Research article

Trends of Particulate Matter $PM_{2.5}$ and PM_{10} Concentrations in Dar es Salaam City Between 2021 and 2022

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Abstract

As many African countries transition to lower middle-income status, there are growing threats to air quality due to rapid development of industrial sectors, increasing urbanization, population growth and motorization. Preliminary air pollution data from a few monitoring networks in African countries indicate elevated levels for daily average concentration of $PM_{2.5}$ and PM_{10} which far exceed the World Health Organization guidelines of 15 μg/m³ and 45 μg/m³ for 24-hour observations. In this study, we explored the concentration levels of $PM_{2.5}$ and PM_{10} in Dar es Salaam city using data recorded by city's first real time network of air sensors between May 2021 and February 2022. The air sensors were strategically installed at various locations based on their primary activity: traffic-heavy areas (DIT, DMDP Magomeni, Makuburi, and Mlimani City), industrial zones (Vingunguti PR School, Buza, Temeke DMDP, Temeke Municipal), residential areas with low traffic volumes (Madale, Kigamboni Municipal, Vijibweni Hospital, Sinza Hospital, Ubungo Municipal), and a landfill site (Pugu Dampo). The results for observations of daily concentrations of $PM_{2.5}$ and PM_{10} based on the activity of the site were: traffic sites, concentrations ranged from 3.39 μg/m³ to 84.84 μg/m³ and 4.03 μg/m³ to 127.3 μg/m³, respectively; industrial sites, concentrations ranged from 7.25 μg/m³ to 89.1 μg/m³ and 9.72 μg/m³ to 116 μg/m³, respectively; residential sites, concentrations ranged from 2.03 μg/m³ to 60.99 μg/m³, and 2.62 μg/m³ to 66 μg/m³, respectively; and landfill site, concentrations ranged from 8.03 μg/m³ to 1008 μg/m³, and 9.96 μg/m³ to 2762 μg/m³, respectively. In general, the highest concentrations were observed at the landfill site (Pugu Dampo) followed by industrial (Vingunguti PR), traffic (DMDP Magomeni), and lowest concentrations were observed at residential site (Kigamboni). These findings indicate that the population living in the monitored areas may be at increased health risk based on the relatively poor air quality. It is recommended that the National Environmental Management Council (NEMC), as the responsible regulatory and enforcement agency in Tanzania, develop a robust monitoring mechanism, strengthen regulations and enforce compliance. Furthermore, we propose a nationwide awareness campaign on solid waste management plans to ensure a safe environment, as well as reduce particulate matters in the cities.

Keywords

Particulate matter ($PM_{2.5}$ and PM_{10}); Air pollution; Air quality; Air sensor, Tanzania

Introduction

Air pollution affects all regions of the world, but populations in low and middle-income countries are the most impacted (WHO, 2021, 2022). According to the latest air quality database, 97% of cities in low- and middle- income countries with more than 100,000 inhabitants do not meet WHO air quality guidelines (Gordon et al., 2014; Bachwenkis et al., 2021; Mboera et al., 2016). As air quality declines, the risk of stroke, heart disease, lung cancer, and chronic and acute respiratory diseases, including asthma, increases for the people who live in them. The global air pollution crisis in urban areas is a major issue that is currently threatening our planet with its several adverse effects on human health (WHO, 2021; 2022).

Tanzania is currently lower middle-income country economically, and thus is rapidly developing its industry and exploiting natural resources to improve economic stability. These development activities are inevitably accompanied by pollutant emissions and thus leading to deterioration of air quality (URT-VPO, 2022; 2019). According to the National Environmental Management Council (NEMC), emissions particularly of Sulphur oxides (SO_x), Nitrogen oxides (NO_x), as well as particulate matter ($PM_{2.5}$ and PM_{10}) concentrations are increasing in Tanzanian cities but are not currently monitored (URT-VPO, 2022, 2019; World Bank Group. 2019, UNIDO 2019). Environmental related pollution complains from the public from 2019 to 2022, show that Dar es Salaam accounts for 88% of air pollution incidents, while Dodoma, Mwanza, Arusha, and Mbeya account for 2 to 4% (URT-VPO, 2022; 2019). Dar es Salaam's resident's complaints regarding noise and air pollution are prevalent due to urbanization, industrialization, and the proximity of polluting facilities such as dumpsites to population settlements (URT-VPO, 2019). According to the Final Energy Report for Tanzania of 2018, only 34% of electricity production in Tanzania is from the clean source (hydroelectric power plant) and the rest come from biofuels (solid biofuels), oil and gas (Netherlands Enterprise Agency, 2018). There is widespread use of solid biomass fuels (such as charcoal and fuelwood) for cooking and Dar es Salaam city accounts for approximately half of Tanzania's total annual consumption of charcoal (URT-VPO, 2022, 2019). With the current Tanzanian population of 61 million of which 7.3 million are in Dar es Salaam city, the reliance on energy sources such as charcoal and fuelwood is expected to grow, thus contributing to increases in air pollutants in city. Apart from pollutants from energy use, the city is dominated by congestion of heavily polluting vehicles where, high quantity of pollutants like carbon monoxide (CO), NOx, and PM are released (URT- HPAP, 2019).

Studies conducted for analyzing traffic congestion in Dar es Salaam city, found the existence of traffic congestion especially during the peak hours of the mornings and evenings (Kiunsi, 2013, and JICA 2007 and 2017). Also, the studies found that the congestion problems were more critical in all major road intersections like at Ubungo (Mandela/Morogoro roads), Magomeni (Morogoro/Kawawa roads), Old Bagamoyo at Mwenge and Nelson Mandela road at Tabata and Buguruni intersection (Kiunsi, 2013, and JICA 2007 and 2017). Dasgupta et al., 2021, studies of traffic congestion in Dar es Salaam city using satellite data, found that driving on primary roads was much faster on Sunday, the least congested day, and somewhat faster on Saturday. Also, the study found that, on weekdays the city experienced traffic jams during the morning and evening rush hours, and with major traffic jam peaks during midnight.

Few studies on air pollution have been conducted in Tanzania via discrete sampling techniques at traffic sites (roadside, road junction, and bus stations), industrial sites, residential, and landfill and their results showed that measured air pollutants were above the WHO recommended values in Dar es Salaam city (Dasgupta et al., 2021, Njee et al., 2016, Jackson, 2009, 2005; Othman, 2010; Ndambuki and Rwanga. 2008; Nkoma and Maenhaut, 2010; Robert et al., 2016; Nkoma et al., 2010).

Figure 1: *Location of Study area*

Other studies have linked poor air quality in Tanzania to acute respiratory infections in children, Chronic obstructive pulmonary disease, Infant Mortality, and respiratory disease mortality (Mboera et al., 2018, Mboera et al., 2019; Kishamawe et al., 2019; Bwana et al., 2019; Ndumwa et al., 2022). Apart from these studies, air pollution control in Tanzania still receives less attention as compared to other environmental issues such as deforestation and water pollution (URT-VPO, 2022; 2019).

Tanzania enacted Environmental Management Regulations of 2007 (Air Quality Standards) that regulate air pollution related issues in Tanzania (URT-VPO, 2022; 2019). The government has implemented projects like Bus Rapid Transit (BRT) system in Dar es Salaam city and Standard Gauge Railway (SGR) from Dar es Salaam to Mwanza to reduce emissions associated with transport sector. The government has also signed several global initiatives to reduce air pollution, among others, the Eastern African Regional Framework Agreement on Air Pollution (Nairobi Agreement, 2008), and the Clean Air Initiative of Sub-Saharan Africa, but concrete action remains limited due to insufficient knowledge about air pollution sources and lack of real-time monitoring (URT- HPAP, 2019; URT-VPO, 2022; 2019). Real time monitoring of air pollution in cities can help to identify the pollution hotspots and track temporal and spatial variations (Hodoli et al., 2021). Air quality data are critical in guiding the policy making and formulating the adequate response and need to address the challenges caused by poor air quality in Tanzania. The objective of this study was to collect baseline data of particulate matter ($PM_{2.5}$ and PM_{10}) across Dar es Salaam. Additionally, to evaluate the 24-hourly average levels of $PM_{2.5}$ and PM_{10} concentrations in Dar es Salaam municipalities with respect to the WHO health risks standards.

Materials and Methods

Description of Study area

Dar es Salaam city (Figure 1) with the population of about 7.4 million, is the commercial capital of Tanzania located along the coast of the Indian Ocean in East Africa. Geographically, it is found between latitudes of 3.36° and 7.00°S and longitudes of 33.3° and 39.0°E. The climate is tropical-coastal, with a mean annual temperature of 26°C, while the average humidity varies between 96% in the morning and 67% in the afternoon. The average annual rainfall of 1100 mm falls mainly in the periods of November to December (short rains) and March to May (long rains).

As the commercial and industrial capital of the country, Dar es Salaam hosts a much higher concentration of trade, services and manufacturing. Administratively, Dar es Salaam city is divided into five municipals: Kinondoni, Ilala, Ubungo, Temeke and Kigamboni (Figure 1). Dar es Salaam city development is partially influenced by the arterial road network consisting of five main radial roads and one ring road all terminating in the Central Business District of Ilala. The five radial roads are Kilwa, Nyerere, Morogoro and New and Old Bagamoyo and the main ring road is the Mandela. These roads are heavily trafficked, with persistent traffic jams most of the day. Mandela Road is the main road for trucks transporting goods between the Dar es Salaam Harbour port and the industrial areas, thus it constitutes a significant part of the traffic, and with the combination of the frequent stop and start mode of the congested traffic, the age and heavy loading of most of the trucks causes large emissions of black diesel smoke. Generally, many roads in the city have very high volume/capacity ratio of cars and many intersections are heavily affected with traffic jams.

Data Sampling Network

PurpleAir monitors were placed at fourteen (14) recording sites across Dar es Salaam city to measure concentrations of particulate matter ($PM_{2.5}$ and PM_{10}) as listed in Table 1 and mapped in Figure 2.

The fourteen air quality stations according to their categories are: Traffic stations (DIT, DMDP Magomeni, Makuburi, and Mlimani City), industrial type (Vingunguti PR school, Buza, Temeke DMDP, Temeke Municipal), residential with low traffic volumes (Madale, Kigamboni Municipal, Vijibweni Hospital, Sinza Hospital, Ubungo Municipal), and Landfill (Pugu Dampo).

The Purple Air PA-II PM Monitor

The air sensor, PurpleAir PA-II is used for the measurement of PM across Dar es Salaam city air quality network. PA-II unit incorporates two Plantower PMS5003 laser optical particle counter (OPC) sensors, which operate by detecting particles as they pass through a laser beam. The particles scatter the laser light based on their size and composition, and this scattered light is captured by a photodetector. The sensor then processes this information using an internal algorithm to estimate the mass concentrations of PM1.0, $PM_{2.5}$, and PM_{10} in micrograms per cubic meter ($\mu g/m^3$). The dual-sensor setup allows for redundancy and cross-verification of measurements, improving the reliability and accuracy of the data collected. The PurpleAir PA-II, also incorporate a Bosch BME280 sensor to estimate temperature and relative humidity. Measured data are recorded on built-in SD card and transmitted via wireless connectivity in real time to PurpleAir database where there are made available for downloads.

Table 1: *Station location ID and Data recording information*

Latitude	Longitude	Station Name	Station ID	Data Points	No. Days Covered
-6.81756	39.28484	Ilala Municipal Office	IL	225	225
-6.85821	39.33384	Vijibweni Hospital	VH	262	262
-6.79087	39.22108	Makuburi Ward Office	Mk	294	294
-6.89192	39.2316	Buza Hospital	BH	286	286
-6.77423	39.21911	Mlimani City	MT	294	294
-6.88663	39.38959	Kigamboni Municipal	KM	273	273
-6.85728	39.26333	Temeke Office	TO	233	233
-6.78887	39.15926	Ubungo Municipal	UM	294	294
-6.78906	39.23956	Sinza Hospital	SH	288	288
-6.80591	39.24623	Magomeni DMDP	MG	202	202
-6.93258	39.12083	Pugu Dampo	PD	279	279
-6.84822	39.22459	Vingunguti PR School	VP	289	289
-6.65815	39.19664	Kondo Secondary	KS	215	215
-6.85484	39.26885	Temeke Municipal	TM	234	234
-6.74115	39.15826	Madale	MD	215	215
-6.814	39.2711	DIT	DT	225	225

Figure 2: *Air quality monitoring stations sites. PD = Pugu Dampo, BH = Buza Hospital, TM = Temeke Municipal, VH = Vijibweni Hospital, KM = Kigamboni Municipal, VP = Vingunguti Primary School, MG = DMDP Magomeni, SH = Sinza Hospital, MK = Makuburi, MT = Mlimani City, UM = Ubungo Municipal, DT= DIT, IL= Ilala Municipal*

Statistical Analysis

To ensure quality control and assurance of the raw data collected from PurpleAir sensors, data points with missing (NaN) or negative values were excluded from the analysis. Additionally, observations were removed when discrepancies between Channel A and Channel B readings exceeded 40 µg/m^3 for either $PM_{2.5}$ or PM_{10}, which could indicate localized pollution events. These anomalies were attributed to transient, nearby sources such as old diesel vehicles, open fires, barbecues, or other localized emissions, especially given the proximity of monitoring sites to busy roads and residential areas.

The raw PurpleAir outputs data were converted to average hourly, daily, and monthly timescales using Python script. For establishing the temporal variability of $PM_{2.5}$ and PM_{10} concentrations across the city, hourly recorded data were randomly selected for analysis to cover week days, weekend days and holidays for traffic, industrial, resident and landfill categories of stations. For establishing trends between Municipals as well as within Municipals, the daily concentrations of $PM_{2.5}$ and PM_{10} were compared among the fourteen stations across the city. Further, the observed daily average concentrations of $PM_{2.5}$ and PM_{10} were compared to the 24- hour average limit stipulated by the WHO standards, of 15 µg/m^3 for $PM_{2.5}$ and 45 µg/m^3 for PM_{10} (WHO, 2021, 2022). For seasonal variation analysis, monthly data were used to identify trends of $PM_{2.5}$ and PM_{10} concentration between wet and dry seasons.

Results

Hourly (Temporal) Variability of $PM_{2.5}$ and PM_{10} concentrations across Dar es Salaam city

Results for hourly variations of PM concentrations recorded between May 2021 and February 2022, showed highest level between 18:00 to 21:00 Hours and lower concentrations between 00:00 to 06:00 Hrs (Figure 3).

Figure 3a and 3b, showed increased PM concentration though in different proportions, between 17:00 to 21:00 Hrs during week days and weekends. Lowest PM concentrations were observed by all selected stations between 3:00 and 6:00, on holiday (Figure 3c). Lower PM concentration on holidays can be attributed to the low human activity related to traffic and industry in holidays, which are the main source of emissions of PM in cities.

Results for trends of hourly PM concentrations for Traffic, Industrial, and residential stations for randomly selected days of week (week day, weekend and holiday), showed higher levels for traffic and industrial station between 17:00 to 22:00 Hrs for week days and weekends and lower levels for all station categories on holiday (Figure 4).

Larger increases of PM concentrations around 17:00 to 23:00 are observed for sampled week day and weekend day (Figure 4.1(a), Figure 4.1(b), Figure 4.2(a), and Figure 4.2(b)) for traffic and industrial stations. For week day and weekend, residential stations also shows a small increases of PM concentrations around 6:00 to12:00, and 18:00 to 21:00 for all sampled days, (Figure 4.1(c) and 4.2(c)).

For holiday observations (Figure 4.3), a general decrease of PM concentrations is observed for all stations. Although traffic still shows higher values than other stations, all stations shows increased level of PM concentrations 06:00 to 09:00 Hrs, and 18:00 to 21:00 Hrs. Therefore, the traffic and industrial activities in Dar es Salaam City are the major contributing source of pollution, because on holiday where the traffics and industrial activities are minimal, there are also corresponding reduced observed PM concentrations.

Pugu Dampo (landfill site) station observations of PM concentrations were very high for observation between August and November 2021 (Figure 5). Unlike other stations, large increases of PM concentrations for Pugu Dampo station were observed 03:00 to 15:00 Hrs for week day and weekend day, while small increases of PM were also observed at the same time on holidays (Figure 5).

For November 4, and November 7, 2021, observed hourly concentrations levels of $PM_{2.5}$ and PM_{10}, were above 100 µg/m^3, between 03:00 and 15:00 Hrs. For December 25, 2021, observed level of $PM_{2.5}$ and PM_{10} were, 44.92 µg/m^3 and 59.29 µg/m^3, respectively.

The reason of increased pollutants concentrations as shown in Figure 5, were associated with open burning that erupted between August and November 2021 at Pugu Kinyamwezi dumpsite.

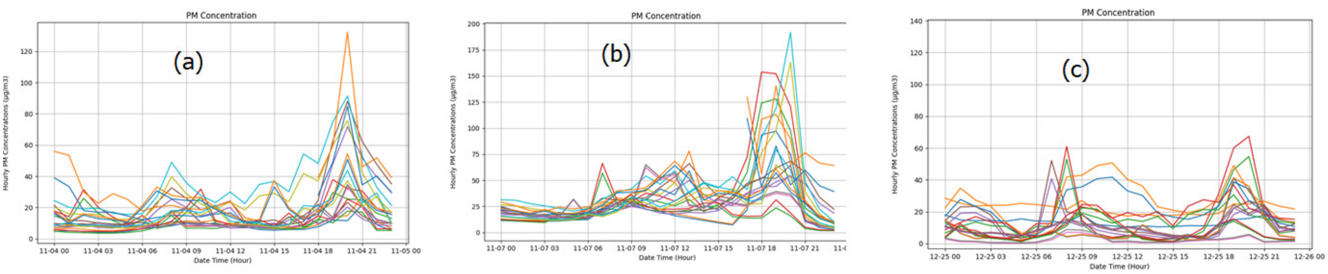

Figure 3: *Comparisons of Hourly PM concentrations for three randomly selected days showing highest PM concentrations between 17:00 to 21:00 Hrs: (a) week day (b) week end (c) Holiday.*

Comparisons of Daily $PM_{2.5}$ and PM_{10} Observation according to station categories

The results of observed daily concentrations of $PM_{2.5}$ and PM_{10} at the fourteen stations between May 2021 and February 2022, showed higher levels between May 2021 and Augast 2021 for all categories of stations, with exceptionaly higher values from the Pugu Dampo station, as shown in Figure 6.

Generally, all observation shows PM concentrations that exceed the WHO limits, with $PM_{2.5}$ concentrations being exceeded more than that of PM_{10} for all stations.

Comparisons of measured daily concentrations of $PM_{2.5}$ and PM_{10} by Municipals, showed Kinondoni and Ilala municipals which are concentrated with businesses and hosts most industries to be with higher levels of PM at all times as compared to Kigamboni municipal which is mostly residential in nature (Figure 7).

The lowest daily $PM_{2.5}$ concentrations (11.79 µg/m^3) and PM_{10} concentrations (14.23 µg/m^3), were observed at Kigamboni (residential) station in Kigamboni Municipal. The highest $PM_{2.5}$ concentration (89.1 µg/m^3) was observed at Vingunguti PR school (industrial) station in Ilala Municipal, while the highest PM_{10} concentration (127.3 µg/m^3), was observed at DMDP Magomeni (traffic) station in Kinondoni Municipal.

Kigamboni Municipal observed daily mean concentrations of $PM_{2.5}$ and PM_{10} ranging from 11.79 µg/m^3 to 20.28 µg/m^3 and 14.23 µg/m^3 to 27.76 µg/m^3, respectively; Ilala Municipal daily mean concentrations of $PM_{2.5}$ and PM_{10} ranged from 18.97 µg/m^3 to 35.35 µg/m^3 and from 23.15 µg/m^3 to 47.9 µg/m^3,

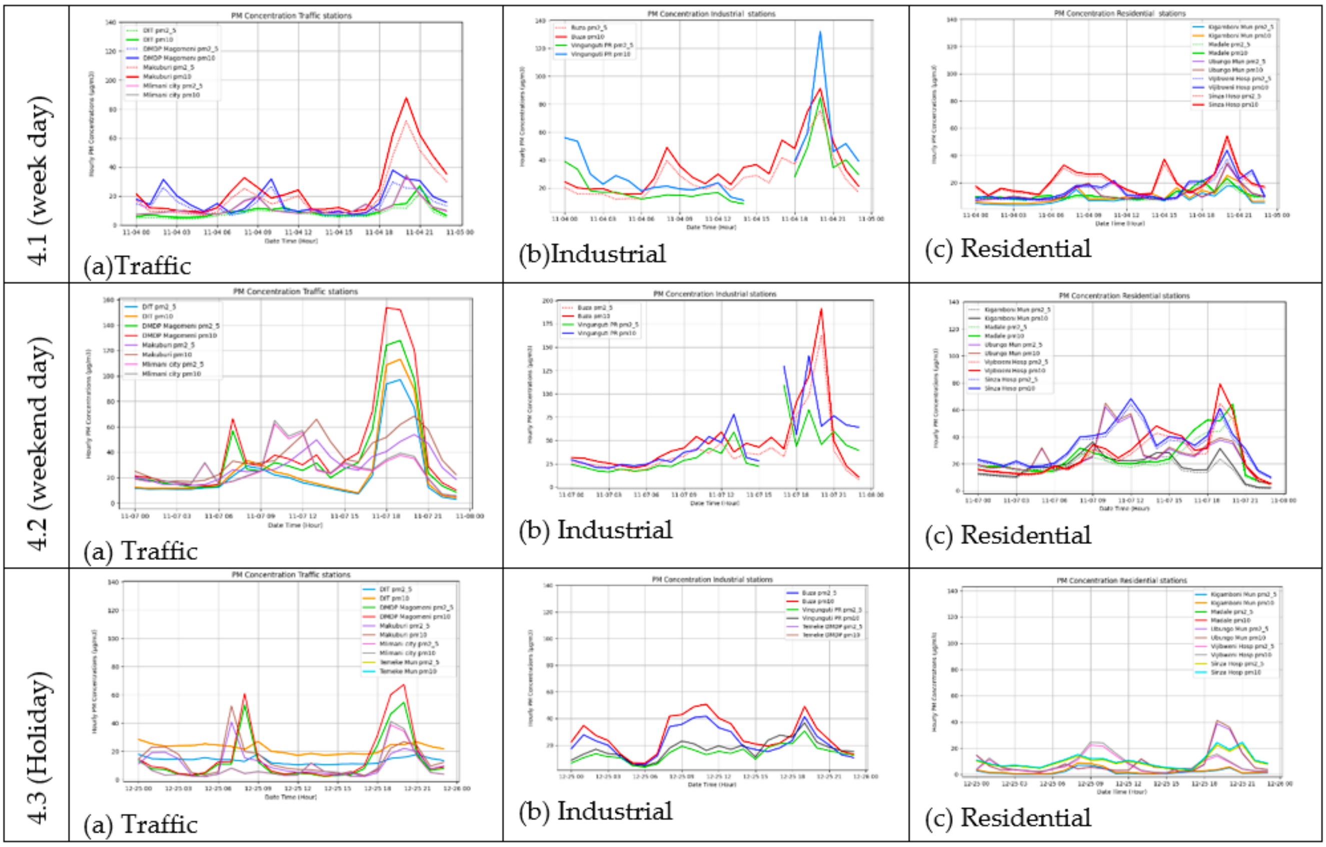

Figure 4: Comparisons of Hourly trends of PM concentrations for traffic, industrial and residential stations on week day, weekend, and Holiday: 4.1-week day, 4.2-weekend and 4.3-holiday.

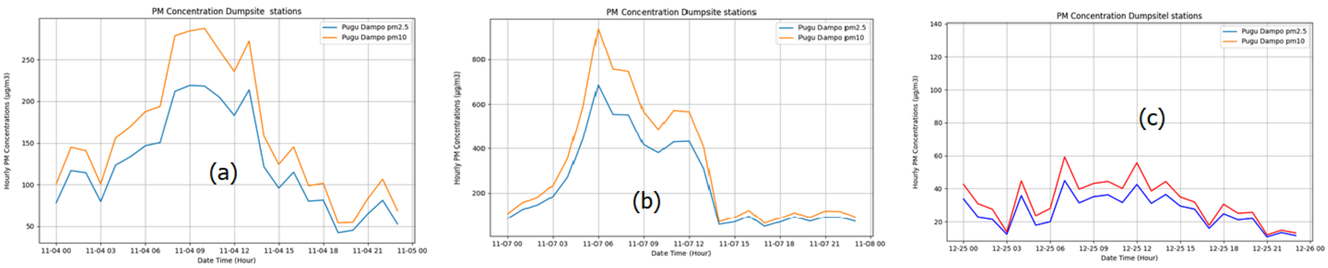

Figure 5: Comparisons of hourly variation of PM for Dumpsite station: (a) Week day, (b) Weekend, (c) Holiday.

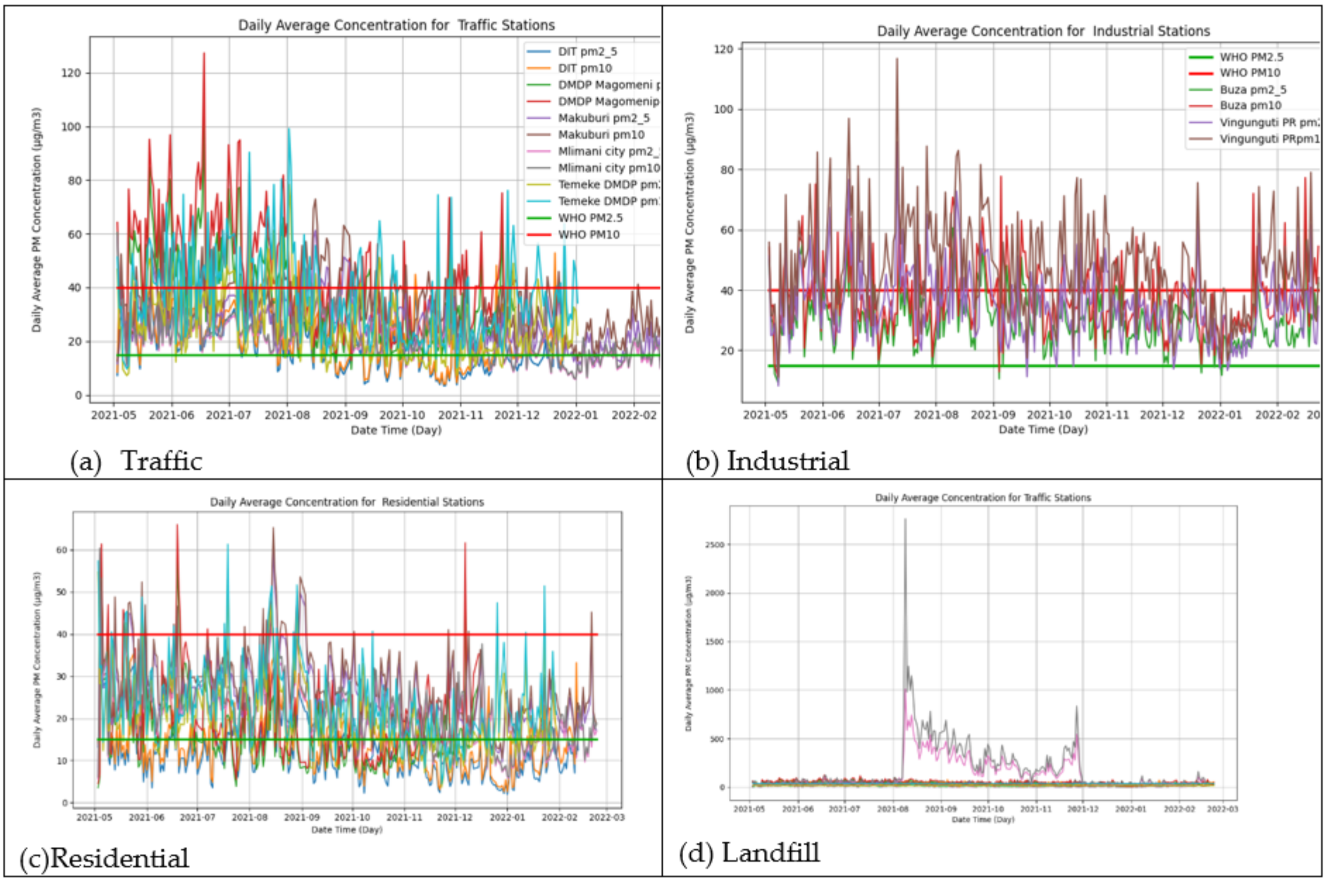

Figure 6: *Daily concentration of $PM_{2.5}$ and PM_{10} Between May 2021 and February 2022: (a) Traffic stations, (b) Industrial stations, (c) Residential stations, (d) Landfill station, green line –WHO $PM_{2.5}$ (15) 24-Hrs limit, Red line- WHO PM_{10} (45) 24-Hrs limit.*

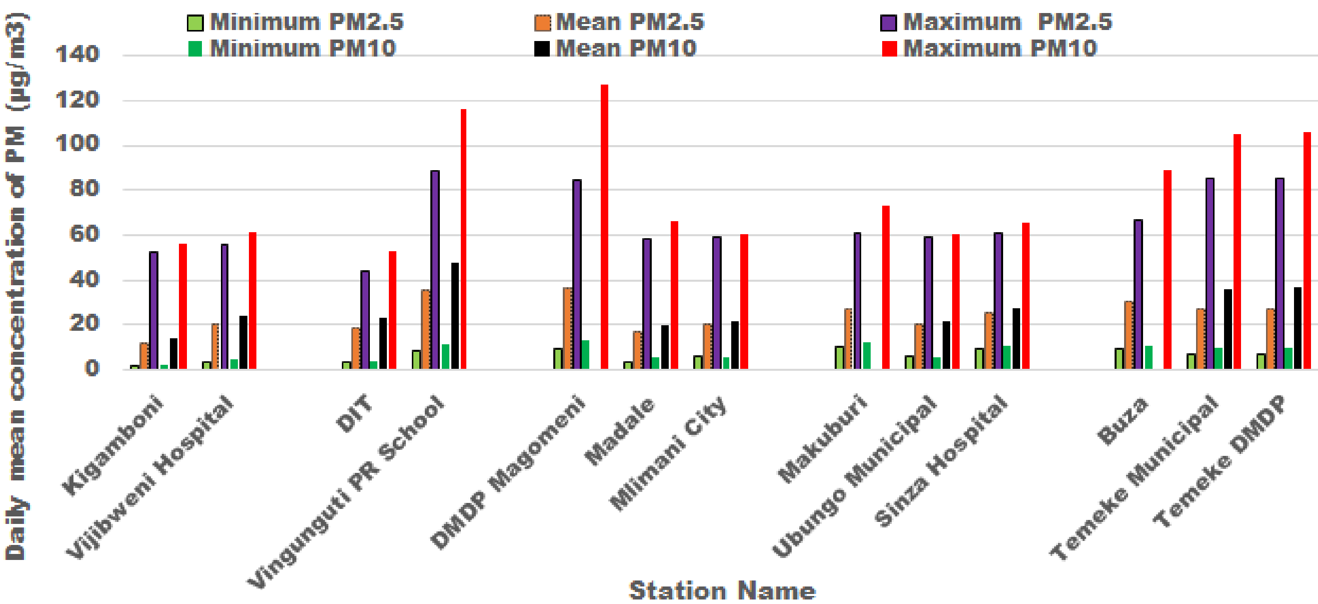

Figure 7: *Daily concentration of $PM_{2.5}$ and PM_{10} Between May 2021 and February 2022: (excluding Pugu Dampo station)*

respectively; Kinondoni Municipal daily mean concentrations of $PM_{2.5}$ and PM_{10} ranged from 17.19μg/m³ to 36.37 μg/m³ and from 20.37 μg/m³ to 45.56 μg/m³, respectively ; Ubungo Municipal observed daily mean concentrations of $PM_{2.5}$ and PM_{10} varied from 20.27 μg/m³ to 26.9 μg/m³ and from 21.74 μg/m³ to 33.67 μg/m³, respectively; Temeke Municipal daily mean concentrations of $PM_{2.5}$ and PM_{10} ranged from 27.47 μg/m³ to 30.53 μg/m³ and from 35.81 μg/m³ to 37.40 μg/m³, respectively.

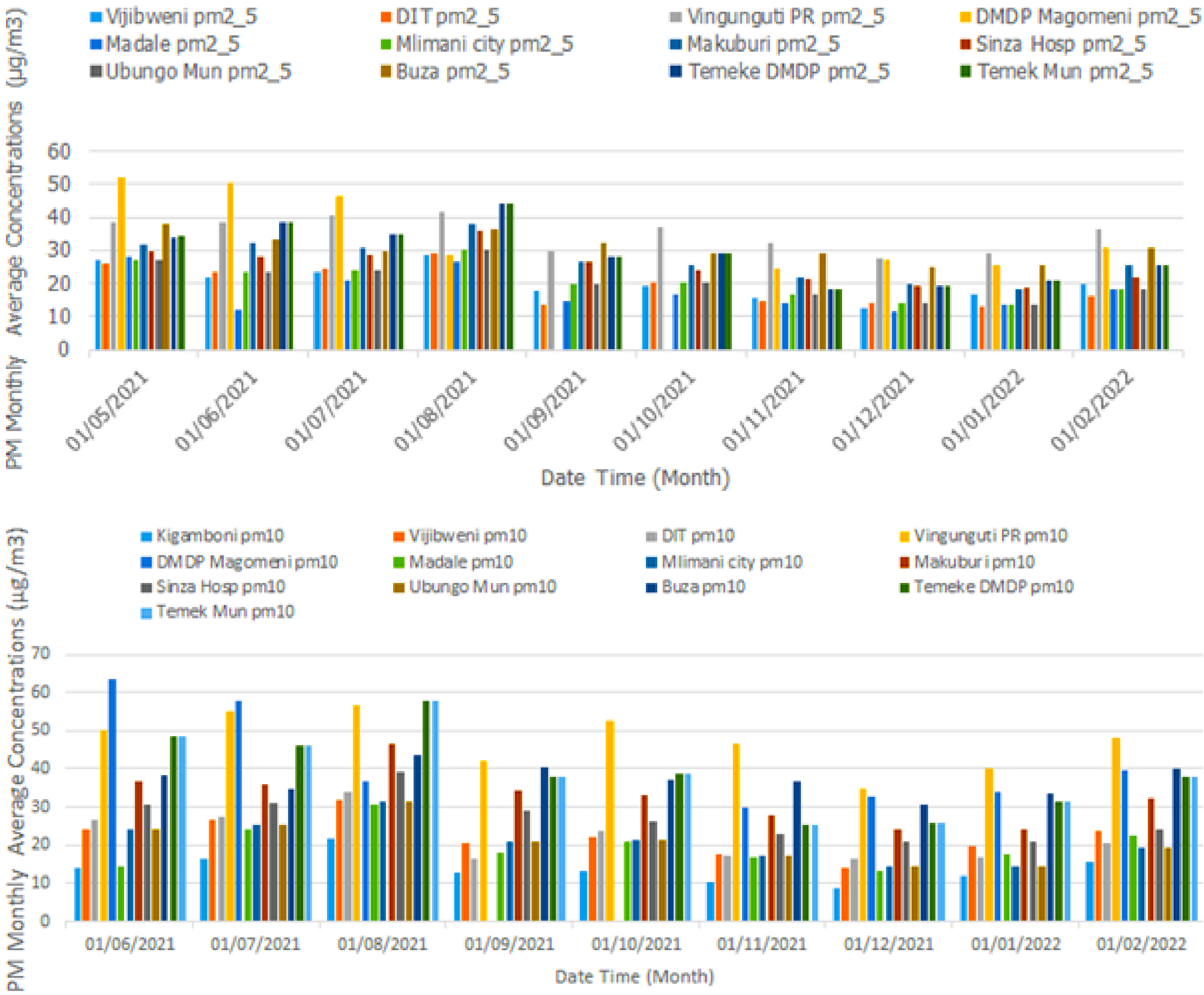

Figure 8: *Monthly Variations of PM concentrations across Municipals: (a) Monthly $PM_{2.5}$ and (b) Monthly PM_{10}.*

Monthly variability of $PM_{2.5}$ and PM_{10} concentrations

The result for monthly mean variation of $PM_{2.5}$ and PM_{10} concentrations across the city, showed higher levels of PM observation between May to August, lower concentration values between September to December and increasing values between January to February (Figure 8).

The highest monthly mean concentrations for $PM_{2.5}$ (50.92 µg/m^3 and PM_{10} (and (63.43 µg/m^3), were observed by DMDP Magomeni station in June 2021. Results of monthly mean concentrations of $PM_{2.5}$ and PM_{10} per Municipality shows that, Kigamboni municipal observations ranged from 7.39 µg/m^3 to 28.71 µg/m^3 and 8.77 µg/m^3 to 31.84 µg/m^3, respectively. The Ilala municipal monthly mean concentrations of $PM_{2.5}$ and PM_{10} ranged from 12.94 µg/m^3 to 41.53 µg/m^3 and 16.39 µg/m^3 to 56.45 µg/m^3, respectively. Results for Kinondoni municipal monthly mean concentrations of $PM_{2.5}$ and PM_{10}, ranged from 11.42 µg/m^3 to 52.19 µg/m^3 and 13.33 µg/m^3 to 63.43 µg/m^3, respectively. For Ubungo municipal the monthly mean concentrations of $PM_{2.5}$ and PM_{10}, ranged from 13.46 µg/m^3 to 37.87 µg/m^3 and 14.37 µg/m^3 to 46.6 µg/m^3, respectively. Results for Temeke municipal showed the monthly mean concentrations of $PM_{2.5}$ and PM_{10} that ranged from 18.12 µg/m^3 to 44.39 µg/m^3 and 25.9 µg/m^3 to 57.92 µg/m^3, respectively.

The Pugu Dampo station, monthly mean concentrations of $PM_{2.5}$ and PM_{10} for observation period of May 2021 to February 2022, showed values ranging from 28.89 µg/m^3 to 382.46 µg/m^3 and 35.41 µg/m^3 to 616.96 µg/m^3, respectively (Figure 8).

Pugu Dampo station observed highest concentrations between August and November, 2021, while lowest concentrations were observed in December 2021.

Discussion

This study reports the first real-time monitoring of $PM_{2.5}$ and PM_{10} using 14 air sensors across the five Municipalities of Dar es Salaam city to estimate baseline PM levels. The result for hourly

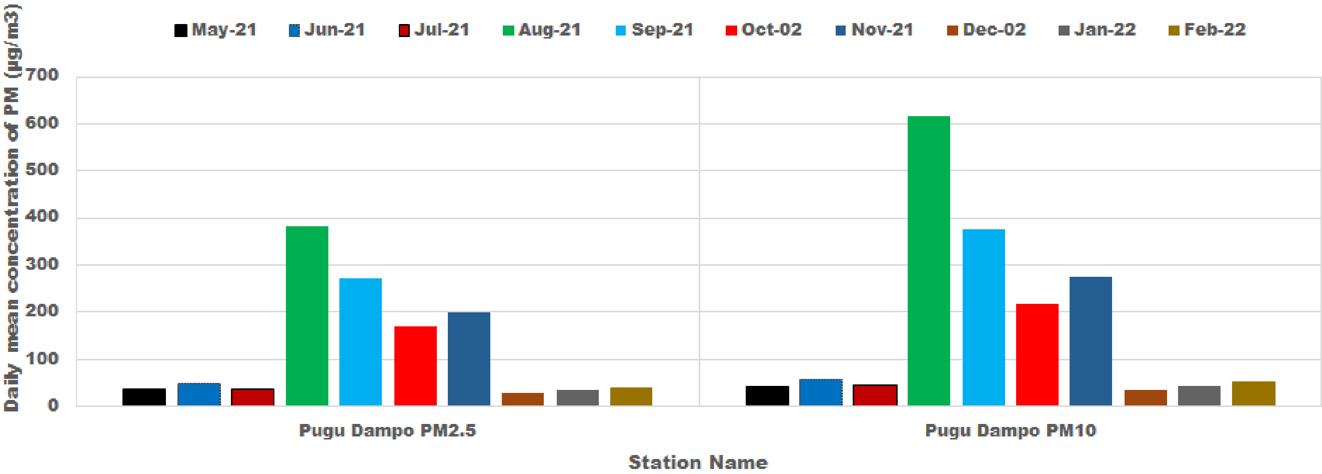

Figure 9: *Monthly variability of $PM_{2.5}$ and PM_{10} concentrations for Pugu Dampo station.*

trends of PM concentrations showed that the city observes increased level of PM concentrations at around 06:00 to 11:00 Hrs and at around 18:00 to 21:00 Hrs at all stations with the later phase being with the highest PM concentrations for traffic and industrial stations, while residential stations observes levels below 70 μg/m^3 in all phases. The result for daily concentrations of $PM_{2.5}$ and PM_{10} ranged from 11.61 μg/m^3 to 130.45 μg/m^3 and from 14.23 μg/m^3 to 184.15 μg/m^3, respectively. The maximum daily values exceed the recommended WHO value of 15 μg/m^3 for $PM_{2.5}$ and 45 μg/m^3 for PM_{10}. The levels of PM concentrations observed at residential site (Kigamboni station) were the lowest while that at the landfill site (Pugu Dampo) were highest.

From the observations of $PM_{2.5}$ and PM_{10} concentrations across the city, we found that PM concentrations varied hourly, daily and monthly per station, per municipal, per categories of recording sites and per day of the week. While residential stations showed lower levels of pollutants concentrations at all times, their peak concentrations levels were observed on week days and lowest levels were observed on holidays. Industrial stations showed higher levels of PM concentration for all observation period, but the levels were highest on weekend days and weekend as compared to a holiday. Generally, we found that the concentrations of PM observed on holidays were lower as compared to that observed on week days and weekends regardless of the categories of the stations (traffic, industrial, residential).

Studies analyzing traffic congestion in Dar es Salaam city, found the existence of traffic jams during morning rush hours of morning and evening (Kiunsi, 2013, and JICA 2007; 2017). Similarly, results for traffic congestion in Dar es Salaam city using satellite data has been reported by Dasgupta et al., 2021, where traffic jams during the morning and evening rush hours were reported on weekdays.

The Pugu Dampo (Dumpsite) station observed the extremely higher values of PM concentrations between August and November 2021. The time coincided with the open fire reported at the Pugu Kinyamwezi dumpsite, which were continually burning for more than three months.

We found that the residential stations measured lowest concentrations of $PM_{2.5}$ and PM_{10}, industrial and traffic stations observed higher levels but highest were observed at the landfill site. Previous study (Jackson, 2009, 2005; Othman, 2010; Ndambuki and Rwanga, 2008; Nkoma and Maenhaut, 2010; Robert et al., 2016; Nkoma et al., 2010), found rural background to be clean and urban traffic sites to be polluted as well as landfills sites. Ilala Municipal sites (Kariakoo, Gerezani) were found to be the most polluted as compared to UCLAS site in Kinondoni (Jackson, 2009, 2005). In this study, $PM_{2.5}$ and PM_{10} at Kigamboni station (residential site) observed low concentrations levels as compared to Pugu Dampo and DMDP Magomeni, which are dumpsite and traffic site, respectively.

The measurements of $PM_{2.5}$ and PM_{10} from other parts of Africa (Wambebe, and Duan, 2020; Bachwenkizi et al., 2021; Maina et al., 2018; Gatari et al., 2019; Lala et al., 2023), found similar results were measured concentrations of pollutants were dominated by urban traffic sites with backgrounds site measuring lower values.

Further, previous studies have found that is a major contributor to urban air pollution in East African, exposing drivers and commuters to poor air quality throughout their commute (Dasgupta, 2021, and Njee, 2016, Jackson MM. 2005; Othman, 2010; Ndambuki and Rwanga, 2008). In this study, we found peaks of PM concentration mostly in the evening rush hours (17:00 – 22:00), common traffic jam hours in Dar es Salaam city. Also, higher levels of PM concentrations were found at night, coinciding with operational hours of many industries, thus implying industries as other source of pollution in Dar es Salaam city.

Spikes of $PM_{2.5}$ and PM_{10} concentrations that exceeds the WHO guidelines for daily $PM_{2.5}$ and PM_{10} of 15 and 45 μg/m^3, respectively, were observed at all stations in the five Dar es Salaam municipals. The presence of high levels of PM concentrations, indicates that the population dwelling in Dar es Salaam city within the sensor location are at health risk due to the relatively poor air quality in these areas.

Conclusion

Dar es Salaam is the main commercial and industrial hub of Tanzania, hosting a high concentration of trade, services, and manufacturing activities, and is therefore considered an air pollution hotspot. Dar es Salaam is the metro city of Tanzania and exhibits the largest population about 9% of the national population (60 million). For air pollution baseline study, the city deployed fourteen air sensors in May 2021 to collect real-time PM concentration data. The analysis of observed data from May 2021 to February 2022 shows that the average daily concentrations of $PM_{2.5}$ and PM_{10} were higher from May to August 2021, decreased during October to November 2021, and rose again from December 2021 to February 2022. The variation can be linked to wet and dry season for the study period, but more analysis of data is required to be performed when at least three-year continuous data are available.

Further, the maximum daily $PM_{2.5}$ and PM_{10} values were observed during rush hours for traffic stations (DMDP Magomeni) and during open burning of wastes at landfill station (Pugu Dampo). Lower daily average values of PM concentrations were observed on holidays (Christmas period), corresponding to the low traffic seasons to and from the business centers.

Based on the air quality findings, it is recommended that the regulatory and enforcement agency (NEMC) develop a more robust monitoring mechanism, regulations and enforcement to protect city dwellers. Furthermore, the city should develop engineering system for waste management, like recycling facilities to sort re-usable items, compost system to process wastes into fertilizers and thus minimize waste for open burning.

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Conflict of Interest

The authors declare no conflict of interest.

References

WHO (World Health Organization). 2021. 'Global air quality guidelines: particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide.' https://apps.who.int/iris/handle/10665/345329.

WHO. 'Global Ambient Air Quality Database'. https://www.who.int/data/gho/data/themes/topics/topic-details/GHO/ambient-air-pollution

WHO. 2022. 'Around 3 Billion People Cook and Heat Their Homes Using Polluting Fuels.'. https://www.who.int/teams/environment-climate-change-and-health/air-quality-and-health/health-impacts/types-of-pollutants (accessed on 10 August 2023).

Gordon, S.B.; Bruce, N.G.; Grigg, J.; Hibberd, P.L.; Kurmi, O.P.; Lam, K.B.; Mortimer, K.; Asanta, K.P.; Balakrishnan, K.; Balmes, J.; et al. 2014. 'Respiratory risks from household air pollution in low- and middle-income countries'. Lancet Respir. Med. 2014, 2, 823–860. [Google Scholar] [CrossRef][Green Version]

Mboera LEG, Rumisha SF, Lyimo EP, Chiduo MG, Mangu CD, Mremi IR, et al. Cause-specific mortality patterns among hospital deaths in Tanzania, 2006-2015. 2018. PLoS ONE 13(10), e0205833. https://doi.org/10.1371/journal. pone.020583

URT-VPO (United Republic of Tanzania Vice President's Office). 2023. 'National Environmental Master Plan for Strategic Interventions (2022 – 2032)'. https://www.vpo.go.tz/uploads/publications/en-1654509088-MASTER%20PLAN-English_eBOOK_FINAL.pdf

URT-VPO (United Republic of Tanzania Vice President's Office). .2019. 'National State of the Environment Report 3, 2019'.https://www.vpo.go.tz/uploads/publications/en-1592550740-State%20of%20Environment_Third%20Report%202019.pdf

World Bank Group. 2019. 'Tanzania-Country-Environmental-Analysis-Environmental-Trends-and-Threats-and-Pathways-to-Improved-sustainability'. http://documents.worldbank.org/curated/en/356211556727592882/pdf/Tanzania-Country-Environmental-Analysis-Environmental-Trends-and-Threats-and-Pathways-to-Improved-Sustainability.pdf

URT (United Republic of Tanzania). 2019. 'Health and Pollution Action Plan'. https://www.unido.org/sites/default/files/files/2019- 10/Tanzania%20HPAP.English_2.pdf

URT-PO-RALG, Dar es Salaam City Council (DCC). THE PROJECT FOR REVISION OF DAR ES SALAAM URBAN TRANSPORT MASTER PLAN IN UNITED REPUBLIC OF TANZANIA FINAL REPORT SUMMARY.https://openjicareport.jica.go.jp/pdf/12319349.pdf

Dasgupta, Susmita and Lall, Somik V. and Wheeler, David, Traffic, Air Pollution, and Distributional Impacts in Dar Es Salaam: A Spatial Analysis with New Satellite Data (March 13, 2020). World

Bank Policy Research Working Paper No. 9185, Available at SSRN: https://ssrn.com/abstract=3554094

Netherlands Enterprise Agency. 2018. Final Energy Report Tanzania https://www.rvo.nl/sites/default/files/2019/01/Final-Energy-report-Tanzania.pdf

National Environment Statistics Report 2017. Dar es Salaam, Tanzania: National Bureau of Statistics. https://www.nbs.go.tz/index.php/en/census-surveys/environmental-statistics/77-national-environment-statistics-report-2017-tanzania-mainland Population and Household Census, 2022, https://sensa.nbs.go.tz/

Dasgupta, S., Lall, S., & Wheeler, D. (2021). Spatiotemporal analysis of traffic congestion, air pollution, and exposure vulnerability in Tanzania. Science of The Total Environment, 778, 147114.

Njee, R. M., Meliefste, K., Malebo, H. M., & Hoek, G. (2016). Spatial Variability of Ambient Air Pollution Concentration in Dar es Salaam. Journal of Environment Pollution and Human Health, 4(4), 83-90.

Jackson M. M. 2009. 'Assessment of air pollution in residential areas of Kinondoni municipality in Dar es Salaam City, Tanzania'. Int. J. Biol. Chem. Sci. 3(4): 786-795. http://ajol.info/index.php/ijbcs

Jackson M. M. 2005. 'Roadside concentration of gaseous and particulate matter pollutants and risk assessment in Dar-es-Salaam, Tanzania'. Journal of Environmental Monitoring and Assessment, 2005, 104: 385-407. https://link.springer.com/content/pdf/10.1007/s10661-005-1680-y.pdf

Jackson M. M. 2005. 'Air pollution in Southern Africa: The case of motor vehicles exhaust contribution in Dar-es- Salaam city'. Journal of Building and Land Development, 2005, 12(1-3): 1-19.

Othman O. C. 2010. 'Roadside Levels of Ambient Air Pollutants: SO2, NO2, NO, CO and SPM in Dar es Salaam City. Tanzania'. Journal of Natural and Applied Sciences (TaJONAS), ISSN 1821-7249

M Ndambuki and S Rwanga. 2008. 'Assessment of Air Pollution in Residential areas: A Case Study of Kinondoni Municipality, Tanzania'. Journal for New Generation Sciences: Volume 6 Number 1, 2008, https://core.ac.uk/download/pdf/222966677.pdf

Mkoma, S.L., Chi, X. & Maenhaut, W. 2010. 'Characteristics of carbonaceous aerosols in ambient PM_{10} and $PM_{2.5}$ particles in Dar es Salaam, Tanzania'. Science of the Total Environment, 408(6), pp.1308-1314. https://sig.ias.edu/sites/sig.ias.edu/files/22-87-1-PB.pdf

Mkoma SL, Maenhaut W, Chi X, Raes N .2009. 'Characterisation of PM_{10} atmospheric aerosols for the wet season 2005 at two sites in East Africa'. Atmos Environ 43, 2009, :631–639. https://doi.org/10.1016/j.atmosenv.10.008

Robert M. Njee, Kees Meliefste, Hamisi M. Malebo, and Gerard Hoek. 2016. 'Spatial Variability of Ambient Air Pollution Concentration in Dar es Salaam'. Journal of Environment Pollution and Human Health, vol. 4, no. 4, 83-90. doi: 10.12691/jephh-4-4-2. https://www.researchgate.net/publication/310423870_Spatial_Variability_of_Ambient_Air_Pollution_Concentration_in_Dar_es_Salaam

Mkoma, S.L., Kimambo, O.N., Mabiki, F.P. and Tungaraza C. T.2010. 'Dependence of Air Quality on Meteorological Parameters in Dar es Salaam, Tanzania'. Journal of Natural and ISSN 1821-7249, 2010. https://sig.ias.edu/sites/sig.ias.edu/files/22-87-1-PB.pdf

Isaya Kapakala. 2013..'Assessing the Effects of Meteorological Parameters on Aerosols over Dar es Salaam, Tanzania'. http://erepository.uonbi.ac.ke/bitstream/handle/11295/55815/Kapakala_Assessing%20the%20Effects%20of%20Meteorological%20Parameters%20on%20Aerosols%20over%20Dar%20es%20Salaam.pdf?sequence=3

Mkoma SL, Wang W, Maenhaut W . 2009. 'Seasonal variation of water-soluble inorganic species in the coarse and fine atmospheric aerosols at Dar es Salaam, Tanzania'. Nucl Instrum Methods Phys Res, Sect B, 267:2897–2902,. https://doi.org/10.1016/j.nimb.2009.06.099

Mboera LEG, Rumisha SF, Lyimo EP, Chiduo MG, Mangu CD, Mremi IR, et al..2018. 'Cause-specific mortality patterns among hospital deaths in Tanzania, 2006-2015'. PLoS ONE 13(10), e0205833. https://doi.org/10.1371/journal. pone.020583

Coleman Kishamawe1, Susan F Rumisha 2, Irene R Mremi 2 3, Veneranda M Bwana 4, Mercy G Chiduo 5, Isolide S Massawe 5, Leonard E G Mboera, 2019. 'Trends, patterns and causes of respiratory disease mortality among inpatients in Tanzania, 2006-2015.'. Trop Med Int Health.;24(1):91-100. doi: 10.1111/tmi.13165. Epub 2018 Nov 8

Bwana VM, Rumisha SF, Mremi IR, Lyimo EP, Mboera LEG, 2019. 'Patterns and causes of hospital maternal mortality in Tanzania: A 10-year retrospective analysis'. .PLoS One. 2019 Apr 9;14(4): e0214807. doi: 10.1371/journal.pone.0214807. eCollection 2019. PMID: 30964909

Ndumwa HP, Mboya EA, Amani DE, Mashoka R, Nicholaus P, Haniffa R, Beane A, Mfinanga J, Sunguya B, Sawe HR, Baker T. 2022. 'The burden of respiratory conditions in the emergency department of Muhimbili National Hospital in Tanzania in the first two years of the COVID-19 pandemic: A cross sectional descriptive study', Infect Dis Ther. 2022 Apr;11(2):787-805. doi: 10.1007/s40121-022-00600-4. Epub 2022 Feb 16. PMID: 35174469

Wambebe, N.M. and Duan, X. 2020. 'Air Quality Levels and Health Risk Assessment of Particulate Matters in Abuja Municipal Area, Nigeria'. Atmosphere, 11, 817; doi:10.3390/atmos11080817.

Bachwenkizi, J.; Liu, C.; Meng, X.; Zhang, L.; Wang, W.; van Donkelaar, A.; Martin, R.V.; Hammer, M.S.; Chen, R.; Kan, H. 2021. 'Fine Particulate Matter Constituents and Infant Mortality in Africa: A Multicountry Study'. Environ. Int. 156, 106739. [Google Scholar] [CrossRef]

Maina EG, Gachanja AN, Gatari MJ, Price H .2018. 'Demonstrating $PM_{2.5}$ and road-side dust pollution by heavy metals along Thika superhighway in Kenya, sub-Saharan Africa'. EnvironMonit Assess, 190:251. https://doi.org/10.1007/s10661-018-6629-z

Gatari, M.J., Kinney, P.L., Yan, B., Sclar, E., Volavka-Close, N., Ngo, N.S., Gaita, S.M., Law, A., Ndiba, P.K. and Gachanja, A.2019.'High airborne black carbon concentrations measured near roadways in Nairobi, Kenya. Transportation Research Part D': Transport and Environment, 68: 554 99-109

U.S. EPA. Air Quality Index (AQI). /www.epa.gov/sites/default/files/2016-04/documents/2012_aqi_factsheet.pdf

Lala, M.A.; Onwunzo, C.S.; Adesina, O.A.; Sonibare, J.A. 2023. 'Particulate Matters Pollution in Selected Areas of Nigeria: Spatial Analysis and Risk Assessment. Case Stud'. Chem. Environ. Eng. 7, 100288. [Google Scholar] [CrossRef]