Discover Environment

Review

Human exposure to $PM_{2.5}$ at selected densely populated traffic sites in Accra, Ghana; A critical review

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Abstract
Road traffic emissions contribute substantially to air pollution. This is pronounced in developing cities experiencing fast growth and industrialization due to the increasing number of poorly maintained vehicles, poor fuel quality, and the importation of overaged vehicles. There is strong evidence connecting vehicle emissions exposure to a host of harmful health outcomes, such as cardiovascular and respiratory disorders. However, limited studies in Ghana have evaluated human exposure to $PM_{2.5}$ pollution at traffic hotspots. The study systematically reviewed literature published between 2005 and 2022 to examine $PM_{2.5}$ exposure trend and health effects at traffic areas in Accra neighbourhoods of varying socioeconomic status (SES). Literature searches were conducted in Scopus, PubMed, Web of Science, Google Advance Search and Google Scholar. A total of 30 empirical studies categorized into three groups based on population, land-use and socio-economic status were analyzed. One-way ANOVA showed that $PM_{2.5}$ concentrations differed significantly by traffic site type, with notable effect observed ($F = 4.78$, $p = 0.022$). The study observed an annual mean ($PM_{2.5}$) of 61.3 µg/m^3, which is higher than the WHO and USEPA annual guideline values of 5 and 9 µg/m^3, respectively, by a ratio of 12.3 and 6.8 times. This puts the urban population, especially those who travel regularly, work, or live at traffic hotspots or roadways, at serious health risk due to high exposure. Promotion of fuel and vehicle emission standards, regular monitoring, public education and awareness creation will help improve urban air quality.

Keywords Vehicular emission · Traffic related air pollution · Particulate matter · $PM_{2.5}$ · Air quality monitoring · Public health

1 Introduction

Clean air is fundamental to human health [41]; nonetheless, air pollution, especially in developing nations is one of the biggest environmental threats to all lives in the world today [18, 59, 67]. According to the 2019 Burden of Disease research, air pollution ranks fourth worldwide in terms of cause of mortality, and it is attributed to about 7 million deaths annually [35, 38]. About 90% of such deaths are reported in lower- and middle-income countries in Africa and Asia. In the same report, air pollution is ranked the second leading risk factor for death, after malnutrition, in Africa. This is because cities in most African countries continue to experience poor air quality compared to the rest of the world due to an increase in road traffic [54]. In the European member states, 307,000 premature deaths were attributed to the exposure of fine

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particle pollution in 2019 (European Environment Agency, 2021) compared with the over 1.1 million deaths in Africa which was associated with air pollution [38, 65].

Sub-Saharan Africa (SSA) cities air quality continues to deteriorate due to rapid population growth, urbanization, and industrialization [5, 37, 54, 87]. This situation has increased the dependence on motor vehicles in cities or urban areas, resulting in significant release of fine particulate matter, greenhouse gases and volatile organic compounds [6]. It is currently estimated that about 1.4 billion vehicles have been registered globally, and their numbers continue to increase sharply [37]. In Ghana, civilian registered vehicles as of the end of 2017 totaled 2,206,415 [6] with Greater Accra, the nation's capital, accounting for over 60% of the total fleets. In 2019, over 12,544 deaths in Ghana; representing 40 deaths per 100,000 people, were attributed to fine particle pollution [65]. The Ghana Environmental Protection Authority (Ghana EPA) estimates that $PM_{2.5}$ pollution in the Greater Accra Metropolitan Area (GAMA) results in 2800 deaths yearly [65].

Vehicular traffic is a major cause of particulate matter (PM) pollution along high-density roads, where vehicular emissions is likely to be higher [73]. The increasing number of road vehicles in Accra has significantly contributed to traffic congestion and PM pollution on major roads, especially at traffic hotspots [4, 5, 8, 54]. Exposure to vehicle emissions is linked with a number of adverse health effects, including cancer, respiratory, and heart disease [4, 5, 28, 73]. Tayarani and Rowangould [73] reported that vulnerable populations are likely to live or work closely to traffic hotspots. In Accra, like major other SSA cities, people live and/or sell at traffic hotspots where vehicular emissions are likely to be higher. Street traders (vendors or hawkers) are among the most vulnerable group with higher risk of PM exposure and, for that matter, at a significant health risk.

A large body of evidence suggests that those PMs of public health concern include particulates with an aerodynamic diameter of less than 0.1 $\mu g/m^3$ ($PM_{0.1}$), 1 $\mu g/m^3$ (PM_1), 2.5 $\mu g/m^3$ ($PM_{2.5}$), and 10 $\mu g/m^3$ (PM_{10}) [4, 5, 7, 19, 25, 28, 74]. Unlike $PM_{2.5}$ and PM_{10} where regulatory bodies such as USEPA, WHO and EU have long set air quality standards, no such standards exist for $PM_{0.1}$ and PM_1. Therefore, most monitoring infrastructure and public health policies only focus on $PM_{2.5}$ and PM_{10}. In urban areas where vehicular traffic is pronounced, $PM_{2.5}$ is a significant air pollutant [28]. $PM_{2.5}$ poses major public health risk because of its small size, which allows it to enter the respiratory system deeply [28, 39]. Despite these well-documented health risks associated with $PM_{2.5}$ pollution, there have been few to no studies in Ghana that have evaluated $PM_{2.5}$ exposure at traffic hotspots. Long-term health studies and cohort data focused on $PM_{2.5}$ are limited despite their better-established public health effects. Addressing this knowledge gap, this study systematically reviews $PM_{2.5}$ pollution at traffic hotspots in Accra. The present study aims to; (i) provide conceptual insights into particulate matter in general (ii) examine $PM_{2.5}$ exposure trend at traffic areas in Accra neighbourhoods of varying socioeconomic status (SES) from 2005 to 2022 and (iii) assess the effects of $PM_{2.5}$ pollution on human health at traffic hotspots.

This research draws insight to create public awareness on $PM_{2.5}$ exposure among street traders at traffic hotspots in Ghana and the subregion to drive local, national, and regional environmental policies to manage the health risk of $PM_{2.5}$ pollution as well as promote behavioural change and take effective action to reduce $PM_{2.5}$ pollution from vehicular traffic.

2 Methodology

The study started with conceptual highlights of important terms such as particulate matter, sources and chemical composition of $PM_{2.5}$, health effects of $PM_{2.5}$, guidelines for $PM_{2.5}$ and overview of traffic related studies in Ghana.

2.1 Study area

The Greater Accra Metropolitan Area (GAMA), is the administrative and industrial hub of Ghana with more than 5.4 million inhabitants making it one of the subregion's fastest-growing metropolitan areas [4, 30]. The findings of the 2021 population census indicate that the pattern of population distribution in Accra tends to the economic and market areas [30]. This has influenced the tendency of the population to use car as a mobility tool. It is evident that the use of private vehicles and minibuses, known locally as 'Trotro' to promote economic activities in the city has increased. More than 60% of all vehicles registered in Ghana operate in GAMA (Musah et al., 2020). An estimated 1.3 to 2.2 million vehicles and 7.1 to 11.2 million passengers travel through GAMA each day on average. About 949,886 passengers and 150,000 vehicles are estimated to move through the traffic on average during peak hours (Ministry of Local Government and Rural Development, 2021). This presents potential public health and environmental impact on the population in Accra.

2.2 Study search

This study highlights on ambient air monitoring studies measured along major traffic routes in Accra, Ghana, during the period of 2005 and 2022 focusing on $PM_{2.5}$ pollution. Identifying relevant studies for the review, key words including "*fine particulate matter*", "*traffic related air pollution*", "*air pollutants*", and "*air quality monitoring in Accra*" were considered. Literature searches were conducted in *Scopus*, *PubMed*, *Web of Science*, *Google Advance Search* and *Google Scholar* [20, 70]. The search focused on studies that evaluated $PM_{2.5}$ pollution at traffic hotspots and their associated health impacts in Accra, Ghana.

Apart from the literature database, reports and documents pertinent to the study were searched on the websites of government agencies such as the Ghana Environmental Protection Agency (Ghana EPA), US EPA, the Accra Metropolitan Assembly (AMA), and the Ministry of Environment, Science, Technology, and Innovation (MESTI). We searched through the websites of international organizations like the United States Agency for International Development Bank, World Health Organization (WHO), and United Nations Environment Program (UNEP) to find pertinent documents and policies for the study. The search terms were conducted in English.

2.3 Study selection

2.3.1 Inclusion and exclusion criteria

The main inclusion criterion was articles that examined ambient fine particulate air pollution levels in Accra neighbourhoods of different socioeconomic status between 2005 and 2022. We also included studies that evaluated the associated health impacts of vulnerable group including children, the elderly, and pregnant women whose activities exposed them to ambient air pollution levels emanating from traffic.

However, we excluded literature from this review if;

1. it was published before 2005;
2. it focused mainly on indoor air pollution;
3. the source of pollution is not traffic related;
4. air quality monitoring locations/sites are not located along traffic routes in business, commercial arears, low density residential neighbourhoods and high-density residential neighbourhoods;
5. evaluated pollutants other than fine particulate matter ($PM_{2.5}$).

2.3.2 Screening and selection process

A total of 850 documents were identified during the search and were subjected to a two-stage systematic screening process including title and abstract screening, and full-text review. Six hundred and twenty-five (625) out of the 850 documents were peer reviewed papers, while 225 papers were retrieved through other sources. Screening of these papers was thoroughly done and excluded 730 papers from the review. We evaluated the remaining 120 papers to determine their eligibility. Ninety (90) papers did not meet the inclusion criteria for which they were excluded, while 30 studies met the inclusion criteria.

To analyze $PM_{2.5}$ emission trends, the present study categorized the sampling sites reported in the traffic related studies into high-density traffic areas (HDTA), low-density traffic areas (LDTA) and commercial/business traffic areas (CBTA) based on sampling category characteristics described below and in Table 2.

a. Commercial/Business Areas (CBTA): Major road areas impacted by heavy traffic induced by public transport including buses, cargo/trailer vehicles, minibuses (locally known as trotro), and taxis [4].
b. High density residential traffic areas (HDTA): densely populated road areas where overaged and poorly maintained vehicles operate and with heavy traffic with varying vehicles.
c. Low density residential traffic areas (LDTA): sparely populated areas where relatively less aged and properly maintained vehicles operate and with moderate traffic.

The data extracted includes but is not limited to author information, year of publication, location of study, category road, $PM_{2.5}$ pollution levels and study findings. Moreover, if a study location was reported in more than one study, the

$PM_{2.5}$ concentrations for the different studies were summed up and averages taken. A total of 60 traffic hotspots (Table 1) were identified with 24 sited at high density residential traffic areas (HDTA), 30 at commercial/business areas (CBTA) and 6 at low-density residential traffic areas (LDTA) (Table 2).

2.4 Study statistical analysis

The mean and range of $PM_{2.5}$ pollution data collated was analyzed. The estimates were provided for the annual mean $PM_{2.5}$ concentration and mean $PM_{2.5}$ concentration for traffic site by land-use category and socio-economic status (CBTA, HDTA & LDTA). One-way Analysis of Variance (ANOVA) was used to examine whether the mean $PM_{2.5}$ concentrations differed significantly across the monitoring site types (CBTA, HDTA & LDTA) and monitoring years (2006–2022). Monitoring site types were treated as categorical independent variables, whiles $PM_{2.5}$ concentrations served as dependent variables. Also, post-hoc Tukey's Honestly Significant Difference (HSD) were carried out where ANOVA results were significant which helped to identify specific group difference [14]. Mann–Kendall test and Sen's slope estimator was used to assess the temporal trends in $PM_{2.5}$ concentrations over the study period. We estimated the average rate of change per year of annual mean $PM_{2.5}$ concentrations using simple linear regression (Figs. 1 and 2).

3 Results and discussion

3.1 Conceptual insights

3.1.1 Particulate matter (PM)

PM is a mixture of liquid droplets and solid particles of inorganic and organic substances, including black carbon, ammonia, mineral dust, sodium chloride, nitrates, and sulfate, that are discharged directly into the air [74, 85]. Particles of PM differ in size, composition, origin and their impact on public health, climate and the ecosystem have been well reported. For their ability to penetrate deeply into the respiratory system, PMs remain one of the critical air pollutants. PM sources are both natural and anthropogenic, including windblown dust, forest fires, sea sprays, motor vehicles emissions, industries (cement, steel, aluminum), and construction sites [4, 5, 25, 28, 41, 69, 74]. PM can also be formed through condensation or the transformation of gases, such as NOx, NO_2 and VOCs, that are emitted into the atmosphere. By their aerodynamic diameter, PM is most commonly classified into course particles (PM_{10}), fine particles ($PM_{2.5}$), ultra-fine fine overlap (PM_1) and ultra-fine particles (UFP or $PM_{0.1}$). Figure 3 demonstrates PM sizes ($PM_{2.5}$ and PM_{10} against the average diameter of human hair (~70 µm) and fine beach sand (~90 µm).

On the basis of their composition which largely drive their toxicity and environmental behaviour, PMs may also be categorized into organic (including hydrocarbons, polycyclic aromatic hydrocarbons PAH)), inorganic (including metals and salts), and biological (including pollen, spores, bacteria, virus) PMs.

3.1.2 Sources of $PM_{2.5}$

Sources and concentrations of $PM_{2.5}$, according to Thangavel et al. [74], differ significantly across the globe due to varying emission sources, climatic conditions, and patterns of dispersion. $PM_{2.5}$ sources are both natural and anthropogenic. $PM_{2.5}$ emission sources depending on the location, and can be emitted via road traffic, dust resuspension, power plants, residential cooking, burning of biomass, smoking, industrial emissions, social and economic development, sea salt, and aircraft [13, 74].

Table 1 Descriptive statistics of $PM_{2.5}$ related studies at selected traffic site by land-use category in Accra

Traffic category	No. study location	Percentage (%)
HDTA	24	40
LDTA	6	10
CBTA	30	50
Total	60	100

Table 2 Characteristics of sampling categories

No.	Sampling category	Traffic volume	Land use	Population density	Sensitive receptors	Emission sources
1	Low density traffic area	< 500–1000 vehicles/day (peak hour congestion)	Residential, minimal commercial, urban green spaces	Low population density (< 200–800 people/km^2)	Schools, parks, play ground	Vehicular traffic, dust resuspension
2	High-density traffic area	> 40,000 vehicles/day (peak hour Congestion)	Mixed residential/commercial	High population density(> 40,000 people/km^2) day–night flux	Schools, markets, churches, hotels, malls	Vehicular traffic, dust resuspension, biomass burning, sea sprays
3	Commercial business traffic area	> 50,000 vehicles/day (peak hour congetion)	High commercial/social centers, low residential	High person density during peak hours (50,000–100,000 persons/km^2	Market centers, malls, hotels, official workplaces	Vehicular traffic, dust resuspension

Source [4, 7, 19, 69]

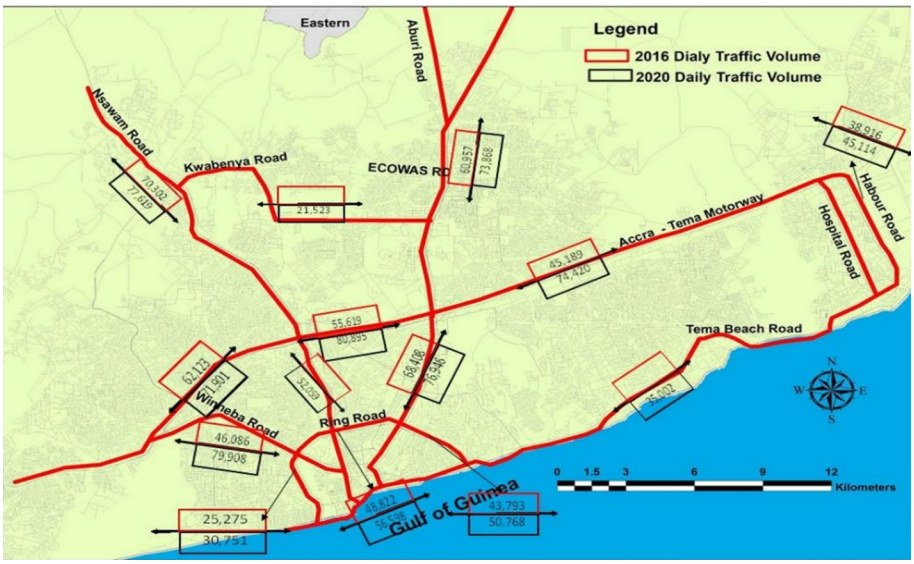


Fig. 1 Average daily traffic (ADT) volumes on selected roads in Accra (Source: Adapted from Ministry of Local Government and Rural Development, 2021)

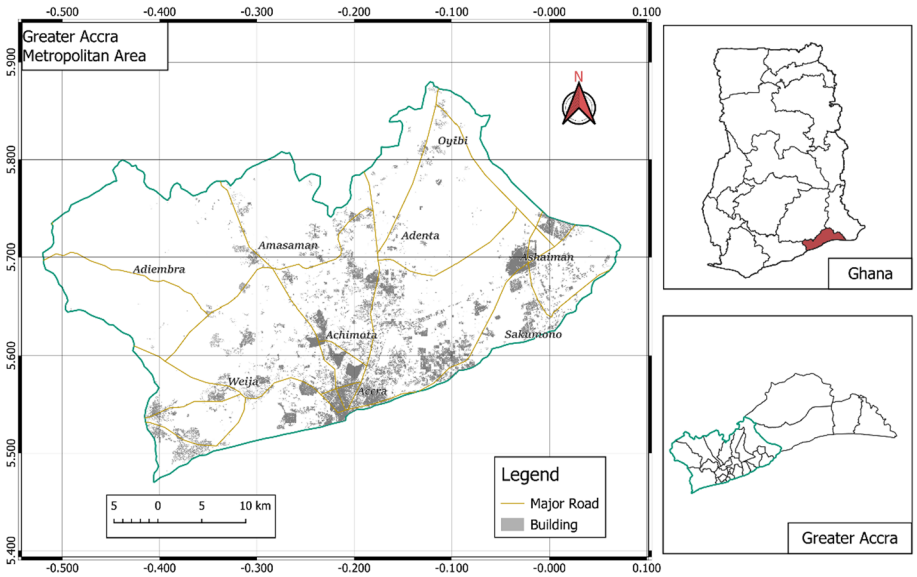


Fig. 2 Traffic site characteristics

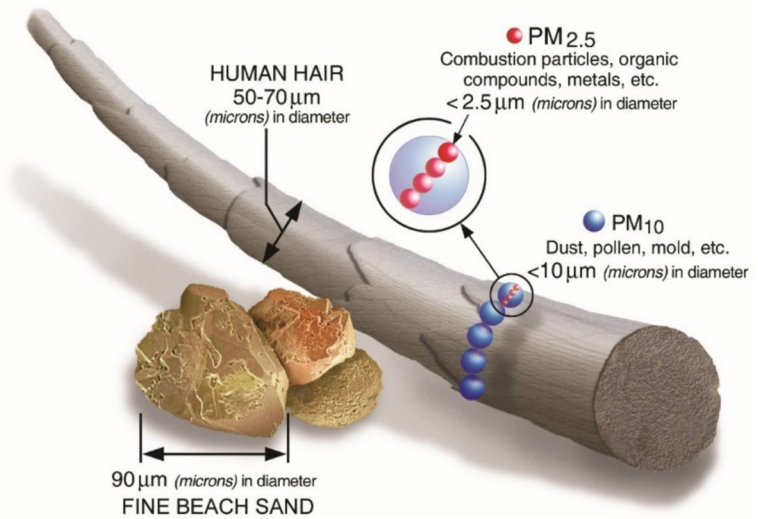


Fig. 3 Particulate Matter size comparison (Source [76])

Traffic emissions is a major $PM_{2.5}$ pollution source in Accra and other SSA cities [4, 28, 41, 54] and in Ghana, they are highest contributor to $PM_{2.5}$ pollution accounting for 25–45% [7, 17, 19], followed by biomass burning (20–35%) [69], soil and road dust (10–25%) [7, 19, 69], industrial emissions (10–20%) [7], and waste burning (5–15%) [19]. Traffic emissions is the dominant $PM_{2.5}$ source (Table 3) largely due to the intensified dependence on motor vehicles that are overaged and have poor maintenance cultures [5]. $PM_{2.5}$ is emitted via vehicle exhaust as tailpipe emissions, while other particulates are also released from non-exhaust sources, including suspended dust, evaporative emissions of fuel, and the wear of tires and brakes, which are also referred to as non-tailpipe emissions. [4, 28]. Accra and many cities in SSA continue to experience significant $PM_{2.5}$ pollution due to heavy vehicular traffic congestion and increasing number of road vehicles (Musah et al., 2020).

The major components of $PM_{2.5}$ include black carbon, aryl hydrocarbons, polycyclic aromatic hydrocarbons, organic compounds, VOCs, heavy metals, minerals, inorganic ions, and biological materials, which account for 79 to 85% total mass [74]. According to Bangar et al. [13], nitrate, ammonium ions, and sulfate are among the elements that make up $PM_{2.5}$, along with Al, As, Br, Ca, Cl, Cr, Fr, K, Mg, Mn, Na, Pb, Ti, and Zn. Table 4 lists the sources and chemical components of PM2.5 in detail.

3.1.3 Public health effects of $PM_{2.5}$

Particulate matter over the years has gained public attention because of its associated health and ecosystem impacts. A large body of research have revealed that, the hazardous effects of particulate matter impact large number of the world's population than any other pollutant [25]. $PM_{2.5}$ is classified as most dangerous to human health because these particles are too fine that when inhaled, they have the ability to penetrate through the lung barrier, as well as enter the bloodstream thereby leading to significant health effects (Fig. 4) [5, 10, 28, 47, 67, 85]. $PM_{2.5}$ exposure is associated with the prevalence of diseases and mortality [31, 74, 85].

Exposure to Traffic-Related Air Pollution (TRAP) has been shown in numerous studies to have a direct negative impact on health. References [4, 27, 28, 34, 36, 49, 67, 72]. As Health Canada [34] reported, these effects ranges from acute to chronic thus, from respiratory symptoms to disease development and premature death. The research findings indicate that there is a higher chance of premature mortality due to heart disease, lung cancer, and stroke in individuals exposed to TRAP.

Numerous studies have documented both short-term (days to weeks) and long-term (months to years) exposure to TRAP [6, 36, 50, 57, 64, 67]. Asthma symptoms are triggered by short-term exposures, which also lead to a localized increase in mortality from respiratory and cardiovascular conditions such as asthma, allergies, chronic obstructive pulmonary disease, and bronchitis. On the other hand, long-term exposures to $PM_{2.5}$ has been associated with a variety of health effects, such as type II diabetes, ischemic heart disease, lower respiratory infections (like pneumonia), Chronic Obstructive Pulmonary Disease (COPD), stroke, and many cancer types, including those of the stomach, colorectal, oral, nasopharynx, esophagus, liver, lung, gallbladder, larynx, skin, bone, cervix, female breast, prostate, brain cancer, and leukemia [28, 36, 67]. Table 5 provides a summary of some commonly reported health effects linked with short- and long-term exposure to PM.

Those with underlying health conditions, children, pregnant women, elderly persons, and those from lower socioeconomic backgrounds are among the vulnerable groups most at risk from the negative health effects of $PM_{2.5}$ pollution near roads [67, 75]. For example, compared to adults, children have higher ventilation rates and lung surface area to weight ratios, which result in larger admissions of respiratory pollutants. This makes them the most vulnerable to $PM_{2.5}$ exposure [67].

A Canadian study found that over 1200 premature deaths were associated with TRAP in 2015 [34]. The study estimated that $PM_{2.5}$, NO_2 and O_3 exposures contributed to 800, 340 and 85 premature deaths respectively. Non-fatal health outcomes on the other hand were estimated at 2.7 million acute respiratory symptom days, 21,000 asthma symptom days per year, and 1.1 million restricted activity days. According to the report, light-duty vehicles, such as passenger cars, also caused 37% of premature fatalities, while heavy-duty vehicles, such as buses and commercial trucks, accounted for 63% of those deaths [34].

It is important to mention that adverse health effects of $PM_{2.5}$ exposures have been observed in association with proximity to roads [28, 49, 72, 75]. Matz et al. [49] reported that about 10 million people in Canada live within 100 m of major roads or 500 m of highways. Because of this, Health Canada's Air Health Effects Assessment Division regularly evaluates the risks of air pollutants on human health in order to influence policies and practices aimed at enhancing air quality [49]. SSA cities including Ghana, have greater percentage of its population live or work within 50 m of highways

Table 3 $PM_{2.5}$ source apportionment studies in Ghana

#	Location	Study focus	Findings on $PM_{2.5}$ sources	References
1	Accra, Ghana	Air pollution studies highlighting on source apportionment	Traffic—43%, Biomass burning—25%, Sulfate-rich aerosol—21%	[7]
2	Accra, Ghana	Spatial, socioeconomic status and temporal patterns of ambient air pollution	Traffic—39%, road dust—27%, burning of solid waste—17%, burning of biomass—10%	[19]
3	Ashiaman, Ghana	Sources of airborne fine particles	Industrial emissions 11.4%, fresh sea salt 15.5%, diesel emissions 18.4%, biomass burning 9.5%, two stroke engines 5.1%, gasoline emissions 15.8%, aged sea salt 6.2%, and soil dust 17.7%	[60]
4	Accra, Ghana	Reviewing air pollution studies for policy action	Road transport—43%, biomass burning—24%, industrial emissions—14%, dust—10%	(Odoi and Gary 2021)
5	Accra, Ghana	$PM_{2.5}$ pollution sources	Road transport 40%, industrial and power plants—11%	[17]

Table 4 $PM_{2.5}$ sources and their chemical composition

	Source	Components
Natural	Aerosols from Sea spray	Sodium (Na)
	Biomass	Potassium (K)
	Burning of coal	Arsenic (As), Aluminium (Al), Cobalt (Co), and Selenium (Se)
	Road dust and Soil	Calcium (Ca), Silicon (Si), and Aluminium (Al)
	Forest fire and volcanic dust particles combustion of coal, petrol, and diesel	Lead (Pb), Zinc (Zn), and Potassium (K), Sulfates (SO4) and Elemental carbon (EC)
	Burning of oil	Iron (Fe), Vanadium (V), Manganese (Mn), and Nickel (Ni)
Anthropogenic	High temperature combustion at heavy industry	Copper (Cu), Lead (Pb), Iron (Fe), Nitrates (NO3), and Zinc (Zn)
	Animal husbandry and fertilizer production	Ammonium (NH_4)
	Emission of VOCs	Tetrachloroethylene, methylene chloride, Xylene, and Toluene

Source: Adapted from [74]

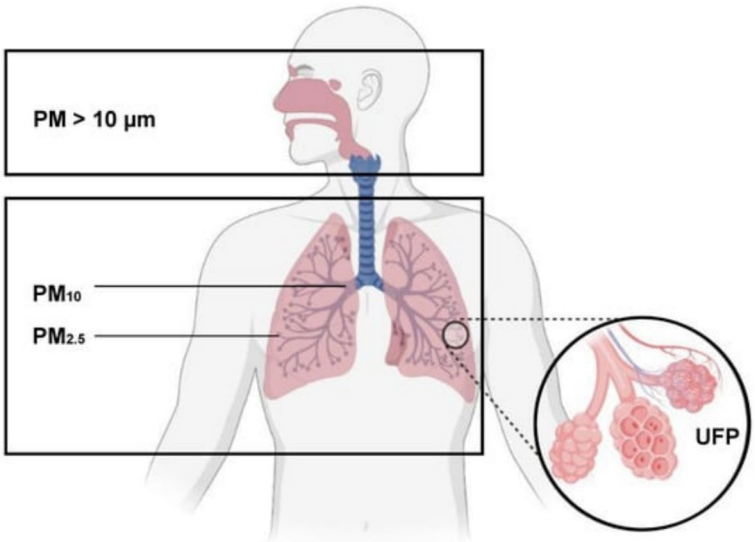


Fig. 4 Deposition of PM in the airways (Source: [31])

or 10 m of major roads. Research has indicated that residing or working close to busy roadways increases the likelihood of experiencing more frequent and severe health issues related to $PM_{2.5}$ exposure [75]. Kumar et al. [43] reported that adverse health impacts of $PM_{2.5}$ pollution are pronounced within 200 m of busy roadways and highways.

3.1.4 Air quality standards for PM

According to Kim et al. [41], clean air is essential to human health and wellbeing, nevertheless, the quality of the air in our immediate surroundings keeps declining. The rate of deterioration according to Amegah et al. [5] is unprecedented especially in SSA cities where the rate of industrialization, urbanization and population growth are high which contribute to severe air pollution. There is mounting evidence that PM pollution has an impact on various organ systems in addition to increasing morbidity and death from lung cancer, cardiovascular disease, and respiratory disorders [4, 28, 31, 41, 74]. Governments in many nations have set air quality regulations to protect public health and have pushed national environmental policies to manage the health risk of air pollution based on evidence of $PM_{2.5}$ exposure impacts [41].

The US Environmental Protection Agency (USEPA) for instance has the mandate to create, modify and enforce air quality standards targeted at safeguarding the general public from the harmful health impacts of $PM_{2.5}$ exposure. Similarly, Ghana's Environmental Protection Agency (Ghana EPA) is in charge of creating rules and regulations regarding pollution of the air, water, land, and automobiles as well as making sure that the environment is protected and improved. Ghana Standards for Environment and Health Protection—Requirements for Ambient Air Quality and Point Sources/Stack Emissions (GS 1236:2019) is the standard for ambient air quality that was published in the gazette in 2019, however, the Ghana

Table 5 Health effects of $PM_{2.5}$

Exposure	System affected	Health effects	References
Short term	Cardiovascular	Increased incidence of myocardial violations and ischemia in persons at risk. Deterioration of heart failure	[68] [82]
	Respiratory	An increased risk of arrhythmias A higher frequency of deep vein thrombosis Increased risk of stroke An increase in wheezing An increased risk of asthma Deterioration of long-term obstructive pulmonary illness Bronchiolitis An increased risk of emergency department visits	[41] [63] [51]
	Cardiovascular	Increased incidence of myocardia infraction Accelerated atherosclerosis development Enhanced coagulability of blood	[86] [68] [51]
	Respiratory	An increase of inflammatory markers that are systemic Increased risk of pneumonia An increase in lung cancer cases delayed children's lung'evelopment Emergence of fresh asthma	J. [66] [45]
Long term	Reproductive	Higher prevalence of premature birth Higher prevalence of low birth weight	[83] [81]
	Brain	Heightened likelihood of Alzheimer's enhanced risk of Parkinson's elevated risk of neurodegenerative illness	[78]

Source: Adapted from [74]

EPA started process of drafting air quality standards in 2007. The Ghana EPA relied on relevant air quality information from the World Health Organization (WHO), USEPA, World Bank, among others. It is important to mention that the USEPA offered invaluable support to the Ghana EPA to build capacity in Air Quality Monitoring in Accra [24].

The pronounced health effects of $PM_{2.5}$ exposure especially to those with asthma or lung disease in both developed and developing countries has called for the revision of the annual guideline for air quality for $PM_{2.5}$. To safeguard the health of the general public, the WHO recently updated its guideline for air quality from 10 to 5 μg/m^3 for $PM_{2.5}$ (WHO, 2021a). Comparably, the National Ambient Air Quality Standards (NAAQS) for $PM_{2.5}$ were strengthened by a final rule that the USEPA released on February 7, 2024. The yearly $PM_{2.5}$ threshold was previously 12 μg/m^3, however, the most recent guideline reduced that to 9 μg/m^3. Nonetheless, the USEPA decided to keep the daily (24-h) standards for primary and secondary $PM_{2.5}$ and PM_{10} at 35 μg/m^3 and 150 μg/m^3, respectively [77].

In 2019, the Ghana EPA created guidelines for ambient air quality, setting a 24-h average $PM_{2.5}$ concentration of 35 μg/m^3. However, an annual benchmark was not created. According to Asghar et al. [10] and Kim et al. [41], the annual average of $PM_{2.5}$ for Chinese and Pakistanis is 35 μg/m^3. Table 6 provides a complete overview of the PM guidelines developed by different governments.

3.2 Overview of traffic related particulate matter ($PM_{2.5}$) studies in Ghana

Several studies have been carried out to characterize particulate matter ($PM_{2.5}$) pollution in roadside and residential neighbourhoods of varying socio-economic status (SES). For instance, Arku et al. [7] conducted a pilot study in two low-income neighbourhoods (Nima and James Town) Accra, Ghana, for 3 weeks between June 30, 2006, and July 20, 2006. The authors assessed the concentration and temporal and/or spatial patterns of pollutants, including $PM_{2.5}$, in ambient air. One (1) sampling site (Nima, NMT) was located next to the main road; two (2) other sites were in the residential areas of Usher Town/James Town (UT/JT) on a secondary road; and one without traffic was also located in Nima (NMC). The mean measurement of $PM_{2.5}$ was 40.2 μg/m^3 in JT and 26.6 μg/m^3, 22.7 μg/m^3, and 22.3 μg/m^3 in Nima main road, secondary road, and no traffic, respectively.

A study in 2008 analyzed particulate matter (PM) over 22 months in four neighbourhoods of Accra of different socio-economic status (SES) and use of biomass as fuel at 11 roadside and residential monitoring sites. Late December and January recorded the highest $PM_{2.5}$ concentrations. This is attributed to dust blown from the Sahara during the period. The mean $PM_{2.5}$ concentration ranged between 39 μg/m^3 to 53 μg/m^3 and 30 μg/m^3 to 70 μg/m^3 at

Table 6 Air quality standards for $PM_{2.5}$

Country/institution	Pollutant	Averaging time	AQL (μg/m^3)	Year	References
WHO	$PM_{2.5}$	Annual	5	2021	(WHO, 2021a)
		24-h	15		
		Annual	15	2021	
		24-h	45		
USEPA	$PM_{2.5}$	Annual	9	2024	[77]
		24-h	35	2024	
	PM_{10}	24-h	150		
EPA Ghana	$PM_{2.5}$	Annual	n/a	2019	(GS 1236:2019)
		24-h	35		
	PM_{10}	Annual	70	2019	
		24-h	70		
European Union	$PM_{2.5}$	Annual	25	2015	[56]
		24-h	n/a		
Member States Russian Federation	$PM_{2.5}$	Annual	25	2010	[56]
		24-h	35		
Egypt	$PM_{2.5}$	Annual	50	2012	[56]
		24-h	80		
Australia	$PM_{2.5}$	Annual	8	nr	[56]
		24-h	25		
China	$PM_{2.5}$	Annual	35	2016	[56]
		24-h	75		
Japan	$PM_{2.5}$	Annual	15	2009	[56]
		24-h	75		
Republic of Korea	$PM_{2.5}$	Annual	20	2015	[56]
		24-h	50		
Singapore	$PM_{2.5}$	Annual	12	2020	[56]
		24-h	37.5		
South Africa	$PM_{2.5}$	Annual	20	2016	[23, 56]
		24-h	40		
Canada	$PM_{2.5}$	Annual	8.8	2020	(Canada, 2023)
		24-h	27		

roadside and residential sites respectively, excluding the dry season [19]. The authors reported that the annual $PM_{2.5}$ concentration increased by 21 μg/m^3–23 μg/m^3 and 11 μg/m^3–14 μg/m^3 in years 1 and 2, respectfully, if harmattan were included. The traffic sites recorded a higher $PM_{2.5}$ concentration compared to residential sites by 8—14 μg/m^3, except for James Town, a low-income and densely populated neighbourhood that recorded the highest residential $PM_{2.5}$ concentration. Daily PM increased at all sites at both morning and evening peaks but pronounced during the morning peaks [19].

Ofosu et al. [60], between February and August 2008, sampled $PM_{2.5}$ mass in ambient air in Ashaiman, a suburb of Accra. Ashaiman community is located 30 km from Accra and 8 km north from the Tema Metropolitan Area. The mean $PM_{2.5}$ over the period was 26.1 μg/m^3.

$PM_{2.5}$ concentrations were measured on a weekly basis using minute-by-minute and gravimetric (filter-based) methods between April 2019 and June 2020 at 146 sampling locations in the Greater Accra Metropolitan Area (GAMA) [4]. These locations consisted of 136 rotating (7 day) and 10 fixed (~1 year) sampling sites based on land-use and source influence, including commercial, business, and industrial (CBI) sites (N1 West–Lapaz, Accra–Tema Motoway, Ring Road Central—Asylum Down), high density residential neighbourhoods (East Legon), peri-urban sites (University of Ghana), and medium or low-density neigbourhoods (Labadi, Ashiaman, James Town, and Nima). Site-specific annual means varied from 37 to 43 μg/m^3 at CBI areas, 35–40 μg/m^3 at high-density residential sites, 32–40 μg/m^3 at medium/low residential sites, and 26 μg/m^3 at peri-urban sites. The annual mean $PM_{2.5}$ concentration at the one (1) year (fixed) sites was 37 μg/m^3.

PM pollution between June and December 2019 was analyzed by Amegah et al. [5] at ten (10) traffic hotspots (Ring Road Central, Barnes Road, Accra City Hall, Adabraka Market Area, Tetteh Quarshie Interchange, Shiashie, Dzorwulu Intersection, Atomic Junction, Kwashieman intersection and Roman Ridge) of Accra. The study examined the respiratory and cardiovascular systems of street vendors as well as those of a control group made up of office workers with and without air conditioning systems due to $PM_{2.5}$ exposure. Higher $PM_{2.5}$ levels were recorded during wet and dry seasons but $PM_{2.5}$ concentration were pronounced during the dry periods. Street traders' annual exposure levels were estimated as 1540.03 μg/m^3, while the controlled group of officer workers working in and without air conditioning environment was 98.51 μg/m^3 and 823.69 μg/m^3 respectively. Cough, catarrh (postnasal drip), and sneezing were among the most common respiratory symptoms that participants reported; however, there was no correlation between these symptoms and participants' work ($p > 0.05$). The common cardiovascular symptoms on the other hand were sharp chest pains, headache, and dizziness. Compared to office workers, who reported a fast pulse of 11.8%, street vendors reported a fast heartbeat of 22.1%, which was linked to their line of work [5].

Raheja et al. [65] monitored $PM_{2.5}$ concentrations at varying sites in Accra from 2018 to 2021 to evaluate the performance of low-cost sensors used in air quality monitoring. In Accra, a total of 17 Clarity Node-S monitors were deployed. A daily average $PM_{2.5}$ concentration of 23.4 μg/m^3 was observed.

However, to date no study in Ghana has analyzed how the trend of $PM_{2.5}$ pollution change overtime. Educating the public about the trend in $PM_{2.5}$ concentration at traffic sites closes the knowledge gap about the effects of pollution control and guide policy decisions.

We aimed to examine the trend of $PM_{2.5}$ pollution in traffic areas in Accra neighbourhoods that differ in terms of Socio-Economic Status (SES) between 2005 and 2022. Analyzing $PM_{2.5}$ emission trend over 17-year period will increase the awareness of $PM_{2.5}$ pollution and health effects in Accra and cities in SSA. This will motivate people to alter their behavior and implement practical measures to lessen air pollution (Table 7).

3.2.1 Human exposure to $PM_{2.5}$ in Accra

Annual Mean $PM_{2.5}$ concentration of 61.30 μg/m^3 was recorded during the review. This exceeds the annual guideline values of 5 μg/m^3 and 9 μg/m^3 recommended by the WHO and USEPA, respectively [77],WHO, 2021b). High Density Traffic Areas (HDTA) recorded the highest annual average mean of 76.85 μg/m^3, followed by the Commercial/Business Traffic Areas (CBTA) of 76.23 μg/m^3 and Low-Density Traffic Areas (LDTA) of 28.81 μg/m^3. Considering the vulnerable group daily experiences as described by [5] at the traffic hotspots, the average exposure of 61.30 μg/m^3 significantly exceeds WHO and USEPA annual guideline value of 5 μg/m^{3}and 9 μg/m^3 by a factor of ~ 12.3 and ~ 6.8 times, respectively. This suggests that the ambient air at traffic hotspots in Accra are poor and unsafe which presents significant health risk to the urban population, especially those who travel regularly, work or live at traffic hotspots or roadways due to prolong exposure to high $PM_{2.5}$ pollution. The yearly average mean of 36.4 μg/m^3 was recorded by Collado et al. [18] as the $PM_{2.5}$ exposure for drivers of Open-Ar Utility Jeepneys (PUJ) in the Philippines. This puts both drivers and passengers at high risk of negative health consequences from PM.

Pronounced health effects including respiratory diseases (asthma, COPD) and cardiovascular disease, including atherosclerosis progression, hypertension,, ischemic stroke, acute coronary syndrome, and cardiac arrhythmias) [42] have been linked to prolonged exposure to high $PM_{2.5}$ concentrations at traffic hotspots in Poland [42], Philippines [18], USA [28], South Africa [23].

Previous research has demonstrated that exposure to $PM_{2.5}$ raises the risk of respiratory and cardiovascular disorders in susceptible populations, such as children, the elderly, and people with underlying medical issues [45, 46, 85]. Children, for example, are more prone to respiratory infections due to their increased breathing rate, immature lungs, and prolonged outside play [85]. A study by L. Liu et al. [46] reported an annual average $PM_{2.5}$ concentration of 59.48 μg/m^3 in the city of Zhengzhou, China from 2018 to 2020. The annual average of $PM_{2.5}$ concentration of 59.48 μg/m^3 was linked to 791,107 outpatient's visits of children's respiratory disease. Xu et al. [84] reported that people over 60 who are exposed to $PM_{2.5}$ have an increased risk of respiratory disorders. Xu et al. [84] examined the correlation between hospital emergency room visits for respiratory disorders and $PM_{2.5}$ exposure. The results indicated that a mean daily $PM_{2.5}$ concentration of 102.1 ± 73.6 led to 92,462 respiratory emergency visits in Beijing, China's urban districts.

A study by Amegah et al. [5] assessed the $PM_{2.5}$ exposure experiences of street traders at traffic hotspots in Accra. The study observed increased respiratory and cardiovascular symptoms among street traders due to $PM_{2.5}$ exposure. Cough, catarrh (postnasal drip), and sneezing were among the most common respiratory symptoms that participants reported; however, there was no correlation between these symptoms and participants' work ($p > 0.05$). The common cardiovascular

Table 7 Comparative summary table of $PM_{2.5}$ studies in Accra, Ghana

Sampling location	Sampling year	Mean $PM_{2.5}$ concentration	Methods	Author
James Town/Usher Town, Accra	2006	40.2	Study used high-resolution spatial monitoring devices used to characterized traffic and solid fuel related pollution in Accra	[7]
Nima Main Road, Accra	2006	26.6		
Nima Secondary Road, Accra	2006	22.7		
James Town/Usher Town, Accra	2007	75	The study applied regression models with socioeconomic, spatial and fuel-use data to temporal and spatial patterns of $PM_{2.5}$ and PM_{10} concentrations monitored over 22 months in four Accra neighbourhoods	[19]
Asylum Down, Accra	2007	57		
Nima, Accra	2007	71		
East Legon, Accra	2007	28		
Ashiaman, Accra	2008	26.1	$PM_{2.5}$ concentrations were sampled at Ashiaman to analyze their elemental and carbonaceous composition as well as identify and apportion pollution sources using Positive Matrix Factorization	[60]
Kaneshie First Light, Accra	2012	106.14	The study quantified air pollution exposures and estimated associated mortality burdens in Accra using health risk assessment modules	[53]
Shangri La, Accra	2012	92.11		
Achimota, Accra	2012	65.27		
La Palm, Labadi, Accra	2012	91.5		
Graphic Road, Accra	2012	108.58		
Kaneshie First Light, Accra	2013	107.97		
Shangri La, Accra	2013	102.48		
Achimota, Accra	2013	88.45		
La Palm, Labadi, Accra	2013	123.83		
Mallam Market, Accra	2013	120.78		
Graphic Road, Accra	2013	124.44		
Waija Junction, Accra	2013	157.99		
Kasoa, Accra	2013	102.48		
Shangri La, Accra	2014	103.7		
Achimota, Accra	2014	100.65		
La Palm, Labadi, Accra	2014	116.51		
Mallam Market, Accra	2014	115.29		
Graphic Road, Accra	2014	114.07		
Waija Junction, Accra	2014	153.11		
Kasoa, Accra	2014	106.75		
Kaneshie First Light, Accra	2015	110.166		
Shangri La, Accra	2015	93.33		
Achimota, Accra	2015	87.23		
La Palm, Labadi, Accra	2015	196.42		
Mallam Market, Accra	2015	90.28		

Table 7 (continued)

Sampling location	Sampling year	Mean $PM_{2.5}$ concentration	Methods	Author
Graphic Road, Accra	2015	100.04		
Waija Junction, Accra	2015	156.77		
Kasoa, Accra	2015	103.7		
Tetteh Quarshie Interchange, Accra	2015	101.6	The plan compiled monitoring data to develop emissions inventories, evaluate health impacts, compare concentrations with standard to guide policy decisions	[24]
Achimota Interchange, Accra	2015	89		
Labadi T-Junction, Accra	2015	196.8		
Mallam Junction, Accra	2015	101.1		
Graphic Communication Group of Companies, Accra	2015	86.6		
Weija, Accra	2015	125.7		
Kasoa, Accra	2015	110.3		
Ring Road Central, Accra	2019	34.25	$PM_{2.5}$ were measured at traffic hotspots in Accra using Purple Air sensors, surveyed activity patterns and health symptoms of street traders and office workers following exposure to $PM_{2.5}$ pollution	[5]
Barnes Road, Accra Central, Accra	2019	37.9025		
Accra City Hall, Accra Central	2019	29.75		
Adabraka Market Area, Accra	2019	26.38		
Tetteh Quarshie Interchange Accra	2019	39.3725		
Shiashie, Accra	2019	33.99		
Dzorwulu Intersection, Accra	2019	43.12		
Atomic Junction, Accra	2019	40.585		
Kwashieman Intersection, Accra	2019	31.57		
Roman Ridge, Accra	2019	34.9925		
James Town, Accra	2020	40	PM2.5 and black carbon was monitored from April 2019 to June 2020 using both gravimetric filter samplers and continuous low-cost sensors	[4]
Asylum Down, Accra	2020	37		
Nima, Accra	2020	35		
East Legon, Accra	2020	34		
Cantonment, Accra	2020	21.67	PM2.5 concentrations were monitored for two years in Cantonments, Accra. Daily and monthly air quality index patterns were analyzed to assess public health implications	[32]
Cantonment, Accra	2021	26.71		
Cantonment, Accra	2022	24.11		

symptoms on the other hand were sharp chest pains, headache, and dizziness. Compared to office workers, who reported a fast pulse of 11.8%, street vendors reported a fast heartbeat of 22.1%, which was linked to their line of work [5]. Dushie et al. [22] also reported breathing difficulty, poor visibility, frequent coughing, and nausea as the common self-reported symptoms by traders due to their exposure to vehicular emissions in Madina, Accra.

3.2.2 Trend analysis of $PM_{2.5}$ concentrations from 2005 to 2022 in Ghana

Over the 17-year study period (Fig. 5), the annual average $PM_{2.5}$ levels in Accra showed a notable increase across traffic sites before 2015. However, by 2019, these same sites experienced a significant decline in $PM_{2.5}$ pollution. The highest annual mean concentration of $PM_{2.5}$ of 116.60 µg/m^3 was recorded in 2015 [53] and the lowest (24.11 µg/m^3) recorded in 2022 [32], showing a general decrease in the last 4 years of the study. Two stages may be distinguished during the study period based on the unique features of the $PM_{2.5}$ concentration trend. In Phase I (from 2006 to 2015), the annual mean $PM_{2.5}$ concentrations increased by 346.75% from 26.1 to 116.6 µg/m^3 in 2008 and 2015 respectively. In contrast, Phase II (from 2019 to 2022) showed a distinct decreasing concentration trend of 31.48% from 35.19 to 24.11 µg/m^3 in 2019 and 2022 respectively. One-way ANOVA was used to evaluate the differences in $PM_{2.5}$ concentrations across traffic site types and monitoring years [14]. The present study revealed a statistically significant effect of traffic site type on $PM_{2.5}$ concentration ($F = 4.78$, $p = 0.022$). Tukey's HSD test revealed that $PM_{2.5}$ concentration at LDTA was significantly lower than both HDTA and CBTA. $PM_{2.5}$ concentration in HDTA was higher than in CBTA, however, they were not statistically different at 5% significance level. For monitoring year, the analysis showed a highly significant effect ($F = 11.84$, $p < 0.001$). Post-hoc Tukey's HSD tests indicated that $PM_{2.5}$ concentrations between 2012 and 2015 were significantly higher compared to the earlier years (2006–2008) and the later period (2019–2022). The study results suggest a clear temporal trend, with distinct peak in $PM_{2.5}$ concentrations between 2012 and 2015.

The Ministry of Energy's shift in policy to support clean energy can be attributed to the drift in the trend of the annual mean $PM_{2.5}$ concentration in Phases I and II. This includes Ghana's use of Liquefied Petroleum Gas (LPG) and low-sulfur fuels [32, 55]. Diesel vehicles is one of the primary contributors of $PM_{2.5}$ pollution in urban areas [33], because diesel is essentially used in the transportation and industrial sectors of national economies, hence responsible for significant PM emission. This is attributed to the increasing number of diesel vehicles in cities which contribute significantly to traffic congestion which leads to PM pollution [42]. Naidja et al. [54] reported that most African cities have car fleets that are older and poorly maintained, and greater number of these vehicles are diesel-powered which uses low-quality fuels with high lead and sulphur. This continues to deteriorate the air quality in African cities which present high health risk to the urban population.

To reduce the potential impact of diesel fuels on global economies, the quality of this commodity is crucial [44]. The National Petroleum Authority (NPA) reviewed the fuel standards to reduce sulphur levels in diesel fuels from 3000 ppm (parts per million) to 50 ppm which was implemented in July 2017 [55]. It is evident that prior to the implementation of the fuel standards, the diesel fuels in Ghana contained high sulphur levels contributing to increasing $PM_{2.5}$ concentrations before 2019 monitoring years. It is important to mention that high quantities of sulphur in diesel fuels present a major challenge that has effect on the combustion and emission characteristics of fuel. It is evident that sulphur emissions contribute significantly to public health and environmental issues. Sulphur content in diesel combustion engines contributes substantially to $PM_{2.5}$ pollution that can penetrate the lungs, thus posing significant health threat. Again, combustion of diesel fuel leads to the formation of sulphur oxides that react with atmospheric water. This process leads to the formation of acid rain which is detrimental to ecological system [44].

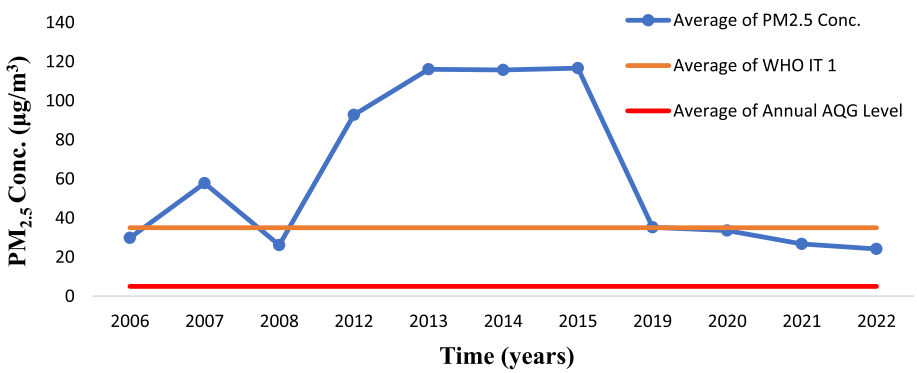


Fig. 5 Trend analysis of mean annual $PM_{2.5}$. WHO AQG of 5 µg/m^3 and Interim Target 1 (WHO IT 1) of 35 µg/m^3 are represented by the horizontal lines

Moreover, the annual mean $PM_{2.5}$ concentration trend can be attributed to the oil and gas discovery and subsequent production in commercial quantities in 2010, which significantly impacted Ghana's economic development. Aryeetey and Ackah [9] reported that oil revenues have contributed to the growth of Ghana's Gross Domestic Product (GDP) and increased commercial activities particularly in Accra due to rapid infrastructural expansion, urbanization and population density. This has led to the significant rise in vehicle ownership and traffic volumes in Accra due to an increase in demand for transportation services. Angnunavuri et al. [6] reported 2,206,415 civilian registered vehicles in Ghana. According to Musah et al. (2020), vehicular ownership increases by 10–30% annually and over 60% of these vehicles operates in GAMA. This over the period has contributed significantly to traffic congestion in Accra. This is evident in Ministry of Local Government and Rural Development (2021) studies where about 1.3 to 2.2 million vehicles and 7.1 to 11.2 million passengers travel through GAMA on daily basis. During daily peak hours, about 949,886 passengers and 150,000 vehicles are estimated to move through traffic intersections on average. As Doumbia et al. [21] reported, the increase in motorized transport in SSA cities is characterized by widespread use of over-age and poorly maintained second-hand vehicles which are associated with elevated levels $PM_{2.5}$ in ambient air. This contributed sharply to the annual mean $PM_{2.5}$ concentration between 2008 and 2015.

However, the observed decreasing trend in annual means $PM_{2.5}$ concentration between 2019 and 2022 can be attributed to policy decisions and legislation aim in pollution abatement. For instance, the passage and implementation of the Customs (Amendment) Act, 2020, (Act 1014) [12, 62] and Ghana Standard for Environment and Health Protection—Requirements for Motor Vehicle Emissions (GS 1219:2018) (Ghana Standard Authority, 2018). The Customs (Amendment) Act, 2020, (Act 1014) banned the importation of salvaged motor vehicles and motor vehicles not exceeding ten (10) years of age from date of manufacturing. The policy further imposes fines between 5 to 100% of the cost, insurance and freight (CIF) where the vehicle's age exceeds ten years [12]. The vehicle emission standard (GS 1219:2018) on the other hand specifies motor vehicle exhaust emissions requirements (Ghana Standard Authority, 2018) to improve ambient air quality by reducing vehicle pollution. As Ayetor et al. [12] and Boateng and Klopp [15] reported, such policy decisions contribute to the reduction in the number of used/overage vehicle imports. Large body of scientific research indicates that older diesel vehicles are major $PM_{2.5}$ emitters, for instance those without diesel particulate filters (DPFs) [11, 12]. This may have contributed to the reduction in mean $PM_{2.5}$ concentration especially in 2022 where the policies were enforced.

The observed decreasing trend in annual mean $PM_{2.5}$ concentration between 2019 and 2022 can partly be attributed to COVID-19 lockdown and restrictions. Studies in Accra showed a significant reduction in $PM_{2.5}$ pollution during the lockdown period [1],Agyemang [2]. Afotey et al. [1] investigated the impact of COVID-19 lockdown on $PM_{2.5}$ pollution arising from traffic emissions. The study showed that $PM_{2.5}$ concentrations decreased significantly from 45.5 to 82.4% compared to 2019 at roadside sites during the lockdown period. This is because the lockdown led to the decline in human mobility, and industrial and commercial activities which resulted in the reduction of motorized transport in Ghana. Scientific studies provide evidence of global decline of ambient air pollutants concentrations during the COVID-19 period in most urban areas. Masum and Pal [48] observed a 40% reduction in daily mean $PM_{2.5}$ concentrations during the COVID-19 restrictions compared to pre COVID-19 period in Bangladesh. Pardo Amaya and Samuel [61] noted 15% reduction in traffic flow patterns and $PM_{2.5}$ concentrations during the COVID-19 restrictions compared to 2018 and 2019 levels in Bogota, Colombia. This can affirm our findings of declining annual mean $PM_{2.5}$ concentration between 2019 and 2022.

Several studies have reported success stories chalked by many developed nations including Japan [33], UK, USA [28] through the use of stricter regulations to reduce sulphur levels in fuels as well as vehicular emissions in controlling atmospheric emissions. Similarly in Europe as Krzeszowiak [42] reported, vehicles with diesel engines that satisfy the EURO 4 standards emit PM which is 4 times lesser that vehicles manufactured before the regulation. The study findings indicate that the recent change in policy and regulations on low sulphur fuel, vehicle emissions and Ministry of Energy Clean energy initiative [32] can be attributed to decreasing $PM_{2.5}$ concentration between 2019 to 2022. Similar to our findings, studies in Tokyo, Japan have reported a decreasing trend in $PM_{2.5}$ concentration over 2 decades (1990–2010) in location with high traffic volumes with regulations targeted at reducing vehicular emissions [33]. Singh et al. [71] conducted a trend analysis $PM_{2.5}$ concentration for six years (2014–2019) for five megacities in India and observed a decreasing trend that differed significantly varying from 1.5 to 4.19 $\mu g/m^3$ (2–8%) per annum.

Table 8 shows that the annual mean $PM_{2.5}$ varied between 34.97 and 108.82 $\mu g/m^3$ for Commercial/Business Traffic Areas (CBTA), 26.1 and 141.54 $\mu g/m^3$ for High Density Traffic Areas (HDTA) and 24.11 and 34.99 $\mu g/m^3$ for Low Density Traffic Areas. The annual mean concentration of $PM_{2.5}$ at HDTA is consistently higher than that of CBTA and LDTA except in 2012, where CBTA recorded a 1.67% higher than HDTA. LDTA recorded the lowest mean annual concentration of $PM_{2.5}$ in all the sampled years. Statistical trend analysis using the Mann–Kendall test indicated a significant decreasing trend in annual mean $PM_{2.5}$ concentrations over the study period ($p < 0.01$). The magnitude of this trend, estimated by

Table 8 Annual mean concentration of $PM_{2.5}$ at traffic site by land-use category

Year	$PM_{2.5}$ µg/m^3 Traffic Site Type			Annual mean $PM_{2.5}$ Conc
	Commercial/Business Traffic Areas (n = 30)	High Density Traffic Areas (n = 24)	Low Density Traffic Area (n = 6)	
2006		29.83		29.83
2007	57	73	28	57.75
2008		26.1		26.1
2012	93.03	91.5		92.72
2013	108.82	128.1		116.05
2014	108.43	128.1		115.73
2015	94.78	141.54		116.60
2019	34.97	36.08	34.99	35.19
2020	37	40.00	30.22	33.53
2021			26.71	26.71
2022			24.11	24.11
Range	34.97–108.82	26.1–141.54	24.11–34.99	

Sen's slope, was approximately − 3.5 µg/m^3 per year. Linear regression analysis corroborated this finding, revealing a statistically significant negative relationship between year and $PM_{2.5}$ concentrations ($p < 0.05$, $R^2 = 0.65$). Overall, the results highlight a long-term decline in ambient $PM_{2.5}$ pollution in Accra. The maximum and minimum annual mean concentration of $PM_{2.5}$ for HDTA occurred in 2015 and 2008 respectively. This can be explained by the fact that the 2015 monitoring was sited along major road network [53] in Accra, whereas, the 2008 monitoring was located on a secondary road in Ashiaman [60]. The WHO annual AGQ of 5 µg/m3 was not met by the annual mean concentration of $PM_{2.5}$ at traffic site type, however, it is interesting to note that HDTA and CBTA exceeded the interim target IT-1 of 35 µg/m^3 by 88.87% and 85.71% respectively [79].

In Fig. 6, CBTA recorded the highest mean $PM_{2.5}$ concentration in 2013, a 90.92% increase from 2007 but decreased sharply by 67.87% in 2019. The HDTA also recorded the highest mean concentration of $PM_{2.5}$ in 2015, a 442.30% increase from 2008, however, decreased steadily by 74.51 in 2019. Traffic site by land-use category mean $PM_{2.5}$ concentration was associated with the monitoring year.

As demonstrated in Fig. 6, HDTA records the highest annual mean concentration of $PM_{2.5}$ over the study period, except for 2012. This severe $PM_{2.5}$ pollution trend can be linked to the location of the monitoring sites in high-density neighborhoods characterized by commercial and residential burning of solid fuels [7], poor road infrastructure, poorly maintained and overaged vehicles [5], lack of green space and high traffic volume. High density neighborhoods including Nima and James Town/Usher Town often have uncontrolled waste combustion, which contribute significantly to the decline in air quality [32]. According to Arku et al. [7], the primary energy source in more than 80% of HDTA homes is wood or charcoal. Moreover, cooking and roadside food vendors are predominant in these locations.

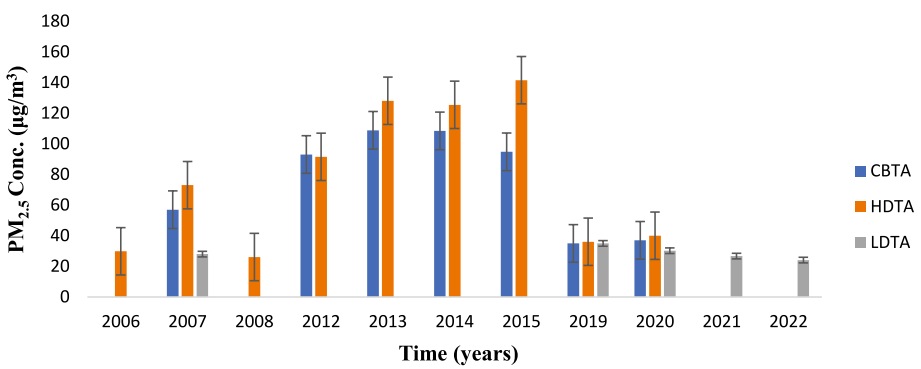


Fig. 6 Traffic site annual mean $PM_{2.5}$

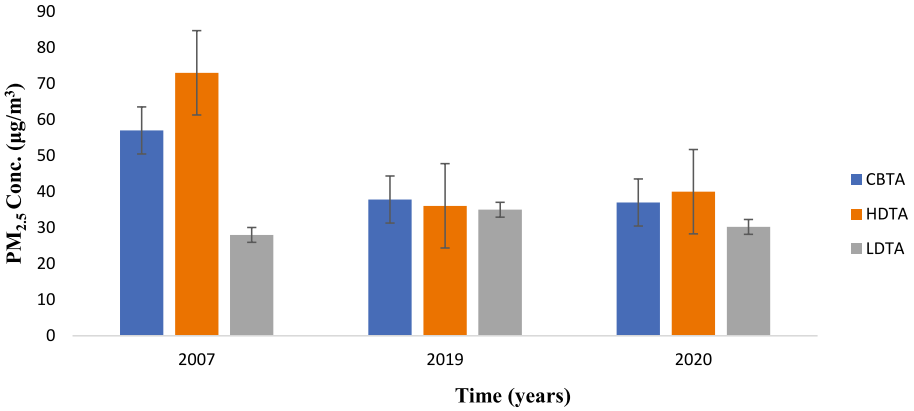


Fig. 7 Comparing mean $PM_{2.5}$ for traffic sites by Land-use category

In contrast, Low density traffic neighborhoods (LDTA) observed a lower $PM_{2.5}$ pollution trend. This trend can be attributed to the fact that LDTA including East Legon, Cantonment and Ridge have improved road network, presence of green space, use of low emission vehicles and medium traffic volume.

The Commercial Business Traffic Areas (CBTA) consistently recorded a higher $PM_{2.5}$ concentration due to their location in city centers predominantly commercial and trading centers together with government offices where the load of traffic is high. At CBTA, all types of vehicular fleets, thus high and low emission vehicles route through these locations resulting in increasing volume of traffic and eventually intensifying the emission of $PM_{2.5}$ concentration. A study presented by Ministry of Local Government and Rural Development (2021), estimated 1.3–2.2 million vehicles as the average daily traffic volume and 7.1–11.2 million passenger trip in GAMA. This contributes significantly to higher traffic volume in the city and thus increases $PM_{2.5}$ pollution in commercial/business traffic areas.

In Fig. 7, we present the mean concentration of $PM_{2.5}$ for the monitoring data of 2007, 2019 and 2020 that featured the three (3) traffic site types (HDTA, LDTA & CBTA). The mean concentration of $PM_{2.5}$ varied between 37 and 57 µg/m^3 for CBTA, 36.08 and 73 µg/m^3 for HDTA and 28 and 34.99 µg/m^3 for LDTA. Evaluating the change in $PM_{2.5}$ concentrations between 2019/2020 study [4, 5] and 2006/2007 study [19] in the traffic areas, an average reduction of 33.64% and 50.58% of mean concentration of $PM_{2.5}$ was recorded in CBTA and HDTA respectively, however, the LDTA recorded an average of 24.96% increase in the concentration of $PM_{2.5}$. The increase in $PM_{2.5}$ concentration at LDTA suggest that the neighbourhoods are significantly losing its urban greenspace to build and commercial infrastructure [4], as a result increase commercial activities in the LDTA. Urban greenspace is an effective strategy of mitigating and overcoming air pollution problems in cities [3].

4 Conclusion and recommendations

This review evaluates human exposure to $PM_{2.5}$ at densely populated traffic sites in Ghana, particularly in major traffic hotspots in Accra. Traffic emissions are noted as a major contributor to elevated $PM_{2.5}$ concentration levels in Accra. Our study revealed that between the years 2005 and 2022, the air quality conditions in Accra's traffic hotspots were unhealthy and did not meet international and national guidelines for air quality. Exposure to such pollution presents an intolerable health risk to the urban population, especially those who travel regularly, work or live at traffic hotspots or roadways at serious health risk due to the prolong exposure to high $PM_{2.5}$ pollution. This undermines Ghana's effort to achieving the Sustainable Development Goals targets 3.9, 11.6 and 11.6.2 of Goal 3 and 11 respectively, hence further action plans for environmental and health protection are required to safeguard the city population.

It is worth noting that while some improvements have been recorded in recent years in Ghana due to regulatory efforts and fuel quality improvements, ambient air pollution levels remain a significant concern. The study recommends the need for targeted interventions, including strict adherence to vehicle exhaust emission standard (GS 1219:2018), investment in clean transport, urban greening, national urban policy framework, and improvement in real-time air quality monitoring and reporting by the Environmental Protection Agency, Ghana. Promotion of public awareness and protective policies for vulnerable groups are also crucial in Ghana.

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Data availability All the data supporting the findings of this publication have been incorporated into the manuscript.

Declarations

Ethical approval and guidelines Not applicable.

Consent to participate Informed permission was not needed as there were no human subjects and/or animals involved in the study.

Consent to publish Not applicable.

Competing interests The authors declare no competing interests.

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