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Traffic air quality index

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HIGHLIGHTS

- The traffic air quality index (TAQI) was proposed as a tool of assessing air quality near roadways, especially in compact settlement areas.
- Degrees of harmfulness were determined for primary pollution from traffic sources, which enabled describing the TAQI with a single value.
- An example was provided of how the TAQI could be used to assess air quality in several real traffic routes in an urban area.

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ABSTRACT

Vehicle emissions are responsible for a considerable share of urban air pollution concentrations. The traffic air quality index (TAQI) is proposed as a useful tool for evaluating air quality near roadways. The TAQI associates air quality with the equivalent emission from traffic sources and with street structure (roadway structure) as anthropogenic factors. The paper presents a method of determining the TAQI and defines the degrees of harmfulness of emitted pollution. It proposes a classification specifying a potential threat to human health based on the TAQI value and shows an example of calculating the TAQI value for real urban streets. It also considers the role that car traffic plays in creating a local UHI.

1. Introduction

Air quality in an urban area is conditioned by complex interactions among numerous factors including climate, meteorology, physiographic, urban and social conditions and mainly air pollution emissions from anthropogenic sources. The most important property of air quality is its chemical composition and exposure level, particularly a share of substances hazardous to humans and the environment. Therefore, the term "air quality" is often limited to concentration levels of particular pollutants (e.g. Sokhi, 2008; Directive of the European Parliament, 2008; Regulation of the Minister of Environment (Poland), 2012). Over 70% of European cities do not meet air quality criteria recommended by the World Health Organization (WHO, 2006). As noted by Crutzen (2004), the rapid development of urban areas observed in the last several decades confirms that they have a considerable impact on air quality not only within a particular city, but also on continents and in the entire world. The urban ecological footprint is much bigger than the area taken up by an agglomeration. Urban areas that do not have many high-emitting industrial plants are primarily polluted by fuel combustion processes in stationary and mobile installations, which emit about 500 chemical compounds (Fenger, 1999). The author determined a mechanism of numerous primary and secondary air pollution substances affecting human health and the environment. The following were isolated:

— Major Air Pollutants — MAP: sulfur dioxide (SO_2), carbon monoxide (CO), lead (Pb), nitrogen oxides (NO_x), particles PM (PM_{10}, $PM_{2.5}$, $PM_{1.0}$), and ozone (O_3),
— Hazardous Air Pollutants — HAP: complex chemical, physical and biological substances of various types including mono- and poly-cyclic aromatic hydrocarbons.

MAP are most often accepted as measurements of air quality in an urban area considering their impact on human health both in the general population and risk groups. Air quality standards are determined by boundary values of concentrations of these substances with regard to their impact on human health and natural and anthropogenic environments.

Urban air quality assessment is a complex issue. The law in the European Union (Directive, 2008) and certain other countries (e.g.

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Nomenclature

CAQ	category of air quality
C_{COb}	measured concentration of CO (μg m^{-3})
C_{CO}	concentration of CO after deducting the background (μg m^{-3})
E_{CO}	linear density flux of CO emitted from traffic sources (μg m^{-1} s^{-1})
E_{ti}	density flux of an i pollutant emitted from traffic sources per linear distance of roadway (mg km^{-1} s^{-1}) or (kg km^{-1} $year^{-1}$)
E_{tR}	density flux of an equivalent pollutant emitted from traffic sources per linear distance of roadway (mg km^{-1} s^{-1}) or (kg km^{-1} $year^{-1}$)
F_C	street canyon factor (m/m) — ratio of the building average height to the total width of the street, H_{Bav}/W
FC_v	values of vehicle fuel consumption (kg s^{-1})
H_{Bav}	building average height (m)
k_i	degree of harmfulness of emitted pollutant i-th in relation to SO_2
L	length of the street (m)
N	traffic volume — vehicle per hour (v/h)
Q_d	direct energy — total energy used by the vehicle in fuel (kJ)
Q_{dL}	flux of heat emitted from traffic sources per linear distance of roadway (kW km^{-1})
Q_F	heat of fuel combustion (kJ kg^{-1})
TAQI	traffic air quality index (mg km^{-1} s^{-1}) or (kg km^{-1} $year^{-1}$)
u_x, u_y, u_z,	components of wind velocity
W	width of the street (m)
w	vehicle velocity (km/h)
Y_{WC}	coefficient considering the street canyon factor F_C.

EPA, 2003; Environment Canada, 2013) specifies the acceptable concentrations of some air pollutants, especially in cities and requires that concentrations be determined by measurement according to a unified method. Measurement results are the basis for preparing and publishing the Air Quality Index (AQI), which is mainly used to assess health risk among the inhabitants of an urban area (or a region). There are differences among the countries as to the methodology of determining the AQI and the considered pollutants (e.g. Air Quality Index EPA, 2003; Environment Canada, 2013; Guide to UK Air Pollution Information Resources, 2013). Measurements also enable to prepare forecasts and verify mathematical models. However, air quality assessment based on measurements in urban areas with a diversified building development and diversified low emissions is error-burdened when results are obtained at a background air pollution measurement plant. It also has limited representativeness when measurements from a local station are used.

Air quality assessment according to mathematical deterministic systems has considerable uncertainty in characterizing meteorological, topographical and urban input data. Analyzing the relation between concentration values obtained after measurements as part of the Urban 2000 experiment and research in Los Angeles and Salt Lake City, Hanna et al. (2003) stated that the basic Gaussian dispersion model adapted to local meteorological and topographical conditions could explain a large part of variables in tests. However, concentration values in specific receptors even differ by a factor of 2 or 3. In compact settlement areas with stationary and mobile low emission sources pollution dispersion is stochastic, in a situation in which a small change in initial conditions causes a radical shift in concentration fields. There are many factors that can affect concentrations, for example, structure of buildings, structure of streets, and topography of city area. Berkowicz et al. (2006) present an application of the Danish Operational Street Pollution Model (OSPM) to model values of traffic pollution concentration in cities based on emission values. A relatively high accordance of calculated and measured concentration values, especially for smaller emissions.

Bagieński (2011) presented a new approach to air quality evaluation in an urban area, especially in compact settlement areas. It consists of basing assessment on non-random magnitudes (i.e. burdened with low uncertainty) and associating a result with its anthropogenic cause (i.e. dependent on humans). Identifying the cause makes it possible to correct it during a specified period of time, which means it is a dynamic element of air quality control. As stated earlier, in cities without many high-emitting industrial plants and with a generally low level of pollution coming from outside an urban area, the basic anthropogenic element that has a dynamic impact on air quality is fuel combustion in stationary and traffic sources. An important (anthropogenic) factor that influences air quality statically is the urban structure. Therefore, an air quality assessment index was proposed that associated air quality with emission size and structure and technical emission conditions ensuing from the development structure. Bagieński (2011) suggested a method of determining the Energy Air Quality Index ($EAQI_s$) with regard to stationary combustion sources, which is particularly important in cities found in areas with cold and temperate climates during the so called "heating season". This paper presents the methodology of determining the traffic air quality index (TAQI) with an example of its application.

Many authors e.g. Baldauf et al. (2013) and Carpentieri et al. (2012) pay attention to the fact that vehicle emissions are responsible for a considerable share of urban air pollution concentrations. Numerous papers (e.g. Fenger, 1999; Park et al., 2004; Berkowicz et al., 2006; Clements et al., 2009; Kim and Guldmann, 2011) present the results of traffic pollution concentration measurements near varying traffic volume streets and analyze the range of the route impact. Research shows that concentration values are highly sensitive to dynamic anthropogenic conditions (traffic volume, vehicle type), urban structure and meteorological conditions. Air pollution dispersion in urban streets is a complex issue and depends on many factors, including:

- Structure of buildings near streets — the height and the relative height of buildings, their shape, including the shape of their roofs. Buildings are responsible for the disturbances in the airflow. The boundary of the wake region (with horseshoe vortex) can approach up to 3 heights of a building and the range of 16 heights at the lee side of the building (Ahmad et al., 2005; Peterka et al., 1985). The cumulative effects of groups of buildings (of compact settlement) make local air flows differ considerably from a flow in an undisturbed area as to direction and velocity.
- Structure of streets — their width, intersections and orientation in relation to the mostly frequent wind directions, but also with regard to, say, a group of trees in a particular street.
- Geometry of street canyons — regular or irregular canyons, height-to-width ratio and length-to-height ratio of a canyon; the so called regular canyon only appears in models. Buildings surrounding real street canyons are diversified as to their height and shape and the type of their facade.
- Vehicle motion — traffic intensity, vehicle velocity, one- or two-way traffic, and heat stream emission. The vehicle wake and the hot exhaust gases generate mechanical and thermal turbulence. This can have an influence on the airflow in the canyon up to 12 m above the road (Qin and Kot, 1993; Kaster-Klein et al., 2000).
- Wind direction and velocity — many authors e.g. Chang and Meroney (2003), Ahmad et al. (2005), Chana et al. (2008), Kim and Guldmann (2011), and Carpentieri et al. (2012), pay attention to the considerable impact that wind direction and velocity have on flow distributions and pollutant concentration in a street canyon.