Mapping of severe annoyance due to aircraft noise

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INTRODUCTION

The application of generalized exposure-response relations for noise annoyance has expanded enormously in Europe due to the implementation of the European Noise Directive. However, residents often do not recognize themselves in the reported results for their neighborhood or community. “You are not only modeling noise, but also our annoyance; what is wrong with asking us?” and “You are averaging out our annoyance with the use of curves” are comments, which are frequently made.

In this paper we address these comments by exploring whether we can adequately describe the percentage severely annoyed due to aircraft noise in small areas, while making use of routinely collected data, without taking into account modeled noise levels in combination with an existing exposure-response relation. Subsequently, we assessed the role of aircraft noise and other area characteristics on the spatial distribution of severe annoyance.

METHODS

The study was carried out in the vicinity of Amsterdam Airport Schiphol. The exposure to aircraft noise is modeled every year in an area of 55 by 71 km around the airport. Within this area eight community health services were approached to participate in the study. Once every four years community health services routinely carry out health surveys among adolescents, adults and elderly in the framework of the "Local and National Public Health Monitor" (van den Brink 2011). One of the purposes of this Monitor is to harmonize local data collection methods, in order to obtain data that can be used for comparisons between regions and for calculating national statistics. In the questionnaire distributed to samples of adults (18 to 65 year old) items on noise annoyance are included. For our study we used the data of nine surveys from community health services carried out in the period 2005-2008 in several parts of the area of 55 by 71 km (Plevier & Mulder 2006; GGD Hollands Midden 2006; Heemskerk & Poort 2007; Verhagen & ten Brinke 2007; De Koning 2008; Dijkshoorn et al. 2009; Schütz & Glazema 2009; ten Brink et al. 2009; van Acker 2009). In seven of the nine surveys, the ICBEN standard annoyance question was used (ISO/TS 15666 2003); since 2006 this question is the standard for assessment of annoyance within the Monitor. Severe annoyance was defined as an answer in one of the three highest categories of the 11 point scale of the ICBEN question; a similar definition was used for the questions on annoyance in the other two surveys.

The study design of the Local Monitor is geared to report at the municipal or regional level. For our study we used a smaller aggregation level: the 4 digit postal code area with, on average, about 6,400 inhabitants (range 29-22,500). The variation in aircraft noise levels is small within postal code areas (Houthuijs et al. 2011). Due to privacy reasons only the number of severely annoyed due to aircraft noise and the total number of responders per postal code area were available for the pooled statistical analysis.

The data-set was supplemented with indicators for aircraft noise and with postal code area characteristics (demographic composition, average socio-economic status, address density, and livability index). The L_{den} (Level day-evening-night) and the annual average number of aircraft noise events per day that exceeded a $L_{A,max}$-level of 60 or 70 dB (NA60 and NA70) were modeled by the Dutch National Aerospace Laboratory based on actual flight tracks. In 1.5 million dwellings we assessed the exposure levels by linking the noise maps with the address coordinates. Subsequently, we obtained the "population weighted" mean exposure level by averaging the noise exposure of the dwellings per postal code area. Statistics Netherlands maintains records of the demographic composition and the address density at different aggregation levels online. A measure of socio-economic status (SES) at postal code level based on income level, unemployment rate, and education level of its inhabitants is calculated every 4 years by the Netherlands Institute of Social Research (Knol 1998). The livability index is based on 50 indicators from the domains: house stock, public space, services, social-economic composition, demographic composition, and community safety & neighborhood nuisance (Leidelmeijer et al. 2008).

Due to the small numbers of study participants per postal code area, the observed mean percentage of severe annoyance on this aggregation level can have a high degree of uncertainty. A Bayesian hierarchical model with spatial effects was applied to improve the estimation per postal code area and to map the study area. It was assumed that the number of cases in an area follows a binomial distribution. p_i is an area specific risk, which, in a general form, is given by:

$$\text{logit}(p_i) = \beta_0 + \beta_{1,j}\,\text{Exposure}_{i,j} + \beta_{2,l}\,\text{Confounder}_{i,l} + b_{struc,i} + b_{unstruc,i} \quad [1]$$

In the equation above, β_0 is the logit baseline risk. The final two terms consider extra variability resulting from unmeasured confounders, data anomalies, and model misspecification. It is expected that this extra variation is more similar for neighboring areas. Hence, the first term is a spatially structured term for any possible spatially unobserved confounders; the second is an unstructured term accounting for non-spatial contributions to the extra variation. An intrinsic conditional autoregressive prior is given to the spatially structured term. This ICAR prior depends on the number of neighboring postal code areas. An independent and identically distributed normal prior is given to the unstructured term (Besag et al. 1991). In model [1] the parameters for the noise exposure and for potential confounders can be excluded to obtain a smoothed map based on the prevalences only. For Bayesian models MCMC is often used to estimate the posterior distribution of the parameters. This is computationally intensive if the number of areas is high. Therefore we estimated the parameters using INLA (Rue & Martino 2009). The fit of the models was compared using the Deviance Information Criterion (DIC) which indicates a balance between the fit of the data to the model and the complexity of the model (Spiegelhalter et al. 2002).

RESULTS

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The mean response of the nine surveys was 53 % (range 41-73 %). The dataset consisted of 480 postal code areas with, on average, 60 responders per area (range 1-354), a total of 28,562 study subjects. The responders are, on average, 1.6 % of the age specific population (range 0.6-2.4 % between surveys). The mean percentage of severe annoyance due to aircraft noise in the study area was 9.9 %.

In Figure 1 the average percentage severe annoyance per postal code area is plotted against L_{den}.

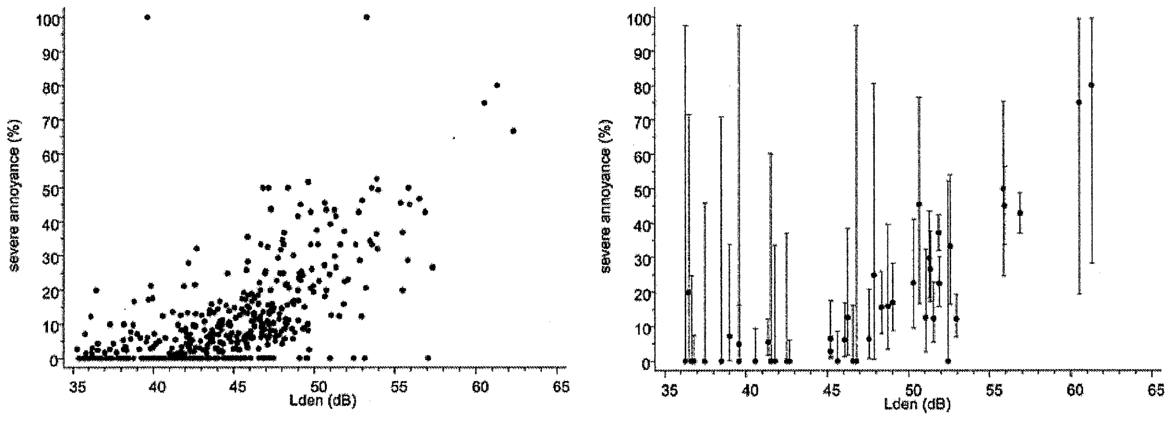

Figure 1: Average percentage of severe annoyance per postal code area and L_{den} (left) and with 95% confidence interval (for selection of areas) (right)

The left hand graph of Figure 1 shows large variation between postal code areas. The right part of Figure 1, which includes the 95% confidence interval for a random selection of postal code areas, indicates that the uncertainty of the percentage is large due to the small number of responders. So, a substantial part of the variation between postal code areas is introduced by the sample size per postal code area.

The large variation hampers the plotting of the percentage of severely annoyed on a map; this will give a rather unstable and variable impression dominated by "outliers" due to small numbers. We applied model [1] (without noise and confounders) to improve the estimation per postal code area. The smoothed percentage per postal code area is given in the left hand graph in Figure 2. The "population weighted" mean exposure levels in L_{den} is shown in the right hand graph in Figure 2.

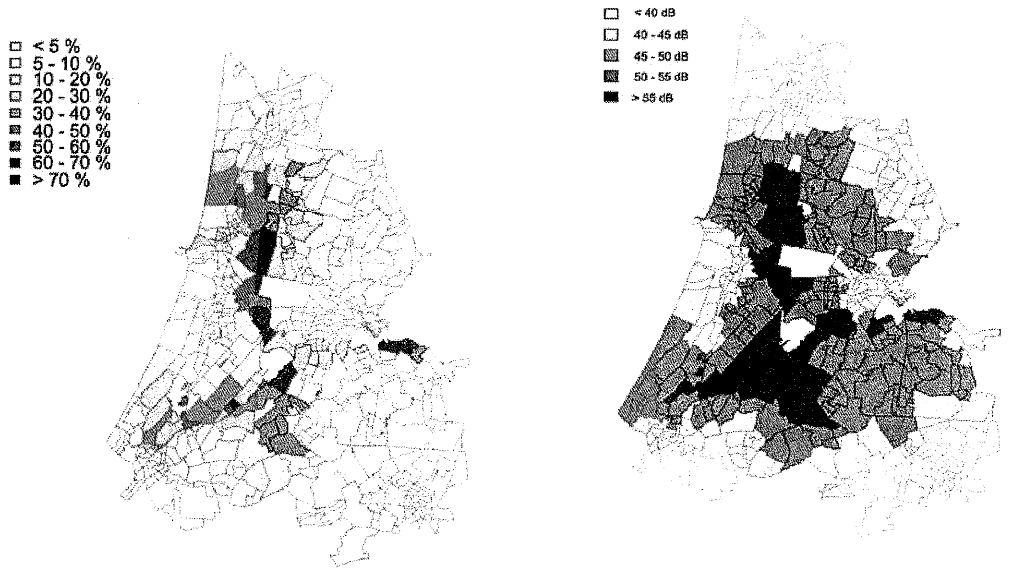

Figure 2: Smoothed percentage of severe annoyance and population weighted mean L_{den} (dB) per postal code area

The applied statistical model (without any noise indicator or potential confounder included) leads to a more valid map than plotting "raw" mean percentages of the postal code areas (not shown for this reason). The smoothed percentages in the left hand graph follow fairly the aircraft noise exposure in the study area (right hand graph).

Influence of aircraft noise indicators and postal code area characteristics

First we assessed the relation between L_{den} and the percentage of severe annoyance. We fitted a non-linear smoothed curve with a second order random walk model to visually check the linearity of the relation between L_{den} and the percentage of severe annoyance on a logit scale (Figure 3).

Figure 3 shows that a linear relation with L_{den} is a good assumption, so it is not necessary to transform the L_{den} to apply model [1]. Moreover, the uncertainty of the estimate substantially increases above 60 dB.

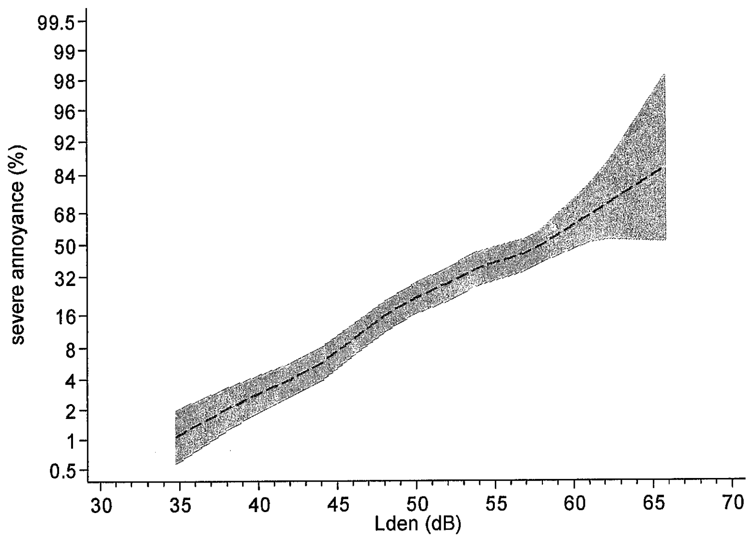

Figure 3: Relation between L_{den} and severe annoyance expressed as percentage on a logit scale

Subsequently, we evaluated the influence of the various aircraft noise indicators and the postal code area characteristics with model [1]. The results of these final statistical models are presented in Table 1.

Table 1: Association between percentage of severe annoyance and L_{den} and SES expressed as odds ratio [and 95% confidence interval] with and without adjustment for survey

Adjustment for survey:	L_{den} (per 10 dB)	SES (highest versus lowest)
no	9.1 [7.0 - 11.9]	1.51 [1.11 – 2.07]
yes	9.7 [7.6 - 12.3]	1.67 [1.23 – 2.27]

Models with L_{den} as aircraft noise indicator fitted better than models with NA60 or NA70 or of a combination of L_{den} and NA60 or NA70, so L_{den} was incorporated in the final model. The odds ratio for L_{den} in Table 1 is expressed per 10 dB change. When we express the effect of the L_{den} over the exposure range (5 percentile of the L_{den} is 35 dB and 95 percentile is 54 dB: a 19 dB difference) the odds ratio is about 70. From the postal code area characteristics, only SES had an influence on severe annoyance. The prevalence was elevated in postal code areas with higher social economic status. The odds ratio was about 1.6 when we compared the postal code area with the highest SES with the area with the lowest SES. We observed differences in the prevalence of severe annoyance between the nine health surveys. Adjusting for differences between surveys improved the fit of the statistical model, but hardly affected the odds ratio of L_{den} and SES (see Table 1).

In Figure 5 we have mapped the spatially structured term of each of the postal code areas after adjustment for L_{den}, SES, and survey.

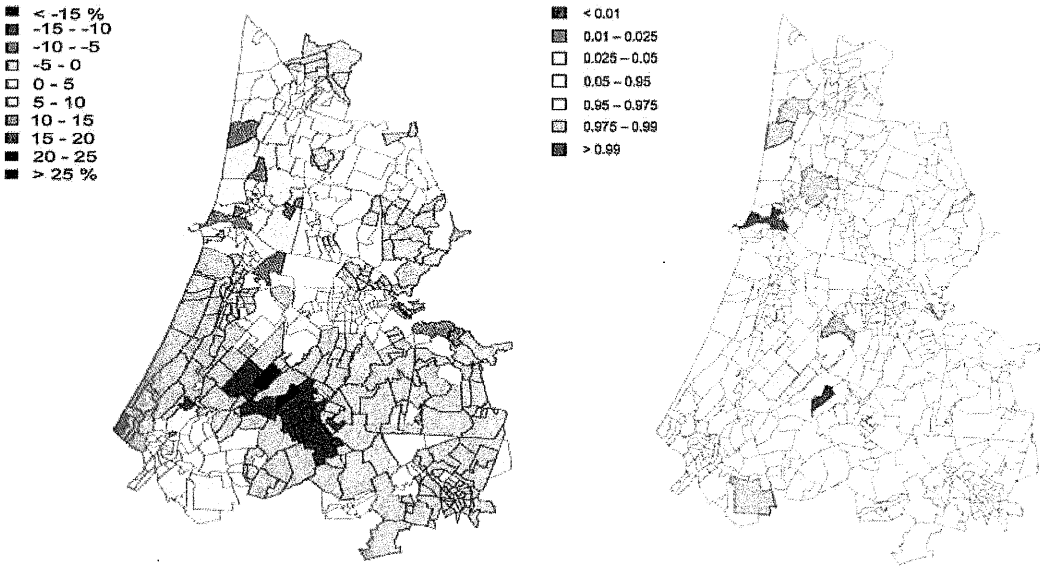

Figure 5: Spatial variation between postal code areas after adjustment for L_{den}, SES and survey. Left as difference in the percentage severe annoyance; right as probability

The spatially structured term is expressed as deviation from the expected percentage based on L_{den}, SES, and survey and as probability. In the left hand map of Figure 5 blue postal code areas have a higher percentage of severe annoyance than expected and earth brown areas a lower percentage. Although the map indicates that substantial differences between postal codes areas exist that might be the result of unmeasured confounders, the right hand map of Figure 5 shows that only in a few cases these differences are statistically significant.

DISCUSSION AND CONCLUSIONS

The applied statistical method makes it possible to map the prevalence of severe annoyance due to aircraft noise. Although the dataset contained over 28,000 subjects, there are on average only 60 responders per postal code area. As a consequence a substantial part of the observed variation in the percentage of severe annoyance between postal code areas is introduced by the sample size per area. This leads to unstable maps if the percentage per postal code area is plotted. We were able to improve the estimation per postal code area by “borrowing” information from participants in neighboring areas. The advantage of this approach, above the mapping of calculated percentage based on noise maps and an exposure-response relation, is that it allows departures from the exposure-response relation so the local impact of the noise source is more accurately reflected in the map. Another advantage is that it is possible to show the uncertainty in the size of the local deviation: not every local deviation is necessarily a statistically significant difference.

The exposure-response relation obtained with routinely collected (aggregated) data was very similar to the ones found in tailored social surveys with individual data that were carried out by RIVM around the airport in 1996 2002, and 2005 (TNO & RIVM 1998; Breugelmans et al. 2004; RIVM & RIGO 2005). The uncertainty of the relation obtained in the present study increased at higher noise levels. This uncertainty is partly caused by the random selection of the responders over the study area (on average, 1 per 60 residents in the age between 18 and 65 year old). As a result, 16 of the 28,562 responders (0.06 %) lived in a postal code area with a mean noise level above 60 dB L_{den}. This small number of participants reflects the governmental policy to limit the number of inhabitants within higher noise contours. However, this low number also leads to concern about the usefulness of routinely collected health data from surveys for the monitoring of the impact of the airport on residents within these contours. Other endpoints than severe annoyance, such as high blood pressure or perceived health, have a much less pronounced relation with noise exposure. Stratified sampling to substantially increase the number of study participants at higher noise levels could overcome this problem.

We found a very strong relation between L_{den} and the prevalence of severe annoyance due to aircraft noise: an odds ratio of about 70 over the 5-95 percentile range of L_{den}. Because of privacy reasons, no personal information about the individual study participants was available. Also due to the nature of the health surveys, no information about noise annoyance related factors (like attitude towards the source, noise sensitivity, expectations about future levels, etc.) was collected. At the postal code area level, no specific noise annoyance related data are available. This hampers the possibility to clarify the deviation of a postal code area from the "mean" relation between L_{den} and the percentage severe annoyance. Information about the average number of aircraft noise events per day that exceed an $L_{A,max}$-level of 60 or 70 dB appears not to have much added value when information about the L_{den} is available. In postal code areas with a lower socio-economic status the prevalence of severe annoyance was – at the same L_{den} level - lower than in areas with a high social-economic status. This is opposite to what usually is found for health outcomes. Other postal code area characteristics (demographic composition, address density, livability index) were not associated with annoyance after adjustment for the spatial pattern. We do not expect that the availability of other potential confounders for the postal code areas would have affected the odds ratios for L_{den} or SES. An important advantage of the applied method is that by the incorporation of the spatial dependency in the model, adjustment for unmeasured confounders can be carried out. The applied hierarchical model is very flexible, so it is possible to incorporate potential confounders. Not only at the level of postal code area, but also at other levels of the model (individual, airport, country) with proper estimation of the standard errors of the parameters.

We found that the prevalence of severe annoyance varied between surveys after adjustment for L_{den}, SES and the spatial dependency. The health surveys were carried out in different areas, seasons and years. Also different sampling methods and questions were used. We were not able to assess whether one of these characteristics could explain the differences between the surveys. Most of these characteristics were clustered and the number of surveys was small in comparison with the number of differences. Further harmonization of the questionnaires and the methods of data collection are in progress and will improve the comparability of data from community health services in future (van den Brink 2011).

Although the Local Monitor is not designed to report on postal code area level, we were able to map accurately the annoyance due to aircraft noise with our statistical model, without using any exposure-response relation or noise data. The small within area variance of the exposure and its strong relation with severe annoyance facilitated the mapping in the study area.

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