Asian Journal of Environment & Ecology

Volume 20, Issue 3, Page 11-23, 2023; Article no.AJEE.97677
ISSN: 2456-690X

PM_{10} Levels and Prevalence of Respiratory Diseases in Communities around the Cement Industries

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJEE/2023/v20i3439

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/97677

Original Research Article

Received: 28/01/2023
Accepted: 31/03/2023
Published: 01/04/2023

ABSTRACT

In the atmosphere, particulate matter of 10 microns (µm) or less in diameter (PM_{10}) is an indicator of air pollution. Their harmful health effects on humans range from minor irritation to chronic respiratory infections. PM_{10} levels were assessed in the ambient air including the incidences of respiratory diseases among communities around the cement industries in Athi River Township in Kenya. The PM_{10} levels were collected for three consecutive days from five sites in Athi River and the control during the rainy and dry seasons. They were analyzed using the gravimetric technique. The prevalence levels of respiratory diseases were evaluated in the community health facilities during the same period. The PM_{10} levels ranged from 111.1–740.7 µg/m^3 and 37.0–351.9 µg/m^3 across the Athi River sites and were significantly (p <0.05) higher than those of the control site that ranged from 9.2–15.3 µg/m^3 and 10.2–13.5 µg/m^3during the dry and rainy seasons, respectively. The study established negative correlations between PM_{10} levels and wind speed besides temperature. On the contrary, positive correlations were observed between PM_{10} and relative humidity during both seasons. Overall, the communities across the Athi River Township

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experienced a significantly ($p<0.05$) higher number of consultation visits and hospital admissions for various respiratory diseases than the control community. The upper and lower respiratory tract infections were more pronounced in the Athi River during the dry than in the rainy seasons. This study calls for comprehensive research and collaborative efforts towards the establishment of environmental-health-driven programs to reduce PM_{10} levels and related respiratory impacts among communities.

Keywords: Community; hospital admission; out-patient services; pm10; respiratory diseases.

1. INTRODUCTION

The PM_{10} is the inhalable mass particle of an aerodynamic diameter of less than or equal to 10 microns (≤ 10 µm). Its aerodynamic property influences the transportation and removal of this particle from the air and deposition within the respiratory system [1]. The airway system is one of the most exposed parts of the human body. This is due to its direct contact with the atmosphere and is consequently exposed to different levels of pollutants in ambient air. The particles of less than 10 µm are capable of penetrating into the lungs and getting transferred to the bloodstream and to the other organs within the human body [2]. Several epidemiological studies have reported the short-term association between elevated PM_{10} levels and increased morbidity and mortality to respiratory and cardiovascular diseases [3]. Exacerbations of asthma-like symptoms, pneumonia, bronchitis, lung cancer, and incidences of lower and upper respiratory tract infections are some of the common cases that cause an increased rate of hospitalizations.

The impacts of air pollution vary and depend on the characteristics of the geographic area, atmospheric conditions, and emission sources [4]. Meteorological factors have a direct influence on the ambient PM_{10} levels since the emission and dispersion of these particles are usually dependent on the prevailing weather patterns such as temperature, relative humidity, precipitation, wind speed and direction [5]. These variations also aggravate the effect of PM_{10} on the respiratory system. Although several studies have suggested that even lower levels of these particles have a greater impact on human health.

Studies are conclusive that there is no threshold level for PM_{10} below which no adverse health effects have been observed. The vulnerable groups that are most affected by these exposures are children, the elderly and those with pre-existing diseases [6]. This is especially true since children take in more amount of inhaled air as compared to adults whereas the elderly have suppressed immune, and those with chronic exposure. Several authors have suggested that reduction of the PM_{10} concentrations in the ambient air has direct health benefits [7]. However, limited data have been established on this association, despite the much higher PM_{10} levels that have been experienced in low and middle-income countries [8]. Public awareness of the detrimental health effects of air pollution is also quite low in these countries where real-time monitoring is limited.

The manufacturing process of cement is an inherent dusty operation and is associated with significant PM_{10} emissions [9]. The pulverized material is emitted in the form of dust (PM_{10}) and may contain heavy metals like chromium, nickel, cobalt, lead and mercury which are hazardous to the environment [10]. They are also associated with respiratory health risks among communities living within the dispersion zone of the cement industries. Lower lung function indices and ventilation capacity have been frequently observed in the exposed group in studies focusing on cement dust exposure and respiratory health [11]. In particular, the research that has been done in Athi River Township revealed that the downwind sites had 24-hour mean ambient $PM_{2.5}$ and PM_{10} levels that were above the WHO ambient air quality guidelines [12]. In the contrast, other atmospheric pollutants that included sulfur dioxide, nitrogen dioxide, ozone, carbon monoxide, hydrogen sulfide, and methane were within the established limits.

The present study was undertaken to determine PM_{10} levels and prevalence of the respiratory diseases among communities around the cement industries in Athi River Township. The study is part of a larger investigation that assessed PM_{10} and $PM_{2.5}$ levels and respiratory health impacts among school-going children in the same community. The findings arising from this study will form a basis for intervention and promote environmental-health-driven policies and systems to protect human health and the environment.

2. MATERIALS AND METHODS

2.1 Study Area and Sampling Sites

The study was carried out in communities around cement industries in Athi River Township in Kenya. The town receives an annual rainfall of 599 mm that is characterized by two climatic wet and dry seasons, with some variations within the months (Fig. 1). The long and short rainy seasons are usually experienced between the months of February to May, and October to December, respectively. These seasons are basically followed by a dry spell that is occasioned by strong winds. The annual temperature varies between 12.8 and 28.3°C and rarely goes below 10.0°C or above 30.6°C.

The predominant wind direction observed during the rainy season is majorly East-South-Easterly whereas during the dry season is East-North-Easterly [11]. Wind speeds varied between 3.3 and 6.4 m/s, and from 1.9 to 4.2 m/s during the dry and wet seasons, respectively.

The township is heavily industrialized with six actively operating cement factories that have an annual capacity of over 8 million tons of cement coupled with long-haul transport, quarrying, and related large-scale commercial activities [11]. The activities that largely affect air quality in the area include diesel-powered emissions, unregulated industries, open burning of wastes, unpaved road dust and use of unclean household fuels [12]. Furthermore, the township is unplanned as evidenced by escalating informal settlements and unpaved traffic roads (Fig. 2). The demographic characteristics that depict the township setting suggest gender disparity with a high proportion of active adults of ≥18-59 years old, followed by children and very few elderly (≥60 years old). A detailed description of the area and ethical issues including research clearance permits were published elsewhere [11].

2.2 Sampling of PM_{10} Levels

In the absence of national air quality monitoring networks and real-time data, the sampling sites for PM_{10} levels were selected around the cement industries within a 2 km radius with respect to the location of the communities. The sampling points were as follows: two industrial sites 1 and 2, two residential sites 3 and 4, and a commercial site 5 in Athi River Township (Fig. 1). Site 6 was a control area in a non-industrial area, with no known sources of PM_{10} exposure. The sampling sites were free from any form of interference in air circulation in the ambient atmosphere. Table 1 gives a summary of the description of the Athi River sampling sites.

2.3 Collection and Analysis of PM_{10} Levels

The PM_{10} levels were sampled from each of the six sites for three hours from morning (9.00 am - 12.00 noon) and afternoon (12.00 noon – 3.00 pm) for three consecutive days. The samples of PM_{10} were collected using a 47 mm polytetrafluoroethylene filter membrane fitted in an air sampler (Model: Ecotec microvolt-1100). This followed a similar protocol and used the same laboratory for gravimetric measurement and analysis as that of [11]. The PM_{10} levels were collected and taken as representative samples of the community exposure during the rainy and dry seasons of April-June and in October, and January-March and September 2019, respectively. The data on daily atmospheric temperature, wind speed, wind direction and percentage (%) relative humidity were also considered as the prevailing weather patterns during the collection of PM_{10} levels in the study area. Overall, the PM_{10} levels were proxy for community exposure and incidences of respiratory diseases in Athi River Township during the dry and rainy seasons.

2.4 Collection of Respiratory Health Data

The study targeted primary healthcare facilities for the collection of respiratory health data for the residents of Athi River Township. The facilities were surrounded by six cement industries that were potential sources of air pollution (Fig 2,). The Athi River health facilities were delineated and coded as H_I, H_2, H_3, H_4 and H_5 while the control was coded as H_0. It should be noted as H_5 was the only public Sub-county hospital in the area while H_I was the largest community health center. Prevalence levels of respiratory diseases (RD) among the communities living around cement industries were established by collecting respiratory health data from the five selected health facilities and comparing them with those of the control. These health facilities were also within the 2 km radius around the sampling sites adjacent to the cement industries. They offered both Outpatient Services (OPS) and Hospital Admissions (H ADM) for RD except the latter which did not have the H ADM services.

The study considered patients who were living in the Athi River Township around the cement industries or control area who received OPS or H ADM from the selected health facilities. The protocol was created for the manual retrieval of respiratory health data from each of the facilities over the study period. The daily respiratory health data including H ADM and OPS together with demographic characteristics of the patients were retrospectively collected during the rainy and dry seasons of April-June and in October, and January-March and September 2019, respectively. The data was essentially summarized to include the date of birth, age and sex subgroups without any individual identifiers. The residential addresses considered patients who were living in Athi River Township or the control area over the study period. The date of admission and discharge was also a prerequisite for those who were admitted over the sampling period.

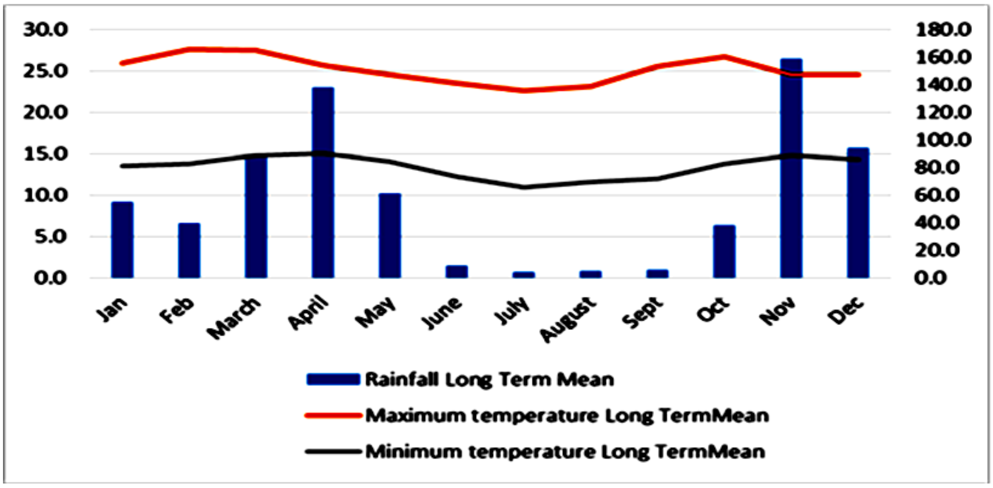

Fig. 1. Variation in annual rainfall and temperature of Athi River Township
Source: Kenya Meteorological Department in Nairobi County (2019)

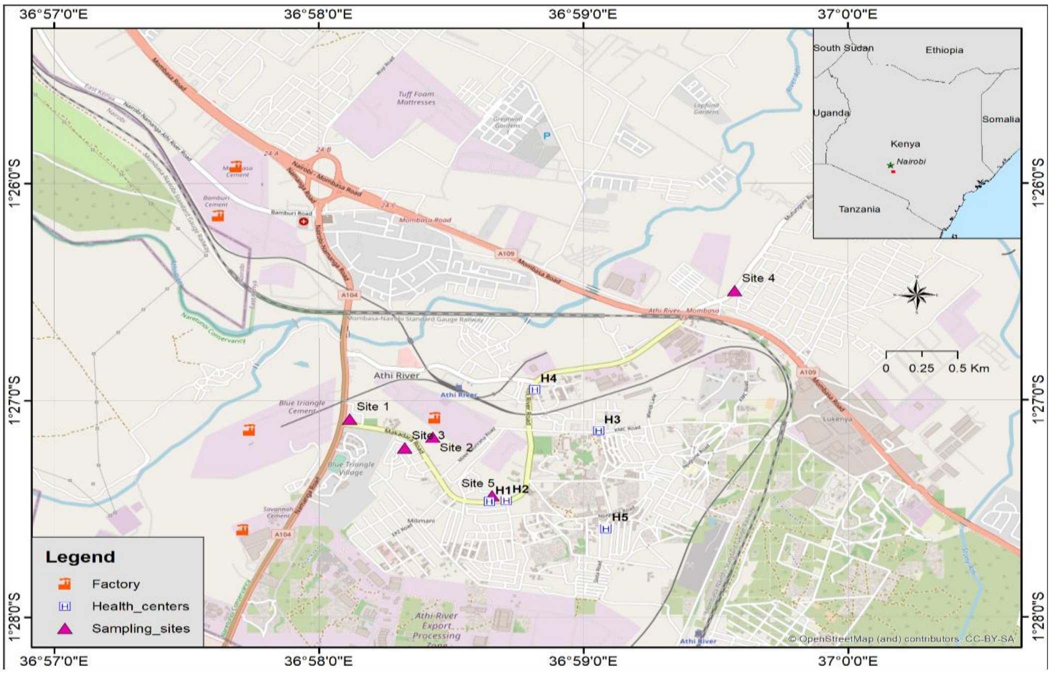

Fig. 2. A map of Athi River Township showing sampling sites, residential areas and community health facilities adjacent to the cement industries (January- October 2019)
Source: Department of Climate Change and Earth Science of the University of Nairobi

Table 1. Description of the sampling sites in Athi River Township

Sampling sites	Longitude	Latitude	Distance from cement industries (km)	Distance from communities (km)	Distance from heavy traffic road (km)	Distance from other industries (km)
Industrial Area-(Site 1)	36^0:58': 6.9888'' E	1^0:27': 5.202'' S	0.5	0.8	0.05	0.35
Industrial Area-(Site 2)	36^0:58':25.8636'' E	1^0:27':10.2564'' S	0.15	1.05	0.1	0.07
Residential Area-(Site 3)	36^0:58': 19.496'' E	1^0:27':13.1868'' S	1.1	0.02	0.05	1.07
Residential Area-(Site 4)	36^0:589':40.3836'' E	1^0:26':29.7384'' S	2.5	0.04	1.0	1.2
Commercial Area-(Site 5)	36^0:58': 39.3132'' E	1^0 :27': 26.4384'' S	1.0	0.08	0.12	1.2

All the collected data were reviewed for completeness. It was apparent that the classification of RD especially for OPS was largely based on the symptoms presented by the patients. In certain cases, patients with severe health complications that were not clearly diagnosed were referred to more equipped hospitals outside the primary health facility. It is, therefore, plausible that some complicated health cases were not recorded in these facilities. In addition, it is apparent that quite a number of complicated respiratory health cases in this study may have been underestimated. This is due to the nature of the ill-equipped medical facilities; it should also be pointed out that cardiovascular diseases were not considered in this study.

3. RESULTS AND DISCUSSION

The PM_{10} concentration was significantly ($p< 0.05$) higher across the five sampling sites in Athi River than those of the control sites (Table 2). This was regardless of the season and time of the day. The concentrations were varying from 111.1-740.7 µg/m^{3}and 37.0-351.9 µg/m^3 in Athi River sites compared to 9.2-15.3 µg/m^3 and 10.2 – 13.5 µg/m^3 of the control sites during the dry and wet seasons, respectively. The increasing industrial activities in the Athi River sites had a special bearing on the atmospheric particle loading that influenced PM_{10} levels [11]. This subsequently explains explicitly that industrial sites 1 and 2 had the uppermost mean PM_{10} levels compared to the other areas in Athi River, irrespective of the time of the day and season. Recent studies also reported elevated PM_{10} levels in the ambient air across the Athi River schools exceeded the WHO-ambient air quality recommended levels and were markedly higher than those of the control during the two climatic seasons [11].

The PM_{10} concentrations differed significantly ($p<0.05$) and the levels were higher during the dry season than the wet season across the five sampling sites. Seemingly the levels, as well as the distribution of PM_{10} within the sampling sites, were affected by various sources and removal processes. The levels were influenced by washout and rainout by aging and particle growth due to seasonal changes. The meteorological factors had a high impact ($p < 0.05$) on these levels where, negative correlations of R= -0.752 and R= -0.783 were observed between wind speed and temperature, respectively, and PM_{10} levels during the dry season. Conversely, a strong positive correlation of R = 0.906 was observed between relative humidity and PM_{10} levels. A similar trend in the correlation values of R = -0.374, R = -0.506 and R = 0.826 was reported between wind speed, temperature and relative humidity, respectively, and PM_{10} levels during the rainy season. Although the correlation was relatively low for wind speed and temperature.

The PM_{10} levels in addition differed greatly ($P < 0.05$) and were higher during the morning hours than those in the afternoon hours for both climatic seasons. Industrial site 1 had the highest mean concentration of 592.6±133.5 µg/m^3 and 302.5±56.6 µg/m^{3}in the morning hours and 271.6±46.6 µg/m^3 and 166.7±37.1 µg/m^3 in the afternoon during the dry and wet seasons, respectively. Similar trends were observed throughout the sampling sites. The higher PM_{10} levels in the morning hours could be attributed to the increase in various polluting activities over the study period. For instance, most off-loading of raw materials and cement was observed to be done in the morning hours.

The differences in the mean PM_{10} levels from industrial sites 1 and 2 of 592.6±133.5 and 271.6±46.6 µg/m^3.and 302.5±56.6 and 166.7±37.1 µg/m^3 during the dry and wet seasons, respectively could be attributed to the variations in the location of these sites relative to cement industries and to some extent the road traffic emissions. This is because Industrial site 1 was sandwiched between the two cement manufacturing industries, whose processes were observed to emit substantial dust thereby contributing to elevated levels of PM_{10}. The dense traffic that involved heavy trucks at a road junction along a busy highway that transported raw materials as well as cement, could also have been a key contributor to the PM_{10} levels that were measured in Industrial site 1. Several authors have further reported very high levels of PM_{10} in the industrial areas in the vicinity of cement industries and heavy traffic density roads [13,11].

Table 2. Comparison of PM_{10} levels across the Athi River and control sites in the morning and afternoon during the rainy and dry seasons

Period	Sampling sites	Industrial 1 (n=3)	Industrial 2 (n=3)	Commercial (n=3)	Residential 1 (n=3)	Residential 2 (n=3)	Control (n=3)
Dry season	Morning 9-00 am -12.00 Mean ± sd (µg/m^3)	592.6±133.5	401.2±70.1	370.4±49.0	246.9±21.4	333.3±37.1	13.7± 1.4
	Afternoon (12.00-3.00 pm) Mean ± sd (µg/m^3)	271.6±46.6	216.0±28.3	160.5±38.6	129.6±18.5	179.0±10.7	11.8± 1.3
Wet season	Morning (9-00 am -12.00) Mean ± sd (µg/m^3)	302.5±56.6	277.8±32.1	246.9±46.6	111.1±18.5	197.5±38.5	11.8±0.91
	Afternoon (12.00-3.00 pm) Mean ± sd (µg/m^3)	166.7±37.1	154.3±28.3	86.4±21.4	43.2±10.7	74.1±18.5	8.60±1.3

It is worth noting that industrial areas 1 and 2 were also near cement industries and were located in areas that had mixed industrial and residential land uses with a busy road transit. Observations made at these sites indicated that road traffic was largely consistent with the peak hours and more vehicles especially heavy trucks were busy in the morning than in the afternoon hours. Heavy trucks entering and exiting the cement industries triggered notable dust emission that was blown by the prevailing wind to other areas within the dust dispersion zones. These visible dust events appeared to be consistent with the movement of trucks which was mainly in the morning hours with the busiest time being 9.00 to 12 noon. This may explain the substantial mean PM_{10} levels that were found in industrial areas, followed by commercial and residential areas regardless of the season. The variability of PM_{10} within the sampling sites could therefore be attributed to the on-site industrial activities.

The location of the residential areas within the cement-producing industrial set-up and commercial zones adjacent to the unpaved road traffic could have strongly influenced the substantial levels of PM_{10} that were reported. Most of these industries were observed to generate dense dust. Cement industries are quite polluting and the presence of six cement industries with heavy vehicles transporting materials on unpaved roads is indeed a great source of exposure [11]. The communities near the industries without buffer zones are vulnerable to these exposures (Fig. 1 and Table 1). Amongst others, atmospheric instabilities along with heavy trucks stir off previously settled dust on the ground, making them airborne. Based on several studies, the cement industry is one of the major sources of aerosol exposure [13-16].

The particles with aerodynamic diameters less than 10µm are of special interest since they are a risk factor for respiratory morbidity. Numerous studies have shown a significant association between PM_{10} levels and increased visits to primary health care for respiratory diseases [17,18]. From a human health perspective, fine particles can penetrate deeper into the respiratory system. These particles also have a longer atmospheric residence time that has been implicated in a decline in lung function. The study supports the notion that reducing PM_{10} exposure levels to fall within the WHO ambient air quality guidelines may be an effective strategy in preventing respiratory disease related to hospital admissions. This suggests that sampling PM_{10} for the 24-hour average is the most recommended as it allows for direct comparison of data with the existing health-based guidelines. Currently, there are no health standards developed for 3-hour average sampling periods, however, our study gives useful data on PM_{10} levels at given peak hours and the prevalence of respiratory diseases during dry and rainy seasons.

The number of patients by age and gender sub-group who sought out-patient services (OPS) and hospital admission (H ADM) for various respiratory diseases (RD) from the sampled Athi River community health facilities (H1-H5) and the control (H0) during the wet and dry seasons is summarized in Fig. 3-6. The Athi River health facilities had a higher number of patients, irrespective of their age group that sought OPS and H ADM during the wet and dry seasons than the control facility H0. The largest facility was H1 and was situated within the Athi River community that had the highest number of cases of RD that sought OPS and H ADM. In almost all cases the RD were strongly influenced by the demographic pattern that was observed in the community with active adults having high incidences of RD, followed by the children and fewer elderly patients. The H ADM for respiratory ailments were also more predominant in adults followed by children and the least was the elderly group.

The gender disparity was observed in the number of admitted cases for RD. The males in the Athi River community had a significantly high number of H ADM than the females. However, more females sought the OPS than males. This suggests that males had more serious RD that required H ADM while more females were likely to seek treatment whenever there was an onslaught of symptoms. The Athi River health facilities were also leading ($p<0.05$) in the number of H ADM cases for RD compared to the control group. The number of these cases differed significantly ($p <0.05$) with age just like the case of OPS. There were however slight variations but not significant ($p>0.05$) in the number of admitted cases by season. As expected, the HI health center had also the largest number of admission.

Both the upper respiratory tract infection (URTI) and lower respiratory tract infection (LRTI) as likely was more prevalent in adults than the children and elderly. It was further observed that cases of LRTIs and URTI in Athi River communities were more pronounced during the wet season and dry seasons, respectively. Similar studies by Were et al. [11] indicated that PM_{10} was greatly influenced by meteorological factors. It is apparent that rainfall lowers PM_{10} levels due to both surface wetting and removal of the coarse particles from the atmosphere. This reduction in PM_{10} levels seemed to lessen the URTI cases to a small extent. Conversely, strong, warm dry winds increased the rate at which dust was lifted and spread causing more PM_{10} levels in the breathing zone causing more URTI complaints. Other studies have also shown that PM_{10} is washed off by raindrops and results in a reduction [19].

There were significantly ($p<0.05$) more consultation visits by female than male for various RD. A high number of these visits were sought during the dry season.

There were also more females who sought OPS for pneumonia and asthma compared to their male counterparts. The number of reported cases of asthmatic attacks and pneumonia was also more pronounced during the wet than the dry season. A survey using a questionnaire in the Athi River communities also found that the majority of inhabitants were using unclean fuels for cooking and lighting in their homes when compared to the control group. This may also explain why more women are afflicted by RD as most of them participate in the cultural roles of cooking. The WHO reported that household air pollution due to the use of unclean fuels coupled with inefficient technologies.

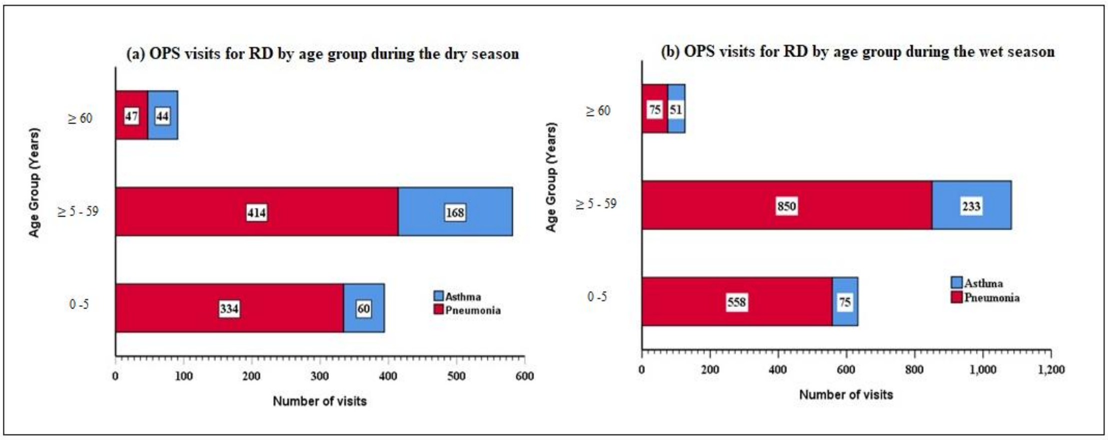

Fig. 3. Outpatient cases by age groups for various respiratory diseases across the Athi River and control health facilities during the wet and dry season (January- October 2019)

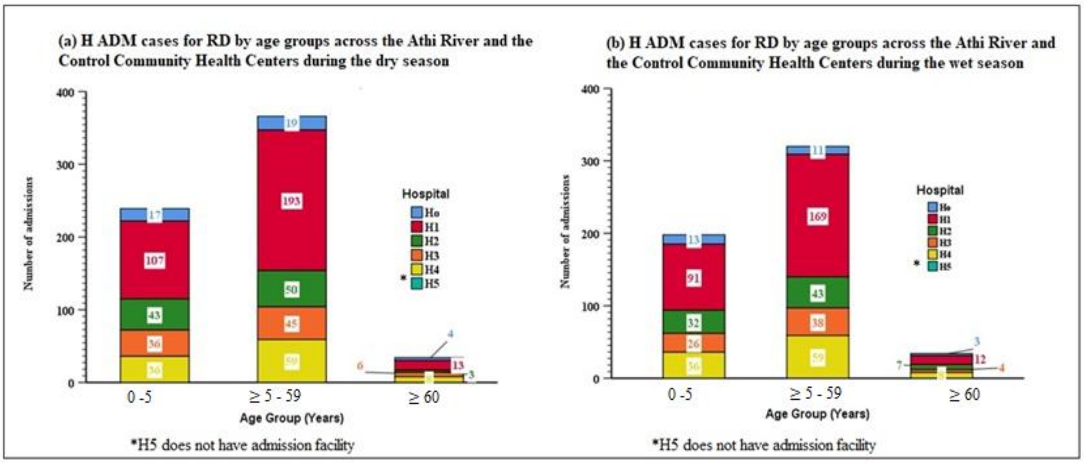

Fig. 4. Admissions for various respiratory ailments by the age groups across the Athi River Health community and control during the wet and dry season (January- October 2019)

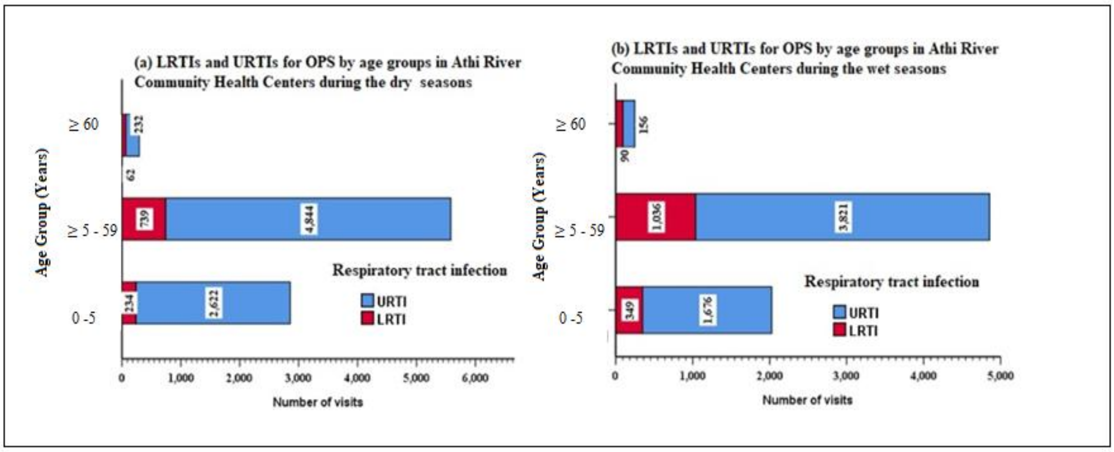

Fig. 5. Outpatient cases by age group for lower and upper respiratory tract infection across the Athi River health community during the wet and dry season (January- October 2019)

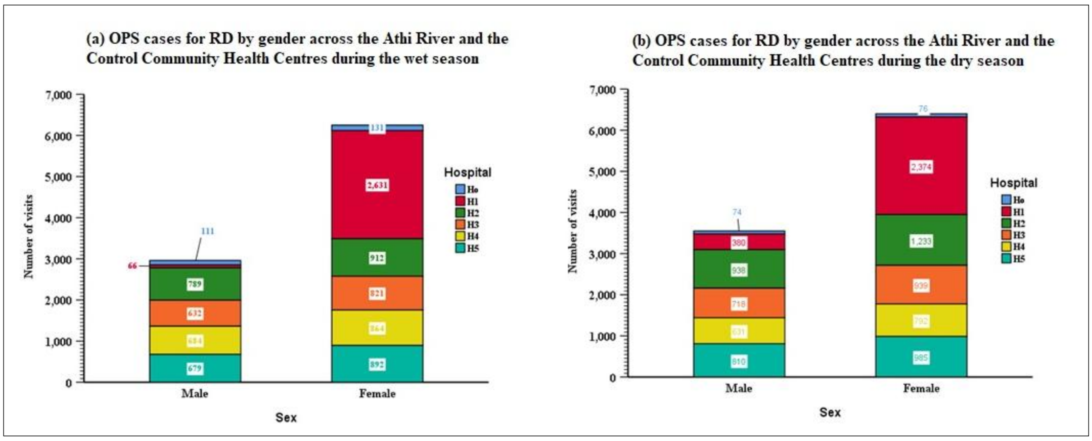

Fig. 6. Outpatient cases by gender the Athi River health facilities and control during the wet and dry season (January- October 2019)

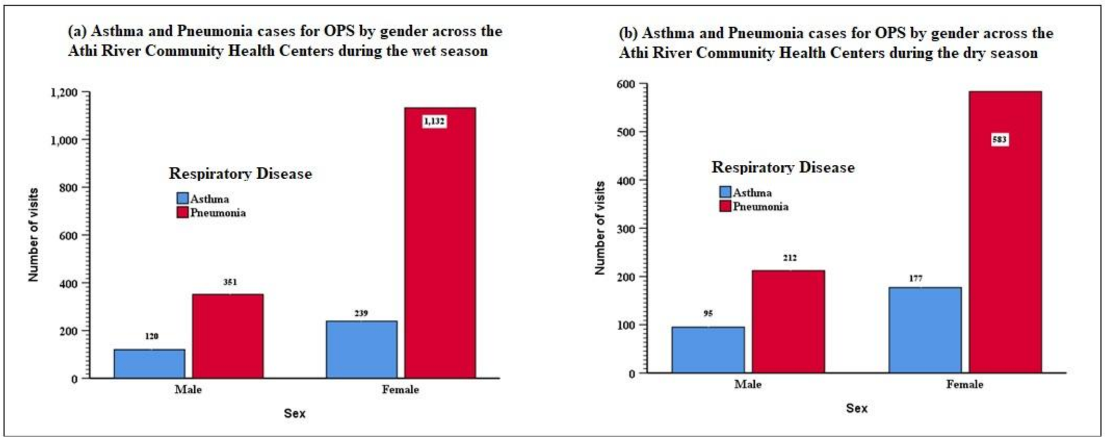

Fig. 7. Outpatient cases by gender for asthma and pneumonia across the Athi River health community during the wet and dry season (January- October 2019)

By and large, the Athi River communities were most affected by PM_{10} exposure that ranged from 111.1-740.7 µg/m^3 and 37.0-351.9 µg/m^3 compared to 9.2-15.3 µg/m^3 and 10.2 – 13.5 µg/m^3 of the control sites during the dry and wet seasons, respectively. This is not surprising as it was observed that most of the Athi River communities were living in the potential sources of pollution that included industrial zones, where the stack heights of several factories including cement were quite low to support the associated emissions. The corresponding health facilities had significantly ($p< 0.05$) higher number of various RD that required outpatient services (OPS) and hospital admissions (H ADM) than the control health facility. This may explain the high incidences of various RD among the communities.

These findings agree with a related study that was conducted in schools in the same area that reported significantly ($p <0.05$) higher PM_{10} and $PM_{2.5}$ levels that exceeded the WHO air quality guideline limit than the control school [20]. In addition, the relative risk (RR) and the odds ratio (OR) indicated a high prevalence of respiratory diseases among children in Athi River schools than their counterparts [11]. At 95% CI, the RR and OR showed strong associations between high PM_{10} and $PM_{2.5}$ levels and increased risk of developing lung function impairment [11]. Most of these cases were concentrated around the Athi River Township where several emission sources including those of the cement industries are also dominant. The Annual Health Report further showed that RD was a common cause of out-patient visits in the health facilities and the incidences of RD were on the rise in the township and exceeded the national average.

Other authors have reported significantly high rates of RD that manifested through exacerbation of asthma and increased hospital visits by communities in close proximity to industrial areas and heavy traffic density emissions compared to those in rural areas [21]. Communities living in the PM_{10} zone area are impacted by RD. Diseases such as chest pain, cough, and eye problems in these communities that have been reported are likely to be emanating from the cement dust. This study agrees with the WHO report that observed that up to 90% of the population lives in cities with elevated PM_{10} levels that exceed the air quality guidelines. Furthermore, 98 % of these cases are in low-resourced countries with more than 100,000 inhabitants, and 8.9 million deaths every year are attributable to ambient PM_{10} alone. The fact that more productive adults are adversely affected by respiratory diseases suggests that the means of support at the household and community level is reduced with direct implications for socioeconomic development.

3.1 Limitations

The study had some limitations as the ambient PM_{10} levels were based on the community level exposure as constraint resources could not allow for the collection of personalized PM_{10} levels. The ambient PM_{10} levels obtained in this study could not be equated directly with the WHO air quality limit especially since the sampling periods were conducted over a fairly short time rather than the 24-hr average. Although contribution of PM_{10} from cement industry is major, there are other diverse sources of pollution in these communities. Repeated admissions or consultation visits by the same patient could not be verified. Most health facilities had limited admission capacities and hence reported cases of admission may not be representative of the prevalence of respiratory diseases in the communities. Individual community health centers also handled collected data and released them differently as available data is given in aggregated form.

4. CONCLUSION

The study assessed PM_{10} levels and the prevalence of respiratory diseases around the cement industries and compared them with the control site during the rainy and dry seasons. The PM_{10} levels were found to be significantly high around the cement industries compared to the control. Similarly, Athi River health facilities reported high incidences of various respiratory diseases with a high number of related admissions and outpatient cases compared to the control. Environmental health-driven programs and strategies are necessary to reduce PM_{10} exposure and the prevalence of respiratory diseases. Setting up appropriate health systems and related policies to reduce PM_{10} exposure is also critical.

ACKNOWLEDGEMENT

We acknowledge support from Wellcome Trust's Health Research Capacity Strengthening Post-Doctoral Fellowship Grant: REF: 080883/E/06/S. We also thank the Department of Chemistry for the technical facility. We further thank the

Geology and Mines Department under the Ministry of Petroleum and Mining and Department of Physics, University of Nairobi for research facility and single out Mr. Jorum Wambua for technical support.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/97677