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AIR POLLUTION AND HEALTH: PARTICULATE MATTER $PM_{2.5}$ MEASUREMENTS IN CANTONMENTS, GHANA

Priscilla Adomako Gyasi[1*], Jesse Nii Okai Amu-Darko[2], Eliasu Issaka[3], Edwina Naa Amerley Amarteifio[1]

[1]*Department of Health Policy and Management, School of Management, Jiangsu University, Zhenjiang, 212013, PR China*

[2]*School of Materials Science and Engineering, Jiangsu University, Zhenjiang, 212013, PR China*

[3]*School of the Environment and Safety Engineering, Jiangsu University, Zhenjiang, 212013, PR China*

Corresponding Author

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ABSTRACT

Particulate matter (PM) air pollution research has improved our understanding of major pollution sources and the quantification of their impact. Although several PM studies have been conducted in Accra, Ghana, in recent decades, few have offered an integrated knowledge of PM sources in the various sub-cities. The purpose of this study was to consolidate data and investigate additional aspects of PM investigations of Cantonments, a residential neighborhood in Ghana's capital. There is evidence of poor air quality in Accra, particularly during the dry season (Harmattan season). From December through February, a severely dry, dusty easterly or north-easterly wind sweeps over the West African coast, causing Harmattan. The $PM_{2.5}$ concentrations for Cantonments for two years and the average monthly air quality indices were analysed and discussed. The results reveal the need to regularly check the daily air quality indices and curb their impacts since it has a notable health effect on the general public.

KEYWORDS: ***$PM_{2.5}$; Air pollution; Public health; Accra; Ghana***

I. INTRODUCTION

Particulate matter, or PM for short, refers to small particles in the air that, when inhaled, can cause major health issues. PM may be classified mostly as PM_1, $PM_{2.5}$, and PM_{10}, but a recent study has revealed another group, $PM_{0.1}$ [1]. $PM_{2.5}$ and PM_{10} are particulate matters with diameters less than 2.5 and 10 micrometres (μm) respectively. Reports suggest that $PM_{2.5}$ is by far the most harmful since it damages the lung cavity [2,3]. PM is composed of solid and liquid particles that are released into the atmosphere as a result of diesel usage, vehicle and agricultural dust, and construction emissions [4]. The structural, molecular, physical, and meteorological features of PM are diverse. It remains suspended in the air and pollutes it due to its size, density, heat conditions, and wind speed [5,6]. Primary PM: this includes soot produced directly into the atmosphere by industrial activities such as electricity-generating power plants, fuel vehicles, and private cars. And secondary PM: is formed in the atmosphere from primary gaseous pollutants like SO_2 and NO_2 gases [7].

According to the Global Burden of Disease (GBD) research, $PM_{2.5}$ causes 5 million deaths per year. Because of their size, they may amass more than PM_{10}, travel longer distances, get sluggish in the atmosphere, stay in the air longer, and disperse far [8]. The consequences have a detrimental impact on the well-being of humans and other living organisms and the ecosystem as a whole. Long-term exposure causes respiratory disorders [9,10], neonatal mortality [11], insomnia [12], age-related macular degeneration [13], and even malignancies of different types.

The city of Accra is the capital and also the largest in Ghana. Accra has a land area of 225.67 km^2 (87.13 sq mi) and a population of 4.2 million people as of 2020. It is divided into 12 local government districts: 11 municipal districts and the Accra Metropolitan District, which is the capital's sole district having city status [14]. Cantonments is an upper-middle-class neighbourhood of the city, in the La Dade-Kotopon Municipal District, in the Greater Accra Region of Ghana [15]. Several dignitaries in the nation, notably the American, Chinese, Norwegian, Mexican, and Bulgarian embassies, as well as Australian, Sierra Leone, and European Union high commissioners are located in the Cantonments area. Due to the nature of the settlement there, there are no known industrial activities there.

Conforming to the Ghana Living Standards Survey VI, approximately 51% of country homes use firewood, whereas roughly 27% use charcoal. This brings the entire ratio of families using dirty fuels to over 78 per cent, with LPG making for only 17 per cent of the total. More than half (52.5%) of Greater Accra Metropolitan Area (which includes Cantonments) households use charcoal, compared to only 27 per cent in other metropolitan areas around the country. In comparison, firewood is used by more than three-quarters (79%) of rural families, whereas LPG is used by only 4.2 per cent [16–18].

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Government and non-government air quality monitoring networks encourage data exchange through network engagement by the public. The Air World Quality Project, for example, gathers and publishes near real-time pollutant concentration estimates on a web-based public platform [19]. Under conventional modalities of knowledge creation, data-sharing activities shift the consumer from a passive recipient of air quality information to an integral role in the collection and distribution of air quality data [20]. The Environmental Protection Agency (EPA) in Ghana frequently analyzes and collects data on air quality. Accra has been one of the most reliable sources of long-term trends in air quality throughout time. However, EPA-Ghana has several challenges in acquiring this data, including funding constraints and malfunctioning equipment, but the current monitoring network has been started since 1997, with only minor interruptions. Furthermore, during the last twenty years, EPA-Ghana has conducted several specialized studies to assess air pollution in specific geographic areas or from specific sources [21].

EPA-Ghana began measuring the quality of air in Accra in 2011, and by 2015, 24 hr PM_{10} and $PM_{2.5}$ samples were being taken at about 10–11 roadside stations. Only monthly summaries were provided, and the majority of the $PM_{2.5}$ data was for 2015. The data from March to November (classified as non-Harmattan season) showed $PM_{2.5}$ levels at selected roadside sites namely South Industrial Area and Graphic Road were averaged at 82 $\mu g/m^3$ and 93 $\mu g/m^3$, and 88 $\mu g/m^3$ and 57 $\mu g/m^3$ for 2015 and 2017 respectively [22]. The EPA samplers utilized for taking these readings were positioned in cages about 5 meters above ground level with an interval of 3.5 meters away from building structures, trees, and other impediments, often within an arc of 270-360 degrees to allow unobstructed air passage.

Another study presented by Arku et al. [23] featured the measurement of two low-incomed suburbs 5 km from each other in Accra (Jamestown and Nima). In both communities, around 80% of homes utilize charcoal and/or wood as their major source of energy. The major highways and most local roads in both neighbourhoods are paved, however, there are some unpaved lanes. Street food cooking and selling are highly widespread in both places; practically they all utilize biomass fuels. The results reveal that average monthly PM_{10} levels in these two areas varied from 58 to 94 $\mu g/m^3$ and $PM_{2.5}$ levels ranged from 22 to 40 $\mu g/m^3$. The detected values in their study were compared with earlier short-term studies on the African continent, such as PM_{10} and $PM_{2.5}$ concentrations of 97 $\mu g/m^3$ and 86 $\mu g/m^3$ in South Africa. PM pollution is also prominent and intensively researched in other African nations along the Gulf of Guinea coast, including Benin, Nigeria, and Cote D'Ivoire [24].

Elevated air pollution emissions are expected to result in increased concentrations of particulate matter $PM_{2.5}$ in the Cantonments area and the city of Accra as a whole, with the average concentration above the suggested guideline limit of 15 $\mu g/m^3$ [25,26]. From December to March, the Harmattan winds (northeastern trade winds) carry dry air from the Sahara to the country, particularly the city of Accra. During dry seasons (Harmattan season), dust storms that reach deep into vicinities such as Cantonments predominate the contribution of Saharan dust to air pollution in the form of $PM_{2.5}$. As a result, $PM_{2.5}$ concentrations are quite high throughout this period. The study aims to determine the extent of particulate matter $PM_{2.5}$ concentrations in the selected Accra suburb (Cantonments) to aid in future planning to avoid a massive increase in $PM_{2.5}$. And also evaluate the efficacy of the action plans of the previous year.

II. GHANA'S ACTION PLAN INTERVENTIONS ON HEALTH AND AIR POLLUTION

Air pollution affects all and sundry; nevertheless, the poor seem to suffer the most. Intervention measures and investments in air quality control, including investments in waste management, walking and cycling, and green spaces promote clean air as well as generate important health and economic benefits and co-benefits. For Accra, according to WHO Urban Health Initiative, it is anticipated that health benefits, in terms of direct health care costs averted to the public health system and ill-health of people and the loss of income, and also mortality costs would well exceed the total investment costs of interventions to control all key sources of air pollution in the city – from transport to waste management [27]. As per Mr. Ebenezer Appah-Sampong (Deputy Executive Director/Technical Services of the EPA), the execution of measures leads to a progressive reduction in Accra's ambient particulate matter levels.

Ghana has been committed to aggressive actions related to Air Quality and Health and is acknowledged as the first country in the world to officially include Short-Lived Climate Pollutants (SLCPs) and other air pollutants into their fourth National Greenhouse Gas Inventory submitted to the United Nations Framework Convention on Climate Change (UNFCCC). The country has made progress through a series of ambitious national action plans to control and minimize health risks related to air pollutants. The main laws that govern air quality in Ghana are the Environmental Protection Agency Act 1994 (Act 490), and the Environmental Assessment Regulations 1999 (LI 1652), which focus on regulating industrial activities. In 2018, Ghana also made public the standards for Environment and Health Protection – thus Requirements for Ambient Air Quality and Point Source/Stack Emissions (GS 1236), and motor vehicle emissions (GS 1219) [28]. These planned actions, regulations, and legislation draw inspiration from Articles 36 (9) and 41 (k) of the National Constitution, which place the responsibility for environmental protection on both the government and the people.

The Environmental Protection Agency (EPA-Ghana) published the Air Quality Management Plan and associated communication plan for the Greater Accra Metropolitan Area (GAMA) to be adopted by the authorities. EPA- Ghana collaborated with the World Bank and the US-EPA) to deploy an enhanced air quality monitoring network, including improved data assessment and reporting. Thus according to them, if the city of Accra adopts a new Air Quality Management Plan, many lives might be spared each year from respiratory and cardiovascular illness, as well as asthma-

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related medical visits, in 2030 and beyond [29]. The action plan included proposals for stricter national emissions standards for vehicles and fuels, industry, and waste burning, along with ambient air quality levels. New Analyses also contributed to projecting future health burdens related to air pollution in the region and beyond. "Since 2015, the US-EPA has collaborated with the Ghana-EPA under the Megacity Partnership, establishing capacity to assess the effects of air pollution reduction measures. When these regulations become the basis of the Air Quality Management, they will considerably enhance the health of individuals living and working in Accra," as emphasized by the Head of Environmental Quality at Ghana EPA. However, some challenges persist with the Air Quality Management Plan. These challenges include inadequate funds and logistics for air quality monitoring, pollution-related health studies, education, and awareness creation by health stakeholders among others; damages to roadside air monitoring stations by vehicular accidents, construction works, and theft of portable monitoring equipment, and; poor electrical supplies to the stationary monitoring stations [30]. For the Air quality monitoring system, air quality is monitored although not in all areas of interest.

As pollution exposures and related illnesses become more prevalent, the Health and Pollution Action Plan (HPAP) was developed to aid governments in identifying, analyzing, and prioritizing current pollution concerns based on health implications. The HPAP also provided extensive information on the key causes of Ghana's pollution problems, as well as recommendations for minimizing their human health implications. A paradigm for addressing pollution was established, within which to pursue an organized approach jointly, following the route of national efforts to combat the issue. To maximize the utilization of resources, there is a need to do away with duplicating efforts, promoting the ability of monitoring and evaluate progress towards the impact of pollution on our health [31]. This habitually will boost the health of our human resources and enhance efforts to build an economically productive and ecologically sustainable society.

In 2016, the first-ever Megacity Partnership between the United States Environmental Protection Agency (EPA) and Ghana EPA presented how decision support tools, such as the BenMAP-CE software, could be utilized in diverse situations to assess the health liability of air pollution. Many of the most rapidly growing urban areas in developing countries experience an amount of health and climate influence from air pollution but have limited data, resources, and capacity to address it [32]. As a result, the Megacities Partnership was created to help selected nations in developing air quality management strategies that can be adopted across cities in Africa and other parts of the world. Many other African regions may learn from the Ghana EPA's model, which other developing-country cities can replicate for air quality control strategy.

One of the behaviours that contribute to poor air quality is uncontrolled waste combustion. The waste management regulation of 1991 governs the reduction of emissions from the open burning of agricultural or municipal garbage (outdoor). The formation of the Environmental Health and Sanitation Directorate (EHSD) resulted in the development of the National Environmental Sanitation Strategy and Action Plan (NESSAP) and the Strategic Environmental Sanitation Investment Plan (SESIP). Among other things, the National Environmental Sanitation Strategy and Action Plan (2010) is an action plan designed to reduce the open burning of municipal and/or agricultural trash and to promote revenue mobilisation. To further enhance the environmental quality of urban living, the National Urban Policy Framework and Action Plan (2012) was launched to highlight the necessity for vigorous public education and legal enforcement against repugnant public attitudes and behaviour that contribute to environmental degradation. These implementations are believed to be steps in the right direction, but the problem persists, particularly in rural regions.

Air quality monitoring in Ghana is frequently confined to a few areas, most of which are in Accra. The Environmental Protection Agencies (EPA) are under-resourced, with employees lacking the necessary technical know-how for air quality monitoring. Aside from that, data collected by the EPA is frequently inaccessible to the public, making it difficult to conduct meaningful air pollution research and hampering the impartial evaluation of air pollution management policies [33]. Various researchers have highlighted that low-cost sensors might be an ideal chance to overcome the air pollution data gap [34]. In light of this, the Ghana Urban Air Quality Project (GHAir) was founded in May 2019 with the overarching purpose of closing Ghana's air pollution data and epidemiologic study gap. This initiative has currently installed low-cost sensors, a combination of PurpleAir sensors, Clarity nodes, RAMPs, and Modulair-PM, in five Ghanaian metropolitan areas [35]. Through these deployments, the initiative has established significant cooperation with metropolitan authorities, particularly the Accra Metropolitan Assembly (AMA).

Indoor air pollution is among the world's major environmental concerns – predominantly for the deprived population in the world who often do not have access to clean fuels for cooking. From the GBD study, 2.31 million deaths were accredited to indoor pollution [36]. Generally, some Ghanaians depend on biomass sources, particularly wood fuels and charcoal, for household needs (cooking, space heating, etc.). Government statistics place biomass fuel consumption at slightly more than 60% of total energy consumption in Ghana [37]. Air pollution from indoor sources is the single largest contributor to the negative health effects of air pollution in Ghana. There has not been a policy for indoor air pollution regulated but various interventions including the introduction of a newly improved clean stove; promotion of the use of liquefied petroleum gas (LPG) and subsidized LPG cylinders for rural areas have been put in place [38]. However, in 2012, Ghana made plans for significant programmes to extend access to LPG in both rural and urban regions. Ghana's Ministry of Energy launched the "Rural LPG Program" which provided free cookstoves and discounted gas to rural populations was launched by the Ministry of Energy subsequently [39]. All these intervention measures have realistically achievable objectives to control and minimize if not eradicate the current situation

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concerning health-related risks associated with air pollution. As emphasized earlier, the burden relies not only on the state but also on the cooperation of the citizens.

The Gyapa project which was initiated in 2002 is one of the longest-running cookstove programmes. The initiative which began in Accra and Kumasi, aimed to reduce smoke and PM levels in urban and rural homes by building a sustainable supply chain for better cookstoves and raising awareness of the health concerns caused by air pollution. Gyapa which means good fire in the Akan dialect (One of the Ghanaian languages) is similar to the Rocket stove concept but has a ceramic liner. The ceramic liner is made from a proprietary composition that combines many clays and binders to improve heat retention, fuel economy, durability, and lightweight. According to the project partners, air quality increased by 40 to 45 %, and children under the age of five were 25 % less likely to die from respiratory disorders [40–44].

III. MATERIALS AND METHODS

Cantonments was selected for this study due to recent high levels of PM concentrations observed from real-time monitoring systems. The area is known to have a lot of government offices, diplomatic offices, schools and homes for various expatriates. There are little or no industrial activities in that environment to make up for the high levels of pollution in the area, especially outside the Harmattan seasons. Figure 1 (a) is the map of Ghana with Accra located in the south. Within Accra, the suburb of Cantonments is enlarged in Fig 1 (b-c) showing both spacial and satellite images. The physical sensors have been reported to have proximity to the United States embassy in the vicinity. The city has a dry equatorial climate with two rainy seasons all year. The first season runs from May to mid-July, while the second runs from mid-August to October. It has the lowest annual rainfall in the country, with an average of 730mm. The relative humidity level is often high, ranging from 65% during the day and 95% at night. The temperature varies just significantly throughout the year. With an annual average temperature of 26.8°C, the monthly average temperature ranges from 24.7°C in August (the coldest month) to 33°C in March (the warmest month) [45]. Data on the $PM_{2.5}$ concentrations for Cantonments were obtained from the online platforms of The World Air Quality Project's website (https://aqicn.org/data-platform/register/). The historical data spans from April 2020 to August 2022. The collected data were compiled and analysed for usage with OriginPro and Microsoft Excel.

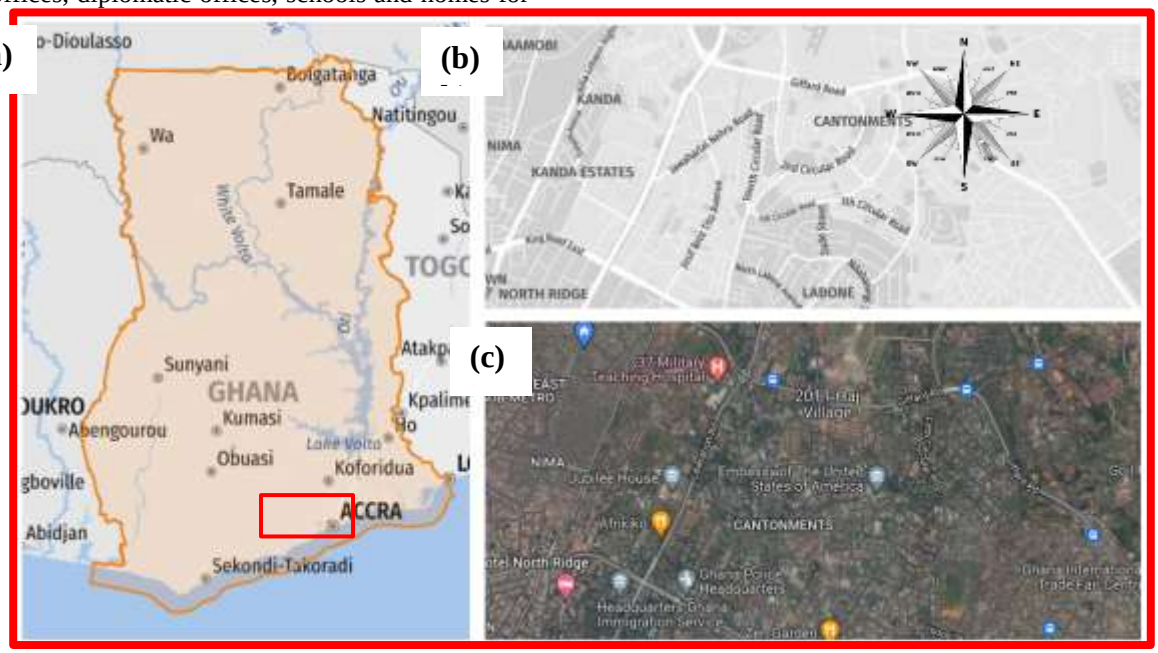

Figure 1 (a)The location of Accra on the map of Ghana (Generated from Mapz.com); (b) Map of Cantonments (c) Google map satellite images of Cantonments.

IV. RESULTS AND DISCUSSION

The PM values are usually very high during the Harmattan season. Figure 2(a) is the real-time air quality index (AQI) measurements from four stations in the city of Accra as 204, 169, 184, and 183 $\mu g/m^3$ for Cantonments, Dzorwulu intersection, Roman Ridge, and Tetteh Quarshie Interchange respectively on the 21st January 2022. The selected date was significant because the Harmattan winds arrived in the city on the said day. The figures are quite alarming showing increases which are about twice the values in just one week. Cantonments is within a very unhealthy region and this is appalling for adults and children with asthma or other respiratory diseases. The results from the other stations were within the unhealthy region which is also quite baleful. These values change on daily basis and it's solely dependent on the recent levels of pollutants detected by the devices in the various measuring stations. Figure 2(b) gives us the summary of the monthly readings from 2020 to 2022 at the Cantonments measuring station. This information obtained from the Air Quality Historical Data Platform showed an increasing trend in the levels of air pollution within 2 years. These data also confirm the fact that October and May are the cleanest months of the year in the locality. Conversely, the poor air quality measured between December and March is general for the

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harmattan season [46]. This confirms the findings by Dionisio et al in 2010 [47]. Comparatively, December 2021 had higher levels than December 2020. Reports suggest 2020 has low levels due to COVID-19 lockdowns and restrictions which minimized major vehicular movements [48–51]. The colour codes on the World Air Quality Project's online platform represent lighted colours for good or fair quality and dim colours for very unhealthy and hazardous respectively. The first colour represents "good" and spans from 0 to 50, and the pollution level is deemed to pose little or no harm. The air quality range of 51 – 100 is satisfactory but may pose a moderate health risk to a very limited number of individuals who are extremely sensitive to these pollutants. People with a history of respiratory disorders are usually advised to restrict their time spent outdoors for an extended period. The average person is unlikely to be affected between the range of 101 – 150. But some sensitive groups may suffer from health consequences. In addition, the "unhealthy" and "very unhealthy" ranges are denoted by bright red and purple colours that can be felt strongly between 151 – 200 and 201 – 300 respectively. The last group includes air quality indices exceeding 300, which are extremely dangerous for the whole population, regardless of past health issues. The various ranges can be categorised as A,B,C,D,E and F for the intervals 0-50, 51-100, 101-150, 151-200,201-300 and ≥300 respectively as depicted in Table 1. The table summarises the average montly values during the period of the study.

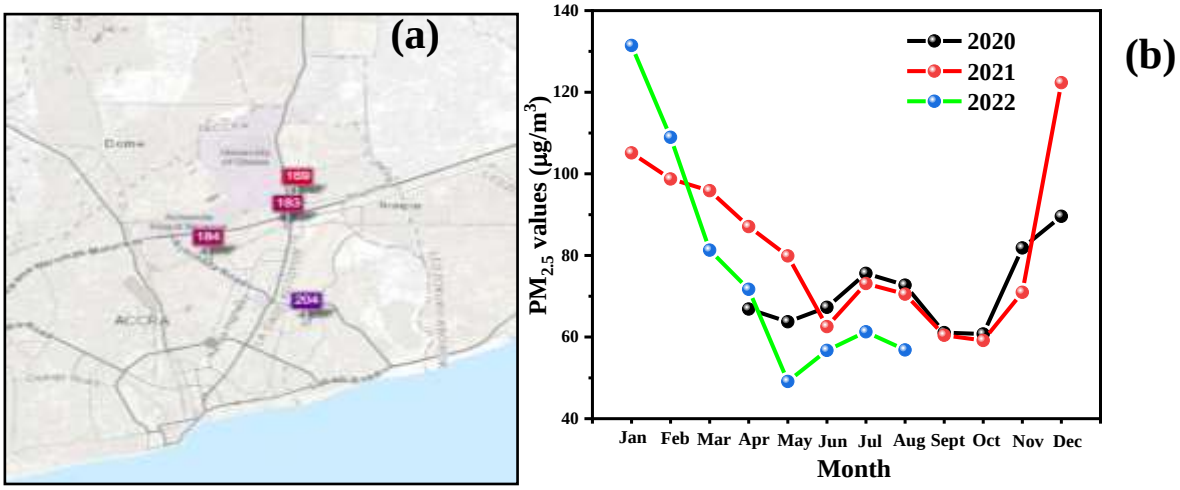

Figure 2. (a) Real-time Air Quality Index of Cantonments and Dzorwulu intersection, Roman Ridge, and Tetteh Quarshie Interchange (Ghana Urban Air Quality Project); (b) Average monthly $PM_{2.5}$ measurements for Cantonments from 2020 to 2022.

Table 1 Average monthly $PM_{2.5}$ measurements for Cantonments from April 2020 to August 2022 and their various air quality categories.

Month	2020	Category	2021	Category	2022	Category
Jan	-	-	105.13	D	131.45	E
Feb	-	-	98.74	C	108.94	D
Mar	-	-	95.87	C	81.29	C
Apr	66.87	B	87.06	C	71.71	D
May	63.74	B	79.87	C	49.10	A
Jun	67.29	B	62.55	B	56.74	B
Jul	75.61	C	73.13	B	61.29	B
Aug	72.71	B	70.50	B	56.84	B
Sept	61.10	B	60.45	B	-	-
Oct	60.74	B	59.16	B	-	-
Nov	81.84	C	70.97	B	-	-
Dec	89.58	C	122.35	C	-	-

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The historical data for the other stations in Fig. 2(a) were inaccessible from the online platform. This limitation hindered the long-term comparison, which can be very informative to ascertain the main levels of the other stations all year round. The data for the pollutants such as NO_2, CO and CO_2 were also unavailable. Obtaining this information in the future can be a driving force to also identify the main activities that make Cantonments quite higher than the others during the harmattan season. Figure 3 gives the detail of the daily $PM_{2.5}$ measurements taken from April 2020 to August 2022. This confirms the earlier mentioned observation that December, January and February have the highest readings all year round. The daily readings for January and February recorded ≥200 μg/m^3. This must have been very uncomfortable and unhealthy for people with various respiratory conditions.

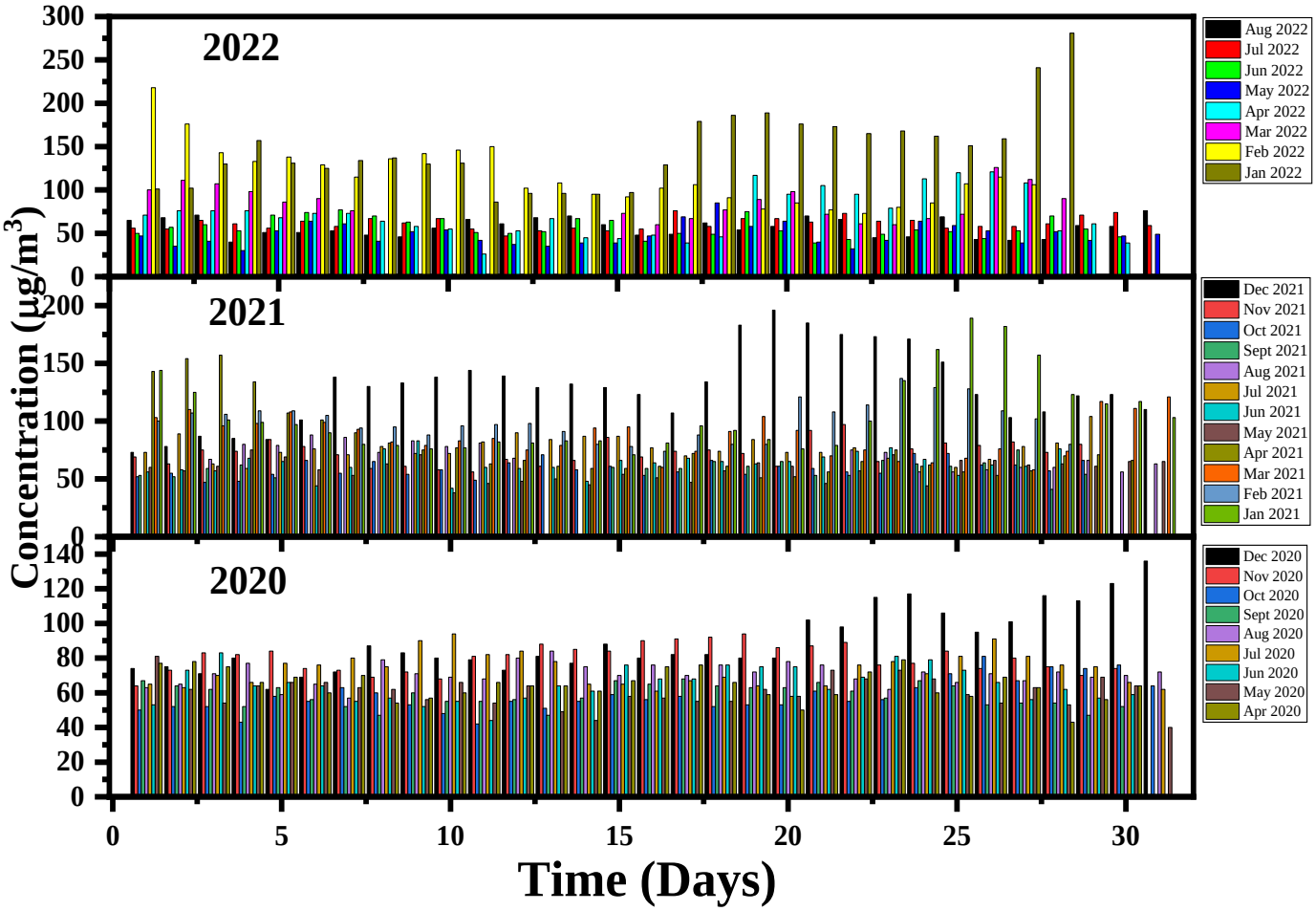

Figure 3. Daily PM2.5 concentrations r for the monitoring station in Cantonments from 2020 to 2022

V. CONCLUSIONS

There is no dispute that $PM_{2.5}$ has become a major source of air pollution in many fast-growing cities. $PM_{2.5}$ not just to pollutes the environment, but also affects public health. Over the last few years, there has been a significant increase in the level of pollutants in the city of Accra, which has had a direct impact on the country's air quality. From the real-time historical data taken for Cantonments, there was an increase in the highest recorded average monthly values: 89.58 – December 2020 and 122.35 – December 2021, and 105.13 – January 2021, 131.45 – January 2022 respectively just for a small portion of a residential area in the city. Many studies that investigated a link found strong and substantial evidence between outdoor ambient air pollution, particularly PM in outdoor air, and ill health and death. Overall, we know that low- to medium equipment, as well as good maintenance and an emphasis on identifying local sources, may be utilized to define further increases in PM levels in complex industrial and urban regions. Such initiatives can resolve the lack of information on air quality in vicinities in Accra, where pollution levels frequently exceed air quality standards. The deductions from this study which stipulate the levels of $PM_{2.5}$ in Cantonments, also provide substantial support for policymakers as a useful instrument for better understanding and aiming to maximize further action plans for the environment and the development of the country as a whole.

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Adomako Gyasi and Edwina Naa Amerley Amarteifio; Supervision: Priscilla Adomako Gyasi and Jesse Nii Okai Amu-Darko; Writing: Priscilla Adomako Gyasi and Jesse Nii Okai Amu-Darko; Review and Editing: Priscilla Adomako Gyasi, Jesse Nii Okai Amu-Darko, Eliasu Issaka and Edwina Naa Amerley Amarteifio.

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Conflicts of Interest The authors declare no competing interests.

Compliance with ethical standards

Research involving human participants and/or animals No human participants or animals were involved in this research.

Informed consent No human participants or animals were involved in this research

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