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ORIGINAL PAPER

Environmental Quality Assessment in Areas Used for Physical Activity and Recreation in a City Affected by Intense Urban Expansion (Fortaleza-CE, Brazil): Implications for Public Health Policy

Camille A. Rocha[1] · Francisco W. Sousa[2] · Maria E. Zanella[3] · Andre G. Oliveira[4] · Ronaldo F. Nascimento[4] · Oscarina V. Souza[5] · Italo M. P. Cajazeiras[5] · Joyce L. R. Lima[1,6] · Rivelino M. Cavalcante[1]

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Abstract The multi-indicators (chemical, biological, and physical), as well as their associated risks to human health, were assessed at the same time as an assessment of the use of sites for physical activity. The sampling was conducted in both the dry and wet seasons in 2014, between 4:30 and 7:30 pm, a period considered the "peak hours" of traffic and also the time that most people practice physical activity. Regarding the chemical indicators, the distribution of carbonyl compound levels should be influenced by the flow of vehicles, while the respirable particles are governed by the number of diesel vehicles. The cancer risk corresponding to the value recommended by National Institute for Occupational Safety and Health (NIOSH) for formaldehyde was exceeded only in the dry season in one location studied. The risk of non-carcinogenic substances showed that acrolein levels at all locations and in the two periods studied might cause adverse effects to the health of the recreation site users. Exposure to respirable particles at levels corresponding to the value recommended by the United States Environmental Protection Agency (US-EPA) was exceeded in all locations during the two study periods. For biological indicators, only the bacteria levels show pollution ranging from medium to high for the two sites in both periods studied. Regarding the physical indicators, the noise levels in the studied sites exceeded the standards recommended by the World Health Organization (WHO) and US-EPA. In most places, the thermal comfort was close to 40, which is classified as "supportable discomfort."

Keywords Environmental health · Public health · Health impacts · Risk of health effect

✉ Rivelino M. Cavalcante
rivelino@ufc.br

1 Laboratory for Assessment of Organic Contaminants (LACOr), Institute of Marine Sciences, Federal University of Ceará, 60165-081 Fortaleza, Ceará, Brazil

2 Laboratory of Materials Chemistry, Environmental and Organic (LQMAO), Federal Institute of Education, Science and Technology, Rua Rodolfo Teófilo 200 Centro, CEP: 62800-000 Aracati, Ceará, Brazil

3 Geography Department, Federal University of Ceará, 60205-181 Fortaleza, Ceará, Brazil

4 Laboratory of Analysis Trace (LAT), Department of Analytical Chemistry and Physical Chemistry, Federal University of Ceará (UFC), 60020-181 Fortaleza, Ceará, Brazil

5 Laboratory of Environmental Microbiology and Fished (LAMAP), Institute of Marine Sciences, Federal University of Ceará, 60165-081 Fortaleza, Ceará, Brazil

6 Undergraduate Course of Public Policy Management (Políticas Públicas/UFC), Federal University of Ceará, 60020-181 Fortaleza, Ceará, Brazil

Introduction

The United Nations estimates that by 2050 the world population will reach 9.6 billion, and 6.4 billion will be urban residents (United Nations 2014a, b). Kourtit and Nijkamp (2013) report that population growth leads to expansion of cities, increases in productivity and excessive costs, such as increased car traffic, and, consequently, an increase in air pollutant levels, reducing environmental health. There is a close relationship between urbanization, green areas, and environmental health; less urbanized locations with a strong presence of vegetation provide greater availability of ecosystem services and have healthier populations (Maas et al. 2006).

Approximately 4 % of the surface of the planet is urban areas, housing more than 50 % of the human population, who use approximately 75 % of the Earth's natural resources and produce a similar amount of pollutants and waste (Redman and Jones 2005; Patel and Burke 2009). In this small urban area, there are social and economic instability, losses in ecosystem services, scarcity of resources, and reduction of green areas (Foley et al. 2005; Knickerbocker 2007; Turner et al. 2007; Breuste et al. 2013). This reduction in green areas in cities reduces the environmental quality (Shafer et al. 2000; Wells and Evans 2003), even in new projects of territorial expansion for urbanization in China (Li et al. 2014).

According to Luengo (1998), environmental quality means the interaction of ecological, biological, economic, social, cultural, technological, and esthetic factors, having as the product of this interaction a healthy and comfortable environment and sustainable human life. Environmental quality can be assessed through environmental indicators that are qualitative or quantitative parameters able to represent the required environmental situation, allowing the monitoring of human impact on the physical, chemical, biological, and socioeconomic domains (OECD 2003; Lopez and Rodriguez 2009).

In recent decades, urban centers have experienced a large decline in environmental quality due to a variety of factors that have a direct impact on urban environmental health (Crutzen 2004; Gurjar and Lelieveld 2005). The car traffic in cities is implicated in compromising the respiratory system due to the decrease in air quality as well as the ambient noise, which affects the nervous, immune, and sensory systems (Shepson et al. 1986; Areskoug 2000; Kim et al. 2012; Tiesler et al. 2013). In addition, the high level of traffic, combined with low arborization and high insolation, especially in the tropics, also interferes with the temperature of urban areas, resulting in increased thermal discomfort in cities (Johansson et al. 2013).

Studies in Brazilian megacities associate high levels of air pollutants with increased cases of respiratory diseases in large urban centers (Rios et al. 2004; Ribeiro and Cardoso 2003; Gonçalves et al. 2005; Sousa et al. 2012). However, urban environmental quality studies are scarce in the literature, although the issue is of global importance (Silva and Mendes 2012; Silva 2015). Most studies address environmental indicators, such as thermal comfort, noise, and air quality, separately to measure the quality of the environment, as well as for the construction of an environmental index (Ho et al. 2006; Błażejczyk et al. 2010; Souza and Giunta 2011; Hunashal and Patil 2012; Pantavou et al. 2014; Bagienski 2015).

The city of Fortaleza is an example of an urban area with intense and rapid expansion. In the last decade, Forteleza experienced a real estate "boom," increasing the population density in addition to an increase of over 100 % in the vehicle fleet (DENATRAN 2015). This sudden growth occurred in a disorderly manner without urban planning and is related to the improvement in the economy. Concomitantly, the lack of planning contributes to the reduction of public areas used for physical activity, sports, and leisure. Thus, people started using squares and sidewalks surrounded by avenues with heavy car traffic, inserted in the highly built-up environment.

Appropriate sites for physical activity and recreation in urban areas are increasingly scarce and becoming inadequate, thus compromising the quality of the environment and, consequently, the health of its users. Even in countries with urban planning, these areas may have a compromised quality due to atmospheric transport of pollutants from unhealthy areas, as well as noise and increasing temperature coming from urban activities. Thus, this study aims to evaluate the environmental quality of sites used for the practice of physical activities and leisure in the city of Fortaleza, and the influence of seasonality based on the environmental multi-indicators (e.g., chemical, physical, and biological). The risk to human health was also estimated, based on the levels of carcinogenic and non-carcinogenic substances. It is believed that the results of this study will serve as the basis for future assessments of these areas, as well as contribute to the creation of public policies related to environmental health in urban cities.

Experimental

Sampling Sites

The city of Fortaleza is located on the Atlantic Coast, in the northeastern region of Brazil with an area of 314.93 km^2 and a population of 2,571,896 people (IBGE 2014). The region has two well-defined seasons, dry (August to December) and wet (January to July), with average temperatures ranging from 25 to 28 °C, an annual average wind speed of 3.5 $m\ s^{-1}$, and medium rainfall of 1600 mm; however, the rains are concentrated between February and May (Sousa et al. 2015). There are approximately 983,000 vehicles in Fortaleza, of which 546,000 (55 %) are considered light vehicles (gasoline-powered and ethanol); 149,000 (15 %) are considered heavy vehicles—diesel-powered (buses, vans, and trucks); and 263,000 (26 %) are motorcycles (DENATRAN 2015).

The sampling was conducted in both the dry and wet seasons in 2014, during the months of June and July (wet season) and September and October (dry season), to check the effect of seasonality on the data. Note that 2014 was marked by low rainfall (1000 mm $year^{-1}$), and thus the dry season predominated during the year (FUNCEME 2014).

This study was conducted in the afternoon, between 4:30 and 7:30 pm, a period considered the "peak hours" of traffic in the city and also the time that most people practice physical activity in the studied sites. The data collection was performed in triplicate, each day at a different location to decrease the measurement bias and all equipment used in the study were located on the sidewalk, at the height of 1.5 m above the ground where people walked. For each study site, user profiles (n = 30) and their length of stay were determined through interviews, and the car flow and the flow of people were measured by filming in the time of sampling and subsequently calculated (Table 1). The sites selected for the study are different in terms of urban activity, flow, and type of vehicles, and building and population density, and they have in common their use for physical activity and recreation (Table 1).

Indicators Studied

Five parameters related to three indicators used in the study are summarized in Table 2.

Chemical Indicators

Carbonyl Compounds and Respirable Particulate Matter

The CCs investigated were as follows: formaldehyde, acetaldehyde, acrolein, propionaldehyde, crotonaldehyde, butyraldehyde, benzaldehyde, isovaleraldehyde, valeraldehyde, *o*-tolualdehyde, *m*-tolualdehyde, *p*-tolualdehyde, dimethylbenzaldehyde, and 2.5 hexaldehyde. The adsorbent solution—0.2 % solution of 2,4-DNPHi—was prepared by weighing 50 mg of pure reagent in 15 mL of HPLC-grade acetonitrile, 9.75 mL of ultra-pure water, and 0.25 mL of concentrated phosphoric acid (H_3PO_4), resulting in a final pH of approximately 2. The adsorbent solution was prepared in the laboratory 24 h before collecting impregnated in cartridges (Sep-Pac C18, Supelco) that have been transported carefully to the sampling site on the following day. For the sampling of CCs, ambient air was pumped through the conjugated system (trap-gas-bomb portable (SKC)/Sep-Pac C18 cartridges) at a flow rate of 0.5–1.0 L min^{-1} (the total sampled air volume was recorded by a gas meter). In the laboratory, the cartridges were slowly eluted with 2 mL acetonitrile (ACN) and 20 μL was injected in triplicate into the Shimadzu (LC-10 AD model) HPLC instrument. The quantification and identification of CCs was based on retention time and absorption spectra. Calibration curves were prepared using six different concentrations of standards (50-1000 μg L^{-1}), with a correlation coefficient (R^2) greater than 0.99. The sampling and instrumental details were recently described by Sousa et al. (2015).

For the RPM assessment, we also used a bomb sampling system portable/filter cassette/cyclone (SKC). The sampling was carried out at a flow rate of 1.5 L min^{-1} for 3 h, for 3 days a week. A 47-mm glass fiber filter with a porosity of 0.7 μm (Millipore) was used. Before and after collection, the filters remained 48 h in an oven at 60 °C for the removal of humidity. After the sampling time, the filters were taken to the laboratory and analyzed by differences in weight between the clean filter and collected, according to the procedure suggested by Kim Oanh et al. (2009).

Biological Indicators

Microbiological Organisms (MOs)

The MOs were collected by spontaneous sedimentation, where plates with culture media for the growth of fungi and bacteria were exposed for at least 1 h in each study site. After the time of collection of microorganisms, the plates were taken to the laboratory and analyzed using the pour plate technique; according Friberg et al. (1999), the pour plate technique is the Standard Plate Count method, which yields the number of CFU per m^3 of air.

Physical Indicators

Thermal Comfort and Noise

The meteorological parameters were measured using a weather station (Davis, VantageVue model). To calculate the thermal comfort, Human Comfort Index (HCI), calculated from the ratio of air temperature/relative humidity/vapor pressure using (Eq. 1), was used (Anderson 1965; Rosenberg 1983):

$$HCI = T_a + \frac{5}{9}(e_a - 10), \qquad (1)$$

where T_a is the air temperature in °C and e_a is the vapor pressure calculated by Eq. 2:

$$e_a = \frac{e_s \times RH}{100}, \qquad (2)$$

where e_s is the saturated vapor pressure of the air calculated using Eq. 3:

$$e_s = 6.1 \times 10^{\frac{(7.5 \times T_a)}{(237.3 + T_a)}}. \qquad (3)$$

Table 3 shows the classification of the degree of thermal comfort due to the HCI values.

The noise was measured by a sound level meter (Instrutherm, DEC-420 model) every second for 3 h, 3 days a week. All measurements were performed in quick response "FAST" on the curve "A" (dB (A)) with an automatic level scale ranging from 30 dB to 130 ± 1.4 dB precision

Table 1 Characteristic of the studied places

Locations and characteristics	Data			
	Flow of people per minute (wet/dry)	Flow of vehicles per minute (wet/dry)	Length of stay (min day^{-1}) in two seasons	Arborization/building index (%)[1]
 *Point 1—Beira Mar Sidewalk* Located on the seafront of Fortaleza, it is approximately 4 km long and receives many people daily. It has volleyball courts and soccer, skating rink and fitness equipment. There is a strong presence of buildings throughout its length, most hotels having robust tourism infrastructure. It is intense real estate speculation target and is one of the postcards of the city	24/32	22/22[a] 0.5/1[b]	60 ± 5	8.84/29.91
 *Point 2—Crasa Sidewalk* Located right angles to one of the busiest avenues of the city, it is 1 km long, 12.000 m^2, and has exercise equipment, a sand court, and a running track. It has modern lighting and fully adapted infrastructure, providing wide accessibility to disabled people. It has little vegetation on site and nearby	15/17	26/29[a] 2/3[b]	60 ± 8	2.45/42.39

Table 1 continued

Locations and characteristics	Data			
	Flow of people per minute (wet/dry)	Flow of vehicles per minute (wet/dry)	Length of stay (min day^{-1}) in two seasons	Arborization/building index (%)[1]
 *Point 3—General Eudoro Correia Square* Also known as Flowers's Square for hosting one of the most traditional fairs of flowers and small plants of the city, it is 25.000 m^2. It is located in a rich neighborhood of the city and is in the center of four streets that receive a heavy car flow daily. It has race track, sports court, soccer field, and fitness equipment. There is a strong presence of vegetation on site	8/11	37/35[a] 1/1.5[b]	60 ± 3	9.15/38.2

[a] Gasoline-powered vehicles and alcohol

[b] Diesel-powered vehicles

[1] Cattony (2016)

and the frequency range of 31.5 Hz to 8 kHz. The data were also analyzed using Microsoft Excel.

Risk to Human Health

Carcinogenic and Non-carcinogenic Substances

The risk to human health was estimated using the model of chronic ingestion per lifetime (CDI, mg kg^{-1} dia^{-1}) (Eq. 4), with variables shown in Table 4. These variables were collected from questionnaires administered to users of the study sites.

$$\mathrm{CDI} = \frac{(\mathrm{CA} \cdot \mathrm{IR} \cdot \mathrm{ED} \cdot \mathrm{EF} \cdot L)}{(\mathrm{BW} \cdot \mathrm{ATL} \cdot \mathrm{NY})} \tag{4}$$

The risk from carcinogenic substances was estimated by multiplying the CDI by slope factor (SF) (0.0455 (mg kg day^{-1}) (Eq. 5) for formaldehyde and 0.0077 (mg kg day^{-1}) for acetaldehyde) individually for each substance according to the Integrated Risk Information System (IRIS) (US-EPA 1992a, 1996, 2004).

$$\mathrm{CR} = \mathrm{CDI} \cdot \mathrm{SF} \tag{5}$$

The non-carcinogenic risk was estimated by dividing chronic ingestion per lifetime (CDI, mg kg^{-1} day^{-1}) by the reference dose (RfD, mg kg^{-1} day^{-1}) (Eq. 6), expressed in the literature, generating the Risk Index or Hazard Quotient, HQ (NRC 1990; DEP 2002):

$$\mathrm{HQ} = \frac{\mathrm{CDI}}{RfD}. \tag{6}$$

If the HQ is less than 1, the exposure to the chemical in question is considered unlikely to cause adverse health effects, otherwise, if the HQ is greater than 1, the likelihood of adverse health effects is high and the remedial action or mitigation is likely to be required. HQ is not a risk measure, but only a starting point for estimating the risk (Williams et al. 2000; Yu 2004). The HQ was calculated only for acrolein and benzaldehyde, as other compounds found in the study do not have a reference dose in the IRIS system.

Individual Daily Exposure Assessment

The exposure for an individual can be calculated as the average of the exposure, expressed as a potential dose

Table 2 Multi-indicators used in this study

Indicators	Parameters	Characteristics
Chemical	1. Carbonyl compounds (CCs)	14 carbonyl compounds (μg m^{-3})
	2. Respirable particulate matter (RPM)	Respirable Fine Particle (≤2.5 μm)
Biological	3. Microbiological organisms (MOs)	Fungi (CFU)
		Bacteria (CFU)
Physical	4. Thermal comfort	Relation (temperature/humidity/vapor pressure)
	5. Noise	Decibel levels (dB)

CFU colony-forming units

Table 3 Human thermal comfort indices

Temperature degrees	Comfort degrees
Between 20 and 29 °C	Comfortable
Between 30 and 39 °C	Comfort varying degrees
Between 40 and 45 °C	Discomfort supportable
Over 46 °C	Discomfort insupportable

Table 4 Description of the variables used in the exposure calculations and estimation of the risk of cancer

Parameter	Description	Value	Unit
CA	Contaminant concentration	–	mg m^{-3}
IR	Inhalation rate (adult)	3.06	m^{-3} h^{-1}
ED	Exposure duration (adult)	4[a]	h^{-1} $week^{-1}$
EF	Exposure frequency	52	$week^{-1}$ $year^{-1}$
L	Exposure time	35[b]	year
BW	Body weight man/woman	75/65[c]	kg
ATL	Life expectancy man/woman	69/72	year
NY	Number of days of the years	365	day^{-1} $year^{-1}$

[a] Average hours that a physical exercise practitioner stays in place per week

[b] Whereas a person practicing exercise for a maximum of 35 years of life

[c] Average weight of exercise practitioners of the sites studied (man/woman)

(PD). The exposure (PD) for an individual (i) due to intake processes (inhalation or ingestion) can be calculated from the equation of the US-EPA. The PDi (μg day^{-1}) (US-EPA 1992b) was calculated for the RPM from the relation of contaminant concentration (C, μg m^{-3}), inhalation rate (RI*, m^3 h^{-1}), and exposure time (T, h day^{-1}) expressed by Eq. 7:

$$PDi = C \cdot \mathrm{RI} \cdot T. \tag{7}$$

* It is estimated that one person (non-asthmatic) in his normal activities presents an inhalation rate of 0.75 m^3 air per hour (m^3 h^{-1}) (low inhalation), while a person performing his functions quickly presents a inhalation rate of 3.06 m^3 h^{-1} (high inhalation) (US-EPA 1997).

Results and Discussion

The results of the multi-indicators used to assess the quality of the environments studied are summarized in Table 5. The average of the total CC concentration (Σ_{CCs}) ranged from 13.2 to 83.9 μg m^{-3}, the average RPM ranged from 12.5 to 190.1 μg m^{-3}, the thermal comfort ranged from 36.0 to 40.0, the average noise ranged from 65.0 to 69.0 dB, and the microbiological organisms on average ranged from 116.2 to 815.0 CFU m^{-3} for fungi and 678.8 to 4223.4 CFU m^{-3} for bacteria.

Chemical Indicators

The CCs can be emitted to the atmosphere from a variety of natural and anthropogenic sources. In remote areas, the natural sources include the burning of forests and volcanic eruptions, while in urban environments the presence of CCs is related to direct emissions (primary sources), especially those derived from fuel combustion, as well as secondary sources formed in situ from the photolysis and hydrocarbon photooxidation and of other atmospheric organic compounds (Schauer et al. 2001; Khwaja and Narang 2008). In recent years, renewable fuels are being encouraged despite strong evidence that the addition of biofuel to diesel or gasoline increases the emission of CCs into the environment (Correa and Arbilla 2005; Song et al. 2010; Ballesteros et al. 2014). The average Σ_{CCs} during the dry period was higher than that during the wet period (Table 5). Throughout the study, point P3 (55.8 μg m^{-3}) showed the highest average Σ_{CCs} followed by points P2 (33.5 μg m^{-3}) and P1 (22.3 μg m^{-3}) (Table 5). The distribution of CCs must be influenced by the primary emission based on the traffic flow because the flow presented the same distribution: P1 (23 vehicles min^{-1}) greater than P2 (32 vehicles min^{-1}), followed by P3 (36.5 vehicles min^{-1}) (Table 1).

Particulate matter in the atmosphere is tiny liquid or solid particles whose sizes range from 0.001 to 100 μm. These particles have natural or anthropogenic sources and can be issued directly from the source (primary form) or formed in the atmosphere (secondary form) through the

Table 5 Values and levels of the studied indicators

Locations	Indicators					
	Chemical		Physical		Biological[c]	
	Σ_{CCs} (μg/m^3)[a]	RPM (μg/m^3)	Thermal Comfort (ICH)[b]	Noise (dB)	Fungi (CFU/m^3)	Bacteria (CFU/m^3)
Point 1 (P1)						
Wet	13.2	12.5	40.0	67.0	102.5-136.68 (116.2)	594.6-806.4 (678.8)
Dry	31.5	24.4	37.3	68.0	102.5-205 (138.2)	1237-1578.6 (1433.4)
Point 2 (P2)						
Wet	15.8	83.4	37.4	69.0	471.5-1175.4 (815.0)	1592.3-3717.7 (2576.4)
Dry	51.3	190.1	37.3	65.0	478.4-724.4 (615.0)	2945.5-5501.4 (4223.4)
Point 3 (P3)						
Wet	27.7	65.4	38.4	66.0	136.7-184.5 (159.0)	567.2-1920.4 (1390.7)
Dry	83.9	99.4	36.0	65.0	198.2-252.9 (231.8)	1681.2-3116.3 (2431.2)

[a] The average of total CC concentration

[b] Value from the formula described by Anderson (1965)

[c] Maximum–minimum (average)

gas–particle conversion processes (Seinfeld and Pandis 1998; Wang et al. 2002). Although there is a great diversity of anthropogenic activities and sources in urban centers, the vehicle fleet emerges as the main source of this pollutant class in these environments (Valavanidis et al. 2006; Armas et al. 2012; Giang and Oanh 2014). The RPM average during the dry period was higher than the average during the wet period (Table 5). Point P2 (136.75 μg m^{-3}) had the highest average throughout the study followed by points P3 (82.2 μg m^{-3}) and P1 (18.45 μg m^{-3}). The distribution of the MPR showed that diesel vehicles govern this distribution. Although point P1 presents the greatest flow of vehicles, at point P2 diesel vehicles have double the flow (Table 1). According to Giang and Oanh (2014), the combustion of diesel releases more particulate matter than gasoline combustion, being responsible for the increase in particulate matter in the atmosphere of large cities. Many factors may influence the state of diesel combustion, such as the maintenance level of the vehicle, engine technology, fuel quality, and driving conditions, among others (Johnson 2009; Huang et al. 2013). Additionally, point P3 still has a higher vegetation index of all the sites studied (see Table 1; Cattony 2016).

Particulate pollutants could be dry deposited on plant surfaces through gravity sedimentation and impaction or simply deposited on the surface wax (Beckett et al. 2000; Nowak 2006; Jim and Chen 2008). Urban vegetation is responsible for the removal of more than 335.000 tons of particulate matter in the US, working as a natural "biotechnology'' to reduce some of the adverse environmental and health effects associated with urbanization (Nowak 2006; Nowak et al. 2006). For example, the ambient particulate concentrations were lower in neighborhoods with dense vegetation (Freiman et al. 2006).

Risk to Human Health

Carcinogenic Substances

The estimated cancer risk for men was assessed using the CDI equation for formaldehyde and acetaldehyde during the wet and dry seasons. Unfortunately, there are no studies on the risk of cancer that consider seasonality. Thus, we compared our data with risk studies of cancer in several occupational environments. The results show that P3 had the highest risk of cancer both as formaldehyde and acetaldehyde, while P1 had the lowest risk levels associated with these substances. In general, the data show that higher risks of cancer are associated with the dry season. On average, cancer risks associated with formaldehyde and acetaldehyde during the dry period are, respectively, 2.9 and 3.5 times higher than those during the wet season, as shown in Fig. 1.

According to the literature, an increased risk of cancer is associated with increased radiation, which causes the photooxidation of hydrocarbons and increases the concentration of CCs in the atmosphere (Pang and Mu 2006). The results obtained during the dry season exhibited a similar trend to the other observed values. The absence of a standard and the similarity in risk values during the winter season may be related to the low intensity of solar radiation and weather instability, which consequently reduce hydrocarbon photolysis (Pang and Mu 2006).

The cancer risk corresponding to the various recommended exposure limits proposed by the US-EPA, OSHA, and NIOSH was estimated. As shown in Fig. 3, the average level of formaldehyde exceeded the recommended exposure limit proposed by NIOSH only in the dry period in location P3. For the other sites, the formaldehyde levels

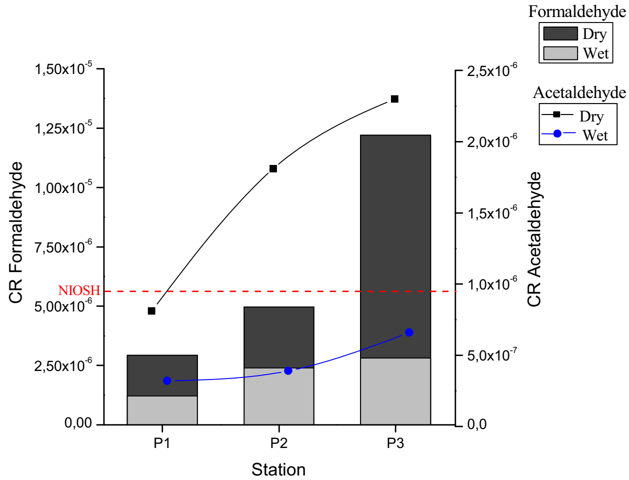

Fig. 1 Cancer risk (CR)

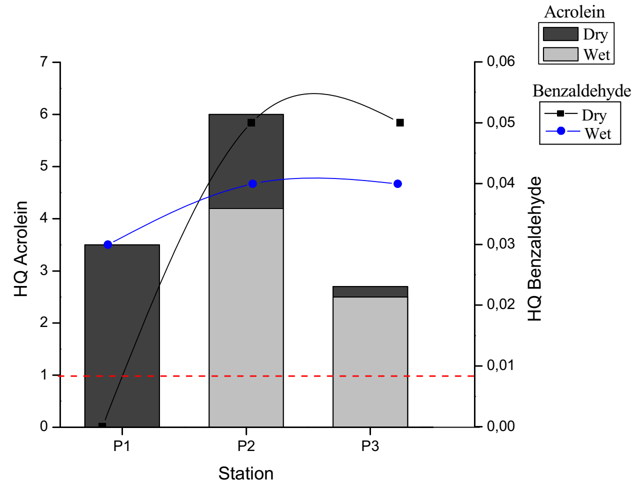

Fig. 2 Non-carcinogenic risk

presented no danger, and the local risks of the acetaldehyde levels are well below the limits set by the agencies. Although the risk of cancer has been calculated only for men, there was a 10 % increase in risk for women in the same scenario. This occurs when using a linear risk model to assess the risk of cancer, as reported by Cavalcante et al. (2005, 2006) and Sousa et al. (2011).

Non-carcinogenic Substances

The results for HQ benzaldehyde and acrolein levels measured in the ambient air of the three study sites and two seasonal periods are shown in Fig. 2. Acrolein showed high HQ values (HQ $>$ 1) for all study sites, indicating that there are likely adverse effects to the health of users, and the cumulative exposure to acrolein may cause some chronic health effects for these people over the exposure period (US-EPA 2003). According Sithu et al. (2010), frequent exposure to acrolein, via inhalation or ingestion, induces platelet activation, which may trigger thrombosis. Moreover, all values for HQ benzaldehyde were smaller than 1, which does not present risks to human health.

As in the calculation for carcinogenic substances, although the risk has been calculated only for men, there was a 5–10 % increase in the risk for women given the same scenario for non-carcinogens. Note that the risk quotient (HQ) is not a measure of risk but is a starting point for estimating the risk (Rodrickus 1992).

Individual Daily Exposure

Exposure was estimated only for RPM because, although it is not classified as a substance harmful to humans and does not present a Slope Factor, Reference Dose, or Hazard Quotient, it has been considered one of the greatest risks to health in urban centers. The corresponding exposure limits recommended by the US-EPA, OSHA, NIOSH, and Standard Brazilian Regulatory (NR-15) were estimated. As shown in Fig. 3, the RPM exposure levels ranged from 6 to 65, exceeding the limits recommended by the US-EPA. The two sites with higher exposures to RPM levels are directly linked to heavy car traffic, showing the direct impact of vehicle emissions on air quality.

Biological Indicators

Aerosols may be formed from bacterial cells and cell fragments, fungal spores, and by-products of microbial metabolism. These particles vary in diameter from 0.3 to 100 mm. Bioaerosols ranging from 1.0 to 5.0 mm typically remain in the air, as larger particles are deposited on the surfaces. The sedimentation of these particles is related to physical factors (form, density, and size) and

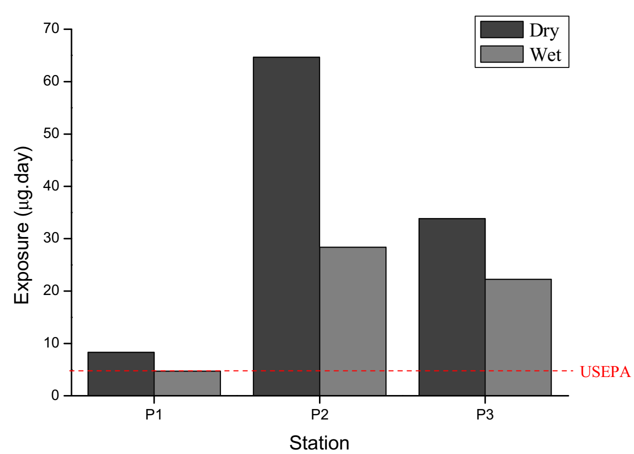

Fig. 3 Individual daily exposure to RPM

environmental parameters such as air currents, humidity, and temperature (Stetzenbach et al. 2004; Gandolfi et al. 2013).

The largest quantity of cultivable microorganisms in the air was recorded at P2 (Table 5). This fact is linked to the high level of particulate matter in the atmosphere of the sidewalk. According to Dowd and Maier (1999), spore-forming bacteria and fungi adhere to dispersed particles in the atmosphere and are able to survive in materials and remain active in air for a long period of time. These microorganisms adhered to RPM can reach the respiratory tract and cause allergies and other diseases (Kurup et al. 2002; Sarica et al. 2002).

There is a scarcity of national and international rules governing the MOs' levels outdoors. The most commonly found and used in the literature is the Polish Norm (Table 6), and the limits it proposes, when compared to the results obtained in this study, classified points 2 and 3 as average pollution sites for bacterial contamination during the winter season. In the dry season, P2 showed high pollution by bacteria and P3 showed average pollution. With regard to contamination by fungi, all three sites sampled in this study were not considered polluted, in both periods.

Physical Indicators

The noise is enhanced by the urban traffic and an excess of noise can cause "diseases by environmental noise" (WHO 2013) due to changes in the human immune system, respiratory illness, stress, and insomnia (Kim et al. 2012; Tiesler et al. 2013). The increase in urban traffic explains the high level of noise found in P2 (Table 5), a place that receives a high flow of vehicles daily. P3 is the point in the study with the highest vehicle flow; however, it had the lowest noise level. This fact is linked to the strong presence of vegetation in the site, which functions as a noise buffer, reducing the noise level (Kragh 1981; Pal et al. 2000; Pathak et al. 2008). As reported by Souza and Giunta (2011), among the main urban variables (flow of vehicles, physical space, city geometry, and building area), the one that most influences the urban noise is car traffic on the roads. Renterghem et al. (2012) confirmed what was observed in this study, namely the role of vegetation in reducing the noise in cities: the trees can decrease 3 dB or more of urban noise, and the nearer the trees, forming a "vegetation belt," the greater the reduction in capacity.

The WHO established a maximum limit of decibels that causes no harm to human health. The limit recommended by the organization is 50 dB. For the US-EPA, the permitted level is 55 dB. The levels found in the three locations studied here exceeded the limit permitted by the WHO by 19 dB and exceeded the US-EPA limit by 14 dB (Fig. 4), which may cause damage to health.

Thermal comfort influences the well-being of people, especially in urban centers, due to low arborization, many vertical buildings, paved streets throughout the city, and heavy car traffic, all of which combine to increase thermal sensation (Johansson and Emmanuel 2006; Emmanuel and Johansson 2006; Johansson et al. 2013). This discomfort is accentuated in urban areas located in the tropics due to high solar radiation (Johansson and Emmanuel 2006; Ali-Toudert and Mayer 2006, 2007; Emmanuel et al. 2007). The data showed that the highest degree of discomfort was in P1 (wet season), classified according to Anderson ICH as "supportable discomfort," followed by point P1 (dry season) and P2 (both periods), which were considered "varying degrees of comfort." P3 showed the lowest degree of discomfort (also "varying degrees of comfort") in both periods (Fig. 5). Note that despite the proximity of the sites studied, the urban activity and the type of vehicle emission, as well as the building and arborization indexes, are not similar (Table 1). At both P2 and P3, there were larger vehicle flows in the study, while P3 presented an arborization index 3.7 times higher than P2, which probably contributes to the highest degree of thermal comfort in that location. According to Gomez et al. (2004), vegetation contributes to the improvement in thermal comfort by the correction of the temperature exchange, providing shade and consequently relief of thermal discomfort to heat.

Table 6 Levels of bacteria and fungi in the air (established by Polish Norm)

Polish Norm categories	Bacteria (CFU m^{-3})	Fungi (CFU m^{-3})
No pollution	<1000	3000–5000
Mean pollution	1000–3000	5000–10,000
High pollution	>3000	>10,000

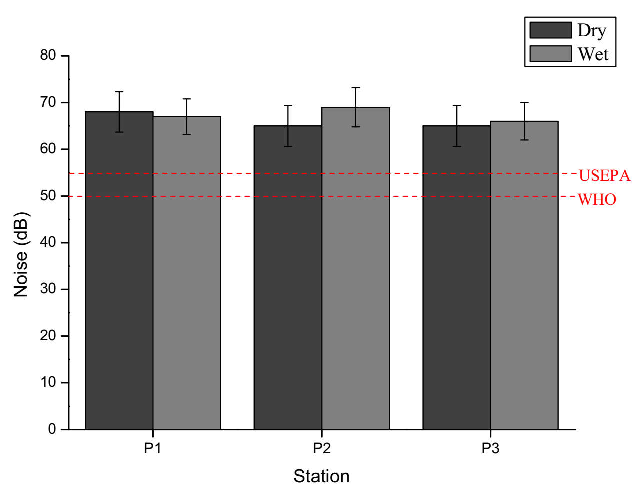

Fig. 4 Noise level

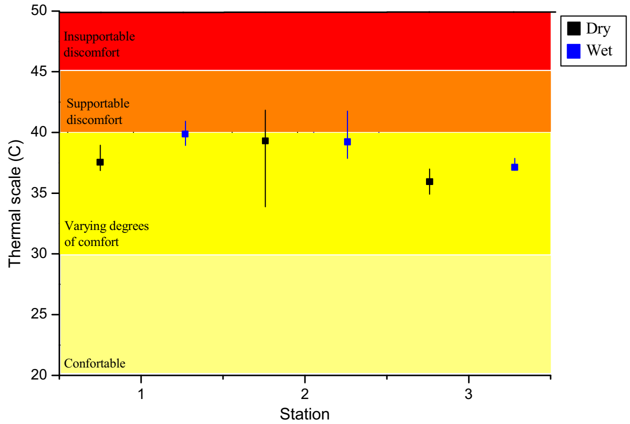

Fig. 5 Human Thermal Comfort Index

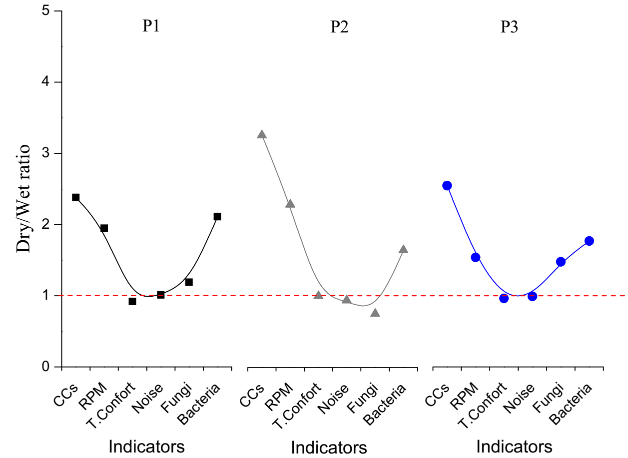

Fig. 6 Dry/wet ratio of the studied environmental indicators

Points P1 and P3 presented a subtle difference in thermal comfort between the seasonal periods. The data showed that the dry season is more comfortable than the wet season at both points. This fact is linked to the regional synoptic conditions and the climate characteristics of the area which has the highest wind speeds in the second semester of the year, when the wind speed can reach the 7.5 m.s^{-1} (Maciel et al. 2012).

However, the thermal comfort calculated here does not take into account the physiological condition or the increase of people's body temperature at the time of physical activity. Several studies indicate, for instance, that for racing the most suitable temperature range is between 8 and 15 °C. For every degree increase, the yield decreases due to the increase in body exhaustion (Suping et al. 1992; Pallotta et al. 2015). In this sense, the thermal sensation between 30 and 40 has a considerable influence on environmental quality, even though people are acclimatized to the tropical conditions.

Influence of Seasonality in the Studied Environmental Indicators

The chemical indicators, followed by the biological indicators, were the most influenced by the seasonality because Dry/Wet (D/W) > 1 (Fig. 6). The ratio D/W of CCs ranged from 2.4 to 3.3, being the parameter most affected by seasons throughout the study. The highest level of CCs in the dry season compared to the wet season of the year is attributed to high production photochemistry (Bakeas et al. 2003; Wang et al. 2007). According to Sousa et al. (2015), CCs' levels are higher in the dry season than in the wet season because the insolation in Fortaleza is approximately 20 % higher in this period. Moreover, in the wet season, the temperature is lower and the relative humidity is higher, which should also contribute to reducing the levels of CCs in the atmosphere (Sousa et al. 2015).

The distribution of RPMs was also controlled by seasonality because the D/W ratio ranged from 1.9 to 2.6. The precipitation "cleans" the air, settling the sedimented particulate matter and reducing resuspension due to soil humidity in this period (Meng et al. 2007; Gioia et al. 2010). Moreover, in the dry period, the highest wind speeds in the region are observed, and the vertical winds must have a great influence on the increase of the resuspension of particulate matter in the studied sites. On the other hand, the particulate levels may be higher in the dry compared to the wet season because of the material imported by long-range transport (Budhavant et al. 2015; Wang and Fang 2016).

Bacteria presented a reason that $D/W > 1$ at all the study sites, while fungi did not show the same behavior. Bugajny et al. (2005) reported that the concentration of microorganisms is strictly related to the air temperature, as bacteria and fungi proliferate faster in warmer periods of the year.

The emission and dispersion of fungal spores in the air can be selectively correlated with various meteorological parameters and depend on the species involved. These microorganisms are reported as effective in the aerosolization process (Després et al. 2012). Comparatively, fungi and fungal structures are more competent to remain dispersed in the air; already the presence of bacteria is closely related to the activities on the surface. In this study, the highest measurements of bacteria in the air can be a reflection of the sources and the local geography. Proximity to busy streets, vegetation, and the presence of winds are determinants of aeromicrobiota.

Seasonality did not present a significant influence on the physical indicators. This may be because of the location in the tropics, where the climatic conditions do not vary significantly as they do in other areas at lower and higher latitudes.

Application in Public Policy

Until the mid-1980s, public health issues were focused on rural areas, especially in developing countries, considering that the large urban centers offered better structure and quality of life for its inhabitants (Gouveia 1999). However, with the rapid growth of cities, the perspective of public health is changing in urban areas. The enhanced urbanization process generated environmental, social, and economic consequences, thus changing the perception of public health and well-being, with the inclusion of the concept of urban health, urban environmental quality, and urban ecosystem health assessment, among others (Su et al. 2010; Khan et al. 2012; Panagopoulos et al. 2016). Thus, there emerges a movement in Canada called "Healthy City" as a strategy of promotion of health and improvement of quality of life of the urban population (Oliveira 2005). One of the great difficulties in modern urban planning is the lack of technical studies and political willingness (Panagopoulos et al. 2016). In the context of the development of public policy, the study may be useful to include the issues in the government's public agenda, especially in places under urban development similar to the city of Fortaleza. The results can assist the public administrator's agenda-building, as well as assisting in the policy-creating process, defining its scope, as well as alternatives to the problem.

Conclusion

The first multi-environmental indicators were once applied to assess the environmental quality of areas used for sport and leisure in a city affected by expansion in the Brazilian semi-arid tropical coast. Regarding the chemical indicators, the distribution of CCs levels should be influenced by the flow of vehicles, while the RPM is governed by the number of diesel vehicles. The risk of cancer exceeded the value recommended by NIOSH for formaldehyde only in the dry season in one location studied. The risk from non-carcinogenic substances showed that acrolein levels at all locations and in the two periods studied might cause adverse effects on the health of the people using the recreational sites. Exposure levels to RPM exceeded the value recommended by the US-EPA in all locations during the two study periods. For biological indicators, only bacteria levels show pollution ranging from medium to high in the two sites during both periods studied. Regarding the physical indicators, the noise levels in the three locations during both periods studied exceeded the standards recommended by the WHO and US-EPA. In most places, the thermal comfort was close to 40, which is classified as "supportable discomfort." The chemical and biological indicators (e.g., bacteria) were most influenced by seasonality, while the physical indicators showed no difference between the dry and wet seasons.

Although studies from the literature with individual parameters show that urban centers and their activities compromise human health, our data show that the synergism of these parameters presents a more critical problem for environmental quality in urban areas. In this sense, studies and environmental standards considering the synergism should be encouraged to facilitate the development of public policies aimed at improving global urban development.

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