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# $G_{den}$: An indicator for European noise maps comparison and to support action plans

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## HIGHLIGHTS

- Noise Exposure in European Cities: classification based on inhabitants exposure distribution
- $G_{den}$ and $G_{night}$: global indicators to rate noise pollution
- Correlations between $G_{den}/G_{night}$ and Highly Annoyed/Sleep Disturbance
- $G_{den}$ new definition reflecting annoyance from different sources
- Hot spot identification in action plan procedures: $G_{den}$ vs. other methods

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## ABSTRACT

Ten years after the approval of the Environmental Noise Directive 2002/49/EC (END) a large experience have been acquired to develop noise maps and action plans: the Noise Observation and Information Service for Europe maintained by the European Environment Agency (EEA) on behalf of the European Commission contains all data delivered in accordance with the END by Members States within the first round of implementation of the END. This large database should be useful to evaluate the pollution of Europe and to guide policy makers to establish best practices. However, local procedures and national methods do not permit a direct comparison of data reported. A comparison within agglomerations in EU is here carried out in order to find suitable indicators to identify most polluted cities despite different methods used. Critical and quiet areas have been assessed in action plans, but national laws and requirements are various, as different indicators used for their identification. The analysis was performed on noise exposure classes distribution, grouping them together using $G_{den}$ and $G_{night}$ indicators to offer a new tool for presenting noise maps of the cities to the public permitting their comparison and for drawing detailed action plans. Strong relationship between these indicators and highly annoyed and highly sleep-disturbed people percentages are obtained. Furthermore, a comparison between $G_{den}$ and Qcity Noise Scoring for local hot spot identification is carried out for the agglomeration of Pisa, where different transportation noise sources are present. The final goal is to define faster methods for suitable indicators calculation in hot spot identifications.



## 1. Introduction

The aim of Environmental Noise Directive 2002/49/EC (END) is to guide a noise policy in Members States offering a common framework in which same indicators ($L_{den}$ and $L_{night}$) are used for homogeneous noise mapping, in order to obtain comparable results, defined procedures for action plans to reduce noise exposure and to improve sound quality and preserve quiet areas, raising public awareness about noise pollution promoting their communications and participation to decisions. Ten years after the END a large database of noise maps is available thanks to the common report mechanism developed by Environmental European Agency, which permits data analysis and evaluations to whom interested. However misinterpretation of available data may occur due to different approaches in modelling noise pollution, local regulations and detailed descriptions of different methods applied. In fact, since difficulties in implementing the END have been already highlighted (Murphy and King, 2010 then European Commission funded EU projects to harmonize procedures and methods to model noise, provided a good practice guide to help Members States (WG-AEN, 2007) for noise mapping, promoted a large process to revise END, including participation of the public. The definition of a common assessment method (CNOSSOS) is an on-going process, including the development of the relative open source software:

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a final version is expected before 2014 after validation tests (Kephalopoulos et al., 2012).

Therefore, this paper intends to analyse data and exposure distribution officially delivered, grouping them according to shapes and national methods for permitting an effective comparison. The research aim is to find useful indicators to evaluate the agglomerations results in terms of global noise pollution in the faster and easier way. The idea is to have a single value representing the noise climate of a city/area. The group noise indicators called $G_{den}$ and $G_{night}$ are applied as estimators of highly annoyed people and highly sleep-disturbed people for each type of noise source reported in the database. In fact, Babisch et al. (2010) pointed out the relevance of evaluating health risk and annoyance perception, instead of considering only noise energy, in order to protect people and improve their quality of life. A comparison between $G_{den}$ and Qcity Noise scoring indicator for hot spot identification is carried out, where a revised $G_{den}$ reflects annoyance from multi reported sources. This application is mostly relevant in defining hot spots: in fact, drawing up action plans, procedures have to be developed for hot spots and critical areas identification; for this purpose different commercial software tools are now available but no homogeneous criteria are used. Moreover, hot spots identification determines long post-process calculation that could not reflect in practice the addresses given by policy makers: they would like to include in the same mitigation action more people as possible to be effective in terms of cost-benefits, but it is not easy to determine the boundaries of any critical areas above all in an automatically and fast way. In fact, it is a matter of simple software implementation the single building most exposed identification, but this is not the case for rating areas and prioritization of their mitigation actions. The need of an indicator of global noise quality improvement therefore arises.

It is important getting a broader perspective not only in terms of wide spaces, but also in terms of time evolution: lots of studies are now trying to analyse perspectives for evaluating effects of mitigation actions along time as an average over the same sampled population. $G_{den}$ has been already proposed to accomplish this porpoise in previous articles (Weber and Jabben, 2010): here a such indicator is also applied to carry out an evaluation of local hot spots in Pisa agglomeration where maps of road, rail and air noise pollution are available. The aim of this test is to verify if a step-by-step approach (like the one proposed within CNOSSOS-EU project, Kephalopoulos et al., 2012) is suitable not only for mapping, but also for action planning, leaving detailed calculation for most polluted zones.

## 2. Material and methods

### 2.1. Comparison of noise exposure class distributions in European agglomerations

There are large differences within reported noise exposure data (available on line at NOISE Viewer - EIONET http://noise.eionet.europa.eu/) simply looking at their distribution shape as already highlighted (van den Berg and Licitra, 2009; De Vos and Licitra, 2012). It was argued that two large groups different from all other distributions could be extracted: the former is constituted by German data that are based on national method of people distribution (VBEB, 2007) and the latter by English data, that are produced all by the same institute (DEFRA). The aim of this work is to go in depth in these data to recognize different groups according specific curves shapes. The analysis is based on incremental ratio between classes of exposure and overall percentage of people reported below 55 dB and over 65 dB of $L_{den}$. In fact, reported data do not include the whole population of the city: it is not clearly stated, for each city, if not reported population could be considered exposed to values lower than 55 dB or if they have been neglected, without knowing their exposure levels. Many cities have considered only the main road network, neglecting the small local roads, whose traffic is hard to estimate, but that could eventually contribute to values higher than 55 dB (Licitra et al., 2012).

In order to carry out this comparison and to find a global rating to be assigned to cities, the $G_{den}$ indicator has been computed. $G_{den}$ has been originally used to compare zones of the same city or the time evolution of a single zone (Jabben et al., 2010); therefore, a revised version of the $G_{den}$ is introduced in order to take into account differences in population amount between European cities. In fact, $G_{den}$ is a group noise indicator in which number of inhabitants is multiplied by noise energy, so its application without any corrections would identify larger cities and not worst polluted ones. The Eq. (1) highlights the revised version of the indicator with the introduction of a weighting factor $1/N_{tot}$:

$$Gden_{norm} = 10.\log_{10}\left(\frac{1}{N_{tot}}\sum_i n_i \cdot^{\frac{Lden_i}{10}}\right) \quad [\text{dBA}] \tag{1}$$

where $N_{tot}$ is the total agglomeration population, $n_i$ is the population exposed to the *i-th* class of exposure and $L_{den\_i}$ is the representative value of *i-th* class of exposure.

In addition to this modification, we need to point out that reference values of external classes could not be given as "central values"; a preliminary assignment of equally spaced class is decided, but further analyses are necessary. Thus, a comparison between different assignments is carried out to evaluate how much $G_{den}$ varies according values assigned to external classes.

### 2.2. $\mathbf{G_{den}}$ and $\mathbf{G_{night}}$ relationship with Annoyance estimation

As a confirmation that these indicators are reliable estimators of health risks and annoyance, a relationship with highly annoyed and highly sleep-disturbed is carried out for the revised formulation of $G_{den}$ and $G_{night}$ for European cities. Analysis to investigate how this relationship changes according to chosen external classes is also provided.

Moreover, annoyance varies according to different noise sources and this issue should be included in calculating a cumulative $G_{den}$ for all sources. Weighted $L_{den}$ proposed by Miedema and Borst (2007) is applied to obtain relationships with source dependent annoyance; $L_{den}$ and $L_{night}$ values for rail(R) and aircraft(A) noise are transformed into equally annoyed road traffic levels ($L_{den}$ weighted as in Eq. (4), $L_{night}$ weighted as in Eq. (6)) as stated by following formulas before calculating $G_{den}$:

$$\begin{aligned}HA_R = {} & 7.239\cdot10^{-4}(L_{den}-42)^3-7.851\cdot10^{-3}(L_{den}-42)^2\\ & +0.1695\cdot(L_{den}-42)\end{aligned} \tag{2.a}$$

$$\begin{aligned}HA_A = {} & -9.199\cdot10^{-5}(L_{den}-42)^3+3.932\cdot10^{-2}(L_{den}-42)^2\\ & +0.2939\cdot(L_{den}-42)\end{aligned} \tag{2.b}$$

$$F_i = \left(-2.374\cdot10^{-4}+1.05\cdot10^{-4}HA_i + \sqrt{2\cdot10^{-7}-5\cdot10^{-8}\cdot HA+1.11\cdot10^{-8}\cdot HA_i^2}\right)^{1/3} \tag{3}$$

$$L_{den_w i} = 46.85+168.9\cdot F_i-0.8843\cdot F^{-1}{}_i \tag{4}$$

And $G_{night}$:

$$HSD_R = 11.3\text{-}0.55\cdot L_{night}+0.00759\cdot L_{night}{}^2 \tag{5.a}$$

$$HSD_A = 18.147\text{-}0.956\cdot L_{night}+0.01482\cdot L_{night}{}^2 \tag{5.b}$$

$$L_{night_w i} = 35.33+\sqrt{67.29\cdot HSD_i\text{-}151.5} \tag{6}$$

Notice that calculation should be performed only for $L_{den}$ values over 42 dB and for $L_{night}$ over 40 dB, otherwise no weighting applies. $G_{den}$ values calculated according to this weighting process are