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Environmental quality health index for cities

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ABSTRACT

This paper presents an urban environmental quality health index based on noise levels and air pollutant concentrations. The *Healthy City Noise–Air* index results from the weighted linear combination (WLC) of two normalised indexes: *healthyNoise* and *healthyAir*. The numerical value of the *Healthy City Noise–Air* index varies between 0 and 1. The index is equal to zero when the noise level is above the legal limit and at least one air pollutant concentration is above the limit value. On the other hand, *Healthy City Noise–Air* is equal to one when the noise level is below the limit value and all of the air pollutant concentrations are at or below the values recommended by WHO. When there is no limit violation, then noise and all the pollutants are considered for the overall environmental quality, which is calculated through a multi-criteria combination of noise and air pollutants concentrations, where trade-off is allowed. The proposed model makes use of multi-criteria techniques for combining, aggregating and standardising noise levels and pollutant concentration data. The dose–effect relationships in relation to the impact of noise and air pollution exposure on human health are comprised in the weighting and standardisation process. This allows the assessment of combined noise and air pollution risk within human health context.

Introduction

The urban argument assumes currently an extreme level of relevance for the governments and the society in general, due to the exponential increase of people living in cities. This often enhances stresses on space, ecosystems, infrastructures, facilities and personal lifestyles. The quality of life in cities especially the environmental dimension is one of the five assessment criteria in the UN-Habitat's CPI (City Prosperity Index) and assumes an important role. Quality of life and environmental conditions have an immediate impact on the quality of people's lives. They affect human health both directly (air, noise, etc.) and indirectly (climate change, biodiversity, etc.). Well-managed urban areas can improve environmental conditions and quality of life. Nevertheless, the uncontrolled growth of cities might lead to a decrease in the quality of the urban environment.

Domestic and industrial sources and mainly motorised traffic are responsible for pollutant emissions and noise which decisively affect the life in today's cities. Due to a generalised increase in mobility and road traffic in urban areas, the total emissions from road traffic have risen significantly, thus becoming the major responsible for the disregard of air quality standards (O'Mahony, Gill, Broderick, English, & Ahern, 2006; Silva, Pinho, & Nurusman, 2014). Urban air pollution and urban noise are major factors that can degrade quality of life in the cities. Motorised traffic is nowadays recognised as the major contributor to environmental noise in urban areas, mainly due to engine noise and rolling noise from tyre friction on the road surface (Boschmann & Kwan, 2008; King & Davis, 2003; OECD, 1995).

Compounds released into the atmosphere from motor vehicle exhaust have an impact on the environment at various geographical and time scales (Highways Agency, 2007). Certain compounds possess an immediate and local effect. For instance, a plume of black smoke is instantly unpleasant for the observers, and chronic releases of black smoke can darken the facades of buildings through particle deposition. Combustion of hydrocarbon fuel in the air generates mainly carbon dioxide (CO_2) and water (H_2O). However, combustion engines are not totally efficient, and not all of the fuel is oxidised. The products of incomplete combustion are more complex and may include carbon monoxide (CO) and particulate matter (PM) containing carbon and other pollutants. Additionally, combustion under high pressure and temperature conditions causes partial oxidation of nitrogen in air and fuel, which forms nitrogen oxides, such as nitric oxide and some nitrogen dioxides (conventionally designated as NOx). Traffic-related air pollution levels can be evaluated by either direct measurements or predictive models. The direct measurement method is only feasible to evaluate actual situations; predictive methods can be applied throughout the planning process from the initial concept to the final detailed design of air pollution abatement measures. However, measurements provide essential information to

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validate the predictive methods. Air pollution is a major environmental risk to health. By reducing air pollution levels, countries can reduce the problem of disease from stroke, heart disease, lung cancer, and both chronic and acute respiratory diseases, including asthma (WHO, 2014).

Noise caused by road traffic is the most often mentioned nuisance by roadside residents. This problem tends to worsen due to the unbalanced development of urban spaces and the significant increase of mobility and road traffic (Silva, Oliveira, & Silva, 2014). Although the exposure of communities to environmental noise is a worldwide concern, most cities are still subjected to noise levels that are a disturbance to human activities. The health effects of environmental noise are well-documented (Moudon, 2009). Traffic noise can cause numerous health problems such as sleep disturbance, high blood pressure and psycho-physiological symptoms (King & Davis, 2003; Ko, Chang, Kim, Holt, & Seong, 2011; WHO, 2011).

According to WHO (2011), 33% of the individuals are annoyed during daytime and 20% have disturbed sleep at night because of traffic noise. Traffic-related noise is becoming the most health-threatening environmental stressors in Europe, and more people are exposed to traffic-related noise than to any other environmental stressors.

This paper proposes an urban environmental quality index based on human heath impact of noise levels and air pollutant concentrations – *Healthy City Noise–Air* index. The work presented here is an evolution of the index *City Noise–Air* (Silva & Mendes, 2012). In this case the dose–effect relationships in relation to the impact of noise and air pollution exposure on human health are adopted in the weighting and standardisation process. This allows the assessment of combined noise and air pollution risk within a human health context.

Health impact assessment of noise and air pollution

Dose–response relationships are functions that relate information on changes in environment noise or air quality for different noise levels or air pollutants to different health outcomes.

The principle is that changes in noise levels or air pollution concentrations for certain pollutants can be statistically related to observed changes in noise annoyance and in health impact due air pollution in a population respectively.

Health impact assessment of noise

Many studies have been conducted to establish a set of relationships that show which annoyance level is associated with a given noise exposure level. The WG2 (2002) by using synthesis curves based on studies conducted in Europe, North America and Australia, proposed relationships between annoyance and noise exposure. The WG2 (2002) recommended one polynomial function for the estimation of the noise annoyance on the basis of the noise exposure of dwellings (Equation (1)).

$$\%A = 1.795 \times 10^{-4}(L_{den} - 37)^3 + 2.110 \times 10^{-2}(L_{den} - 37)^2 + 0.5353(L_{den} - 37) \quad (1)$$

where $\%A$ is the noise annoyance (%) and L_{den} equivalent continuous sound level during the entire day (dB(A)).

Health impact assessment of air pollution

Outdoor air pollution is a major environmental health problem affecting everyone in developed and developing countries alike (WHO, 2014). Adverse health outcomes due to environment air pollution exposure are a major public health issue. Epidemiologic studies in Europe and worldwide have measured increases in mortality associated with air pollution (WHO, 2000, 2001, 2003, 2004, 2005, 2011). Quantification of impact of air pollution on the public health has increasingly become a critical component in the policy discussion (e.g. Garcia-Aymerich, Tobias, Anto, & Sunyer, 2000; Kunzli & Tager, 2000; Ostro, 1994; Sahsuvaroglu & Jerret, 2007). One way to quantify this impact on public health is by establishing of dose–response relations. These response relations are functions that relate information on changes in ambient air quality for different pollutants to different health outcomes.

According to Ostro (1994) the estimated health impact can be represented by the following relationship (Equation (2)):

$$dH_i = slope_i \times p_i \times dA \quad (2)$$

where dH_i is the change in population risk of health effect i (–), $slope_i$ is the slope from dose–response curve for health impact i (–), p_i is the population exposed at risk of health effect i (pop) and dA is the change of the environment concentration of the pollutant under consideration (variable).

Estimating the effects of air pollution on various health outcomes involves calculating the partial derivative or slope (b_i) of the dose–response function (Equation (2)), to provide an estimate of the change in the prevalence of a given effect associated with a change in outdoor air quality (dA).

Through regression analysis, coefficients are estimated; the next step involves multiplying this slope by the population exposed and susceptible to air pollutant effect into consideration (p_i). Finally the calculation of health effects of air pollution involves the change in air quality (dA) under consideration. It could be relevant to consider the change from current air pollution levels to some ambient air quality standard, either a local one, or the WHO air quality guide line.

Thereafter the dose–response curves of the major urban air pollution will be presented.

Particulate matter

Particulate matter affects more people than any other pollutant. The most health-damaging particles are those with a diameter of 10 microns or less (≤PM10), which can penetrate and be lodged deep inside the lungs. Chronic exposure to particles contributes to the risk of developing cardiovascular and respiratory diseases, as well as of lung cancer (WHO, 2014). Epidemiologic studies provide dose–response relationships between concentrations of ambient particulate matter and several adverse health outcomes including mortality, respiratory hospital admissions, emergency room visits, and others. Among these studies, statistically significant relationships have been found using several alternative measures of particulate matter (TSP, PM2.5, British smoke, and others).

According to Ostro (1994), recent studies have been linking particulate matter to mortality and the results present remarkably consistent conclusions. The mean effect of a 10 $\mu g/m^3$ change in PM10 concentration implied by these studies varies between 0.31 and 1.49 percent, with a mean of 0.96 percent (0.096 by 1 $\mu g/m^3$ of PM10). Thus, Ostro assumed that the effects of PM10 can be expressed as follows (Equation (3)):

$$\text{Central percent change in mortality} = 0.096 \times dPM10 \quad (3)$$

where, $dPM10$ is the change of the concentration of PM10 ($\mu g/m^3$) in the environment.

Ozone

Excessive ozone in the air can have a strong effect on human health. It can cause breathing problems, trigger asthma, reduce lung