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Black Carbon Aerosols Impact of Khartoum Petroleum Refinery at Khartoum State

A. S. Ibrahim & F. I. Habbani†

Department of Physics, Faculty of Science, University of Khartoum, Khartoum, P. O. Box 321, Sudan

†Author for correspondence, E-mail: habbanif@yahoo.com Tel:+249912891550

Abstract

Since black carbon **(**BC) contributes directly and indirectly to the Earth's radiation balance change and to adverse health effects, it is of interest not only for climate research, but also for urban and regional air quality studies. In this paper results are presented of a study that was made of the black carbon concentration due to the impact of Khartoum petroleum refinery emissions at Khartoum State. In order to measure the black carbon concentration in the atmosphere, a sample of air is drawn through a filter medium with portable MiniVol samplers and the stain produced is measured by a reflectometer. The results of study were statistically analyzed and compared with data found in the literature.

Keywords: Black carbon; refinery emissions; MiniVol samplers; reflectometer.

1. Introduction

Black carbon (BC) is formed through the incomplete combustion of coal, oil and gas (fossil fuels), or wood, waste and ethanol (bio-fuels), and is emitted in both anthropogenic and naturally occurring soot (Jacobson, 2007). The most widely used global emission inventory estimates that about 8 million tons of black carbon and 37 million tons of organic carbon are emitted (Bond et. al, 2004). The major source contributions for black carbon include 40 percent from coal and oil burned in industrial and mobile sources, 18 percent from residential bio-fuels for heating and cooking (wood, agricultural and animal waste), and 42 percent from open biomass burning, including intentional burning in agriculture and forestry as well as wildfires (see Fig.2). Because BC particles are both very small and very inert, they can remain in the atmosphere for extended periods before being removed by scavenging processes. This poses a potential health problem, as these particles can penetrate deeply into the lungs and act as absorption sites for toxic pollutants (Charlock and Sellers, 1980). It is estimated that BC is responsible for more than 90% of light absorption and

25-45% of overall visibility reduction (Hamilton and Mansfield, 1991).

In atmospheric science, aerosol BC constitutes a pollutant of interest for two main reasons (Garivait and Chaiyo, 2006): (i) Its own direct and indirect effects due to its physical, chemical and physiological properties, and (ii) its use as a tracer to indicate the movement of meteorological air masses. The direct and indirect effects include: (i) Its great porosity characteristics and so its ability to adsorb other species from the vapour phase, especially organics, which are generally toxic. As BC particles are usually of micron and sub-micron sizes, they are readily inhaled and so act as vehicles for the transport and localized deposition of harmful compounds to the human respiratory system. (ii) Its capacity to provide a surface that may catalytically promote other atmospheric chemical reactions, especially in the presence of water. It has been observed that the presence of aerosol BC can lead to increased production of aerosol acidity. (iii) The large optical absorption cross-section of BC leads to the

extinction of radiation, both infrared and visible, in highly polluted cities, which resulted in gray skies and visibility reduction. Because of this property, BC is an important contributor to the Earth's radiation balance. Estimates of climate forcing ranges from 0.27 to 0.54 W.m-2, leading to the warming of the atmosphere. (iv) Carbonaceous aerosols may, under certain conditions, become condensation nuclei, and hence changing the size distribution, optical properties and rainfall potential of clouds. The incorporation of BC into cloud droplets would also significantly affect the cloud albedo and rainfall potential. It was reported that smoke emissions from the Indian subcontinent have perturbed the pattern of monsoonal rains over Southeast Asia. (v) The presence of BC in an air mass is an indicator of the "history" of the air mass being impacted by combustion emissions, and so the resulting information may help public awareness development. For all these reasons, BC is of interest not only for climate research but also for urban and regional air quality studies.

On the other hand, the capability to perform the BC measurement in real-time provides temporal variation or time integration information of the air mass. This is more and more required to support decision-making in air quality management, in climate change mitigation, in emission source investigation and control strategy and in investigation of risk areas related to human health exposure to fine particulate matter (PM10 or PM2.5).

Developed countries were once the primary source of black carbon emissions, but this began to change in the 1950's with the adoption of pollution control technologies in those countries (Ramanathan and Carmichael, 2008). The European Union and United States could further reduce their black carbon emissions by accelerating implementation of black carbon regulations. Existing regulations also could be expanded to increase the use of clean diesel and clean coal technologies and to develop second-generation technologies.

Today, the majority of black carbon emissions are from developing countries and this trend is expected to increase (Tami Bond, 2007). The largest sources of black carbon are Asia, Latin America, and Africa (Tami Bond, 2002). China and India account for 25-35% of global black carbon emissions.

2. Materials and Methods

2.1 Sampling sites and descriptions:

The petroleum refinery is situated 60 km north of Khartoum North central area. The study involved ten locations south of the refinery, including five in Khartoum North rural area (Saqqai, Tamim Al-Ahamda, Kabbashi, Al-Khogalab and Um Al Qora Shamal) and the rest are in the urban area (Halfayat Al Muluk, Shambat, Wad Nobawi, Assamrab and Khartoum North Light Industrial Area), as shown in Fig.1. PM2.5 and PM10 samples were obtained from a rooftop at 4-8m above ground level (see Fig.3), at the ten sampling locations. The PM samples were collected during the period from 1 to 23 January 2010.

2.2 Samples collection:

12 hours sampling period during 24 hour (using programming timer) PM2.5 and PM10 samples were collected at the sampling locations using two battery powered Minivolume samplers (Airmetrics, Oregon, USA) operating at flow rates of 5 l/min Fig.4 (Cao, J. J., et. al, 2003). PM samples were collected on 47mm Millipore, 0.45µm pore size filters. Wind direction, speed and other climate parameters during, the sampling period were recorded in Table 1.

2.3 Optical carbon analyses:

The first stage in calculating the ambient concentration of black smoke is to measure the darkness of the smoke stains obtained from the sampler. This is carried out using a photo-electric reflectometer. This instrument emits a steady light onto the smoke stain, which is reflected back from the smoke stain to a photo-sensitive element. The electrical response is then amplified to produce a meter reading. The darker the stain, the less light is reflected, so a low meter reading corresponds to a dark surface, and a high reading to a light surface. The Reflectometer reads on a scale of 0 (black) to 100 (white). This reflectometer reading, together with the measured volume of air sampled, and the filter clamp size, is used to calculate the ambient concentration of black smoke from a standard calibration.

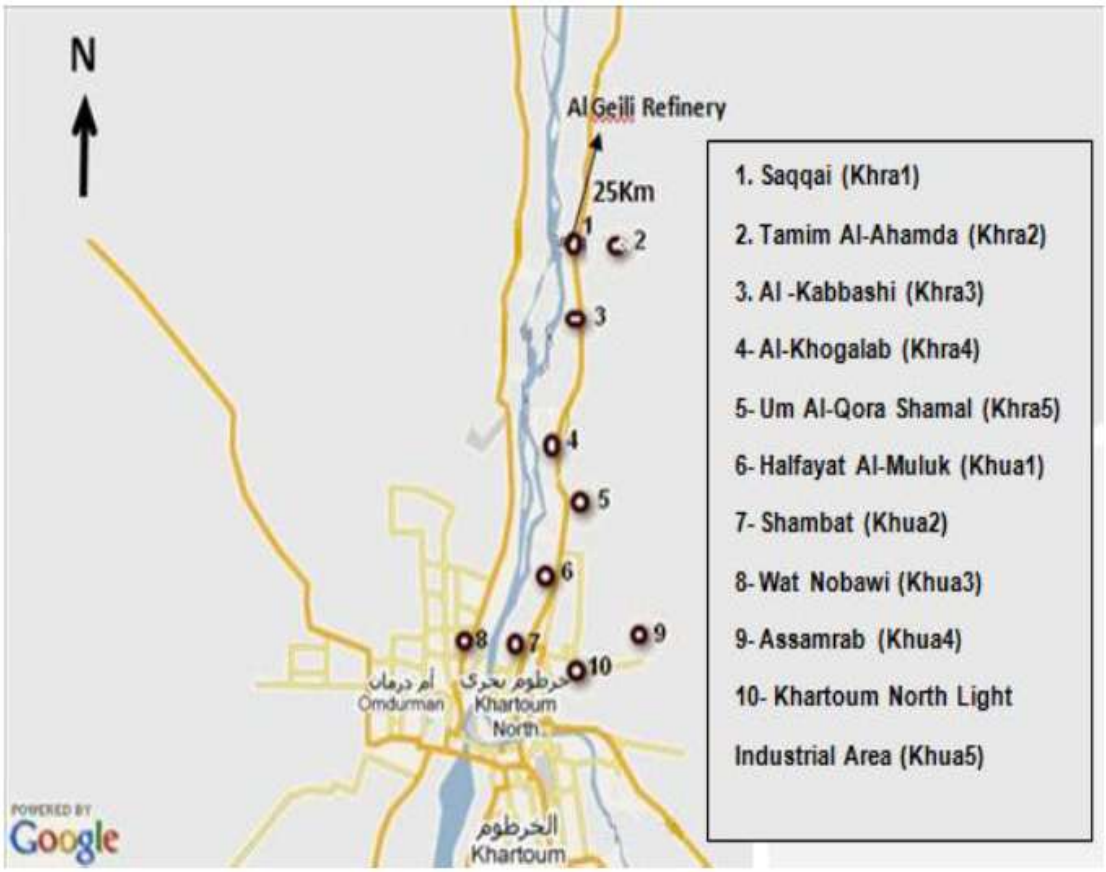

Fig. 1: Samples locations in the study area

2.4 Smoke Stain Reflectometer:

From a reflectometr measuring head a light from a tungsten lamp passes through an orifice of a photocell to project a well defined spot on the sample, and then reflected to the photocell. Accurate positioning of the head is effected by placing over the sample a detachable mask with a half-inch aperture and locating rim, into which the head is then inserted.

A lead from the measuring head is connected to a display unit on which the readings 0 to 100 are indicated.

A white /grey standard, marked with its reflectance value, is supplied with each instrument.

2.5 Linearity check:

The mask and the measuring head are located on the white standard and the sensitivity control adjusted to produce a reading of 100. They are then transferred on to the grey standard and the new reading is taken. This should be equal the value given on the standard within ±1½ divisions.

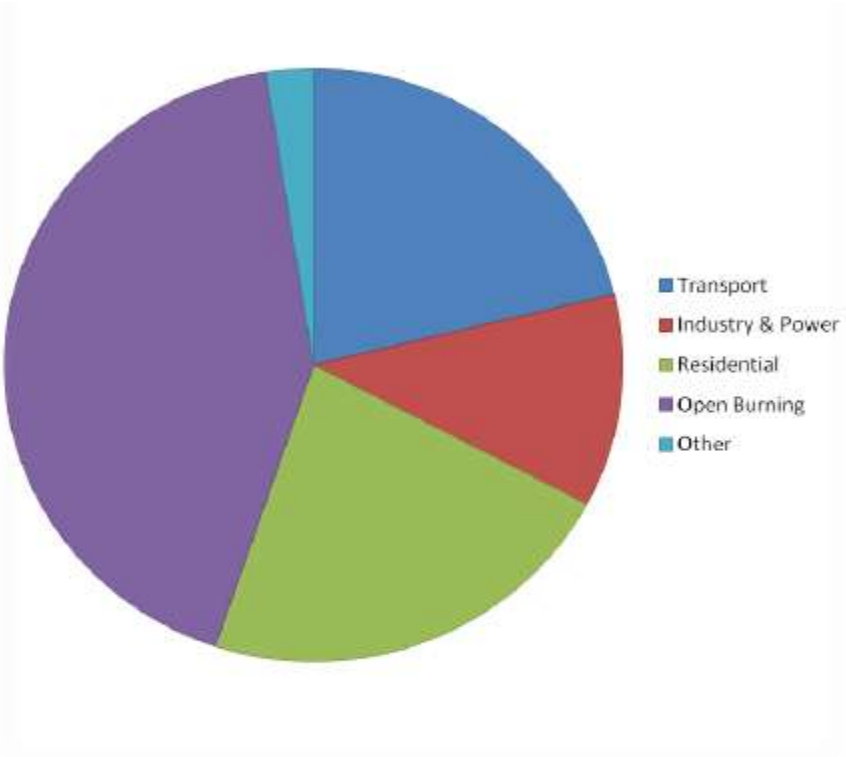

Fig. 2: Global Black Carbon Emissions Estimates (Bond Inventory 7.2.3, based on energy use in 2000). All emissions are in thousand metric tons per year. Total emissions are estimated to be uncertain by a factor of two.

Fig. 3: Two MiniVol samplers placed at one of the measuring sites on a Roof-top.

Fig. 4: MiniVol air sampler layout

Table 1: Atmospheric conditions existing at each sampling day, measured at Khartoum Bahri city center [http://www.wunderground.com].

Sampling day	Temperature maximum (°C)	Temperature minimum (°C)	Mean temperature (°C)	Wind direction	Wind speed Km/h	Anerage humidity (%)
2/1/010	31	17	24	N/N	9	21
3/1/010	27	17	19	NW/NNW	10	15
4/1/010	31	19	25	NW/N	8	16
5/1/010	23	22	23	NNW/NW	11	16
6/1/010	33	19	26	NNW/NE	9	17
7/1/010	34	24	28	N/ENE	8	22
9/1/010	33	19	26	NNE/NE	11	28
10/1/010	35	22	24	NNE/NE	12	26
11/1/010	36	35	36	NE/ENE	10	14
12/1/010	36	32	36	ENE/NNE	8	8
13/1/010	35	26	30	NNW/NNE	11	10
14/1/010	33	21	23	NNW/NNE	9	12
16/1/010	36	28	28	NNW/NW	8	17
17/1/010	34	24	28	N/ENE	7	15
18/1/010	31	20	28	NW/N	15	17
19/1/010	29	17	23	NW/NNW	17	16
20/1/010	19	19	19	NNW/N	12	24
21/1/010	29	25	29	N/N	12	9
23/1/010	30	30	-	N/-	13	10
24/1/010	30	16	23	ENE/NNE	18	6

2.6 Reflectometer calibration:

If linearity check gives acceptable reflectance values, one of five control filters (taken from the same lot/batch of filters as the sampling filters) was centrally placed over the white standard, reflectance from the center of the filter was measured and adjusted the reading to 100.0; measurement repeated four times using different location of measuring head for each measurement (5-point method) and readings was recorded in a data form. Without re-adjusting the reflectance reading, reflectance for the other four control filters was measured using the 5-point method. The filter with the median average reflectance was designated as the primary control filter, unless the standard deviation of the five measurements was more than 0.5 units (if it was higher a new filter was selected and the procedure repeated).The primary control filter was used in each analysis session to set the reflectometer to 100. Sampled filters were measured at the five standard locations as well.

2.7 Reflectance measurement:

The reflectance of all filters was measured using the M43D Smoke Stain Reflectometer (Diffusion Systems LTD), shown in Fig.5, which measures the reflection of the light incidence in percent.

2.8 Calculation of BC concentrations:

To calculate the mass concentration of elemental carbon in the atmosphere in μg/m³, use was made of the Cohen method (Bamford, 2010). The area density, D, was calculated using the following equation:

$$D(\mu g/cm^2) = \frac{100}{2aF} ln \frac{R_0}{R} \quad (1)$$

where a = 5.27m²/g and F = 1.00 For 47mm nucleopore filter and R0, R are the unloaded and loaded filter reflectance respectively. With the volume of air sampled (V) and the filter collection area (A) known, the mass concentration was determined using the following equation (Bamford, 2010):

$$M = \left(\frac{DXA}{V}\right) \quad (2)$$

Fig. 5: The Smoke Stain Reflectometer that was used for measurement of the black carbon.

3. Results and Discussion

During the month of January 2010, measurements were carried out for twenty air particulate samples. The samples were collected from ten different locations in the Northern Khartoum urban and rural area.

In Table 2 coarse (PM10) and fine (PM2.5) fractions of BC concentrations (conc.) with mean and standard deviation (SD) values are shown according each sampling site. The (SD) values in this table are due to the daily variations in environmental factors (direction and velocity of wind, temperature, source strength …etc) and the different of the distances from the sources. For the two particle modes the mean values of the BC concentration in the rural area was relatively less than its values in the urbane area.

Fig. 6 is the graphical representation of BC concentrations in Northern Khartoum rural and urban area. In Fig. 7 a comparison is shown between the values of the BC coarse fraction concentrations and those of the fine ones, as can be seen the BC fine fraction (PM2.5) concentrations are greater than those of the coarse fractions PM10. This is due to existence of anthropogenic sources (the refinery and biomass burning).

In Table 3 a comparison is made between BC concentrations level in fine fraction mode in Khartoum North rural area and the distances between the sample sites and

Al Geili Refinery (in kilometres). And it can be seen from Fig.8 that the PM2.5 concentration is respectively related to the distance from the refinery.

Conclusion

The purpose of this paper is to highlight some measurement issues associated with ambient black carbon, to provide background information to aid interpretation of the data.

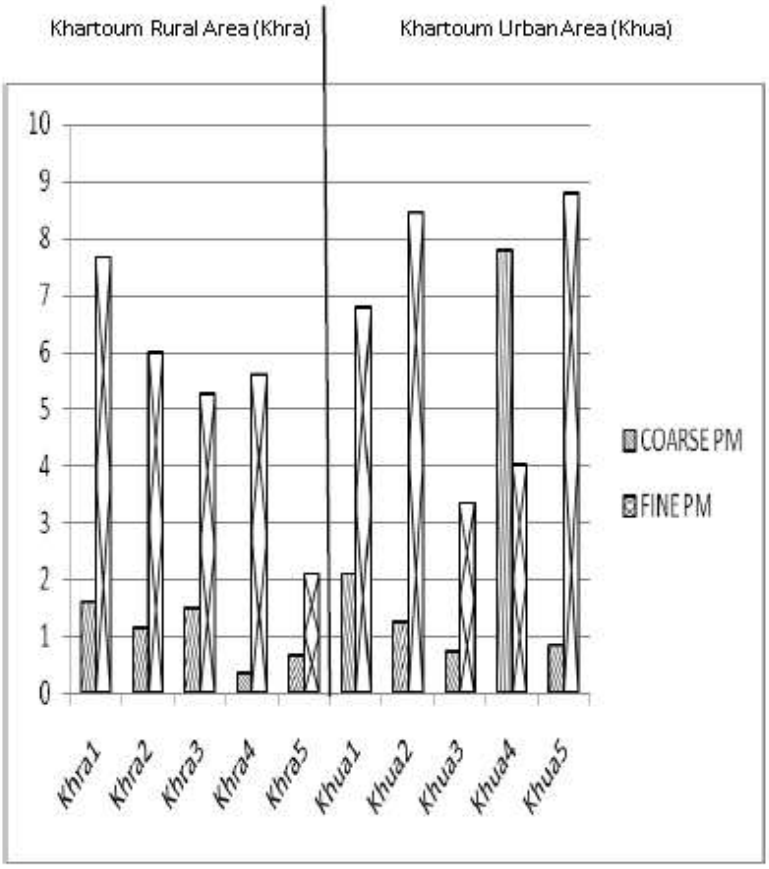

Fig. 6: Comparison of PM_{10} and $PM_{2.5}$ concentration levels of BC and comparison of their levels in rural and urban areas in Northern Khartoum area.

Table 2: BC Concentrations (conc.), Mean Values and Standard Deviation (SD) for Coarse and Fine Particles in aerosols in Khartoum Northern rural and Urban Area in January 2010.

Measurement Area	Sample Sites	PM_{10}(BC) conc. μgm^{-3}	PM_{25}(BC) conc. μgm^{-3}
Rural Area	Khra1	1.6	7.65
	Khra2	1.15	5.98
	Khra3	1.49	5.26
	Khra4	0.38	5.60
	Khra5	0.67	2.09
Mean value (μgm^{-3})		1.06	4.43
(SD) average μgm^{-3}		0.64	2.83
Urban Area	Khua1	2.09	6.78
	Khua2	1.25	8.45
	Khua3	0.72	3.34
	Khua4	7.80	4.00
	Khua5	0.85	8.78
Mean value (μgm^{-3})		2.54	6.27
(SD) average μgm^{-3}		2.99	2.50

Table 3: Concentrations of BC with the distances from the refinery

Sample sites in rural area	Distance from the refinery Km	PM_{10} conc. $\mu g\, m^{-3}$	PM_{25} conc. $\mu g\, m^{-3}$
Khra1	20	1.6	7.65
Khra2	22	1.15	5.98
Khra3	25	1.49	5.26
Khra4	40	0.38	5.60
Khra5	43	0.67	2.09

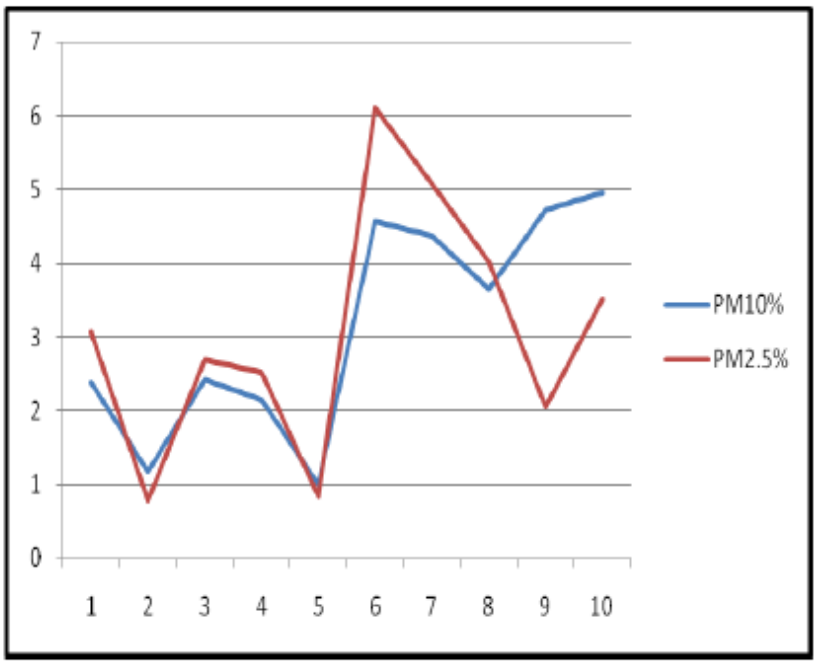

Fig. 7: Comparison of PM2.5 & PM10 (BC)

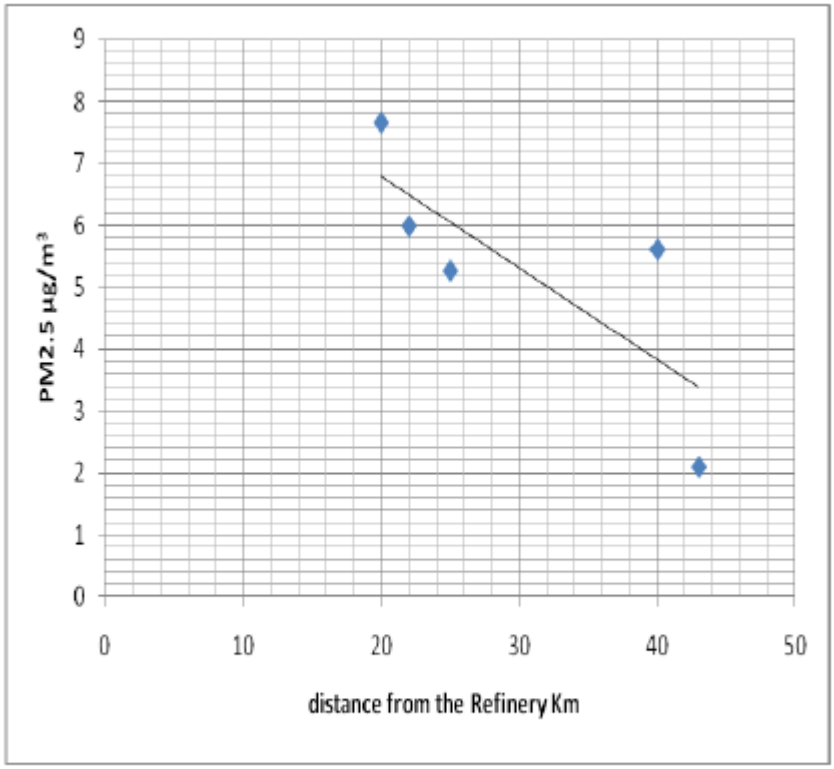

Fig. 8: Fine fractions of BC concentrations in Khartoum North Rural area in relation to the distances from Al Gaili petroleum refinery.

The main conclusions are that, the BC concentrations in PM2.5 in the nearest locations to the refinery are higher when compared to the urban locations except Shambat and Khartoum North light Industrial area. The observed black carbon of PM2.5 fraction in the study area was in the range of the reported in the literature for urban areas such as Bern (4.2), Zurich (1.8), Edinburgh (5.7), Auckland (1.2) and Brisbane (1.8), but lower when compared to cities like São Paulo (4.1-7.6), and Santiago (3.5-10.4) (Soluri et al., 2007) .

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