Estimating the Population Exposed to Transportation Noise: a Case Study on Poznań City

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Abstract

European Union Directive 2002/49/EC relating to the assessment and management of environmental noise (named as END) in article 6 paragraph 3 states that "harmful effects may be assessed by means of dose-effect relations referred to in ANNEX III". In this still unfinished ANNEX III there are formulas which present how to calculate the number of people affected by a given noise. The dose-effect relations have been recently presented in WHO document "Environmental Noise Guidelines for the European Region". These Guidelines allow to predict the percentage of people who will be affected by a specific kind of noise. E.g. it is shown how to calculate the percentage of highly annoyed people for a given value of noise index, L_{den}. In our paper we propose how to calculate the total number of people affected by noise in their living conditions and discuss the implementation of methods recommended in ANNEX III in Poland.

Keywords: ANNEX III, number of people affected by noise

1. Introduction

The main purpose of the Environmental Noise Guidelines for the European Region [1] is to provide recommendations for protecting human health from exposure to environmental noise originating from various noise sources. EU Member States agreed that recommendations from these guidelines should be observed in constructing the revision of ANNEX III of the Environmental Noise Directive (END). The recommendations introduced in the working version of ANNEX III [2] refer only to noise produced by three kinds of transportation sources: road traffic, railway and aircraft. The recommended L_{den} values for these three kinds of environmental noise sources could be a preventative measure for the occurrence of four specific types of harmful health effects associated with high noise levels: ischaemic heart disease, stroke, high annoyance and high sleep disturbance. Such harmful effects may be assessed by means of dose-effect relations presented in WHO document, as well as, in the ANNEX III (Equations (3) to (20)).

The basic aim of ANNEX III is to define the best assessment method for calculating the number of people affected by noise produced by various transportation noise sources. The proposed methods are quantitative and are designed to calculate separately the number of inhabitants exposed to each of the three kinds of transportation noise. These calculated values can later be ranked according to the relative importance of a particular noise source.

In sum, ANNEX III contains methods allowing to calculate the number of people affected by three kinds of noise sources with respect to four types of harmful effects. However, the guidelines neglect the data informing about the population structure of the considered urban area. Therefore it is not possible to calculate the relationship between the number of affected people and their living conditions. For example, the regulations in ANNEX III do not allow to relate a given place in a city to highly annoyed people exposed to road traffic. Such data are important in constructing an efficient action plan which recommends means to reduce noise in a given area in a city under consideration. The higher the number of highly annoyed people in a given area the more vital is the action towards reduction of noise. Since ANNEX III is still unfinished it should be decided if it should focus on a general or a more specific solution. The first, general approach will consist in proposing methods allowing to calculate the total number of highly annoyed people in a whole city. In such a case, one has to answer the question how these calculations can be used in constructing an efficient action plan? The second, specific approach will demand much more work, but would be easier to implement.

2. Methodological problems in a working version of the Annex III document

Before ANNEX III will be established as a law in noise management some important methodological problems should be addressed. We will discuss one of them.

The document assumes that harmful effects of noise causing an increase in the risk of ischaemic heart disease (*IHD*), as well as an increase in the risk of stroke (*STR*), can be quantified by the relative risk. This assumption can be presented in the form of the following equation:

$$RR = \frac{P_{\text{event when exposed}}}{P_{\text{event when not exposed}}} \tag{1}$$

where *RR* is the probability of an event occurring (e.g. developing a disease) in the exposed group to the probability of the event occurring in the non-exposed group. The *RR* values are calculated for each kind of noise source separately.

The calculations of *RR* for a given harmful effect and noise source require insertion in the equation of (1) the specific values of L_{den} at which risk of *IHD* or *STR* starts. An example of such specified equation for the incidence rate of the *IHD* for road traffic is:

$$RR_{IHD,i,road} = \begin{cases} \exp((\ln 1.08/10) \cdot (L_{den} - 53)) \quad \text{for } L_{den} \text{ greater than 53 dB} \\ 1 \quad \text{for } L_{den} \text{ equal or smaller than 53 dB} \end{cases} \tag{2}$$

Values for other kinds of noise sources and harmful effects could be calculated without problems. The problem arises when we want to calculate the number of people affected by given harmful effect caused by particular noise source - $N_{x,y}$

$$N_{x,y} = PAF_{x,y,i} \cdot L_y \cdot P \tag{3}$$

$$N_{x,y} = PAF_{x,y,i} \cdot M_y \cdot P \tag{4}$$

where $PAF_{x,y}$ is the population attributable fraction, P is the total population of the area under assessment (the sum of the population in the different noise bands). To perform these calculations we need data of incidence rate, L_y and mortality rate, M_y. These data should be obtained from statistics on health region or country where the area is located. However, in some countries (e.g. in Poland) such data are difficult or even impossible to obtain.

This problem does not occur, when two other harmful effects: high annoyance (*HA*) and high sleep disturbance (*HSD*) are taken into consideration. These harmful effects can be quantified by the absolute risk (*AR*) defined as: "Occurrence of the harmful effect in a population exposed to a specific level of environmental noise". There are well known equations (see: (7), (8) and (9)) for three different kinds of noise sources which can be used for the quantification of the number of highly annoyed (*HA*) people. Similar equations (see: (10), (11) and (12)) could be applied in calculations of the number of highly sleep disturbed (*HSD*) people.

For *HA* and *HSD* the total number N of people affected by the harmful effect y (number of attributable cases) due to the source x is derived (for each combination of noise source x - road, railway, aircraft, and harmful effect y - *HA*, *HSD*) by the following equation:

$$N_{x,y} = \sum_j (n_j \cdot AR_{j,x,y}) \tag{5}$$

where $AR_{x,y}$ is the absolute risk of specific harmful effect (*HA*, *HSD*) and n_j is the number of people that are exposed to the *j-th* exposure band of noise. What needs clarification is the decision which approach to choose: general or specific. What should be calculated: the number of affected people for the whole city or the number for a given area in the city?

3. The current, legally recommended in Poland, method of calculation of the number of people affected by noise

Noise maps in Poland are calculated for five kinds of noise sources separately: tram, railway, road, aircraft and industry noise. In addition, the map for each kind of noise source has several layers with different noise level recommendations. Within each layer the places (expressed in a number of people in a given layer - *m*) where the recommended L_{den} value is exceeded are identified. For these places the difference (ΔL) between the actual L_{den} value and the recommended one is calculated. These parameters are input values for the equation for index *M*, which is related to the number of people exposed to a given kinds of noise source:

$$M = 0.1m(10^{0.1\Delta L} - 1) \tag{6}$$

The difficulty in calculating index *M* is that there are no rules how to relate its value to the different areas. As can be seen from equation (6) neither the number of people exposed to a given noise source nor the dose –response relationship for different harmful effects are calculated.

4. Environmental noise guidelines implementation in Poland. A case of Poznań

In our opinion, the environmental noise guidelines can currently be implemented in Poland in a limited form, only for two harmful effects: high annoyance (*HA*) and high sleep disturbance (*HSD*). Our calculations are performed for three kinds of noise sources: road traffic, rail noise (rails + trams) and aircraft noise.

To assess the actual number of (*HA*) or (*HSD*) people in the studied area it is recommended to use local exposure response function (*ERF*) (the exposure response function was earlier called dose-response relationship). However, in Poland such data are not available. In such case the generalized *ERFs* (cf. questions 7 to 13) can be applied.

We decided to divide the whole city of Poznań into squares 200x200 m. There are 6902 squares which cover the whole city ~262 km^2. Each square represents one point in the maps of *HA* and *HSD* people. The results are presented in a form of two different maps (for *%HA* and *%HSD* respectively) and as two numbers: *%HA* and *%HSD*, for the whole Poznań.

The new acoustic map for Poznan constructed along these lines has already been calculated. The results of these new calculations will be compared to the *M* values calculated earlier.

4.1. *Calculations of the number of highly annoyed people due to road, railway and aircraft noise*

The input data to this calculations are the number of residents of the given square in Poznań exposed to each kind of noise source, in 5 dB classes ranging from 55 dB to at least 75 dB L_{den} . Using the *ERF* for high annoyance, for each kind of noise source separately, the absolute risk (*AR*) of *HA* people for each L_{den} value was calculated. By multiplying this *AR* value by the total number of people exposed to a given L_{den} we obtain the number of *HA* people. Having those two numbers: the number of people exposed to a given value of L_{den} and the number of *HA* people, it is possible to calculate the *%HA* people for each L_{den}.

There are three equations which should be applied to calculate the *AR* value for road traffic, railway and aircraft noise:

$$AR_{HA,road} = (78.9270 - 3.1162 \cdot L_{den} + 0.0342 \cdot L_{den}^2)/100 \tag{7}$$

$$AR_{HA,rail} = (38.1596 - 2.05538 \cdot L_{den} + 0.0285 \cdot L_{den}^2)/100 \tag{8}$$

$$AR_{HA,air} = (-50.9693 + 1.0168 \cdot L_{den} + 0.0072 \cdot L_{den}^2)/100 \tag{9}$$

These equations are valid under the assumption that the harmful effects of noise causing high annoyance start at: L_{den} = 40 dB for road traffic, L_{den} = 34 dB for railway noise and L_{den} = 33 dB for aircraft noise. To obtain the number of *%HA* people in a given square area we have to divide the number of all people exposed to a given kind of noise source (for all L_{den} values in a given square area), by the number of *HA* people in this same area and multiply it by 100. The same procedure should be repeated for each specific noise source. The maps showing the percentage of *%HA* people and the *M* index for three kinds of noise sources are presented in Fig. 2(a), (b), (c) respectively.

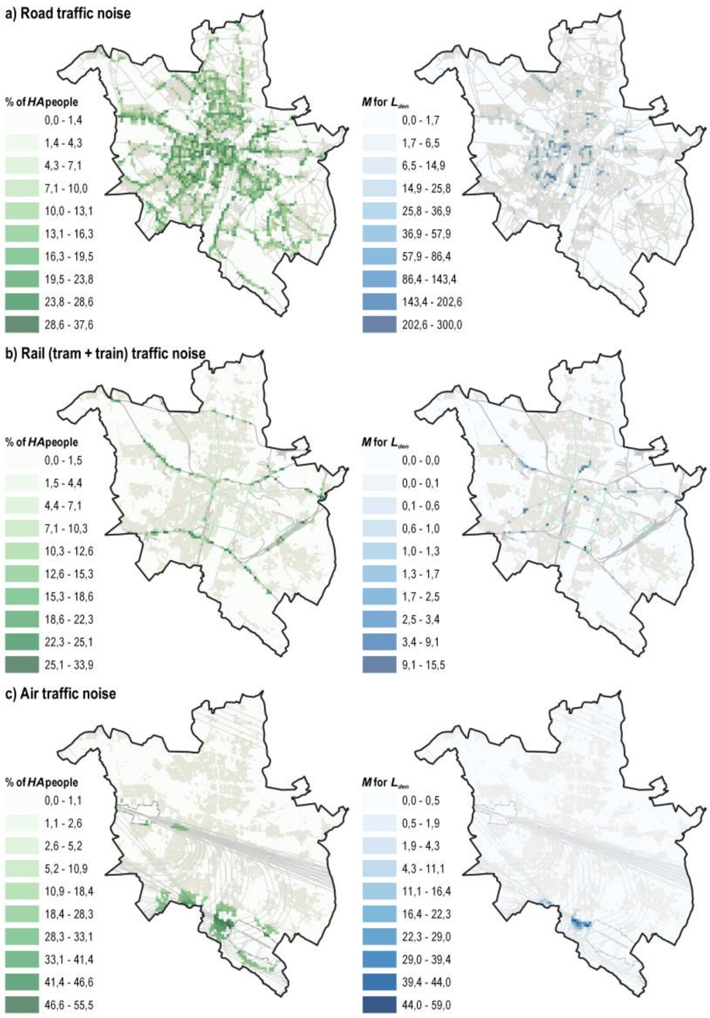

Figure. 1. Noise map of Poznań representing *%HA* people and index *M*, exposed to the (a) road traffic noise, (b) rail noise and (c) aircraft noise

As can be seen from the Figure 1, the method of calculations proposed here is much more precise than predictions based on the *M* index. The number of highly annoyed people is higher than predicted with *M* index and the endangered areas are delimited more accurately (see also Table 1.).

4.2. *Calculations of the number of highly sleep disturbed people due to road, railway and aircraft noise*

The same procedure was applied when calculating the number of highly sleep disturbed (*HSD*) people. There are three equations which should be applied to calculate the *AR* value for road traffic, railway and aircraft noise:

$$AR_{HSD,road} = (19.4312 - 0.9336 \cdot L_{night} + 0.0126 \cdot L_{night}^2)/100 \tag{10}$$

$$AR_{HSD,rail} = (67.5406 - 3.1852 \cdot L_{night} + 0.0391 \cdot L_{night}^2)/100 \tag{11}$$

$$AR_{HSD,air} = (16.7885 - 0.9293 \cdot L_{night} + 0.0198 \cdot L_{night}^2)/100 \tag{12}$$

These equations are valid under the assumption that harmful effects of noise causing sleep disturbance start at: L_{night} = 43 dB for road traffic, L_{night} = 43 dB for railway noise and L_{night} = 33 dB for aircraft noise. The maps presenting %HSD people for three kinds of noise sources are presented in Fig. 2(a), (b), (c) respectively. Analyzing the diagrams in Fig. 2 a similar conclusions can be drawn. The number of highly sleep disturbed people is higher than predicted with *M* index and the endangered areas are delimited more accurately. In the case of aircraft noise the endangered areas in the maps are similar to those delimited with the index *M*, but the number of affected people is larger than index *M* predicts.

4.3. *Calculations of the number of highly annoyed and highly sleep disturbed people for the whole city of Poznań*

In a generalized approach to *HA* and *HSD* harmful effects of noise for the whole city we calculated one value for each kind of noise source separately. These values can be compared to the values obtained with the *M* index. Table 1. shows that the use of index *M* results in the underestimated number of *HA* and *HSD* people.

Table 1. The *%HA* and *%HSD* people, the absolute number of *HA* and *HSD* and index *M* calculated for three kinds of noise sources for the whole city of Poznań

Source	*% of HA*	*N of HA*	*M for* L_{den}	*% of HSD*	*N of HSD*	*M for* L_{night}
Road noise	10.92	55 632.4	11 014.1	3.26	16 601.0	8 843.1
Rail noise	0.27	1 360.2	119.5	0.73	3 714.0	147.5
Air noise	1.08	5 504.0	747.2	0.04	219.2	112.3

4.4. *Calculations of the number of highly annoyed and highly sleep disturbed people due to two or more concurrent noise sources*

It is well known that in everyday life people are exposed to noise that is produced by several different sources. The question is: how can we calculate the overall harmful effects

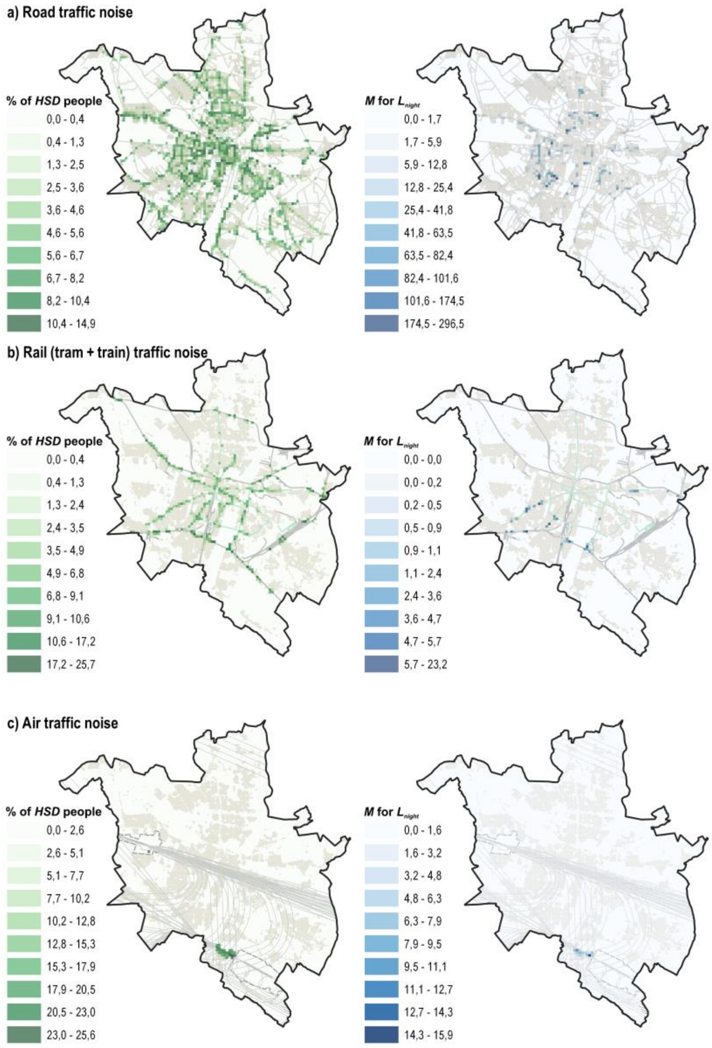

Figure 2. Noise map of Poznań representing percentage and index *M* of highly sleep disturbed people exposed to the (a) road traffic noise, (b) rail noise and (c) aircraft noise

generated concurrently by two or three noise sources? Based on the results of our preliminary study [3] we propose the summation of the number of people exposed to different kinds of noise sources at the same time with a special weighting. The weighting depends on deciding which noise source is dominant. Generally, we take into account 100% of people for the dominant sound source and 50%, 25% or 0% for the other noise sources. Such summation was performed for the *HA* harmful effect. For the *HSD* effect we simply summed up, with equal weight, the number of people *HSD* from all three kinds of noise sources. The map representing the *HA* and *HSD* people from all noise sources is presented in Fig. 3.

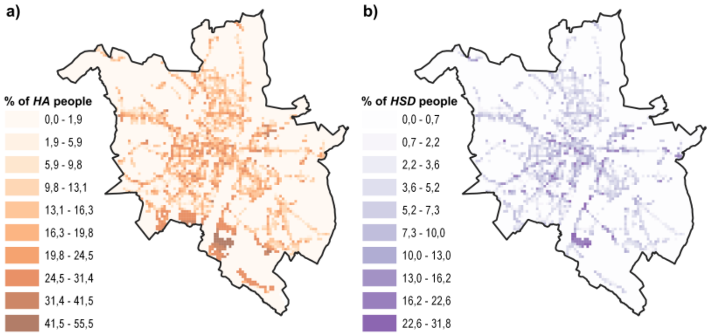

Figure 3. Noise map of Poznań representing the percentage of highly annoyed (a) and highly sleep disturbed (b) people

5. Conclusions

In this study we presented a case study of an implementation of the assessment methods for harmful effects of noise proposed in ANNEX III. Our study allows for the following conclusions:

- Two out of four harmful effects recommended in ANNEX III can be considered in the assessment process in Poland. These are: high annoyance (*HA*) and high sleep disturbance (*HDS*). The results of our calculations are presented both in the form of maps displaying the endangered areas, and generally as the number of the *HA* and *HDS* people in the whole city of Poznań
- The numbers of highly annoyed and highly sleep disturbed people were calculated based on the well documented exposure response functions. The hitherto calculated ΔL value (equation (6)) which is used for calculation of the index *M* has no reference to any harmful effects.
- We have shown that calculated number of *HA* and *HSD* people significantly differs from the one calculated with index *M*
- Finally, we propose a new method of summation of the number of people affected by two or more concurrent noise sources.

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