

# Spatial Variability of Ambient Air Pollution Concentration in Dar es Salaam

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**Abstract** Epidemiological evidence shows health effects of ambient air pollutants. Such effects have been evaluated in different regions of the world but scarcity of pollution measurements in Sub Saharan Africa (SSA) limits understanding of pollution levels and related health risks. Our aim was to assess spatial variability of concentrations of key air pollutants in a major African city. Particles smaller than 2.5 and 10  $\mu\text{m}$  ( $\text{PM}_{2.5}$  and  $\text{PM}_{10}$ ), the absorbance of  $\text{PM}_{2.5}$ , and  $\text{NO}_2 / \text{NO}_x$  were measured in dry season at locations close to identified pollution sources. Higher  $\text{PM}_{10}$ ,  $\text{PM}_{2.5}$  and soot concentrations were measured compared to typical European concentrations.  $\text{NO}_2$  concentrations were moderate.  $\text{PM}_{10}$  ranged from 86  $\mu\text{g}/\text{m}^3$  at the urban background to 248 $\mu\text{g}/\text{m}^3$  at the landfill site, likely related to unpaved roads.  $\text{PM}_{2.5}$  varied from 27 $\mu\text{g}/\text{m}^3$  at the harbor site to 49 $\mu\text{g}/\text{m}^3$  at the traffic site. Measured  $\text{PM}_{2.5}$  concentrations were several times higher than the global 2005 modelled values based upon satellite and chemical transport modelling.  $\text{PM}_{10}$  and  $\text{PM}_{2.5}$  concentrations were 1.8 and 1.6 times higher at the traffic site compared to the urban background, a larger contrast than in most western studies. Suburban  $\text{PM}_{10}$ ,  $\text{PM}_{2.5}$  and soot absorbance concentrations were higher than at central urban location. The high soot concentrations document that combustion sources including motorized traffic contribute to the high PM concentrations. Average  $\text{NO}_2$  concentrations ranged from 8  $\mu\text{g}/\text{m}^3$  to 109  $\mu\text{g}/\text{m}^3$ . Emissions from road traffic vehicles were shown to have the strongest influence on all ambient pollutants, although emissions levels where roads were unpaved were associated with elevated levels of particulates. Spatial variability of particulate matter air pollution was larger and showed different patterns than reported in European / North American study areas. Ambient pollution monitoring with mitigation measures targeting road traffic emissions are necessary in averting negative health consequences of ambient pollution in SSA cities.

**Keywords:** ambient air pollution, concentration, variability, Africa.

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## 1. Introduction

Ambient air pollution is an established risk factor for diseases affecting respiratory system. Evidence is mounting on the role of air pollution in exacerbating other disease endpoints particularly lung cancer, cardiovascular diseases, and on its negative effects to the health of children exposed early in life [6,11,17].

Recognition of the growing problems of ambient air pollution and its negative implication to public health led to adoption of control measures including emission standards for factories and automobiles in industrialized countries [1,8]. Application of pollution controls are now reported to have significantly reduced pollution levels in most of Europe and North American cities [15,24]. Contrariwise, air pollution levels have been on the increase in most developing countries [15]. Recent analysis of global data on ambient air pollution suggests

an increasing trend of urban ambient pollution levels in cities of developing countries with highest increase recorded for Africa region [35]. Ambient particulate air pollution is now estimated to contribute 3.7% of premature deaths and 3.1% of global Disability Adjusted Life Years (DALY). Africa contribute 5% of the global burden due ambient air pollution [34].

Information on levels of ambient air pollution for Sub Saharan Africa (SSA) is still scanty [4,16,26,29,32]. Air pollution data for most cities is obtained from small discrete monitoring programs rather than established networks, leading to uncertainty about particulate levels. Uncertainty in exposure further limits estimation of related public health impact [32]. Paucity of pollution data necessitates the use of regional estimates and isolated monitoring data in the determination of attributable disease burden for SSA [2,3,27,33]. The available data is largely limited in precision and ability to reflect on spatial variability within relatively small geographical areas such

as contrast between city neighborhoods or between urban and regional backgrounds.

The present study provides an analysis of variability in particulate ( $PM_{10}$  and  $PM_{2.5}$ ) and selected gaseous ( $NO_2$ ,  $NO_x$ ) ambient pollutants in Dar Es Salaam city. We compare measured pollution levels and spatial variability patterns with a large European monitoring effort conducted with the same monitoring methods in approximately the same time period [10,13]. Our study adds ambient pollution data whilst describing variability between selected locations within the city. It is essential for determining pollution impact to the health of residents while enriching the scarce information base for Tanzania and wider SSA region.

## 2. Methodology

### 2.1. Study Area

Dar es Salaam is a coastal city lying between latitudes  $6.83^\circ$  and  $6.89^\circ$ S and longitudes  $39.24^\circ$  and  $39.30^\circ$  E. To the East it is bordered by the Indian Ocean joining the East African coastal belt. Part of the coast is a large natural harbor located in the central area of the city.

Location and trade advantages of Dar Es Salaam have made it a center for manufacturing, services, and the center for government bureaucracy for Tanzania. The city had a population of nearly three million inhabitants with an annual growth rate of 4.39%, making it the number three fastest growing city in Africa and ninth in the world (The City Mayors Foundation 2011). Average annual temperature ranges from  $20$  to  $35^\circ$  C. The months of July through August are the coolest in a year.

### 2.2. Sampling Design

Outdoor-air samples were collected in five monitoring locations to assess spatial variability of air pollution in the city (Figure 1). 24-hour average integrated samples were collected on 30 weekdays from July 3<sup>rd</sup> to August 11<sup>th</sup> 2006. Pollution monitoring involved sample collection at locations influenced by identified pollution sources (motorized traffic and pollution from landfill site) and background locations in central urban and suburban areas. Sampling involved active monitoring of  $PM_{10}$  and  $PM_{2.5}$  and passive monitoring of  $NO_x$  and  $NO_2$ . Soot absorbance coefficient were determined in laboratory. A portable weather station was used to monitor meteorological parameters in concurrence with the ambient pollutants.



Map modified from Tanzania Meteorological Agency Version (Robert Mussa 2007).

Figure 1. Map of Dar Es Salaam showing monitoring locations

### 2.3. Sampling Site Selection

Site selection criteria included distance of at least 100m from a road way ( $\geq 25,000$  day vehicles capacity) or other sources identified, for a background site. Traffic and landfill sites had to be within 75 m from a major roadway or landfill site. Official permission for monitoring activities were sought from government authorities of the districts involved. Three background locations urban,

suburban and harbour, and two source locations (traffic and landfill), were identified as classified elsewhere [9,19]. The urban background site was situated at a back yard of a nursery school ( $06^{\circ}48'43.07''$ S,  $39^{\circ}16'44, 05''$ E) the suburban background was located at a residential house ( $06^{\circ}49'52, 03''$ S,  $39^{\circ}15'33.04''$ E) about 3km from the urban background site. The harbour background site was located within 2km from the Dar es Salaam harbour ( $06^{\circ}51'01'09''$ S,  $39^{\circ}17'00.63''$ E) nearly 5km from the urban background location. The harbour site was selected

to identify large scale influences of the harbour and associated activities. The traffic site was located at a residential and business flat along Bibi Titi Muhamed, a ring road around the city centre connecting a few main entry-exit ways to the inner city (06'48'46, 07"S, 39'17'00. 07"E) approximately 500m from the urban background

site. Landfill location was situated at a backyard of a residential building neighbouring a municipal landfill site (06'52'12.96"S, 39'16'53.91"E), about 6.5km from the background location see [Figure 1](#). Waste burning was common at the landfill site which was surrounded by dense low income community.

**Table 1. Characteristics of monitoring locations**

Characteristics	Urban background	Harbors	Landfill	Sub urban background	Traffic
Distance to nearest street (m)	110	40	10	5	5
Distance to nearest major street (m)	400	400	800	300	5
Distance to nearest intersection (m)	250	400	400	80	250
Distance to nearest traffic lights (m)	800	NA	NA	NA	250
Total street width (m)	20	10	10	20	25
Total height of surrounding buildings (m)	4	4.5	3	3	NA
Sampling height above street (m)	2.5	4	1	7.5	2
Traffic count cars (day <sup>-1</sup> )	2,167	-	124	186	20,124
Trucks (day <sup>-1</sup> )	124	-	1,176	-	6,687

Characteristics of monitoring locations and traffic intensities for near roads are summarized in [Table 1](#). Traffic counting was done in streets nearest to monitoring sites to obtain 24hourly estimate traffic flows. Motor vehicles moving in both drive directions were counted in 15min intervals with the aid of stop watch [28]. Counting was done between 10:00am and 12:00pm to avoid morning and afternoon rush hours. Day (24 hourly) traffic counts were obtained by multiplying the average 15min traffic flow rate by 96 (4quarter hours \* 12 \* 1.29 hours a day).

## 2.4. Air Pollution Monitoring

Twenty four hourly PM<sub>10</sub>, PM<sub>2.5</sub>, NO<sub>2</sub>, and NO<sub>x</sub> samples were collected simultaneously from the five locations. Samplers were installed from Monday to Friday and collected continuously for 30 weekdays in six consecutive weeks from Tuesday to Saturday. New filters were installed between 10.00am and 2.00pm and exposed filters were collected within the same range or time. The time interval between collection of an exposed filter at the first location and installation of a new filter at the last location was about 2hr. The sequence of sample installation and collection from site to site was from Traffic to Urban background, to Harbours background, Landfill, and to Sub urban background for last five of six monitoring weeks.

Meteorological data (wind speed, wind direction, temperature, barometric pressure, relative humidity and rainfall) were collected at TMA's at Dar Es Salaam International Airport synoptic station. We collected concurrent measurements of weather parameters using Vantage Pro Weather station (Davis Instruments Corp., Hayward, CA: 2001-2003.) and later requested official weather data from the safe synoptic station in the [5]. Weather station was located about 10.5km from urban background location. Meteorological parameters measured correlated highly with measurements from TMA  $r = 0.9$  for wind speed, 0.82 temperature, 0.72 relative humidity, and 0.997 barometric pressure; except for rainfall ( $r = 0.43$ ). Rainfalls were scanty and in few of the monitoring days, the average rainfall was 0.4ml/day.

Twenty four hour PM<sub>10</sub> mass concentration were monitored by using single stage Harvard Impactors [21] mounted with 25mm diameter Teflon filters. PM<sub>2.5</sub> were

collected using PM<sub>2.5</sub> GK<sub>2.05</sub> cyclones [BGI, Waltham MA] [7]. PM<sub>2.5</sub> samples were collected on Anderson Teflon filters 37mm mounted into the cyclone. Both the impactors and cyclones were connected to battery driven pumps (BGI 400) operated at flow rate of 4l/min [28].

Nitrogen oxides (NO<sub>x</sub> and NO<sub>2</sub>) were collected using Ogawa passive samplers in accordance with the protocol (Ogawa & Company, USA, Inc.).

## 2.5. Laboratory Analysis

Analysis of collected samples was done at the Institute for Risk Assessment Sciences (IRAS) laboratories, in the Netherlands. Gravimetric analysis of Teflon filters involved weighing of the filters before and after exposure in Dar Es Salaam using MT5 analytical microbalance (Mettler-Toledo, Greifensee, Switzerland), at 1µg precision. Filters were weighed at least twice in each weighing session and an average weight was taken between consecutive readings within 5µ (Raphael 2008) [10,13,14]. Filters were conditioned at respective temperature and relative humidity of (21 ± 0.5°C) and (35 ± 5%) for 24hr [7,28].

Reflectance of PM<sub>2.5</sub> filters was measured using an EEL smoke stain reflectometer (Model 43D, Diffusion Systems Ltd.), reflectance measurements were taken from five different spots of exposed filters from which average reflectance was determined arithmetically (Raphael 2008). Measured reflectance was transformed to absorbance using the ISO 9835 method (ISO, 1993). Procedures for reflectance measurements and absorbance calculations are also described by [13,14,19,28]. Particle absorbance was calculated for PM<sub>2.5</sub> only to allow comparison with other studies. Particle absorbance in this article therefore refers to PM<sub>2.5</sub> absorbance.

Ogawa samplers was transported through cold chain maintained at 4°C at all the time between laboratory and field station.

Analysis of NO<sub>x</sub> and NO<sub>2</sub> involved extraction from filters and sample screens and subsequent treatment with Sulfanilamide, N-(1-Naphthyl)-ethylenediamine dihydrochloride (NEDA) and nitrite solutions according to analytical procedures described in the protocol (Ogawa 1998). Absorbance of nitrogen solutions were determined by saltzman method using Hatch spectrophotometer operated at 545nm wavelength. The NO<sub>2</sub> and NO<sub>x</sub> absorbance

values were then converted into weights using the absorbance of bands and the slope of standard  $\text{NO}_2$  solution curve. The same protocol was also used by [10].

## 2.6. Quality Control and Quality Assurance

Field blanks and duplicate samples were taken for quality assurance and quality control. Mean blanks were subtracted from all samples. All duplicate samples and at least a third of blank  $\text{PM}_{10}$  and Ogawa samples were taken at the urban background location. A duplicate and a blank sample were taken for all the pollutants in each sampling week.

## 2.7. Statistical Analysis

Comparison is made of the levels of measured pollutants between the five monitoring locations. Temporal variability in pollution levels during this relatively short and stable monitoring period was not significant, hence the focus of our analysis was on the special pattern of the measured pollutants. We identified an urban background as representative of the urban pollution situation without the influence of any immediate pollution sources. Univariate analysis and means procedures were employed to generate descriptive summary statistics. Median ratios were calculated to compare pollutants concentration across locations; T-test was used to test for statistical significance of the observed differences between concentrations in different locations. We used median ratios to facilitate comparison of the locations to the referent urban background.

## 3. Results and Discussions

### 3.1. Pollutants Concentrations and Weather

Mean blank weights for  $\text{PM}_{10}$ ,  $\text{PM}_{2.5}$  and reflectance coefficients were  $5.4\mu\text{g}$  ( $n=5$ ),  $-26.3\mu\text{g}$  ( $n=6$ ), and  $-1.95$  ( $n=6$ ); mean blank  $\text{NO}_x$  and  $\text{NO}_2$  concentrations ( $n=5$ ) were  $12.62\mu\text{g}/\text{m}^3$  and  $1.84\mu\text{g}/\text{m}^3$  respectively. Average temperature, relative humidity, wind speed, and barometric pressure during study period were  $23.4^\circ\text{C}$  ( $22.6 - 24.4$ ),  $82.0\%$  ( $77.3 - 87.2$ ),  $3.1\text{ms}^{-1}$  ( $1.6 - 5.0$ ), and  $1011.2\text{mbar}$  ( $1006.4 - 1014.2$ ) respectively. South Eastern winds were predominant for 52% of the monitoring days and wind was fluctuating for the rest of the monitoring days. Rainfalls were recorded in 8 of the sampling days with a maximum of 6.9mm; generally scarce and sporadic rainfalls. Weather conditions were stable throughout the monitoring period with narrow ranges for each of the meteorological components. Respective maximum ranges in temperature and wind speed were within  $2^\circ\text{C}$  and  $4\text{ms}^{-1}$ .

### 3.2. Spatial Variability

Concentrations of measured pollutants are summarized in Table 2 and Table 3 and Figure 2-Figure 5. Table 2 and Table 3 document that PM and  $\text{NO}_2$  concentrations differed substantially and statistically significant from the concentrations measured at the urban background site. The spatial patterns differed per pollutant, e.g. the  $\text{PM}_{10}$  concentrations were higher at the suburban and landfill site compared to the urban background whereas the  $\text{NO}_2$  concentration was lower.

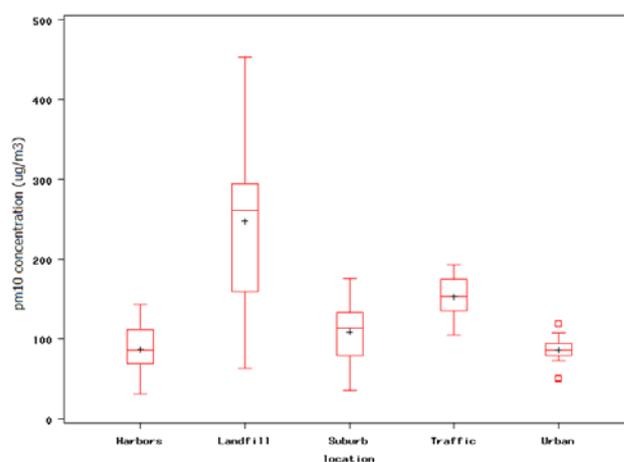


Figure 2. Box plots of  $\text{PM}_{10}$  concentration across locations

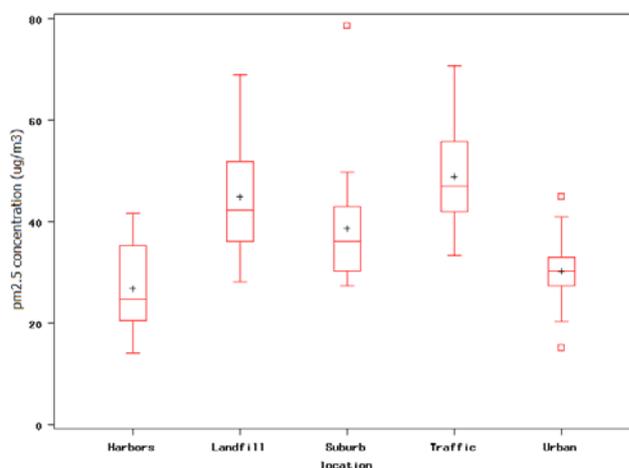


Figure 3. Box plots of  $\text{PM}_{2.5}$  concentrations across locations

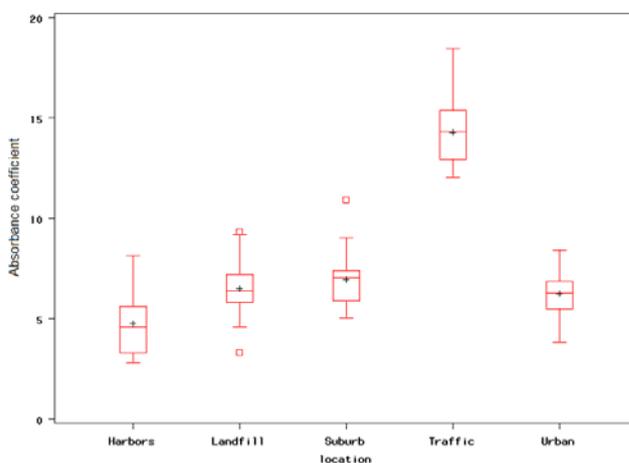


Figure 4. Box plots of absorbance coefficients across locations

The traffic site had higher concentrations compared to urban background site of each of the pollutants measured. Compared to the European ESCAPE study, traffic / background ratios were much higher for  $\text{PM}_{10}$ ,  $\text{PM}_{2.5}$ , Absorbance and  $\text{NO}_x$  [13,14]. ESCAPE study was a large monitoring effort using similar (PM sampling) or the same ( $\text{NO}_2$  and all lab analyses including weighing and reflectance) measurement procedures as the current study. ESCAPE monitoring was performed in 2009-2010, reasonably close to the current monitoring effort (2006). Median  $\text{PM}_{10}$  and  $\text{PM}_{2.5}$  traffic / background ratios in the European study were 1.23 and 1.14 respectively. The

higher ratios found in the current study are likely due to higher resuspension of street dust related to the warmer and drier climate and the higher soot concentrations. The median traffic / urban background ratio was 1.38 in ESCAPE versus 2.4 in the current study. The difference is likely due to the extensive use of diesel soot filters in Europe and the older age of vehicles in Dar es Salaam. High levels of soot we observed in Dar es Salaam are consistent with previous results which suggested high contribution of combustion, not only in Dar es Salaam but also in other cities in Sub-Sahara Africa [2,3,12,26].

Studies that analysed elemental composition of particulate matter reported high levels of bromine in Dar es Salaam, suggesting contribution of biomass combustion [5,22]. Elevated levels of bromine and potassium also related to biomass combustion were reported in Nairobi Kenya [16]. Our results point out the importance of vehicular emissions as a contributor of soot particles to the total pollution levels. Growing potential for high emissions from traffic vehicles for Dar Es Salaam was projected more than a decade ago [25]. Rapid increases in the number of vehicles and high emissions from older vehicles and diesel engines, particularly commuter minibuses were some of areas of concern.

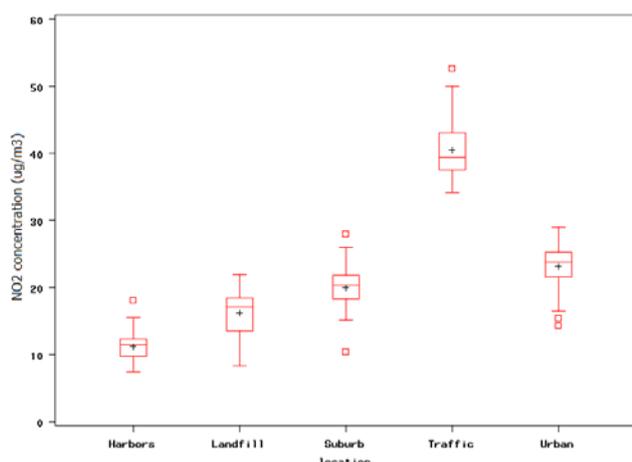


Figure 5. Box plots of NO<sub>2</sub> concentrations across locations

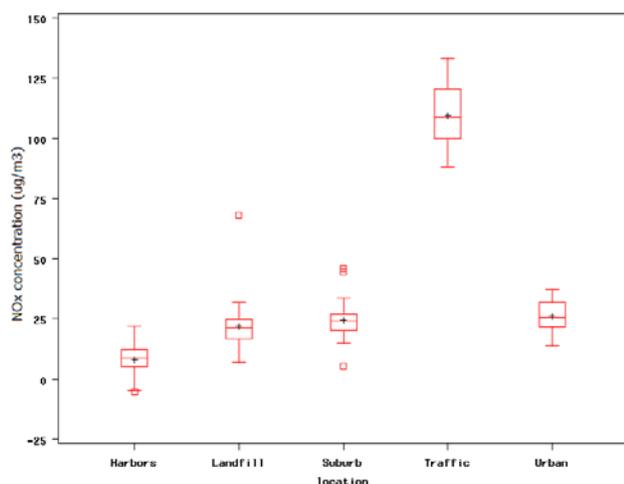


Figure 6. Box plots of NO<sub>x</sub> concentrations across locations

The traffic-background ratio for NO<sub>2</sub> in our study was similar to that reported for ESCAPE where a median ratio of 1.63 was found. In contrast the Dar es Salaam NO<sub>x</sub> ratio of 4.1 was much higher than reported for ESCAPE

(median 1.93). A possible explanation is again the use of diesel soot filters in Europe which have been shown to result in larger fractions of NO<sub>2</sub> in primary traffic emissions. Collectively, these results document that the exhaust mixture from traffic in Dar es Salaam differs from Europe substantially.

Table 2. Spatial variability of air pollutants

Pollutants	Location	Mean	Standard deviation	Minimum	Maximum
PM <sub>10</sub> (µg/m <sup>3</sup> )	Urban	86.0	14.3	50.1	119.3
	Harbours	87.2	30.0	31.6	143.4
	Landfill	248.0	97.7	62.9	453.2
	Suburb	108.9	37.9	35.1	175.4
	Traffic	152.9	24.6	104.9	193.3
PM <sub>2.5</sub> (µg/m <sup>3</sup> )	Urban	30.1	6.1	15.2	45.0
	Harbours	26.8	9.4	14.1	41.6
	Landfill	44.9	11.7	28.1	69.0
	Suburb	38.7	12.8	27.3	78.6
	Traffic	48.8	9.3	33.3	70.8
PM <sub>2.5</sub> absorbance coefficient	Urban	6.2	1.0	3.8	8.4
	Harbours	4.7	1.5	2.8	8.1
	Landfill	6.5	1.4	3.3	9.3
	Suburb	6.9	1.5	5.0	10.9
	Traffic	14.3	1.7	12.0	18.4
NO <sub>x</sub> (µg/m <sup>3</sup> )	Urban	26.2	7.0	13.7	37.3
	Harbours	8.0	6.3	-5.4	21.9
	Landfill	22.0	10.7	7.0	68.0
	Suburb	24.3	8.2	5.3	46.1
	Traffic	109.4	12.4	88.1	133.2
NO <sub>2</sub> (µg/m <sup>3</sup> )	Urban	23.1	3.6	14.4	29.0
	Harbours	11.2	2.4	7.4	18.1
	Landfill	16.2	3.4	8.3	21.9
	Suburb	20.0	3.5	10.4	28.0
	Traffic	40.5	4.6	34.1	52.7

Whereas the traffic site located at the central business area had all the measured pollutants consistently higher compared to urban background, the roadside measurements at the **landfill location** had the highest particulate concentration (PM<sub>10</sub>). The fine particulate concentration was also elevated but not as much as the PM<sub>10</sub>. The roadside site at land fill was at an unpaved road and most of the streets near the sub urban background site were unpaved. Unpaved roads and other surfaces likely explain the high coarse particle concentrations. Soot and NO<sub>x</sub> concentrations were not statistically different from the urban background site where as NO<sub>2</sub> concentrations were significantly lower than that of urban background. Our hypothesis that the landfill site was significantly affected by burning of waste was thus not confirmed.

PM<sub>10</sub>, PM<sub>2.5</sub> and soot concentrations were higher at the **suburban background** compared to the urban background, while NO<sub>2</sub> and NO<sub>x</sub> concentrations were lower. In Western study areas, suburban concentrations are typically modestly lower. Unpaved roads and possibly local combustion sources other than traffic likely explain the pattern.

**Table 3. Median ratio of pollutants at different sites with urban background**

pollutants	harbour	landfill	suburban	traffic
PM <sub>10</sub>	1.0	3.0*	1.3*	1.8*
PM <sub>2.5</sub>	0.9	1.4*	1.2*	1.6*
Absorbance	0.8*	1.1	1.1*	2.4*
NO <sub>2</sub>	0.5*	0.7*	0.9*	1.8*
NO <sub>x</sub>	0.3*	0.8	0.9	4.1*

\*Statistically significant different from urban background (paired t-test result, P-value < 0.05).

Also noteworthy is the **harbours background location** which measured lower than urban background in all median pollutant concentrations. In the overall, harbours background location appears to have measured the lowest among sites.

### 3.3. Comparison of PM Levels with Previous Studies

Levels of all pollutants except NO<sub>2</sub> were substantially higher than measured in Europe [10,13,14]. Absorbance coefficient measured at urban background in Dar es Salaam were about four times as high as the urban background values for European cities which ranges from 0.8 to 3.0 absorbance coefficient [13,14]; the absorbance level we measured at Traffic site were multiple factors to orders of magnitude higher than measured averages in European cities. High levels of soot we observed in Dar es Salaam are consistent with previous results which suggested high contribution of combustion, not only in Dar es Salaam but also in other cities in Sub-Sahara Africa [2,3,12,26].

The PM<sub>2.5</sub> concentrations measured in our study were several fold higher than reported in the global burden of disease (GBD) modelling study for the year 2005 [6]. In the GBD study, large scale (0.1 \* 0.1 degree) estimates of PM<sub>2.5</sub> were made by combining satellite observations and chemical transport models. Annual average PM<sub>2.5</sub> levels were below 10 µg/m<sup>3</sup>.

The relatively high levels of ambient pollutants measured in our study could be due to a combination of the following factors: First, we measured only during one month of the dry season and hence our average likely exceeds the annual average. Yet the dry season encompasses about eight months, this cannot explain the full difference with the satellite data. Second, we report data from specific point locations versus area-average values for the GBD data. We observed high spatial variability within the city of Dar es Salaam, suggesting that part of the difference could be due to the different spatial scale. We furthermore do not have monitoring data from outside Dar es Salaam. Third, because of the lack of surface monitoring data from SSA, there is considerable uncertainty regarding the modelled data. Notwithstanding, the levels of particulate component (PM<sub>10</sub> and PM<sub>2.5</sub>) were comparable with some of the published concentrations from Dar Es Salaam. PM<sub>10</sub> concentrations measured at traffic and landfill sites were comparable to levels reported by [22] [223.1 – 121.44 µg/m<sup>3</sup>]. Observation of higher concentrations at traffic site was also consistent with finding by [20] who reported Total Suspended Particulate (TSP) concentrations of 744 - 1161µg/m<sup>3</sup> at traffic, and 98 µg/m<sup>3</sup> at background locations.

Jackson [20] reported that the Suspended Particulate Matter (SPM) concentrations at traffic locations were above WHO standards applicable at the time of publication: Likewise, the average concentrations we found were higher than WHO Interim target (IT) IT-1 (150µg/m<sup>3</sup>) for traffic and landfill sites; IT-2 (100µg/m<sup>3</sup>) for suburban background; and IT-3 (µg/m<sup>3</sup>) for harbor and urban background locations [36]. However, direct comparison cannot be made between our results and those from [20] because different particulate fractions (PM<sub>10</sub> versus TSP) were measured. Koleleni [22] on the other hand reported collected weights (µg) rather than concentrations making our comparison even more complicated [5].

The particulate concentrations we found on the other hand were higher than reported from one monitoring campaign and some global estimates. Our results were near factor 2 higher than reported by [26] who measured both PM<sub>10</sub> as well as PM<sub>2.5</sub> at traffic location. We noted however that particulate samplers in their case were placed at least 10m above the ground which might have allowed resettlement of some particulates. Urban background particulate concentration measured were also about factor 2 higher than reported by [5] i.e. 40µg/m<sup>3</sup> 10 µg/m<sup>3</sup> for PM<sub>10</sub> and PM<sub>2.5</sub> respectively. The urban monitoring location (Dar es Salaam Institute of Technology (DIT) referred by [5] was well within 1km from our urban background location but only 50m from traffic intersection earlier recorded second highest TSP concentration [967 µg/m<sup>3</sup>] in the city [20]. The urban background concentration we measured were much higher than the estimates given by Wheeler et al. [33] where an estimated regional concentration of 37µg/m<sup>3</sup> was assigned to describe levels for Tanzania. While the results could reasonably correctly provide an overall estimate for the country situation, they may not account for the large variation between or even within cities and towns.

The high concentrations reported from three independent studies points to the likely high pollution levels in the city. Our study has also found background PM<sub>10</sub> concentrations to be substantially higher and consistently so in different neighborhoods. The observed higher particulate levels we measured were also true for PM<sub>2.5</sub> measurement where none of the background concentration we measured were as low as 17 µg/m<sup>3</sup> reported in [5]. The lower levels measured previously [5] could possibly be explained by the earlier study having been done a few years before ours and that measurements in their case were done in wet season. Particulate concentration measured in wet seasons have often been lower than dry season due to particle wash out effects by rain [5,22,23]. Nonetheless, higher PM<sub>10</sub> and PM<sub>2.5</sub> in our study were consistent in all background as well as source site locations.

Results of this study are rather comparable to those from a similar study done in the city of Accra whose monitoring period coincided with ours. We observed overlaps in concentration ranges for both PM<sub>10</sub> and PM<sub>2.5</sub> particularly for background locations. Average particulate concentrations from Accra study ranged from 57.9 µg/m<sup>3</sup> to 93.6µg/m<sup>3</sup> PM<sub>10</sub>, and 22.3 µg/m<sup>3</sup> to 40.2 PM<sub>2.5</sub> (Raphael E. Arku et al. 2008) which compares well with our range 86 - 108µg/m<sup>3</sup> PM<sub>10</sub> and 26.8µg/m<sup>3</sup> - 38µg/m<sup>3</sup> PM<sub>2.5</sub> in our background locations. Even though the background PM<sub>10</sub>

levels in two of the three Accra sites were substantially lower than we measured in Dar es Salaam. Our measurements for background sites were more than factor two the annual average concentrations reported for South Africa (30–40  $\mu\text{g}/\text{m}^3$ ) [36].

The urban background  $\text{PM}_{10}$  concentration we measured were in range of annual averages reported for Latin America, Caribbean (30–118  $\mu\text{g}/\text{m}^3$ ), and Asian cities (50–130  $\mu\text{g}/\text{m}^3$ ) but higher than reported for Europe (26.3 – 32  $\mu\text{g}/\text{m}^3$ ), North America i.e. in USA (14–63  $\mu\text{g}/\text{m}^3$ ), and Canada (20–28  $\mu\text{g}/\text{m}^3$ ) [36,38]. Notwithstanding, the background concentrations were higher than estimated by the World Bank in 2005. The World Bank's  $\text{PM}_{10}$  concentrations estimates for Tanzania were the same as estimated for the Netherlands [33]. Conversely, the background  $\text{PM}_{2.5}$  concentrations we measured were higher than those that are being reported from Dutch cities: 17 - 20  $\mu\text{g}/\text{m}^3$  for Amsterdam [18,31], 16.8  $\mu\text{g}/\text{m}^3$  Rotterdam urban, and 16.9  $\mu\text{g}/\text{m}^3$  an average for many cities [13,14,19].

### 3.4. $\text{PM}_{2.5}$ / $\text{PM}_{10}$ Fraction

Mean  $\text{PM}_{2.5}$  composition of  $\text{PM}_{10}$  particles (fine particle fraction) were 35.5%, 37.8%, 36.7%, 22.2%, and 31.7% respective for urban, harbours, suburb backgrounds, landfill, and Traffic locations. The fine particle composition was significantly lower in Landfill and Traffic compared to urban background location ( $P < 0.0001$ , and  $P = 0.0173$  respectively). Fine particle fractions at harbour and suburban did not differ from that of urban background location. The relative low fine particle composition in the two traffic and landfill locations could partly be due to increased resuspension of coarser particles ( $\text{PM}_{2.5-10}$ ) due to vehicle activities near the locations and high coarse particles resuspension from an unpaved road at the landfill site [37], this observation is similar to that of Accra study where traffic location had the least fine particle composition [2,3]. The coarse particles we measured were higher than what can be roughly estimated from [5], (25%); but lower than 45% deduced from collected weights reported by [22]. The  $\text{PM}_{2.5}/\text{PM}_{10}$  ratio we measured at urban background was within the range of concentrations measured at Accra (0.33% to 0.43) but slightly lower than measured at background site [2,3]. Urban background  $\text{PM}_{2.5}$  fraction measured in this study was lower than the typical values reported in USA (0.44) and Europe (0.42–0.82) [13,14].

## 4. Conclusion

Ambient air pollution concentrations measured in the city of Dar es Salaam were much higher than projected earlier.  $\text{PM}_{10}$  and  $\text{PM}_{2.5}$  levels measured in this study were several factors higher than those shown to elicit public health effects and exceeded the WHO's global interim standards on ambient particulates. We have related the elevated levels of particulate with particle resuspension from unpaved roads mainly in peri-urban areas in addition to exhaust emissions. The high levels of soot absorbance particularly at traffic location confirm that vehicular exhaust emission plays a leading role as a source of fine particulates. These results allude to the growing risk of excess diseases caused by ambient air pollution in major cities of SSA. Continuous monitoring and application of

mitigation measured targeting vehicular sources are necessary to reduce public health consequences of ambient pollution in Sub-Sahara African cities.

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