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A methodological approach to the environmental quantitative assessment of urban parks

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A B S T R A C T

This study proposes an integrative methodology for the environmental assessment of urban parks. Since most of the studies that investigated the environmental effect of urban parks have focused on only one or two nuisances, a difficulty exists in evaluating the overall influence of urban parks on environmental quality. Moreover, the small number of studies that have tried to suggest methodological approaches for a quantitative environmental assessment of urban green spaces did not base their assessment methods on the analysis of in-situ objective measurements of air pollution, noise and climatic nuisances and their cumulative impact in a specific location. The proposed methodology is based on verified and feasible methods: in-situ measurements, data analysis, indexing by standard indices and finely scaling according to a common denominator of unified criteria, in an attempt to evaluate environmental quality. This approach enables identification of the specific nuisance that dominates the environment quality level and comparison between the different sites along the year. The proposed assessment method can offer an applicable tool for urban planners and architects in the planning process, so as to achieve ideal environmental quality for the benefit of urban inhabitants. The findings emphasize the importance of public green spaces in the urban tissue and justify investment in these spaces in terms of sustainable development.

Introduction

Urban environments are increasingly exposed to severe conditions of thermal stress, air pollution and noise nuisances (Evance, 1983; Lam, Ng, Hui, & Chan, 2005), which critically influence the health and wellbeing of the cities' inhabitants. Numerous studies have shown that urban parks bear the potential to attenuate some of the negative effects of urbanization, improve microclimate conditions, decrease air pollution concentrations and attenuate noise levels, thereby transforming cities into more pleasant environments (De Ridder et al., 2004; Feliciano et al., 2006; Lam et al., 2005; Schnell et al., 2012). A review of the main studies that deal with the effect of green open spaces on environmental nuisances reveals the following main points:

The effect of green spaces on human comfort

Although a lot has been written on the thermal impact of urban parks on urban microclimates, not many experimental studies were carried out on the subject until the 1990s. Most of these studies focused mainly on the cooling effect within the park area and found that urban parks can yield a temperature reduction of up to 4 °C (Avissar, 1996; Givoni, 1991; Jonsson, 2004; Shashua-Bar & Hoffman, 2000; Spronken-Smith & Oke, 1998; Zoulia, Santamouris, & Dimoudi, 2009). According to Bowler, Buyung-Ali, Knight, and Pullin (2010)'s (2010) systematic review on the cooling effect of urban green spaces, it seems that the majority of the studies to date have focused on the hot season. Although the cooling effect of urban parks is mostly important during hot season, it can have a negative effect on human comfort during cold season. Only few studies have been conducted during both hot and cold seasons (Cohen, Potchter, & Matzarakis, 2012; Hamada & Ohta, 2010; Lin & Matzarakis, 2008; Mahamoud, 2011; Yahia & Johansson, 2012) found that parks cooling effect during the winter is less pronounced than during the summer and can reach up to 1–2 °C. Studies showed the direct connection between the size, density and quality of the park's vegetation cover and air temperature in and around the park (Katayama, Ishii, Hayashi, & Tsutsumi, 1993; Potchter, Yaacov, & Bitan, 1999; Satio, Ishihara, & Katayama, 1991), but this influence is limited to ranges of 50–100 m from the park's edge.

However, despite the large number of studies examining the cooling effect of urban parks, there is a dearth of studies that

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quantify the impact of urban parks on the human thermal sensation using thermal physiologically significant indices (Cohen et al., 2012; Mayer & Matzarakis, 2006; Potchter et al., 2010; Thorsson, Honjo, Lindberg, Eliasson, & Lim, 2007). As results from those studies which investigated the human thermal conditions in urban parks using such indices, it seems that the air temperature differences are not sufficient measuring method to assess the thermal sensation for humans. During the summer, sun radiation and air temperature are more significant in influencing human's thermal sensation, while during the winter wind velocity is more significant (Cohen et al., 2012; Cohen, Potchter, & Matzarakis, 2013; Lin, 2009). Thus, the overall effect of the climatic variable should be examined, by using the thermal physiologically indices.

The effect of green spaces on air quality

Air quality within urban areas has deteriorated as a result of increasing urbanization, vehicles use, energy production and industrialization – all of which are reflected in increased pollutant emissions to the atmosphere (Kanakidou et al., 2011). Previous studies have suggested the use of urban vegetation to mitigate urban air pollution and to improve local air quality within the urban green spaces (Bealey et al., 2007; Freiman, Hirshel, & Broday, 2006; McDonald et al., 2007; Nowak et al., 2000; Nowak, Crane, & Stevens, 2006). Although estimates of the attenuation effect of urban vegetation on levels of air pollution have been proposed (Beckett, Freer-Smith, & Taylor, 2000; Donovan, Stewart, Owen, MacKenzie, & Hewitt, 2005; McDonald et al., 2007; Powe & Willis, 2004; Yang, McBride, Zhon, & Sun, 2005), most of these studies were conducted through the application of models or by direct measurements that took place in a specific location such as highways (Suppan & Schadler, 2004), main urban streets (Kaur, Nieuwenhuijsen, & Colvile, 2005) or in green areas only (Mazzeo, Venegas, & Choren, 2005). Only a few studies were based on direct measurements in urban built areas and urban parks simultaneously (Cavanagh, Zawar-Reza, & Wilson, 2009; Cohen & Potchter, 2012; Kuttler & Strassburger, 1999; Lam et al., 2005; Yin et al., 2007, 2011). These latter studies indicated lower concentrations of pollutants such as NO, NO_2, CO, RSP, PM_{10}, TSP, SO_2 and NO_x within urban parks in comparison to the adjacent street canyons and lower concentrations of such pollutants in the parks' centers relative to their edges. Studies also indicate an increase in O_3 concentration in park areas during the summer season in comparison to the O_3 values in the nearby built area (Kuttler & Strassburger, 1999).

However, a dearth of studies examines the seasonal impact of urban vegetation on numerous air pollutants simultaneously. Moreover, the existing literature has not adequately quantified the overall impact of urban parks using the Air Quality Index (AQI) or similar, comparable indices.

The effect of green spaces on noise

Previous studies have raised interest in the effect of urban vegetation in reducing urban noise nuisances (Fang & Ling, 2003, 2005; Lam et al., 2005; Maleki & Hosseini, 2011; Papafotiou, Chronopoulos, Tsiotsios, Mouzakis, & Balotis, 2004). These studies indicated that noise attenuation between 6 and 27 dBA depends on noise source level and distances, as well as tree structure, planting density, soil structure, tree-belt width, foliage size and density. Bucur (2006) summarized studies regarding noise reduction by urban forest, and concluded that efficient reduction of noise levels within the urban tissue can be achieved through planting a combination of trees and shrubs at a high density. However, Tyagi, Kumar, and Jain (2006) indicated that vegetation is a selective noise filter, as it is generally more effective in sound attenuation for higher frequencies. Nevertheless, as with air pollution and the general effect of green spaces, the existing literature has paid inadequate attention to the seasonal impact of urban vegetation and parks on noise level through the application of a noise index to quantify this impact. Although no universally accepted noise criterion has been established for parks, the World Health Organization recommends 55 dBA or below for outdoor playgrounds (World Health Organization, 2001), while Brown (2004) cautions that noise classification is of limited value in urban open spaces, due to the subjectivity in human annoyance responses.

It appears from a review of the relevant literature that most of the studies investigating the environmental effect of urban parks focused on one type of nuisance only, while only a few studies investigated two or more types of nuisances simultaneously in specific urban sites. Moreover, there is a dearth of studies that investigate the overall effect of urban parks on microclimate, air pollution and noise at one specific site and their accumulative effect on parks' users' comfort. Since people in urban open spaces are simultaneously exposed to all environmental conditions and nuisances, a holistic assessment of these spaces is required.

A small number of studies have suggested methodological approaches for a quantitative environmental assessment of urban green spaces. Bolund and Hunhammar (1999) suggested analyzing the environmental services given by urban ecosystems (street trees, parks, forests, wetlands, etc.) and their substantial impact on the quality-of-life in urban areas. De Ridder et al. (2004) proposed an integrative methodology for evaluating the role of green spaces and its multiple benefits based on air quality, micro-scale climate and noise modeling. However, none of these studies based their assessment methods on an analysis of in-situ objective measurements of the three nuisances and their overall impact, as the present study attempts.

Objectives

The aim of this study is to develop a methodology for the environmental assessment of urban parks. The methodology concentrates on three environmental nuisances (climate, air pollution and noise), which have the greatest impact on park visitors, and offers an integrated examination of these nuisances. Since urban parks are in use throughout the year, their environmental assessment should relate to seasonal and diurnal variables, which change during the year.

Methodology

Methodological approach

The methodological approach applied in the present study is an integrative one and included five stages: (1) in-situ measurements; (2) data analysis and indexing; (3) data scaling; (4) accumulative assessment of the examined environmental nuisances; and (5) grading of overall environmental assessment for the specific site (Fig. 1).

In-situ measurements

Simultaneous measurements of climatic variables, air pollution variables and noise level were conducted at the investigated sites at repeating days and seasons. Climatic variables were monitored by fixed automatic meteorological stations, which measured air temperature and relative humidity at a height of 1.8 m, wind direction and wind velocity at a height of 2 m and global and net radiation at the height of 1 m. The resulting data was stored by a Campbell 21X data loggers.

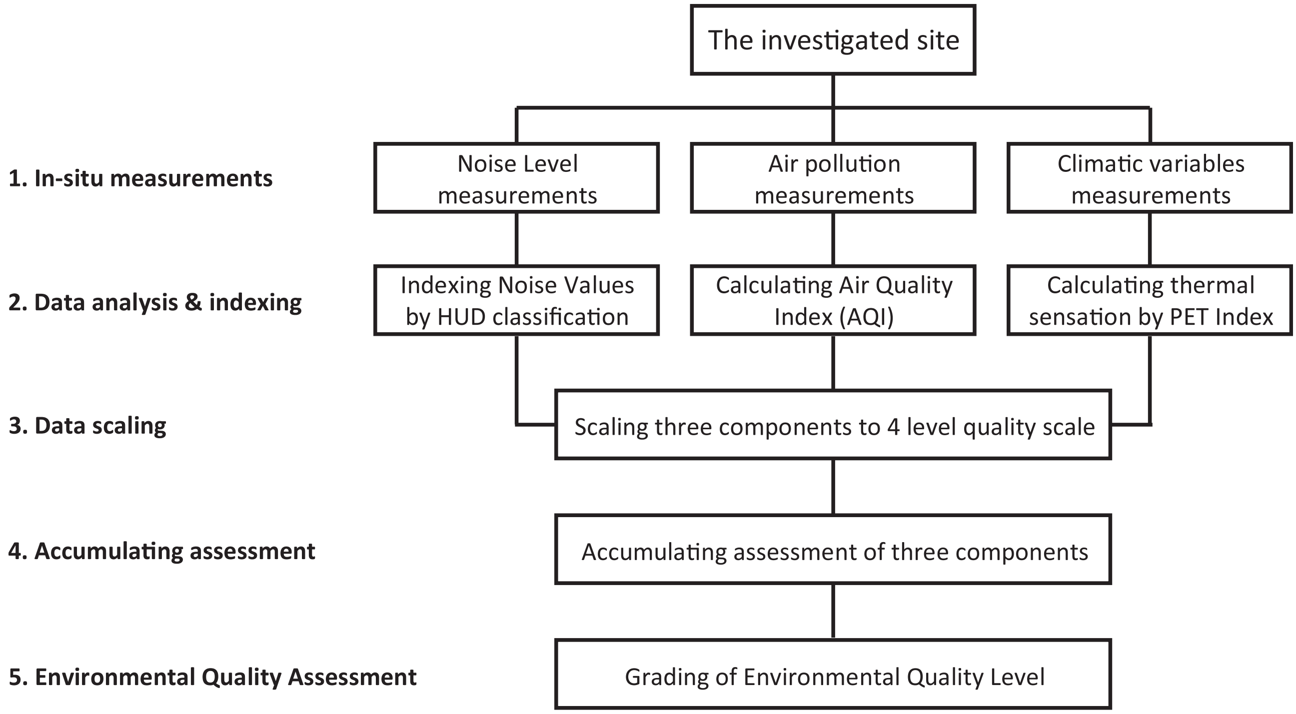

Fig. 1. Flow chart of the Methodological Approach for Environmental Assessment of urban open spaces.

Air pollution monitoring included the main pollutant as defined by the Israeli Ministry of Environmental Protection: NO_x, CO, O_3 and PM_{10} (http://www.sviva.gov.il/subjectsEnv/SvivaAir/AirQuality). **CO** was monitored by Drager Pac III sensors, NO_x data was monitored by 42C $NO-NO_2-NO_x$ Monitor Labs 9841A, O3 data was monitored by TEi 49C and PM_{10} data was monitored by TEOM1400AB, approved by USEPA. Data was collected consecutively and stored in data loggers.

Noise measurements were recorded with a Quest pro DL dosimeter ranging from 40 to 110 dB, with a resolution of 0.1 dB. The noise sensors were calibrated before each study using a QC-10 calibrator (114 dB, 1000 Hz). The average noise level per minute over the run time was measured.

All instruments were calibrated, checked and compared under the same conditions, both prior and subsequent to the experiment. Table 1 summarizes the type of measurement instruments used for data collection and their sensors' accuracy.

Table 1
Measured environmental variables, instruments' and sensors' accuracy.

Variable	Symbol	Unit	Instrument	Accuracy
Air temperature	Ta	°C	Campbell HMP45C-type	±0.2 °C
Relative humidity	RH	%	Campbell HMP45C-type	±2%
Wind direction	Wd	degree	Young 05103 anemographs	3°
Wind velocity	Ws	m/s	Young 05103 anemographs	±0.3 m/s
Global radiation	Gr	w/m^2	Kipp &Zonen pyranometer CMP6	±0.075 w/m^2
Net Radiation	Nr	w/m^2	Siemens-Erskine, Fredericksund	5%
Carbon monoxide	CO	ppm	Drager Pac III sensors	1 ppm
Nitrogen oxide	NO_x	Ppb	42C $NO-NO_2-NO_x$ Monitor Labs 9841A	±0.4 ppb
Respiratory particles matters	PM_{10}	$\mu g/m^3$	TEOM1400AB	±1.5 $\mu g/m^3$
Ozone	O_3	ppb	TEi 49C	1 ppb
Noise	Leq	dBA	Quest pro DL dosimeter	0.1 dB

Data analysis and data indexing

The second stage involved analyzing and indexing the measured data according to accepted indices suitable for each nuisance as follows:

Climatic conditions indexing. We selected the Physiological Equivalent Temperature (PET) index to analyze the measured climatic variables, since it is the most commonly applied index for the evaluation of human thermal perception (Cohen et al., 2013; Lin, 2009; Lin & Matzarakis, 2008; Matzarakis, Rutz, & Mayer, 2007; Müller, Kuttler, & Barlag, 2013; Thorsson et al., 2007). The PET index was calculated as per a nine-point Thermal Sensation Vote scale suggested by Matzarakis and Mayer (1996) and adopted by ASHRAE (2005). The PET index was calibrated for Coastal Mediterranean Climate (Cohen et al., 2013).

Air pollution level indexing. Air pollution level is a consequence of several pollutants that may affect people's health within a few hours or days after breathing the polluted air. Our indexing of this nuisance was based on the Pollutant Standards Index (PSI) used by the Israeli Ministry of Environmental Protection (http://www.sviva.gov.il/subjectsEnv/SvivaAir/Pages/AirMonitoringSystem.aspx; http://www.svivaaqm.net/Default.rtl.aspx).

This method is based on the Air Quality Index (AQI) of the US Environmental Protection Agency (EPA) (EPA-456/F-09-002, 2009), which is assessed as per regulation of the USA Clean Air Act for the major air pollutants: CO, SO_2, PM_{10} and O_3. As for the Israeli index, the PSI calculates five pollutants: CO, SO_2, NO_x, PM_{10} and O_3. In this particular study we did not consider SO_2, since its concentrations in Tel Aviv are very low (the maximum average values measured within a 30 min range between 4 and 29 ppb) 2010 air quality report (http://www.sviva.gov.il/InfoServices).

In order to calculate the AQI, the PSI of each of the measured pollutant was calculated according to the Equation (1):

Table 2
Pollutants Standard Index (PSI) and the breakdown values for Air Quality Index (AQI) calculation.

NO_x (ppb) 30 min avg.	PM_{10} (μg/m^3) running 24 h avg	O_3 (ppb) 30 min avg.	CO (ppm) 30 min avg.	PSI breakdown values	AQI values
0–249	0–59	0–58	0–4.7	0–49	51–100
250–499	60–149	59–116	4.8–9.5	50–99	1–50
500–600	150–349	117–203	9.6–14.7	100–199	0 to (–) 199
601–1200	350–419	204–407	14.8–29.6	200–299	(–) 200 to (–) 400

$$\text{PSI} = (\text{Ihi} - \text{Ilow})/(\text{BPhi} - \text{Bplow})*(\text{Cp} - \text{BPlow}) + \text{Ilow} \qquad (1)$$

While:

Ihi = high PSI value of a pollutant according to measured concentration,
Ilow = low PSI value of a pollutant according to measured concentration
BPhi = high breakdown point for pollutant
BPlow = low breakdown point for pollutant
Cp = concentration of pollutant

Therefore, the Air Quality Index will be: AQI = 100 – PSI.

We define the AQI for the investigated site as the worst case of the calculated PSI among the measured pollutants. Table 2 presents the AQI principles: the measured pollutants and the relevant standards for concentration values.

Noise level indexing. Since noise nuisance is based on one variable, direct measured data was indexed according to the US Department of Housing and Urban Development (HUD)'s classification for noise levels in residential environments, which have been used by former noise studies in the urban environment (e.g. Sofer, Potchter, Ganaim, & Ganaim, 2012; Tsai, Lin, & Chen, 2009; Zannin, Diniz, & Barbosa, 2002). This classification originally involved a four noise quality assessment scale, as presented in Table 3.

Data scaling

In order to assess the integrated environmental conditions in the investigated sites, we had to convert all the nuisances' scales into a common denominator of unified criteria of four grades for each nuisance, from low to high annoyance or from the best case to the worst case. Hence, we adopted the following classification:

Human thermal sensation is assessed according to the PET Index, which classifies thermal sensation according to a nine-point scale by Matzarakis and Mayer (1996) and ASHRAE (2005). For the purpose of this study, this index was converted into a four-level discomfort scale (Table 4), whereby we define the "neutral" thermal sensation (19.1 > PET°C < 26) as the "no-discomfort" level, graded 4. The classifications "slightly cool" and "slightly warm" are defined here as a "medium" discomfort level and graded 3. We define the "cool" and "warm" classifications here as a "high" discomfort level and grade them 2. The worst classifications, "cold" and "very cold" and "hot" and "very hot" (12 < PET°C > 34.1) are defined here as the "very high" discomfort level and graded 1.

Air pollution is assessed according to AQI values based on the definition "level of health concern," which is adopted here from the AQI of the EPA (EPA-456/F-09-002, 2009) (Table 5). For the purpose of this study, the EPA's AQI was converted to a four-grade scale as follows: the "low" level of health concern (51 > AQI<100) is graded as "environmental air quality grade" 4. The "medium" level of health concern is graded 3. The "high" level of health concern is graded 2. The "very high" level of health concern (–400 < AQI > –200) is graded 1.

We scale noise level according the HUD classification as follows (Table 3): the "clearly acceptable" classification (L_{Aeq} > 49 dBA) is defined here as the "low" level of health concern and graded as "environmental noise quality grade" 4. We define the "normally acceptable" classification as a "medium" level of health concern and grade it 3. The "normally unacceptable" classification is defined here as the "high" level of health concern and graded 2. The "clearly unacceptable" classification (L_{Aeq} < 76 dBA) is defined here as a "very high" level of health concern and graded 1.

Accumulating assessment of the environmental nuisances

The fourth stage of the methodology was to sum the accumulative assessment of the three environmental nuisances. There is a dearth of studies that quantify the combined and cumulative effects of environmental nuisances on human discomfort in outdoor urban environments (Candas & Dufour, 2005; Pellerin & Candas, 2003). Few studies that tried to assess the combined and partial effect of each of several nuisances on discomfort level did find marginal interaction (Schnell et al., 2012, 2013). Accordingly, and in order to simplify the methodology, we assumed that all the components of the suggested methodology has an equal impact on human environmental sense of discomfort.

Therefore, following the data indexing and data scaling of each of the environmental nuisances (by PET, AQI and noise classification), the quality grades of all the three components were summed.

Table 3
Noise level values, The U.S. Department of Housing and Urban Development (HUD) noise classification, level of health concern and the relevant environmental noise quality grade.

Noise level values (dBA)	Noise level classification	Level of health concern	Environmental noise quality grade
$L_{Aeq} \le 49$	Clearly acceptable	Low	4
$49 < L_{Aeq} \le 62$	Normally acceptable	Medium	3
$62 < L_{Aeq} \le 76$	Normally unacceptable	High	2
$L_{Aeq} > 76$	Clearly unacceptable	Very high	1

Table 4
The Physiological Equivalent Temperature (PET) index scale for the human thermal sensation in Mediterranean climate, the thermal sensation, discomfort level and the relevant Environmental thermal sensation grade.

PET value for Mediterranean climate	Thermal sensation	Discomfort level	Environmental thermal sensation grade
$8 \le X$	Very cold	Very high	1
$8.1 < X \ge 12$	Cold	Very high	1
$12.1 < X \ge 15$	Cool	High	2
$15.1 < X \ge 19$	Slightly cool	Medium	3
$19.1 < X \ge 26$	Neutral	None	4
$26.1 < X \ge 28$	Slightly warm	Medium	3
$28.1 < X \ge 34$	Warm	High	2
$34 < X \ge 40$	Hot	Very high	1
$40.1 <$	Very hot	Very high	1

Table 5
Air Quality Index (AQI) values, level of health concern and the relevant environmental air quality grade.

Air quality index (AQI) value	Level of health concern	Environmental air quality grade
51–100	Low	4
1–50	Medium	3
0 to (–) 199	High	2
(–) 200 to (–) 400	Very high	1

Table 6
Values of the accumulative assessment and the environmental quality levels and grades.

Accumulative assessment value	Environmental quality	
	Level	Grade
10–12	Good	A
7–9	Moderate	B
4–6	Poor	C
3	Very poor	D

The result shows the value of the overall cumulative environmental assessment for each of the investigated sites, for a specific time. The summed amounts can range from 3 to 12 (Fig. 6).

Grading of overall assessment

As a final stage, we scored the values of the cumulative environmental assessment and categorized them as four grades of environmental quality level: Good, Moderate, Poor and Very poor in descending order, from the "Good" quality (A) to the "Very poor" quality (D), as is presented in Table 6.

This form is repeating the format that was used in each nuisance classification method, which demonstrated four levels of health concern (in noise and air pollution grading) and four levels of thermal discomfort, in increasing order. Grade 4 at each of the nuisance's classification described the best conditions achieved while grade 1 described the worst conditions achieved. Thus, accumulative "worst" grades of three nuisances should give the value 3 while the accumulative "best" grades of three nuisances should give the value 12.

Study area and study time

The study was conducted in the Mediterranean city of Tel Aviv, Israel, located at 32°06′N and 34°47′E. The city is situated on a plain along the east coast of the Mediterranean Sea. Tel Aviv has a population of 404,800 and comprises the core of the largest metropolitan area in Israel, home to a population of 3.4 million (Statistical Abstract of Israel, 2012). Tel Aviv's climate is subtropical Mediterranean, with a rainy winter and dry summer, defined as Csa according to the Köppen classification (Potchter & Saaroni, 1998). Tel Aviv's climate is characterized by two main seasons: a hot, humid, summer (average temperature 23–30 °C, average relative humidity 72–83%) and a mild, wet winter with stable weather episodes (average temperature 8–23 °C, average relative humidity 55–60%) (Bitan & Rubin, 1994).

Since the climate of Tel Aviv is characterized by two main seasons that can demonstrate the two extreme conditions in terms of climatic conditions and air pollution, the other two seasons (spring and autumn) will not supply the range of conditions that can be expressed by the indexing and grading methodology used. Therefore, in this particular case study, measuring campaigns were conducted during a winter and a summer weeks.

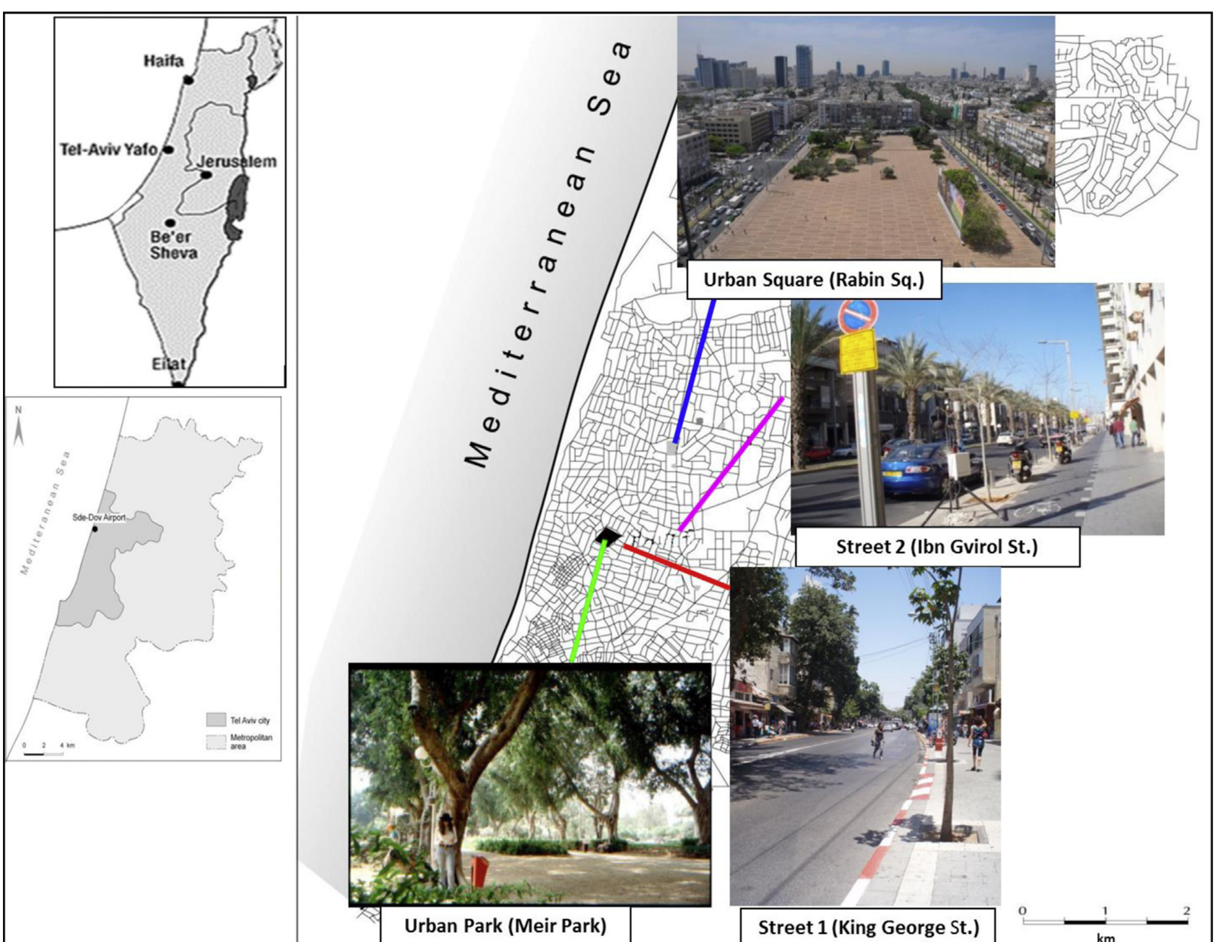

Fig. 2. Map of Tel Aviv with the location of the investigated sites.

Table 7
Data of the climatic variables: air temperature (T_a), vapor pressure (VP), wind velocity (WS) and mean radiant temperature (T_{mrt}) and calculated PET values in winter and summer measurements campaigns.

Variable (unit)	Season	Winter				Summer			
	Site	Urban park	Urban square	Street 1	Street 2	Urban park	Urban square	Street 1	Street 2
	Value								
Air temperature (°C)	Max	22.0	23.2	24.1	24.3	27.4	29.6	27.7	27.9
	Min	10.9	11.5	12.	13.3	23.8	24.5	24.6	24.8
Vapor pressure (hPa)	Max	22.9	22.5	26.9	21.6	22.9	22.5	26.9	21.6
	Min	21.3	21.2	22	21	21.3	21.2	22	21
Wind velocity (m/s)	Max	1.2	1.6	1.4	1.6	1.2	1.2	1.6	1.9
	Min	0.0	0.1	0.0	0.2	0.0	0.0	0.3	0.2
Tmrt (°C)	Max	22.7	35.7	33.9	37.5	28.3	58.4	54.5	56.1
	Min	11.0	12.0	12.1	12.6	22.7	18.0	21.7	21.9
PET (°C)	Max	22.2	25.1	27.0	28.0	25.9	41.3	39.7	39.9
	Min	12.7	11.0	11.8	12.5	23.7	21.6	22.3	22.8

The suggested methodology is appropriate for examination of any kind of open spaces, but together with the demonstration of the methodology, the authors are bringing a specific case study, which compared the environmental quality assessment of three different urban environments.

A simultaneous examination of several types of nearby urban open spaces within the same urban tissue and a comparison of their respective environmental qualities is necessary in order to assess the environmental quality of an urban park. Therefore, this study examined four sites: an urban park, an urban square and two adjacent street canyons located in the core of the city, in vicinity each to the other and at a similar distance from the sea (Fig. 2)

- Urban Park (Meir Park) – a medium sized (28,000 m^2) urban park, with a variety of mature tree, shrubs and lawn. The monitoring station was situated under mature Evergreen trees in a well-developed *Ficus microcarpa* tree-lined avenue and was well shaded (tree cover 85%, SVF 0.077).
- Street 1 (King George St.) – a two-lane street canyon, with four-storey buildings on both sides ($H/W = 0.8$, SVF 0.456).
- Urban Square (Rabin Square) – a medium sized (20,000 m^2) urban paved, open square (SVF 0.716).
- Street 2 (Ibn Gavirol St.) – a four-lane north-south street canyon, with four- to six-storey buildings on either side ($H/W = 0.6$, SVF 0.302).

The monitoring stations were situated at the center of each of the open spaces (Park and Square), at similar distances from the roadside edge. The adjacent street canyon monitoring stations were situated at a similar distance from these open spaces.

The study was conducted over the course of one winter and one summer. The winter measuring campaign took place from January 20 to 23, 2009. The month of January is considered one of the coldest months of the year, with solar radiation at its lowest. The measurements were conducted under stable weather conditions, with short episodes of unstable conditions characterized by eastern air flow accompanied by dust. The summer measuring campaign took place from June 27 to July 1, 2010. Climate conditions were generally stable during this period, characterized by hot temperatures, clear skies, moderate wind speed, and sun radiation at its peak.

Table 8
Maximum and averaged (in brackets) concentration values of the measured pollutants in the investigated sites during the winter and summer campaigns.

Season	Variable (unit)	NO_x (ppb)	PM_{10} (μG/m^3)	O_3 (ppb)	CO (ppm)
	Site				
Winter	Urban park	620 (85)	64 (24)	47 (25)	3
	Urban square	360 (63)	144 (56)	44 (24)	4
	Street canyon	1114 (435)	218 (73)	44 (24)	6
Summer	Urban park	83 (17)	80 (32)	94 (36)	0.1
	Urban square	104 (20)	59 (25)	91 (33)	0
	Street canyon	253 (24)	160 (37)	84 (32)	1.5

Results

In-situ measurements

Following the methodological approach, the first stage of the environmental assessment is simultaneous in-situ measurements of climatic variables, air pollution and noise. A brief description of the main results demonstrates the complexity of the winter and summer measuring outcomes.

Climatic measurements

Table 7 presents the climatic variables that were measured in the investigated sites. During both seasons in the daytime, air temperature (T_a) values in the park were the lowest in comparison to the other sites. The highest T_a values were measured during the summer in the urban square, and the corresponding summertime measurements were slightly lower in the street canyons; during the winter, in contrast, the highest T_a values were measured in the street canyons and were slightly lower in the urban square. During the nighttime, the air temperature differences between all sites were small. During all seasons, the ambient relative humidity was the highest in the urban park in comparison to the other sites under investigation, due to the respective temperature differences. However, vapor pressure values were only slightly higher in the urban park. The lowest wind velocity values were recorded in the urban park in all seasons. Yet, wind speed at all sites did not exceed 2.0 m/s. During the night, wind velocity dropped and calm conditions prevailed at all sites.

Air pollution measurements

During the morning and evening, when traffic is at its peak and the synoptic conditions are relatively stable, the various pollutants' values were found to be at their peak as well. The highest NO_x and PM_{10} values were measured in the street canyons. The highest concentrations of pollutants were measured during the winter, with the exception of Ozone. During the winter, Ozone values were lower than 50 ppb at all sites, while in the urban park, the Ozone value was slightly higher than in the street canyons and in the square, to the extent of this pollutant being insignificant as a nuisance. During the summer, the highest NO_x and PM_{10}

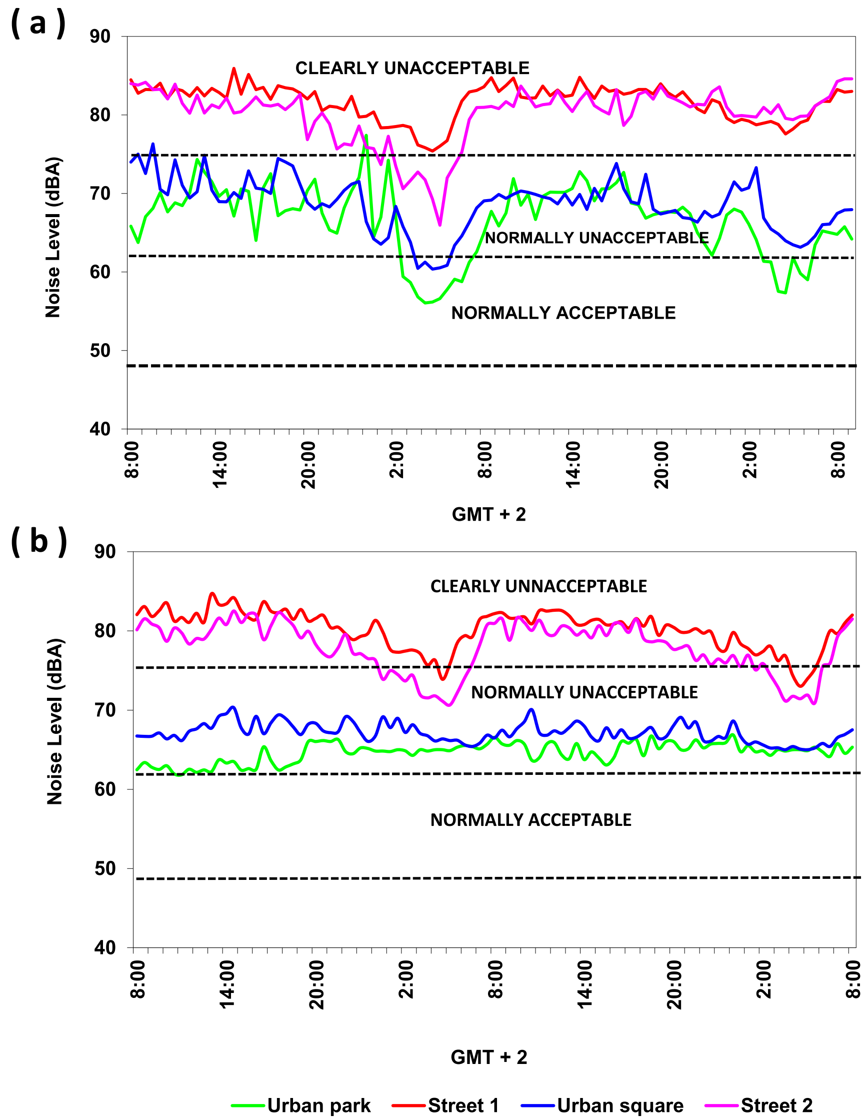

Fig. 3. Noise level at four sites during (a) winter and (b) summer measurements.

concentrations were measured in the street canyons. The highest Ozone values in this season were measured in the urban park, up to 10 ppb higher than the respective values of Ozone in the street and in the square (Table 8).

Unexpectedly, during the summer, the lowest PM_{10} concentrations were found in the urban square, while the PM_{10} concentrations in the urban park were slightly higher. This finding can be explained by the local climate conditions. During the winter, the main source of PM_{10} is long-range particle transference from the Sahara desert or Sinai due to synoptic conditions. During the summer, in addition to the emissions from traffic, anthropogenic activity (sports and recreation activity) and animal activity (a dogs' corner) lift up dry sand and dust from the soil. This phenomenon occurs neither in the winter when the soil is moist, nor in the paved urban square. CO concentrations were very low at all the investigated sites during both seasons, and are hence insignificant.

Noise measurements

Noise level at the four investigated sites show small seasonal variation. The highest values were recorded in the street canyons (86 dBA), while the lowest values were measured in the urban park (56 dBA). The notable findings in this regard are the differences in noise level between the urban park and the adjacent street canyon (~23 dBA), in comparison to the differences between the urban square and the adjacent street canyon (~17 dBA) (Fig. 3).

Data analysis and indexing

The second stage of the methodological approach of this study is data analysis and indexing. Indexing is necessary for two reasons: First, in order to classify the nuisance's degree, it is necessary to define it according to human sensation or health concern. Second, as two environmental nuisances (climate and air pollution) are composed of several components or variables, it is necessary to calculate all these components variables into one comprehensive value. Since many indices exist, this study adopted a verified index for each nuisance.

Analysis and indexing of climatic variables

On the basis of the climatic data collected at each of the investigated sites, the Physiological Equivalent Temperature (PET) index

Table 9
Calculation of AQI values and environmental air quality level according to measured air pollutants concentrations in the street canyon and in the urban park during a winter and summer day.

Season and site	Pollutant (unit) / Time	CO (ppm)	NOx (ppb)	PM10 (μg/m^3)	O3 (ppb)	AQI value	Environmental air quality level
WINTER Street canyon	6:00	0.0	**789**	57	34	-131.1	High
	7:00	1.5	**995**	52	22	-161.1	High
	8:00	5.1	**1114**	111	29	-178.5	High
	9:00	6	**1094**	106	11	-138.5	High
	10:00	2	**587**	138	15	-86.1	High
	11:00	0.1	**304**	218	24	39.4	Medium
	12:00	0.0	136	**156**	34	38.7	Medium
	13:00	0.0	181	**94**	40	36.5	Medium
	14:00	0.0	**439**	73	42	12.8	Medium
	15:00	0.0	**427**	42	43	15.2	Medium
	16:00	0.1	**531**	65	37	-30.7	High
	17:00	0.0	**518**	74	28	-47.4	High
	18:00	0.3	**526**	74	18	-51.5	High
	19:00	0.2	**552**	87	5	-48.5	High
	20:00	0.0	**549**	81	4	22.7	High

Season and site	Pollutant (unit) / Time	CO (ppm)	NOx (ppb)	PM10 (μg/m^3)	O3 (ppb)	AQI value	Environmental air quality level
WINTER Urban park	6:00	0.0	180	31	34	64.5	Low
	7:00	0.0	295	25	22	41.2	Medium
	8:00	0.0	620	24	15	-22.9	High
	9:00	0.0	374	29	11	65.0	Medium
	10:00	0.0	144	41	16	71.7	Low
	11:00	0.0	68	**64**	24	78.0	Low
	12:00	0.0	23	**19**	35	76.7	Low
	13:00	0.0	27	**22**	41	76.7	Low
	14:00	0.0	22	**19**	42	76.7	Low
	15:00	0.0	26	**13**	43	76.7	Low
	16:00	0.0	33	**19**	38	76.6	Low
	17:00	0.0	66	**13**	29	76.9	Low
	18:00	0.0	113	**15**	17	77.3	Low
	19:00	0.0	75	**25**	5	77.6	Low
	20:00	0.0	39	**18**	23	77.8	Low

Season and site	Pollutant (unit) / Time	CO (ppm)	NOx (ppb)	PM10 (μg/m^3)	O3 (ppb)	AQI value	Environmental air quality level
SUMMER Street canyon	6:00	0.1	151	132	5	60.4	Low
	7:00	0.0	**253**	92	7	49.4	Medium
	8:00	0.0	203	28	24	55.8	Low
	9:00	0.0	52	31	37	56.2	Low
	10:00	0.0	26	43	45	56.8	Low
	11:00	0.0	20	45	56	51.5	Low
	12:00	0.0	19	38	**68**	42.9	Medium
	13:00	0.0	18	38	**78**	29.6	Medium
	14:00	0.0	12	38	**70**	34.3	Medium
	15:00	0.0	16	37	**61**	47.5	Medium
	16:00	0.0	20	39	**62**	46.4	Medium
	17:00	0.0	13	38	**63**	45.7	Medium
	18:00	0.0	9	77	30	57.6	Low
	19:00	0.0	10	47	34	58.1	Low
	20:00	0.0	9	13	28	58.4	Low

Season and site	Pollutant (unit) / Time	CO (ppm)	NOx (ppb)	PM10 (μg/m^3)	O3 (ppb)	AQI value	Environmental air quality level
SUMMER Urban park	6:00	0.0	54	80	9	72.1	Low
	7:00	0.0	73	42	14	71.3	Low
	8:00	0.0	50	13	27	71.5	Low
	9:00	0.0	20	37	39	67.3	Medium
	10:00	0.0	19	44	50	58.1	Medium
	11:00	0.0	16	31	**66**	44.4	Medium
	12:00	0.0	19	43	**77**	34.4	Medium
	13:00	0.0	18	52	**87**	26.0	Medium
	14:00	0.0	16	48	**94**	30.7	Medium
	15:00	0.0	15	54	**70**	40.3	Medium
	16:00	0.0	16	39	**60**	49.0	Low
	17:00	0.0	13	57	**71**	39.6	Low
	18:00	0.0	13	25	34	68.6	Low
	19:00	0.0	9	28	33	68.9	Low
	20:00	0.0	11	33	30	69.1	Low

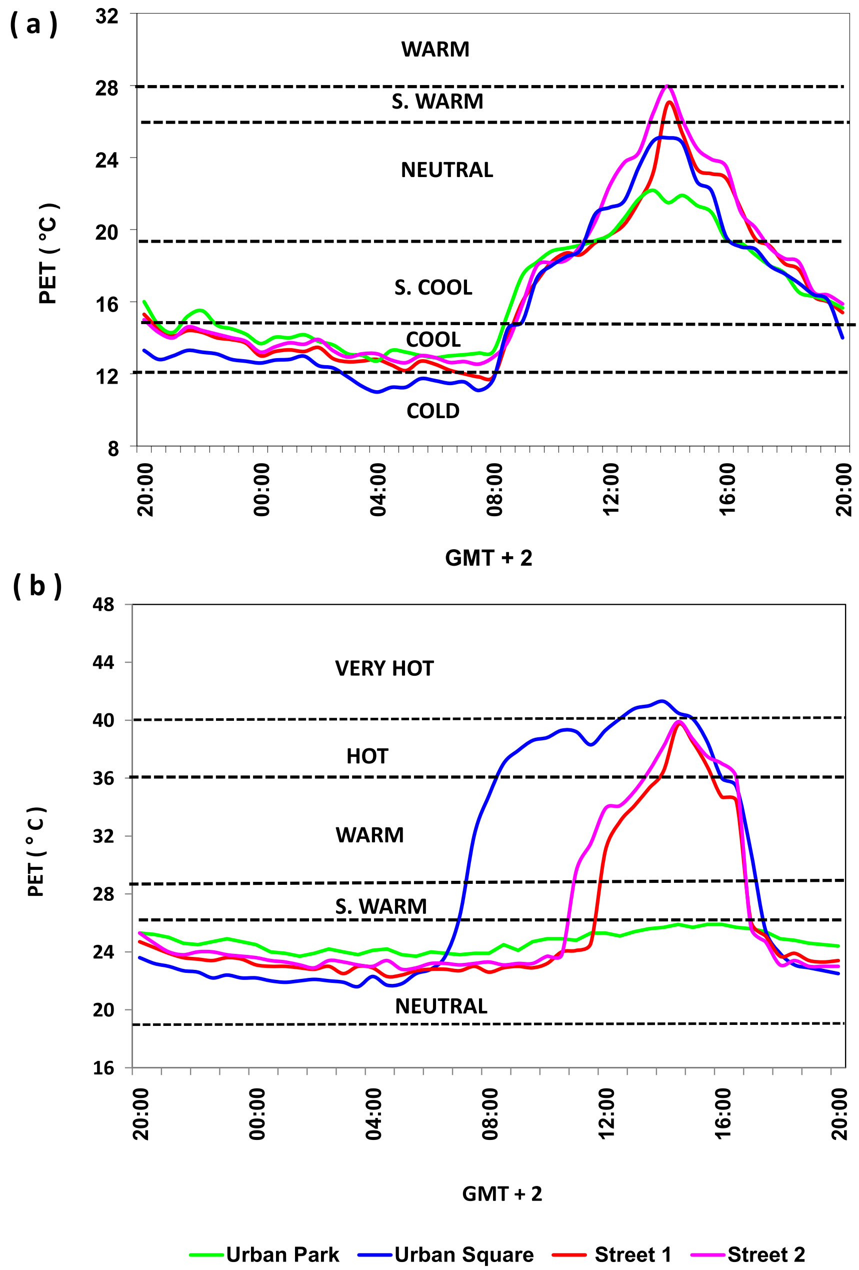

Fig. 4. PET values at the investigated sites during (a) winter and (b) summer measurements.

was calculated using the Rayman Model. This analysis revealed the following:

At midday in winter, "neutral" PET classification prevailed at all sites, while in the exposed street canyon, "slightly warm" conditions existed from 12:00 to 16:00. A short time after sunset, "slightly cool" thermal conditions existed at all sites. At night-time, PET values in the urban square reached "cold" thermal conditions, while in the urban park the thermal conditions were "cool". During the summer, "neutral" PET classification prevailed in the urban park during all day and night hours, while in the urban square "hot" and "very hot" thermal conditions prevailed from 8:00 until 17:00. In the exposed street canyon "warm" and "hot" thermal conditions existed from 11:00 until 17:00. At night, the "neutral" PET grade prevailed at all the investigated sites (Fig. 4).

Analysis and indexing of air pollution

Air pollution indexing was conducted in two steps. The first step included calculation of Air Quality Index (AQI) according to the PSI equation, Equation (1) and Table 2, as described in the methodology section above. An example of the indexing process for a winter and a summer day in the street canyon and in the urban park is provided in Table 9. For each hour, concatenation values of CO, NO_x, PM_{10} and O_3 were averaged, and the AQI was calculated in accordance. Environmental air quality level was determined on the basis of the AQI value.

Generally, during the winter, high NO_x concentrations in morning and evening hours caused a decrease in AQI values and consequently reduced the environmental air quality level, except for a short dust blowing episode, during which PM_{10} values increased and became the dominant component in decreasing the

Stage (3): data scaling

Stage (4): accumulating assessment

Time	Air Quality (AQI)		Thermal Sensation (PET)		Noise		Accumulative Value
	Value	Grade	Value	Grade	Value	Grade	
0:00	-100.3	2	13.0	2	79.83	1	5
1:00	1.2	3	13.3	2	78.36	1	6
2:00	9.7	3	13.5	2	78.51	1	6
3:00	11	3	12.7	2	78.42	1	6
4:00	9.5	3	12.8	2	76.03	1	6
5:00	21	3	12.2	2	76.20	1	6
6:00	-131.1	2	12.5	2	79.51	1	5
7:00	-161.1	2	12.0	1	82.92	1	4
8:00	-178.5	2	11.8	1	83.57	1	4
9:00	-138.5	2	16.5	3	82.98	1	6
10:00	-86.1	2	18.2	3	84.70	1	6
11:00	39.4	3	18.6	3	82.12	1	7
12:00	38.7	3	19.7	4	79.83	1	8
13:00	36.5	3	21.6	4	83.16	1	8
14:00	12.8	3	27.0	4	82.52	1	8
15:00	15.2	3	23.4	4	83.30	1	8
16:00	-30.7	2	22.8	4	83.67	1	7
17:00	-47.4	2	19.5	4	83.20	1	7
18:00	-51.5	2	18.1	3	82.82	1	6
19:00	-48.5	2	16.3	3	83.25	1	6
20:00	22.7	3	15.0	2	83.97	1	6
21:00	34.8	3	14.9	2	82.25	1	6
22:00	34.8	3	14.5	2	81.28	1	6
23:00	34.8	3	13.9	2	80.28	1	6

STREET

AQI
+ PET
+ NOISE

Time	Air Quality (AQI)		Thermal Sensation (PET)		Noise		Accumulative Value
	Value	Grade	Value	Grade	Value	Grade	
0:00	67.2	4	12.7	2	66.42	2	8
1:00	67.1	4	12.8	2	63.52	2	8
2:00	67.1	4	12.5	2	68.34	2	8
3:00	66.6	4	11.8	1	63.79	2	7
4:00	66.8	4	11.0	1	61.26	3	8
5:00	67.1	4	11.3	1	60.53	3	8
6:00	66.5	4	11.6	1	63.39	2	7
7:00	45.7	3	11.6	1	66.32	2	6
8:00	28.3	3	11.7	1	69.05	2	6
9:00	66.8	4	14.9	2	69.88	2	8
10:00	66.8	4	18.0	3	69.91	2	9
11:00	65.7	4	18.9	3	70.13	2	9
12:00	64.3	4	21.2	4	69.56	2	10
13:00	63.3	4	23.5	4	68.07	2	10
14:00	62.2	4	25.1	4	68.51	2	10
15:00	62.4	4	22.7	4	67.95	2	10
16:00	62.2	4	19.6	4	69.05	2	10
17:00	62.4	4	18.9	3	73.81	2	9
18:00	63.2	4	17.6	3	68.93	2	9
19:00	63.6	4	16.4	3	72.44	2	9
20:00	63.2	4	15.6	3	68.37	2	9
21:00	62.9	4	14.6	2	67.74	2	9
22:00	61.6	4	13.9	2	67.80	2	9
23:00	60.3	4	13.6	2	67.71	2	9

SQUARE

AQI
+ PET
+ NOISE

Time	Air Quality (AQI)		Thermal Sensation (PET)		Noise		Accumulative Value
	Value	Grade	Value	Grade	Value	Grade	
0:00	80.1	4	13.6	2	75.40	2	8
1:00	75.2	4	14.0	2	66.98	2	8
2:00	73.2	4	14.2	2	67.02	2	8
3:00	69.5	4	13.6	2	58.66	3	9
4:00	74.8	4	13.0	2	56.04	3	9
5:00	77.6	4	13.3	2	56.60	3	9
6:00	64.5	4	13.0	2	59.07	3	9
7:00	41.2	3	13.0	2	61.23	3	8
8:00	-22.9	2	13.2	2	64.96	2	6
9:00	65.0	4	15.4	3	65.86	2	9
10:00	71.7	4	18.2	3	71.89	2	9
11:00	78.0	4	19.1	4	69.92	2	10
12:00	76.7	4	19.4	4	69.62	2	10
13:00	76.7	4	20.6	4	70.43	2	10
14:00	76.7	4	22.2	4	71.27	2	10
15:00	76.7	4	21.9	4	72.61	2	10
16:00	76.6	4	21.0	4	70.57	2	10
17:00	76.9	4	19.3	4	71.39	2	10
18:00	77.3	4	18.0	3	68.77	2	10
19:00	77.6	4	16.5	3	66.84	2	9
20:00	77.8	4	16.1	3	69.52	2	9
21:00	78.2	4	15.7	3	67.56	2	8
22:00	78.3	4	15.3	3	72.74	2	9
23:00	78.6	4	14.9	2	63.58	2	8

PARK

AQI
+ PET
+ NOISE

Fig. 5. The process of conversion from specific index scales for each nuisance to a unified criterion for typical winter day (5.1) and for typical summer day (5.2).

Stage (3): data scaling

Stage (4): accumulating assessment

STREET
AQI
+ PET
+ NOISE

Time	Air Quality (AQI)		Thermal Sensation (PET)		Noise		Accumulative Value
	Value	Grade	Value	Grade	Value	Grade	
0:00	67.7	4	23.1	4	77.62	1	9
1:00	67.6	4	23.0	4	78.41	1	9
2:00	67.2	4	22.8	4	77.08	1	9
3:00	66.8	4	22.5	4	78.11	1	9
4:00	65.8	4	22.9	4	76.91	1	9
5:00	62.8	4	22.4	4	76.14	1	9
6:00	60.4	4	22.8	4	76.23	1	9
7:00	49.4	4	22.7	4	80.15	1	9
8:00	55.8	4	22.6	4	81.31	1	9
9:00	56.2	4	23.0	4	80.91	1	9
10:00	56.8	4	23.2	4	80.93	1	9
11:00	51.5	4	24.1	4	80.46	1	9
12:00	42.9	3	31.0	3	80.85	1	7
13:00	29.6	3	34.1	1	81.27	1	5
14:00	34.3	3	36.5	1	80.68	1	5
15:00	47.5	3	38.5	1	81.57	1	5
16:00	53.0	4	34.7	1	80.78	1	6
17:00	54.7	4	26.1	3	80.82	1	8
18:00	57.6	4	23.7	4	81.63	1	9
19:00	58.1	4	23.4	4	81.88	1	9
20:00	58.4	4	23.4	4	80.76	1	9
21:00	59.8	4	23.0	4	79.84	1	9
22:00	61.3	4	23.0	4	80.33	1	9
23:00	61.9	4	22.7	4	79.91	1	9

SQUARE
AQI
+ PET
+ NOISE

Time	Air Quality (AQI)		Thermal Sensation (PET)		Noise		Accumulative Value
	Value	Grade	Value	Grade	Value	Grade	
0:00	79.7	4	22.2	4	66.53	2	10
1:00	85.4	4	21.9	4	66.69	2	10
2:00	87.7	4	22.1	4	65.98	2	10
3:00	96.1	4	21.9	4	65.22	2	10
4:00	96.9	4	22.3	4	65.30	2	10
5:00	97.1	4	21.8	4	65.48	2	10
6:00	95.7	4	22.8	4	65.73	2	10
7:00	94.4	4	26.5	3	65.41	2	9
8:00	79.6	4	34.8	1	66.92	2	7
9:00	68.7	4	37.9	1	67.13	1	6
10:00	62.3	4	38.8	1	67.24	1	6
11:00	52.5	4	39.2	1	67.73	1	6
12:00	42.4	3	39.3	1	67.00	1	5
13:00	33.8	3	40.8	1	67.45	1	5
14:00	41.2	3	41.3	1	68.41	1	5
15:00	48.5	3	40.1	1	67.33	1	5
16:00	53.9	4	36.0	1	68.03	1	6
17:00	50.90	4	30.9	2	67.11	1	7
18:00	74.5	4	23.9	4	67.63	1	9
19:00	71.5	4	22.9	4	67.08	1	9
20:00	76.3	4	22.5	4	67.30	1	9
21:00	73.5	4	21.7	4	67.00	1	9
22:00	70.0	4	21.4	4	67.51	1	9
23:00	71.9	4	21.3	4	67.20	1	9

PARK
AQI
+ PET
+ NOISE

Time	Air Quality (AQI)		Thermal Sensation (PET)		Noise		Accumulative Value
	Value	Grade	Value	Grade	Value	Grade	
0:00	71.2	4	24.5	4	65.89	2	10
1:00	71.7	4	23.9	4	64.75	2	10
2:00	72.6	4	23.9	4	64.73	2	10
3:00	73.0	4	24.0	4	64.28	2	10
4:00	72.6	4	24.1	4	64.33	2	10
5:00	72.7	4	23.8	4	64.90	2	10
6:00	72.1	4	24.0	4	65.32	2	10
7:00	71.3	4	23.8	4	64.15	2	10
8:00	71.5	4	23.9	4	64.54	2	10
9:00	67.3	4	24.1	4	65.22	2	10
10:00	58.1	4	24.9	4	65.51	2	10
11:00	44.4	3	24.8	4	63.66	2	9
12:00	34.4	3	25.3	4	65.72	2	9
13:00	26.0	3	25.4	4	64.34	2	9
14:00	30.7	3	25.7	4	65.78	2	9
15:00	40.3	3	25.7	4	64.73	2	9
16:00	49.0	3	25.9	4	63.07	2	9
17:00	39.6	3	25.6	4	65.70	2	9
18:00	68.6	4	24.9	4	66.32	2	10
19:00	68.9	4	24.6	4	65.74	2	10
20:00	69.1	4	24.4	4	66.03	2	10
21:00	68.9	4	23.4	4	65.00	2	10
22:00	68.9	4	23.8	4	66.24	2	10
23:00	68.9	4	23.8	4	65.71	2	10

Fig. 5. (*continued*).

WINTER			
Time	Environmental Quality Level		
	Street canyon	Urban square	Urban park
0:00	C	B	B
1:00	C	B	B
2:00	C	B	B
3:00	C	B	B
4:00	C	B	B
5:00	C	B	B
6:00	C	B	B
7:00	C	C	B
8:00	C	C	C
9:00	C	B	B
10:00	C	B	B
11:00	B	B	A
12:00	B	A	A
13:00	B	A	A
14:00	B	A	A
15:00	B	A	A
16:00	B	A	A
17:00	B	B	A
18:00	C	B	B
19:00	C	B	B
20:00	C	B	B
21:00	C	B	B
22:00	C	B	B
23:00	C	B	B

SUMMER			
Time	Environmental Quality Level		
	Street canyon	Urban square	Urban park
0:00	B	A	A
1:00	B	A	A
2:00	B	A	A
3:00	B	A	A
4:00	B	A	A
5:00	B	A	A
6:00	B	A	A
7:00	B	B	A
8:00	B	B	A
9:00	B	C	A
10:00	B	C	A
11:00	B	C	B
12:00	B	C	B
13:00	C	C	B
14:00	C	C	B
15:00	C	C	B
16:00	C	C	B
17:00	B	B	B
18:00	B	B	A
19:00	B	B	A
20:00	B	B	A
21:00	B	B	A
22:00	B	B	A
23:00	B	B	A

Accumulative assessment value	Environmental Quality	
	Level	Grade
10 to 12	Good	A
7 to 9	Moderate	B
4 to 6	Poor	C
3	Very Poor	D

Fig. 6. Environmental quality level of the investigated sites in (a) winter and (b) summer.

assessed air quality level – an effect that was less dominant in the urban park. During the summer, O_3 concentrations during midday caused a decrease in AQI values and consequently reduced the air quality level – once again, an effect that was more dominant in the urban park (Table 9). This process of air pollution indexing was conducted for all the investigated sites, so as to identify which air pollutant dominates the environmental air quality level in each site throughout the year.

Analysis and indexing of noise level

As described in the methodology section, the noise level was indexed according the U.S. HUD's classification, and the data analysis revealed differences in noise pollution. During all measurement campaigns, the noise level in the urban park and in the urban square was classified as "normally unacceptable" during most of the time, while during late night and early morning hours it was classified as "normally acceptable." The noise level in the street canyons was higher in comparison to the noise in the open spaces, and was classified as "clearly unacceptable" during most of the measurement hours – except for a few hours, late at night, during which it was classified as "normally unacceptable." During none of the seasons was the "clearly acceptable" classification (lower than 49 dBA) measured at any of the sites (Fig. 3).

Data scaling

The next step was to classify each nuisance index to a common denominator of unified criteria of four grades – from its best case to its worst case – as presented in the methodology. PET values were scaled to four thermal discomfort levels, as presented in Table 4, Air Quality Index values were scaled to four grades (Table 5), and noise values were scaled according to the HUD classification (Table 2). The scaling process is demonstrated in stage (3) of Fig. 5.1 and 5.2. In this stage, it is possible to assess the quality grade of each nuisance at certain times of the day for a specific site.

Cumulative assessment of environmental nuisances

At this stage, the grades of all three nuisances (environmental noise grade, environmental air quality grade and environmental thermal sensation grade) for each of the investigated sites were summed. The result of this task is creating the cumulative assessment value, as is presented in stage (4) of Fig. 5.1 and 5.2

In the case study demonstrated here the cumulative assessment values ranged from 5 to 10, according to the actual conditions during the specific measuring campaigns.

Grading of environmental quality level

The summed results of the environmental quality values that were accumulated in the former stages were graded in this stage as per the environmental quality level and grades presented in Table 6, thus forming an environmental assessment for each of the investigated sites for specific time. This is the final step of the evaluation process, as demonstrated by Fig. 6, which displays the environmental quality grade for the investigated sites on a winter and a summer day and enables identification of which environmental components ameliorate or deteriorate environment quality.

During the winter in the park, a "Good" environmental quality level existed at midday for 8 h, "Moderate" quality level existed for 15 h and "Poor" quality levels existed for 1 h only. In the street canyons during the same period, "Poor" environmental conditions existed for 17 h – from late night, morning and early evening – due to the combined effect of low grades of air quality, environmental thermal sensation and noise quality. In the urban square, the environmental quality levels were slightly lower than those of the urban park, especially during morning hours (07:00–09:00), due to lower environmental thermal sensation and noise quality grades.

During the summer in the urban park, a "Good" environmental quality level existed for 17 h and a "Moderate" environmental quality level existed for 7 h during daytime. In the urban square, a "Poor" environmental quality level existed for 8 h at midday, due to the combination of low grades of environmental thermal sensation and of noise quality; a "Moderate" environmental quality level existed for 9 h in the morning, late afternoon and evening; and a "Good" quality level was found for 7 h during late night and early morning. In the street canyons, "Poor" environmental quality level existed for 5 h during midday, due to a combination of low environmental thermal sensation and noise quality grades, and a "Moderate" quality level was recorded for 19 h, during the afternoon, night and morning.

These findings prove that overall, throughout the year and in consideration of a range of environmental variables, the best environmental quality level exists in the urban park, in comparison to other urban open spaces.

Discussion

This study proposes a methodological approach for the environmental assessment of urban parks. To date, only small numbers of studies have attempted to suggest methodological approaches for a quantitative environmental assessment of urban green spaces (Bolund & Hunhammar, 1999; De Ridder et al., 2004; Haq, 2011), but none of these based their assessment on analysis of semiannual in-situ objective measurements of air pollution, noise and climatic variables and their overall impact on a specific site. The present study proposes an integrative methodology consisting of feasible in-situ measurements, data analysis and data indexing based on verified indices and overall data scaling, in an attempt to evaluate environmental quality. As per this methodological approach, four open space sites in the center of the city of Tel Aviv were investigated: an urban park, an urban square and two street canyons.

The notable finding of the study is the superior environmental quality level of the urban park in comparison to other urban open spaces, in both summer and winter.

This quantitative assessment method enables identification of the nuisances that dominate the environment quality level in each of the investigated sites during the different seasons of the year. Examination of the summer season shows that since the influence of noise on the environmental quality level is similar at all sites and air pollution values were relatively low, it appears that the thermal conditions play a significant role by dominating environmental quality levels: aggravating thermal conditions in the urban square, as described by Lin (2009) and Cohen et al. (2012) and relieving thermal conditions in urban parks, as described by Potchter, Cohen, and Bitan (2006) and Cohen et al. (2012). Concerning air pollution, Kuttler and Strassburger (1999) and Nowak et al. (2000) reported an increase in Ozone concentration in urban parks during the summer season. Despite increased Ozone values (94 ppb 30-min mean value in the park and 78 ppb 30-min mean value in the street canyons), AQI level in both sites shifted from "low" to "medium", but the outcome of this shift on the accumulative assessment is insignificant, and therefore its effect on environmental quality level grading is minor.

During the winter, the picture is more complex. No single nuisance proved to be dominant in the street canyons, but rather, the combination of dominant nuisances shifted from hour to hour. The thermal discomfort level in the street canyons was classified as "high" and "very high" (grades 1 and 2) during evening, night and morning, while in the urban park, the trees had a moderating effect on thermal conditions, as reported by Hamada and Ohta (2010) and by Cohen et al. (2012), and thermal discomfort was defined as "high" and "medium". High air pollutant concentration, especially concentrations of NO_x and PM_{10}, together with "high" and "very high" thermal discomfort levels, caused a "Poor" environmental quality level in the street canyons. During daytime, when pollutant concentrations declined and temperatures increased, the environmental quality level in the street canyons improved. Although the thermal discomfort level in the urban square classified as "high" during the evening, night and morning, the square's physical characteristics as large, open and exposed to the ventilating wind causes a reduction in air pollution. Therefore, the environmental quality level in the urban square was classified as "Good". The comfort thermal conditions in the urban park, together with the low level of air pollution and – to a certain extent – the noise reduction experienced there, created a "Good" environmental quality level during midday. When thermal conditions became cool and discomfort level classified as "medium" and "high," the environmental quality level was defined as "Moderate." Under specific synoptic conditions during the winter, when the main source of PM_{10} is long-range particle transference from the Sahara desert, tree belts serve as an efficient barrier and capture the dust, especially while the dust is settling.

Examination of noise levels demonstrates that noise values at all the investigated sites ranged between "high" and "very high". This analysis shows that in a noise polluted urban areas, vegetation is a selective noise frequency filter, as Tyagi et al. (2006) and Feliciano et al. (2006) noted, although its effect on noise quality level is not a dominant one. Reduced values of noise level in the urban park and in the urban square results primarily from noise level attenuation caused by the distance from the traffic-related noise source (street canyons), while the effect of the vegetation barrier is only secondary and generally more effective with higher frequencies (Tyagi et al., 2006).

We thus conclude that the methodology presented here provides a better understanding of the elements that contribute to improved environmental quality in open urban spaces during the seasons of the year. Such an understanding will help to achieve sustainable management of the cities in era of environmental crisis.

Conclusions

Parks and open spaces serve important environmental functions. It is widely purported that urban parks can cleanse the air, reduce the noise and ameliorate the microclimate inside their boundaries. Yet all the while, not many studies have suggested a quantitative assessment tool to evaluate these functions. The novelty of this study is found in the holistic environmental concept of the benefit of urban park, the simultaneous measurements of three different nuisances at different sites during various seasons, and the integrative methodological approach offered here for the environmental quantitative assessment of urban parks.

The methodology proposed in this study provides a convenient, integrative and feasible tool based on verified and accepted categorizations for the three main environmental nuisances (thermal stress, air pollution stress and noise stress), which are the most harmful to human health. The methodology is based on empirical data that is usually monitored by researchers or by official agents (municipalities, the EPA, regional monitoring authorities) and therefore is universally applicable. This assessment method can offer a beneficial tool for urban planners and architects in the planning process, helping to attain the ultimate environmental benefits from urban open spaces for the wellbeing of urban inhabitants. Such a contribution emphasizes the importance of public green spaces in the urban tissue and justifies an investment in these spaces in terms of sustainable development.

The methodology supplying an examination tool which can be used in the future for investigating the influence of the urban park on the urban environment (by examining over distance of 50, 100, 500 m from the park).

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