



## ASSESSMENT OF HARMFUL HEALTH IMPACT OF ENVIRONMENTAL NOISE

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**Abstract** – Environmental noise is an unavoidable phenomenon in urban environments. Even though efforts are continuously being made to reduce exposure to environmental noise, it still presents a problem, mostly due to rapid development of urbanization and transportation. Road, railway, and aircraft traffic are the main contributors to the overall environmental noise load. The ever-decreasing quiet zones in urban areas impact the health and well-being of urban population. Excessive exposure to noise can potentially cause a number of physical or psychological health effects, such as sleep disturbance, restricted communication, annoyance, cognitive impairment, and stress. The cardiovascular system can also be affected by prolonged exposure to traffic noise. Nevertheless, the precise impact of environmental noise has to be determined through risk assessment.

**Keywords:** environmental noise, burden of disease, DALYs

### 1. INTRODUCTION

The scope of disease burden on a population is disease-specific. Over the past few decades, the disease burden has been systematically measured across many countries for the purpose of comparison. A burden of disease (BD) can be defined as the impact of a specific disease over a specific area as indicated by financial cost, mortality, or morbidity. BD is quantified by the WHO-developed summary measures of population health.

Summary measures of population health combine information on mortality and non-fatal health outcomes to provide a single-number representation of the health of a specific population. To that end, several indicators have been developed during the last 30 or so years to adjust mortality to reflect the impact of morbidity or disability. Based on the object of quantification, the measures are divided into two main categories: health expectancies and health gaps [2,7,11].

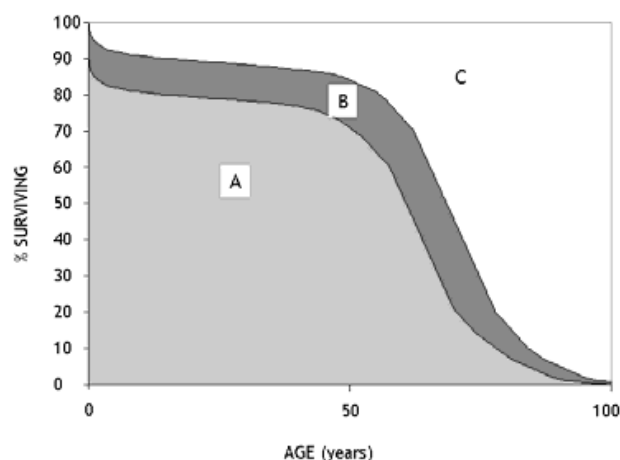
**Health expectancies** measure life years gained or years of improved quality of life. The following are some of the indicators included in this group:

- active life expectancy (ALE),
- disability-free life expectancy (DFLE),
- disability-adjusted life expectancy (DALE),
- healthy-adjusted life expectancy (HALE),
- quality-adjusted life expectancy (QALE).

**Health gaps** measure lost years of full health as compared to an “ideal” health status or the accepted standard. This group includes the following indicators:

- years of potential life lost (YPLL),
- years of healthy life lost (YHLL),
- quality-adjusted life years (QALY),
- disability-adjusted life years (DALY).

Both categories use time and multiply the number of years lived (or not lived, in the event of premature death) by the “quality” of those years. The adjustment of the years of healthy life lived is called “quality adjustment” (expressed as QALYs), whereas the adjustment of the years of healthy life lost is called “disability adjustment” (expressed as DALYs) [1,13]. Accordingly, QALYs represent a gain that is to be maximized, whereas DALYs represent a loss that is to be minimized. The QALY approach weights the quality (also called “utility”, as this falls within cost-utility analyses) on a scale from 1, indicating perfect health and the highest quality of life, to 0, indicating no quality of life, i.e. death. The DALY approach reverses the scale goes: a weighted 0 indicates perfect health (no disability), while a weighted 1 indicates death. The disability weighting in the DALY approach proved to be its most difficult aspect and has even sparked some controversy [1]. Figure 1 shows a typology of summary measures of population health.



**Figure 1.** A typology of summary measures [11]

LEGEND: A = time lived in optimal health,  
B = time lived in suboptimal health,  
C = time lost due to mortality

## 2. BURDEN OF DISEASE FROM ENVIRONMENTAL NOISE

Noise is a major issue in urban environments, as it affects a large section of the population. So far, most environmental noise assessments have been focused on the annoyance it causes for humans or on the extent to which it affects daily human activities. Earlier assessments of the potential health impact of noise exposure have been insufficiently comprehensive [3].

There is a consensus among public health experts that environmental risks constitute 24% of the burden of disease. Such percentage is to a large extent due to widespread exposure to environmental noise from road and rail infrastructure, airports, and industrial sites. Every third individual experiences diurnal annoyance and every fifth individual suffers from nocturnal sleep disturbance due to traffic noise. Epidemiological evidence suggests that chronic exposure to high levels of environmental noise increases the risk of cardiovascular diseases such as myocardial infarction. Therefore, noise pollution is regarded as both an environmental nuisance and a public health threat.

Risk assessment of environmental noise requires knowledge of the following parameters:

- the nature of the health effects of noise;
- the exposure levels that instigate the health effects and the changes in the extent of the effects caused by increased noise levels; and
- the number of people exposed to hazardous levels of noise.

The WHO has developed and implemented quantitative risk assessments based on EBD (Environmental Burden of Disease) methodology to help the Member States quantify several environment-related health problems [14].

The specific health manifestations of environmental noise included:

- cardiovascular diseases,
- cognitive impairment,
- sleep disturbance,
- tinnitus, and
- annoyance.

Estimating the environmental burden of disease (EBD) due to environmental noise requires a quantitative risk assessment approach. Risk assessment involves hazard identification, population exposure assessment, and determination of the corresponding exposure-response relationships. The EBD is expressed as DALYs.

### 2.1 Exposure assessment

Noise exposure assessment requires that several factors be considered, such as

- the measured or calculated/predicted exposure, described in terms of an adequate noise metric; or
- the distribution of noise exposure of the population.

Population noise exposure is based on the noise mapping mandated by the Environmental Noise Directive (END), using the annual average metrics of  $L_{den}$  (day-evening-night

equivalent level) and  $L_{night}$  (night equivalent level) proposed by the Directive:

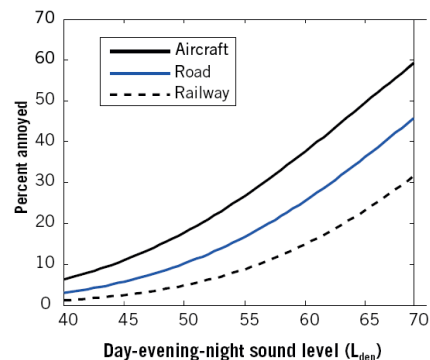
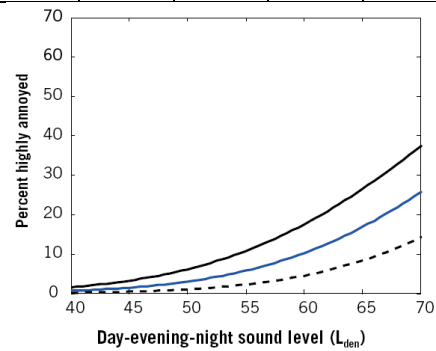
$$L_{den} = 10 \cdot \log \left[ \frac{1}{24} \left( 12 \cdot 10^{\frac{L_{day}}{10}} + 4 \cdot 10^{\frac{L_{evening}+5}{10}} + 8 \cdot 10^{\frac{L_{night}+10}{10}} \right) \right] \quad (1)$$

with  $L_{day} = L_{eq,12h}$ ,  $L_{evening} = L_{eq,4h}$ ,  $L_{night} = L_{eq,8h}$ , and  $L_{Aeq,t}$  the A-weighted equivalent sound pressure level over  $t$  hours outside at the most exposed facade.

Synthesis curves for the exposure-response relationships between  $L_{den}$  and %HA (proportion of highly annoyed persons) or %A (proportion of annoyed persons) are presented in the EC "Position paper on dose response relationships between transportation noise and annoyance" [4]. The curves follow from a comprehensive set of data from 46 studies on traffic noise and annoyance (20 on aircraft, 18 on road traffic, and 8 on railway noise) conducted in Europe, North America, and Australia between 1971 and 1993 [9,10]. Table 1 and Figure 2 show the proportion of highly annoyed and annoyed persons as a function of the  $L_{den}$  exposure for each traffic noise source. The data unequivocally shows that air traffic noise causes more annoyance than road traffic for any given noise level, just as road traffic causes more annoyance than railway traffic.

**Table 1.** Percentage of annoyed (%A) and highly annoyed (%HA) persons for various noise exposure levels ( $L_{den}$ ) for aircraft, road traffic, and rail traffic [4]

$L_{den}$ [dB(A)]	Aircraft		Road traffic		Rail traffic	
	%A	%HA	%A	%HA	%A	%HA
45	11	1	6	1	3	0
50	19	5	11	4	5	1
55	28	10	18	6	10	2
60	38	17	26	10	15	5
65	48	26	35	16	23	9
70	60	37	47	25	34	14
74	73	49	61	37	47	23



Source: Adapted from EC 2002.

**Figure 2.** Percentage of highly annoyed (top) and annoyed (bottom) persons as a function of exposure to aircraft, road, and railway noise ( $L_{den}$ )

## 2.2 Estimation by means of disability-adjusted life years (DALY)

DALYs represent the sum of potential years of life lost due to premature death and the equivalent years of “healthy” life lost due to ill health or disability.

The burden of disease in the general population is expressed in terms of DALYs through the equation

$$\text{DALY} = \text{YLL} + \text{YLD}. \quad (2)$$

YLL denotes the number of “Years of Life Lost” calculated by the equation

$$\text{YLL} = \sum_i (N_i^m \cdot L_i^m + N_i^f \cdot L_i^f), \quad (3)$$

where  $N_i^m(N_i^f)$  is the number of deaths of males/females in age group  $i$  multiplied by the standard life expectancy  $L_i^m(L_i^f)$  of males/females at their age of death.

The YLLs constitute the mortality component of the DALYs and they are proportional to the number of deaths and the average age of death:

$$\text{YLL} = \text{Number of Deaths} \cdot \text{Life expectancy at age of death}$$

YLD denotes the number of “Years Lived with Disability” calculated by the equation

$$\text{YLD} = I \cdot \text{DW} \cdot D, \quad (4)$$

where  $I$  is the number of incident cases multiplied by a disability weight (DW) and an average duration  $D$  of disability in years. DW applies to every health condition and ranges between 0 (full health) and 1 (death).

The YLDs constitute the morbidity component of the DALYs.

Disability weights are essential for DALY calculation, as they enable direct comparison of morbidity and mortality. DW reveals the severity of a disease on a scale from 0 (perfect health) to 1 (the worst possible health). The disease severity is inversely proportional to the length of healthy life of afflicted persons.

With the use of DWs, non-fatal health outcomes and deaths can be measured under a common unit [6]. DWs quantify time lived in various health states to be valued on a scale that factors societal preferences in. The DWs commonly used for calculating DALYs are measured on a scale from 0 (full health) to 1 (death) (see Table 2.).

DW values for various disease states have been heavily discussed among researchers. They are typically extracted from expert panels. WHO provides a fairly comprehensive list of DWs [8] recommended for use. If an appropriate DW is not included in the list, an expert committee may be formed to determine the appropriate DW by analogy with other known DWs.

**Table 2.** Disability weight vs health condition [5]

Health condition	Disability weight
Mortality	1.000
Non-fatal acute myocardial infarction	0.406 (WHO)
Ischaemic heart disease	0.350 (de Hollander, 1999)
High blood pressure	0.352 (Mathers, 1999)
Primary insomnia	0.100 (WHO, 2007)
Sleep disturbance	0.070 (WHO, 2009)
Annoyance	0.020 (WHO, preliminary) 0.010 (Stassen, 2008) 0.033 (Müller-Wenk, 2005)
Cognitive impairment	0.006 (Hygge, 2009)

These examples reveal the issue of data evaluation. The number of people suffering from myocardial infarction is relatively low, whereas the number of people experiencing sleep disturbance and annoyance is high.

Estimation of the total burden of disease requires another approach, which involves the following steps:

- estimation of the exposure distribution in a population;
- selection of one or more relevant relative risk estimates from the literature, usually from a newer meta-analysis;
- estimation of the population-attributable fraction using the formula for population-attributable fraction.

This approach is called the exposure-based approach. Likewise, the number of cases can sometimes be directly estimated based on exposure (the outcome-based approach).

The attributable fraction is the proportion of noise-related disease in the population. The attributable fraction (also known as impact fraction or population-attributable risk) refers to the hypothetical reduction in disease incidence if the population were completely unexposed compared with the actual exposure pattern. It may also be difficult to specify the accuracy of the fraction of the outcome attributable to environmental noise. In order to estimate the population-attributable risk percentage for a population, the exposure distribution and the exposure-response relationship have to be known. To calculate the attributable risk percentage (AR%), the population-attributable risk percentage (PAR%), and the population-attributable risk (PAR) for each noise category [12], the following formulae can be used:

$$\text{AR}\% = (\text{RR} - 1) / \text{RR} \cdot 100 \text{ [\%]}$$

$$\text{PAR}\% = P_e / 100 \cdot (\text{RR} - 1) / (P_e / 100 \cdot (\text{RR} - 1) + 1) \cdot 100 \text{ [\%]}$$

$$\text{PAR} = \text{PAR}\% / 100 \cdot N_d \quad (5)$$

RR = relative risk,

$P_e$  = percentage of the exposed population [%],

$N_d$  = number of subjects with disease (disease incidence).

It is also possible to use a generalized formula for calculating the population-attributable fraction (PAF). This formula is better suited to multiple comparisons for large relative risks.

$$\text{PAF} = \{ \sum (P_i \cdot \text{RR}_i) - 1 \} / \{ \sum (P_i \cdot \text{RR}_i) \} \quad (6)$$

$P_i$  = proportion of the population in exposure category  $i$

$\text{RR}_i$  = relative risk in exposure category  $i$  compared to reference level  $P_i = 1$

$$\text{PAR} = \text{PAF} \cdot N_d \quad (7)$$

The above estimates of disease burden from environmental noise rely on the available information on exposure distributions in the population and exposure-response

relationships for each specific health outcome. In addition, the estimates are heavily dependent on the selected disability weight. However, the calculations of DALYs cannot be completely accurate because the information about various environmental aspects is somewhat limited and frequently relies on assumptions and guesswork (see Figure 3). Consequently, the estimates are to be taken provisionally, especially for cognitive effects and ischaemic heart disease, for which no reliable exposure-response relationships are available. Nevertheless, such calculations could provide valuable information for risk assessment, as well as for assessments of noise-related economic cost. Hence, it is recommended that the estimates of disease burden from environmental noise should be frequently updated.

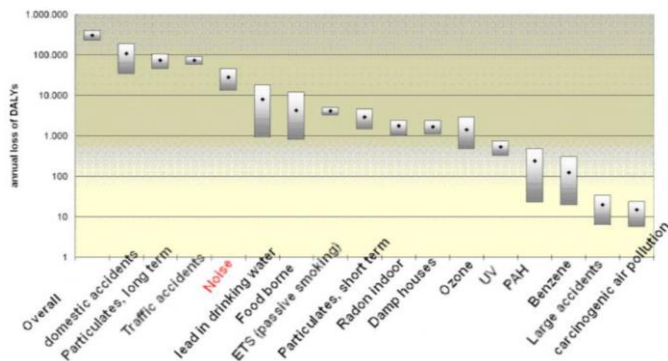


Figure 3. Estimate of DALYs from different environmental aspects [5]

## CONCLUSION

Environmental noise represents not only a source of nuisance but also a threat to both public and environmental health. The estimation of DALYs lost due to environmental noise in the Western European countries is 61,000 years for ischaemic heart disease, 45,000 for cognitive impairment in children, 903,000 for sleep disturbance, 22,000 years for tinnitus, and 654,000 years for annoyance. When considered together, the disease burden would range from 1.0 to 1.6 million DALYs. This implies that no less than 1 million healthy life years in the Western European countries, including the EU Member States, are lost annually due to traffic-related noise [15]. Sleep disturbance and annoyance due to road traffic noise are prevalent in the disease burden from environmental noise in Western Europe. Unavailability of exposure data for South-eastern Europe and the Newly Independent States prevents estimations of the disease burden to be made for the whole WHO European Region.

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## REFERENCES

- [1] Arnesen TM, Norheim OF. *Disability Adjusted Life Years - possibilities and problems*. National Institute of Public Health, Oslo, Norway. Available from URL: <http://iier.isciii.es/supercourse/lecture/lec2911/index.htm>. Accessed: April 8, 2009.
- [2] Atanackovic-Markovic Z, Bjegovic V, Jankovic S, et al. *The burden of disease and injury in Serbia*. Serbian Burden of Disease study - an EU funded project managed by the European Agency for Reconstruction. Belgrade: Ministry of Health of the Republic of Serbia; 2003.
- [3] de Hollander AE et al. *An aggregate public health indicator to represent the impact of multiple environmental exposures*. *Epidemiology*, 1999, 10:606–617.
- [4] EC. *Position paper on dose response relationships between transportation noise and annoyance*. 2002, European Commission, Office for Official Publications of the European Communities: Luxembourg.
- [5] European Environment Agency, *Good practice guide on noise exposure and potential health effects*, ISBN 978-92-9213-140-1, doi:10.2800/54080, 2010
- [6] International Organization for Standardization. *Description and measurement of environmental noise. Part 2. Guide to the acquisition of data pertinent to land use*. Geneva, 1991 (ISO 1996-2).
- [7] Jankovic S. *Summary measures of population health and their relevance for health policy*. In: Galan A, Scintee G, editors. *Public Health Strategies*. A handbook for teachers, researchers, health professionals and decision makers. Laga: Hans Jacobs Publishing Company; 2005. p.190-207. Available from URL: <http://www.snz.hr/phsee/publications.htm>. Accessed: August 14, 2009.
- [8] Mathers CD et al. *Global burden of disease in 2002: data sources, methods and results*. Geneva, World Health Organization, 2003 (Global Programme on Evidence for Health Policy Discussion Paper No. 54).
- [9] Miedema, H.M. and C.G. Oudshoorn. *Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals*. *Environ. Health Perspect.*, 2001. 109(4): pp. 409–16.
- [10] Miedema, H.M. and H. Vos. *Exposure-response relationships for transportation noise*. *J Acoust Soc Am*, 1998. 104(6): pp. 3432–45.
- [11] Murray CJL, Lopez AD. *Assessing health needs: the Global Burden of Disease Study*. In: Detels R, McEwen J, Beaglehole R, Tanaka H, editors. *Oxford Textbook of Public Health - Fourth edition*. New York: Oxford University Press Inc.; 2004. pp. 243-54.
- [12] Prüss-Üstün A et al. *Introduction and methods: assessing the environmental burden of disease at national and local levels*. Geneva, World Health Organization, 2003.
- [13] Tulchinsky TH, Varavikova EA. *Measuring and evaluating the health of a population*. In: Tulchinsky TH, Varavikova EA. *The New Public Health. An Introduction for the 21st century*. San Diego: Academic Press; 2000. pp. 113-68.
- [14] WHO, *Quantifying environmental health impacts* [web site], Geneva, 2010 ([http://www.who.int/quantifying\\_ehimpacts/en/](http://www.who.int/quantifying_ehimpacts/en/), accessed 21 July 2010).
- [15] WHO Regional Office for Europe, *Burden of disease from environmental noise - Quantification of healthy life years lost in Europe*, ISBN: 978 92 890 0229 5, 2011