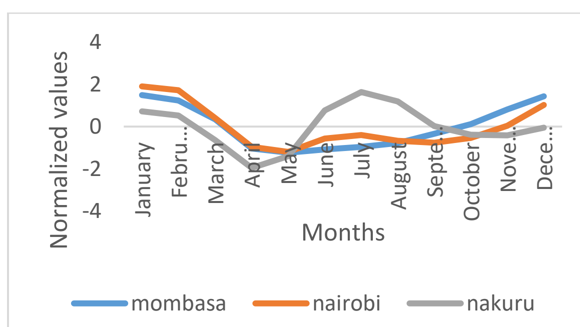


Figure 9. Normalized monthly CO values

Ozone

Tropospheric ozone gas was observed to have an almost similar trend for all cities over the study period, as shown in *figure 10.* Between 1990 and 2019, ozone gas increased highest in Mombasa by 15.5%, followed by Nakuru with 12.1% and Nairobi with 10.8%.

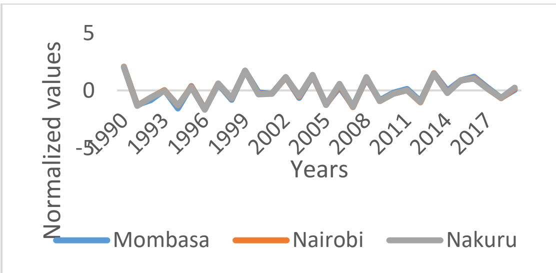


Figure 10. Normalized annual ozone values

Monthly variations over the study period were observed to have a bimodal structure, with peaks in April and September in all three cities. Nakuru had the highest peak in April while Mombasa had the highest peak in September (Figure 11).

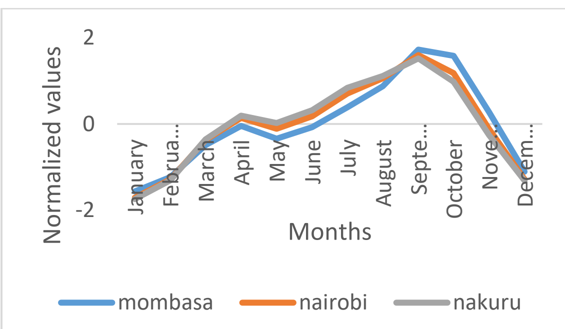


Figure 11. Normalized monthly ozone values

The slightly above average ozone values observed in April came as a result of higher temperatures shown in Figure 1. However, the presence of rainfall at that season meant that a good percentage of ozone particles in the atmosphere were washed away, not allowing for much of its presence in the air.

Temporal analysis of respiratory infections

Figure 12 shows the temporal patterns of morbidities and mortalities of lower respiratory infections, consisting mainly of pneumonia and bronchitis, for children ranging from 0 to 14 years.

For children below 1 year, and those between 1 and 4 years, it was observed that morbidities of lower respiratory infections were highest in Nairobi, followed by Nakuru and finally Mombasa. The numbers increased from 1990 to 2010, then started decreasing towards the end of the study period. Between ages 5 – 14, morbidities of lower respiratory infections showed an increasing number for all genders over the study period of 30 years, with Nairobi leading followed by Nakuru and Mombasa respectively.

Mortality rates for LRI cases in all children between 0 and 14 years of age was found to be highest in Nairobi, followed by Nakuru and Mombasa. A decre2se for mortality was observed in children below 1 year and those between 1 and 4 years over the study period, while an increase for children between 5 to 14 years despite the numbers being smaller.

It is worth noting that in the study's starting period, LRI cases in these children were lower for both morbidities and mortalities, except for mortality cases for children between 1 – 4 years, where it was highest from 1990 decreasing with time.

Air pollutants and pediatric respiratory infections

Tropospheric ozone was left out in this section due to its low correlation with climatic factors. It had a very low relationship with minimum temperatures and rainfall due to its heavy variability, thus not a strong factor in this study.

From the multiple regression analysis conducted between $PM_{2.5}$, lower respiratory morbidities and mortalities for all three cities (Table 1), it was observed that Mombasa and Nairobi had a *p-value* of <0.05 for both morbidities and mortalities, showing statistical significance; while Nakuru had a p-value of >0.05 for mortalities, showing a lack of statistical significance.

Table 1. Regression results between PM2.5, morbidities and mortalities

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-1.31125E-15	0.120906496	-1.1E-14	1	-0.2480796	0.24807964
morbidities	1.0595318	0.195484704	5.420024	9.87E-06	0.65843032	1.46063328
mortalities	-0.413205348	0.195484704	-2.11375	0.043918	-0.8143068	-0.0121039
			Mombasa			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-5.38862E-16	0.065065099	-8.3E-15	1	-0.1335026	0.13350256
morbidities	1.032767284	0.071935906	14.35677	3.7E-14	0.885167	1.18036757
mortalities	0.325988432	0.071935906	4.531651	0.000107	0.1783881	0.47358872
			Nairobi			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	7.51902E-16	0.110492852	6.8E-15	1	-0.22671261	0.226712606
morbidities	1.08970422	0.23718116	4.594396	9.06E-05	0.603048678	1.576359761
mortalities	-0.321849093	0.23718116	-1.35698	0.186026	-0.80850463	0.164806449
			Nakuru			

The coefficients of $PM_{2.5}$ against morbidities and mortalities of LRIs in children indicated the following: in Mombasa, as $PM_{2.5}$ increased, morbidities of LRIs in children increased while mortalities decreased; in Nairobi, as $PM_{2.5}$ increased over the study period, both morbidities and mortalities of LRIs in children increased; and in Nakuru, as $PM_{2.5}$ increased, morbidities of LRIs in children increased, while mortalities decreased.

As $PM_{2.5}$ increased, morbidities of LRIs in children was also found to be increasing for all ages, mostly between 5-14 years, in all three cities. Nairobi had the highest effect due to black carbon from vehicles and organic carbon from waste as these children were more exposed to these particles more, especially when schools were open.

The high temperatures observed in Mombasa creates a pressure gradient, which causes winds to transport sea salt further inland increasing the pollutants. This in turn causes LRIs in children, but in smaller numbers alongside other factors such as weather, environment, et cetera.

Nakuru had moderate cases for both LRI morbidities and mortalities of all three cities.

Particulate matter showed a direct relationship with morbidities, whereas one increased, the other also increased, and brought about mainly by black carbon, organic carbon and SO_4. The p-value of mortalities, which was >0.05, showed no statistical significance, meaning that other factors played a role in the decreasing numbers, which may not have been identified in this study. Multiple regression between carbon monoxide, morbidities and mortalities of LRI in children below 14 years (Table 2) showed that Mombasa had *a p-value* of >0.05 for both morbidities and mortalities, showing no statistical significance, while Nairobi and Nakuru had a p-value of <0.05 for morbidities only indicating statistical significance.

Carbon monoxide coefficients for Nairobi and Nakuru indicated that as CO increased in the atmosphere, incidence cases of lower respiratory infections increased. Young children are at more risk from CO poisoning which occurs when they are exposed more to it. According to Olson and Smollin (2008), unborn babies are at the highest risk of CO poisoning as their fetal hemoglobin mixes more readily with CO than that of an adult. Additionally, as they breathe faster than adults and have higher metabolic rates, they inhale two times more air than adults, risking permanent organ damage due to the higher exposure. On the other hand, carbon monoxide deprives oxygen to the blood cells resulting to shortness of breath, especially on physical activities. These results concur with recent studies including Wang *et al* (2019), who noted that CO increased the total outpatient visits in Yichang, China.

The increasing amounts of CO in Nakuru and Nairobi can also be attributed to the climate observed as seen in Figure 3, where rainfall was found to be highest in Nakuru and Nairobi. Increasing amounts of precipitation over a region implies that emitted carbon monoxide from vehicle emissions, industries and other sources will not only be 'washed' down but will also disperse less compared to drier areas. Thus, Nakuru and Nairobi will also note an increase in the morbidities of pediatric respiratory infections where weather plays a role in influencing its occurrence.

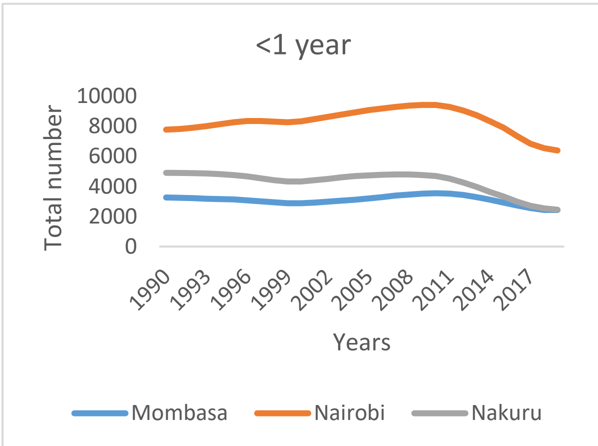
A multiple regression analysis as shown in *Table 3* revealed that the p-value of SO_2 was <0.05, which was statistically significant for morbidities of pediatric LRIs for both three cities.

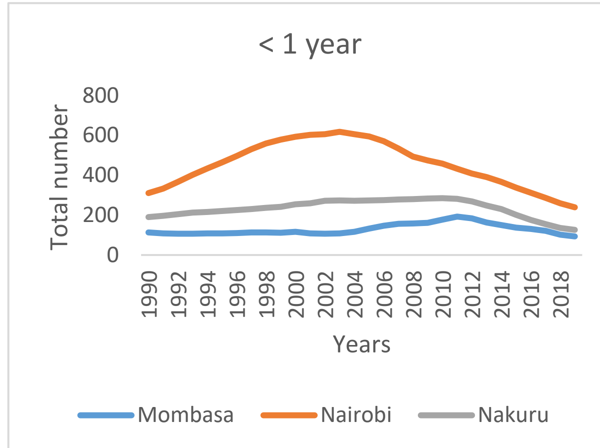
The coefficients obtained, being positive, showed that as sulfur dioxide increased in the atmosphere, morbidities of LRIs in children increased in all cities, translating to more cases expected in hospitals within those cities. Similar results were also obtained on a Kenyan policy brief on *towards realization of vision 2030,* on air pollution within Nairobi, noting an annual increase of sulfur dioxide over a 37-year study period (Muthama, 2021).

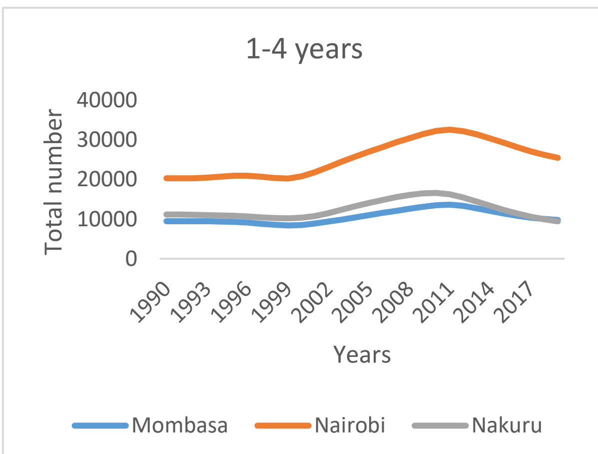
Table 2. Regression results between CO, morbidities and mortalities

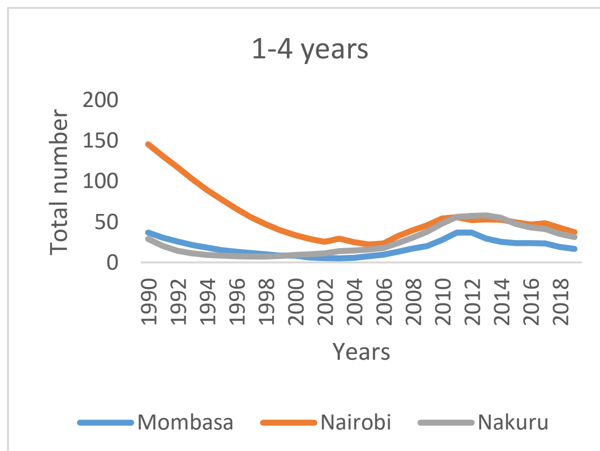
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-9.00972E-16	0.18305193	-4.9E-15	1	-0.3755915	0.37559154
morbidities	0.286973197	0.295963025	0.969625	0.34084	-0.3202928	0.89423916
mortalities	0.027047791	0.295963025	0.091389	0.927858	-0.5802182	0.63431376
Mombasa						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	1.55077E-15	0.124930978	1.24E-14	1	-0.2563372	0.25633719
morbidities	0.822122395	0.13812356	5.952079	2.4E-06	0.5387163	1.10552853
mortalities	0.190476251	0.13812356	1.379028	0.179204	-0.0929299	0.47388239
Nairobi						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.15297E-15	0.164140238	1.31E-14	1	-0.33678795	0.33678795
morbidities	0.888791195	0.35233928	2.522544	0.017851	0.165850708	1.611731682
mortalities	-0.468449813	0.35233928	-1.32954	0.194794	-1.1913903	0.254490674
Nakuru						

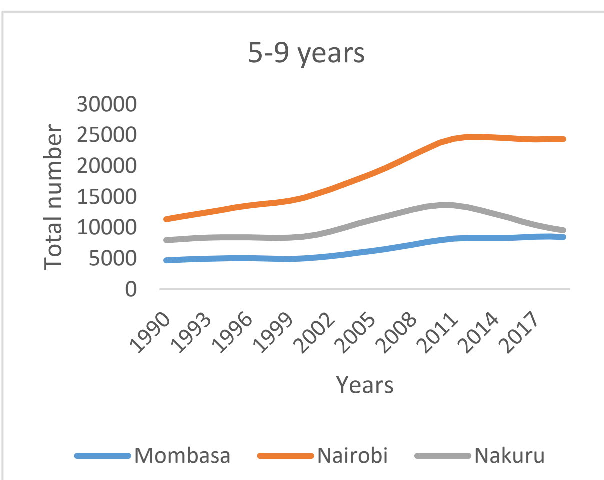
Morbidity | **Mortality**

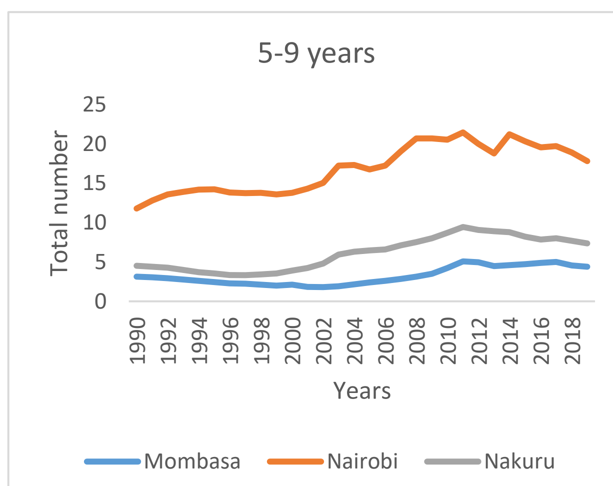


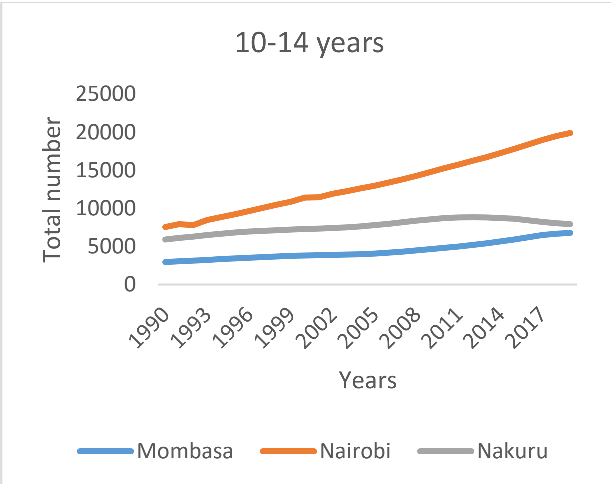












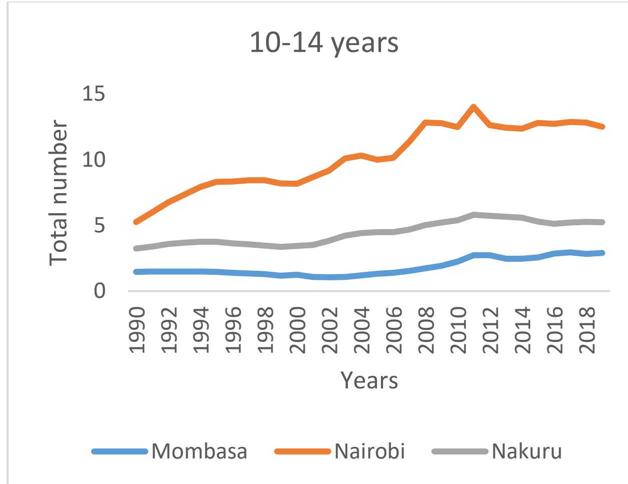


Figure 12. Morbidities (left) and Mortalities (right) of LRI's in children

Table 3. Regression results between SO_2, morbidities and mortalities

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-1.95203E-15	0.112131486	-1.7E-14	1	-0.2300748	0.23007481
morbidities	1.051376048	0.181297045	5.79919	3.6E-06	0.67938524	1.42336686
mortalities	-0.33865189	0.181297045	-1.86794	0.07266	-0.7106427	0.03333892
			Mombasa			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-1.48998E-15	0.062266808	-2.4E-14	1	-0.1277609	0.12776094
morbidities	0.985739311	0.068842118	14.31884	3.94E-14	0.844487	1.12699167
mortalities	0.103580071	0.068842118	1.504603	0.144035	-0.0376723	0.24483243
			Nairobi			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-4.3838E-16	0.144514157	-3E-15	1	-0.29651856	0.296518557
morbidities	0.796285169	0.310210431	2.566919	0.016121	0.15978594	1.432784399
mortalities	-0.15823569	0.310210431	-0.51009	0.614132	-0.79473492	0.47826354
			Nakuru			

Short term exposures to sulfur dioxide harms the respiratory system particularly of children, making breathing difficult. Additionally, the formation of sulfur oxides can contribute to acid rain, and even formation of particulate matter which penetrates deep in the lungs increasing health problems.

Discussion

Temporal patterns of climatic factors and atmospheric pollutants

Minimum temperatures observed in all three cities was found to be increasing at different rates, with Nairobi leading followed by Nakuru and Mombasa respectively; while MAM and OND seasons had higher temperature values. The National Climate Change Response Strategy (2010) also noted similar results, stating that the trends over inland areas of the country showed a steeper increase in minimum temperatures than maximum temperatures since early 1960s.

Rainfall patterns in the country were found to be changing, with observed increment in Nairobi and Nakuru and a decrease in Mombasa city; while seasonal variations showed still higher rainfall amounts over MAM season compared to OND season. Rainfall amounts observed in the recent years are relatively lower compared to the 1960s, with trends of decreasing amounts in most parts of the country hence increasing desertification and aridity. Long rainy seasons are becoming shorter and drier while short rainy seasons become longer and wetter. However, most seasons depict the same patterns of rainfall observed, with increased frequency of droughts and heavy rainfall (Government of Kenya, 2018).

Studies conducted by Liu *et al.,* (2020) and Zhou *et al* (2020) pointed out that precipitation mainly enhances the removal of aerosol particles of sizes <1µm and 2.5-10 µm, agreeing to the results obtained in this study. Hong *et al.,* (2019) in a study on the impacts of climate change on future air quality in China found out that rising temperatures led to an increase in evaporation, which increased precipitation amounts that washed air pollutants in the atmosphere; while extreme climate events increased greatly $PM_{2.5}$ values.

Increasing urbanization and development of the country has resulted to an increase in air pollutants in the atmosphere, posing serious threats to respiratory health across all ages. The Nairobi County air quality action plan (2019-2023) notes that rapid urbanization and increasing motorization enhances air pollution in most cities, with limitations in air quality monitoring which do not provide a favorable environment for air quality control (NCC, 2019).

Particulate matter (2.5) components, i.e., black carbon, organic carbon, sea salt, dust and sulfates, all showed an increase over the study period. The increasing motorization in the three cities, more-so private cars, increases vehicular emissions which contributes to black carbon rising in the atmosphere. Higher values were mainly attributed to rush hour times in cities as well as traffic congestion and poorly maintained and older vehicles and decreased as one moved away from the cities (NCC, 2019).

The rising levels of particulate matter (2.5) and its components translates to a long-term exposure of these pollutants which are increasing the disease burden and mortality in most countries in Africa and Asia. The State of Global Air (2020) reports that $PM_{2.5}$ contributes to a large percentage of deaths globally, ranging from cardiovascular to respiratory diseases, affecting the most vulnerable who constitute of children and the elderly (Health Effects Institute, 2020).

The study also found out that other atmospheric pollutants, i.e., Sulphur dioxide, carbon monoxide and ozone increased in the three cities, agreeing to studies conducted previously. Birgen *et al.,* (2017) in a study on sulphur dioxide levels in Athi River found out that SO_2 values increased in the area, mainly attributed to industries around such as Bamburi and Mombasa cement factories and fuel combustion from vehicles passing along Namanga-Mombasa highway. Additionally, higher temperatures and lower precipitation periods led to the increase of SO_2 concentration in the area due to the lack of natural washout processes that precipitation offers.

Carbon monoxide, sulfur dioxide and $PM_{2.5}$ had more impact on pediatric morbidities and mortalities of lower respiratory infections, with sources mainly from emissions from motor vehicles, the use of fossil fuels, industrial activities and power generation.

Temporal patterns of pediatric lower respiratory infections.

Our study found out that children below 5 years showed declines in both morbidities and mortalities from 2010 onwards, despite their numbers being higher. Ritchie and Roser (2018) observed that deaths from communicable diseases such as respiratory infections, accounted for more than 73% of global deaths. They further noted that, compared to the early 90's where a quarter of all deaths were in young children, fewer deaths were observed in 2017 on children, accounting to only 10% of all deaths, agreeing to the results we obtained in this study. The fewer numbers for both morbidities and mortalities could also be attributed to the less exposure to cold weather and pollution that these children face, hence reducing such infections.

Children between 5 – 14 years showed an increase in lower respiratory morbidities and deaths over the study period for both three cities due to their exposure to atmospheric pollutants from daily activities of growing up. Despite their global deaths ranking between 1 and 2%, LRIs rank as the third cause of death in Kenya, amounting to roughly 580 deaths per year (Ritchie and Roser, 2018).

Improved healthcare services and affordability offered by the government in the past two decades have helped reduce mortalities of children, including most Sub-Saharan countries, compared to the 1990s where healthcare services were scarce and expensive. In Kenya, the total health spending doubled between 2001 and 2013, while insurance cover grew with support from external donor financing, increasing health access to most families through both private and public hospitals (Keats *et al.*, 2018).

Furthermore, under the Millennium Development Goal 4 (reducing child mortality), the Kenyan government launched a *Child Survival and development Strategy* as an effort to accelerating child survival and provide a framework for children. The strategy guided by the National Health Sector Strategic Plan 2 and Vision 2030, together with *Malezi Bora Strategy* helped in infant and childhood mortality declines in the country (UNDP, 2021). This can be witnessed in the results where we found out lower and reducing values of lower pediatric respiratory cases for children of 4 years and below.

Relationship between air pollution and lower pediatric respiratory infections

Climate change is linked to air pollution both as a cause and its effect. It is most likely to have greater effects on children with respect to air pollution since their lungs are still growing, and any exposures will affect them for longer durations of time. In this study, the number of morbidities and mortalities for LRIs in children are increasing in the three cities, especially for children above 5 years, which may result from spending more time outdoors where the concentration of air pollution is higher.

Increasing temperatures play a huge role in the dispersion of pollutants, and with the changing climate, we expect the rising temperatures to enhance dispersion further causing more harm even to places that had fewer cases of pediatric respiratory infections. The increase in precipitation over certain areas will assist in the reduction of certain pollutants while increasing the effects of other pollutants, although delayed short and long rains periods will have an influence on the spread. This is because precipitation may wash down the pollutants available after emissions in the atmosphere, while also acting as a blanket for emitted pollutants such as SO_2 increasing their effects on that locality.

CO and SO_2 have relatively shorter life spans in the atmosphere, and if distributed equally, their harmful effects will be smaller. However, the concentration of these pollutants in localized areas influenced by climate change and variability, as well as topographical factors influencing respiratory health effects, as witnessed to our results, agreeing with the results of Speight (2020). This can be witnessed on how carbon monoxide, sulphur dioxide and particulate matter (2.5) have much impact during JJA season for Nakuru compared to Nairobi and Mombasa.

Ritchie and Roser (2019) found out that outdoor air pollution worsens for countries which industrialize in order to transform from low to middle incomes, and that the two key local air pollutants with more diverse health impacts happen to be ozone and particulate matter. Furthermore, deSouza (2020) in a study found out that motor vehicles contributed majorly to pollution in Nairobi, compared to other cities in the country, agreeing with our findings where we saw higher cases of morbidities and mortalities of lower pediatric respiratory infections in the same city.

The State of Global Air (2020) report ranked Kenya among the top ten countries in Sub-Saharan Africa with the highest burden of $PM_{2.5}$ deaths, affecting mostly young children (Health Effects Institute, 2020). This concurred with our study which found out similar results, agreeing to the report on increases of $PM_{2.5}$, where it also observed its influence on pediatric LRIs morbidities and mortalities across the three cities.

This study had several limitations, i.e., potential confounders were not included in the models used; there was limited inference to climate change from air pollutants though their relationship is well established in research; and the effects of other weather elements were not considered.

Conclusion

The atmospheric pollutant that affect most in all three cities in terms of both morbidities and mortalities of lower pediatric respiratory infections is particulate matter (2.5). Sulphur dioxide and carbon monoxide only have effects on morbidities of pediatric LRIs, and not on mortalities across all cities. The exposures to these harmful pollutants, mainly particulate matter (2.5), is likely to worsen their respiratory health across all three cities, even though carbon monoxide does not affect children in Mombasa. These pollutants will be further enhanced by the changing climate where increasing temperatures and reducing rainfall quantities encourage them to disperse far and wide causing more harm.
This study has thus produced more insight on pediatric respiratory diseases and air pollution under the changing climate, aiming in formulation and strengthening of policy development and monitoring of LRIs in the health sector while helping the country achieve Vision 2030 and the Sustainable Development Goals on health. Understanding the influence of climate change through air pollution will offer better results in assessing and tackling lower respiratory diseases in children within the country.

The following were some of the recommendations that arose from the study
Set up of equipment and sites to assist in monitoring air pollutant levels in cities mainly, from both private and public sectors.

Storage and archiving of health data by governments and private sectors, with local ease of availability which will assist in research and policy making. More research on linking climate change, air pollutants and respiratory infections across all ages, which will assist in strengthening existing policies on health, transport and other related sectors.

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