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Neighbourhood sonoscapes
Context sensitive noise impact mapping

Summary

Road traffic noise exposure contour maps are difficult to interpret by non-experts who are neither familiar with the road traffic noise exposure measures nor their associated impacts. An alternative is to map impacts such as annoyance. However, in urban areas the noise impacts are multi-factorially determined and context sensitive. In particular people become more annoyed by a given noise level at the most exposed façade of their dwelling when their neighbourhood soundscape is even noisier. In this paper a two-stage approach is applied to national noise exposure data to a) make use of contextual soundscape[1] information in determining noise impacts and to b) build contiguous neighbourhood sonoscapes[2] delimiting neighbourhood areas with similar noise impacts. Several methods were tested utilising a Geographical Information System (GIS) package and resulted in one preferred method:

Neighbourhood sonoscapes delimiting neighbourhoods consisting of dwellings with more or less the same noise impacts are constructed in 4 steps:

1. Dwellings are partitioned into separate classes according to the seriousness of the previously determined noise impact for residents, and assigned to separate geographic impact class layers.
2. For each separate class layer, buffers are constructed by drawing circular areas around each dwelling and merging overlapping areas. These buffer areas cover a somewhat larger area than the dwellings each of them are based upon.
3. By subsequent buffering with negative prefix the too large buffers are confined to only cover the immediate vicinity of the dwellings.
4. In the final stage the different layers for each noise impact class are projected down to one and the same layer and assigned a value according to their neighbourhood sonoscape quality. In areas where overlap occurs, the quality is no better than that for the dwellings with the highest noise impacts.

Our approach is an example of a generic 2nd-generation spatial impact modelling that should prove applicable to many types of impact assessment.

With appropriate classification and class labels neighbourhood sonoscapes provide an environmental labelling of the expected perceived sound quality of urban neighbourhoods for consumers, the public and planners. Neighbourhood sonoscape maps may also be utilised for national stratification and subsequent two-stage cluster sampling of the population. The advantage of this approach is that focussed traffic counts, extended sound modelling and monitoring of noise abatement procedures, population composition etc. can be undertaken for a limited representative set of neighbourhood sonoscapes. This increases the quality and can dramatically reduce the cost of monitoring changes in noise impacts over time – especially as the result of noise abatement measures. Optimal stratified cluster sampling would ensure that more resources are allocated to urban areas where there are environmental problems than simple random sampling allows.

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[1] The term *neighbourhood soundscape* denotes the spatial distribution of noise levels in the immediate neighbourhood of an apartment/dwelling.

[2] Neighbourhood sonoscape denotes contiguous areas that are defined for dwellings having more or less the same perceived soundscape quality.

1. Introduction

1.1 Background and objectives

For assessing the environmental quality of urban areas, environmental modelling is often applied. Emission models combined with dispersion or propagation models are applied, and the results displayed as imission maps often in the form of air pollution or noise contour maps. Dwellings or other areas of interest are geocoded, and assigned exposure values according to their locations within the contours. However, exposure contour maps are often difficult to interpret for the non-experts that are unfamiliar with the exposure measures, how they are calculated or measured, people's reactions to a given level of exposure, and how different levels of reactions might be assigned meaningful descriptive or normative labels. Exposure maps are also limited in that they often fail to take into consideration modifying factors.

Impact mapping is an alternative approach to mapping exposures. In simple situations where the impacts are a direct result of a single exposure, impact maps can be derived directly from the exposure via exposure-effect relationships. In more complex situations that are typical for the urban city areas, annoyance reactions to environmental exposures are context dependent (Lercher and Kofler 1996), (Kastka and Noack 1987), (Paulsen and Kastka 1995), (Klæboe, Kolbenstvedt, Clench-Aas and Bartonova 2000), (Klæboe, Kolbenstvedt, Fyhri and Solberg 2004) . It is therefore of interest to explore 2nd generation exposure impact mapping where situational factors, known population characteristics, the spatial distribution of exposures in the vicinity of the dwelling, multi-source situations or the level of other environmental exposures, modify exposure-effect relationships.

There are several avenues in the analyses of multi – exposure multi-response relationships. Graphical techniques where transparent overlays of separate exposure or impact maps are often used. These are of utility but in the simplest cases (simple assessment of interaction effects, limited number of assessments). An alternative is to combine Geographical Information System (GIS) routines with stochastic modelling. In the simplest forms a combined exposure measure is calculated, and the impact assessed on the basis of exposure-effect relationships for the combined measure. This is the approach applied in this paper to defining and labelling neighbourhood sonoscapes that provide information on the perceived soundscape quality of urban neighbourhoods.

A multi-level approach might be utilised in cases where there is good information on the relevant exposures and impacts for each urban area. In a two level model the overall exposure for each urban area is modelled in the second stage and perhaps categorized into a distinct number of separate classes Thereafter single-exposure single-impact relationships are developed for relationships within each urban area that are dependent on the overall exposure or estimated urban area class membership. Class criteria and the assignment of city areas to different classes could also be undertaken on the basis of expert opinion. Thereafter separate single exposure-effect relationships could be developed for each class of city areas. More sophisticated approaches might utilise Structural Equation Modelling to simultaneously link several exposures to several reactions (Klæboe 2000).

The approach taken in this paper is to calculate a combined exposure measure based on the proximal exposure (at the most exposed façade of a dwelling) and more distal road traffic noise exposure - that in the immediate neighbourhood. This is undertaken by applying spatial routines in a GIS. Thereafter exposure-effect relationships based on this combined exposure measure is applied and the resulting impacts assessed for each dwelling in a city area. These calculations provide the calculated expected impact for the given exposure situation.

The expected impact (in our case annoyance with road traffic noise) is in the second stage of the calculations regarded as attributes of the respective dwellings. A second set of spatial routines is applied in order to delimit contiguous urban areas where these attributes are more or less the same. This results in contiguous neighbourhood sonoscapes that indicate the quality of the perceived soundscape associated with the neighbourhood.

1.2 Noise annoyance mapping taking the neighbourhood soundscape into account

As predictor of noise annoyance from road traffic, noise exposure is often calculated at the most exposed side of the dwelling or apartment. Klæboe et al. (2004), undertook a study on whether the neighbourhood soundscape - the noise in the immediate neighbourhood of the dwelling, also has an impact on noise annoyance. The research hypothesis was that people react stronger to noise when road traffic levels in the neighbourhood exceed the noise level at the most exposed façade of the dwelling. Such is the case for people living in apartments facing side streets and backyards or in second row dwellings that are shielded by intervening building structures. When these residents leave their dwellings to shop, walk or wait for public transport, they encounter the noise levels associated with the main street. This adverse neighbourhood soundscape was hypothesized to result in stronger annoyance reactions even when at home.

Five socio-acoustical surveys featuring 3950 respondents were used to test the hypothesis (Klæboe et al. 2004). Results indicated that the neighbourhood soundscape has a substantial impact on noise annoyance. They concluded that exposure-effect relationships not taking the neighbourhood soundscape into account are misleading. In particular the annoyance reducing effect of shielding an apartment where thought to result in an overestimation of the associated annoyance reductions, while the effect of traffic reductions reducing noise both at the apartment and in the neighbourhood where thought to be underestimated.

Based on Klæboe et al. (2004), and the neighbourhood definitions used, we have tried different techniques to delimitate the neighbourhood sonoscapes. The main objective is to find a method of delimiting noise neighbourhoods that are assigned to different classes according to the expected degree of annoyance calculated for each dwelling on the basis of the noise level at the apartment and in the immediate neighbourhood. Neighbourhood sonoscapes will be classified by degree of annoyance. At this early stage, neighbourhood sonoscape class labels are the virtual noise levels associated with the combined exposure measure (neighbourhood adjusted noise level). After qualitative surveys in neighbourhood soundscapes, the sonoscapes associated with the different noise impact levels will be assigned meaningful labels according to how residents perceive them. As the process of providing new categories and terms for the environment allows people to “perceive” these, the labelling and limits will be determined over time by societal processes.

When finalised, the project results can easily be extended to, and implemented in, the national mapping of noise annoyance. Characterizing all dwellings could make it possible to do stratifications by neighbourhood sonoscape quality. The advantage of such stratification is that the whole population is allocated to distinct contiguous areas. This allows a limited set of sonoscapes to be drawn randomly in a first stage cluster analysis. At the second stage, residents are drawn by simple random sampling within each neighbourhood sonoscape. As the sonoscape is contiguous, it is possible to obtain good traffic measures for the limited area, undertake more sophisticated noise modelling and monitor the noise-abatement measures undertaken in the area. This is much more cost-efficient than drawing random samples from the whole population, where each respondent lives in widely disperse areas, along different roads and with different characteristics. For such random sampling methods the costs of obtaining decent traffic counts, noise modelling, and inventories of the type of road surface, noise abatement measures etc are prohibitive.

Furthermore the delimitations between neighbourhood sonoscapes of different quality are thought to be useful for the land use planner as a first overview, but the delimitations could also be made available to the general public as a type of consumer labelling of the perceived soundscape quality.

The work is carried out as part of a research work package headed by Ronny Klæboe at The Norwegian Institute for Transport Economics. The work package is part of a cross-institutional research program by a consortium consisting of The Norwegian Institute of Public Health (NIPH), The Norwegian University of Science and Technology (NTNU), SINTEF Telecom and Informatics (SINTEF), Statistics Norway (SSB), and The Norwegian Institute for Transport Economics (TØI).

1.3 Use of the results

Data for the results presented in this report are gathered pursuant to The Statistics Act and reservations of use may come into force. Confidentiality is handled with particular care in Statistics Norway. Most importantly, the issue of confidentiality must be considered in more detail before (and if) sonoscape maps are disseminated to a wider public. Dissemination of sonoscape maps at a detailed (large scale) level, may affect ground property value. However, in most applications of the work presented in this report, issues of confidentiality will not be relevant.

At the present stage, only test results are presented and further adjustments of the methodology will be done. Furthermore work still remains concerning adjustments in class intervals and in coining appropriate labels for the sonoscape classes. As a consequence, the maps and results presented here are preliminary.

When finalised, the project results can easily be extended to, and implemented in, the national mapping of noise annoyance currently being carried out by Statistics Norway. Implementation in the national mapping of noise annoyance is a prerequisite for presenting the results as official statistics, but the results can all the same be used for other applications as described in 1.2.

2. Terms and definitions

The term *neighbourhood soundscape* denotes the spatial distribution of noise levels in the immediate neighbourhood of an apartment/dwelling. Each apartment thus has its own associated neighbourhood soundscape, and there are as many neighbourhood soundscapes as apartment/dwelling location. As road traffic noise is often the major contributor to the neighbourhood soundscape in city areas, we have chosen initially to focus on the road traffic noise levels in the neighbourhood of a dwelling. Future developments include taking multi-source situations into account.

Overlay
In using overlay operations new map data bases (for example coverages) can be created from the spatial intersection of two coverages, an input coverage and an overlay coverage.

Buffer
A buffer is a zone defined to lie within a specified distance around polygon- point- or line-features. Buffers can be generated at a constant, or attribute dependent distance.

Kriging
This interpolation method assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. Kriging is a statistical method that quantifies the correlation of the measured points through variography. When making a prediction for an unknown location, kriging weights the surrounding measured values to derive a prediction for an unmeasured location. The weights are based not only on the distance between the measured points and the prediction location, but also on the overall spatial arrangement among the measured points.

Inverse distance weighting (IDW)
Inverse distance weighted interpolation determines cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance.

Neighbourhood
The neighbourhood is, in this study, defined as the area within 75 metres from the dwelling at hand.

Neighbourhood sonoscape
Denotes contiguous areas that are defined for dwellings having more or less the same perceived soundscape quality.

Neighbourhood difference indicator, L_{diff}
To clearly differentiate in the statistical analyses between the impact of the noise level at the apartment from the additional road traffic noise load from the neighbourhood, a difference indicator has been developed. This indicator is simply the number of decibels that the neighbourhood soundscape noisiness indicator exceeds the noise exposure level at the dwelling ($L_{diff} = L_{neigh} - L_{eq}$). (Klæboe et al. 2003)

Neighbourhood adjusted noise level, NAL
The neighbourhood adjusted noise level (NAL) is calculated on the basis of the noise level at the dwelling (L_{eq} dB) and the maximum of the equivalent noise levels in the neighbourhood (L_{neigh} dB). These are combined into a noise level NAL_{eq} (Neighbourhood adjusted L_{deq}) at each dwelling by using the formula $L_{eq} + 0.4 (L_{neigh} - L_{eq})$. The relative weight of 0,4 was determined from multivariate impact modelling where the degree of annoyance has been determined as a non-linear function of the linear combination of $L_{Aeq,24h}$ and L_{diff} . (Klæboe et al. 2004).

3. Data sources

The official register for Ground -properties, Addresses and Buildings (GAB)
GAB consists of three mutually linked registers where the A- and G-part comprise all addresses and ground-properties. The B-part comprises information of all buildings larger than 15 m^2 including their co-ordinates. The G-part comprises information about all ground-property size etc. The register is under the responsibility of the Norwegian Mapping Authority.

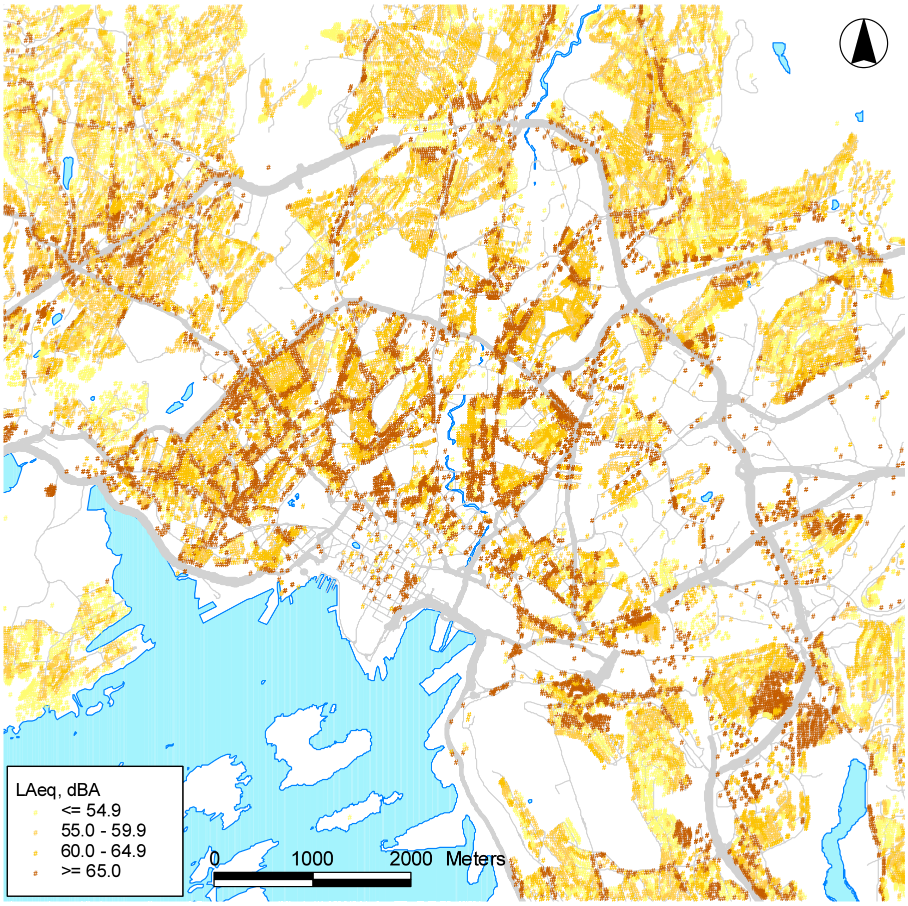
Road database
The Norwegian mapping authority maintains a database of all drivable roads of 50 m or longer. The roads records, has key fields for the possibility of merging traffic data.

Road traffic noise data
Statistics Norway has developed a GIS-model for calculation of noise on assignment of the Norwegian Pollution Control Authority (SFT). The model quantifies noise produced from roads, railways, airports, industry and other important sources. The noise level is calculated for each dwelling in Norway. In this study only preliminary results from road traffic noise calculations where utilized.

For the most heavily noise exposed areas the model uses data from the VSTØY-model, a survey-based road traffic noise calculation system for dwellings. For areas where data from the VSTØY-model are not available, Statistics Norway has developed a simple supplementary calculation based on the Nordic Prediction Method (NMT). These calculations are based on data from the road database (Vegdatabanken) concerning speed, heavy vehicle traffic, AADT (Annual average daily traffic) and ascent. Buildings between the dwelling and noise source blocking the noise are also being taken into account. For local roads where neither VSTØY-calculations nor road-traffic counting are available, the noise level is calculated on basis of a distribution of national traffic on local roads. The NMT method incorporates a 3 dB addition to take into account façade reflection. The LAeq values are therefore roughly equivalent to corresponding free field L_{den}-values.

Figure 1 show the $L_{Aeq,24h}$ values for some Oslo dwellings. Compared to more detailed and precise calculations utilizing exact building extent and elevation, the results from the national mapping effort are coarser and omit extreme noise level gradients. Dwellings near a main street with exceptional shielding conditions are assigned more similar noise level to surrounding dwellings than is actually the case.

Figure 1. Road traffic noise level ($LA_{eq,24h}$) at dwelling. Oslo.



Source: Statistics Norway
Map source: Statistics Norway and The Norwegian Mapping Authority LKS 82003-596

4. Method

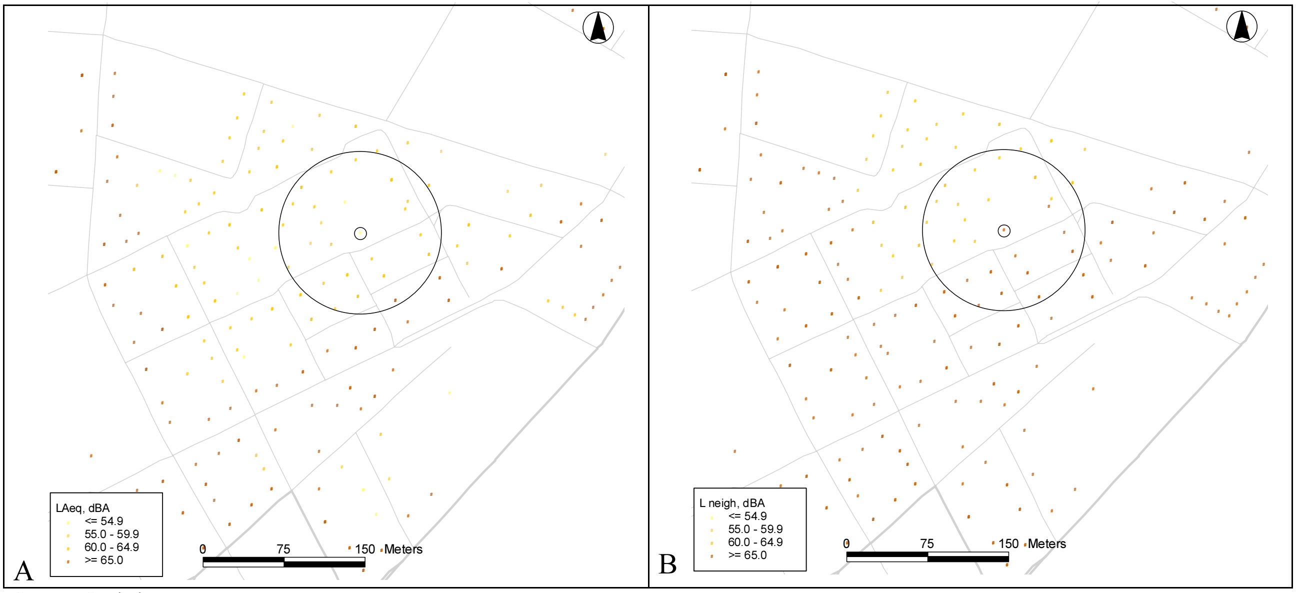
The methodological steps up to the calculation of neighbourhood adjusted noise level (NAL) are extracted from previous work (Klæboe et al. 2004). The calculations and production procedures are implemented, adjusted and ultimately adapted within the software environment of Statistics Norway. This is done in order to experiment with different neighbourhood radiuses, parameter values and to easily implement the calculations on national data sets. Future socio-acoustic analyses where questionnaire data are analysed using exposure data for the dwelling and neighbourhood from the national mapping efforts, will allow fine-tuning the relative impact weight (40%) of the neighbourhood difference indicator.

4.1 Assigning a neighbourhood noise indicator (L_{neigh}) to dwellings

The neighbourhood noise level indicator is calculated for each dwelling. The calculations are done by finding the highest equivalent noise level from all dwellings or roads within a certain distance of a target dwelling, and assigning this noise level to the target dwelling. The neighbourhood is thereby defined as a circular area in relation to the dwelling. This is in accordance with the methodological approach developed by (Klæboe et al. 2004). Ideally the neighbourhood could have been determined on the basis of activity patterns and actual usage of the different parts of the neighbourhood. Lacking activity data a simpler geometric definition of the neighbourhood was chosen. The results are dependent on the chosen distance. In (Klæboe et al. 2004) the radius was set to 75 metres. A smaller radius ensures that more distant roads that perhaps are less important are assigned less weight while a larger radius ensures that somewhat more distant roads but with perhaps much higher traffic volumes are not so easily excluded. In this study we have tested the effect of distances varying from 50 to 150 metres. The method can be described as consisting of 4 steps:

1. Identification of the population of equivalent noise levels at dwellings (addresses) within a certain distance from each target dwelling
2. Finding the highest of these equivalent noise levels (as well as number of residents etc.) in this population of dwellings
3. Merging L_{neigh} back to the target dwelling
4. If the noise emission from the nearest road within the specified distance exceeds L_{neigh}, it is replaced with roadside exposure value.

Figure 2. Noise level (A) and neighbourhood noise level (B) (each neighbourhood noise level is determined by circle areas around each of the dwellings with the same radius as shown for one target dwelling illustrated below)

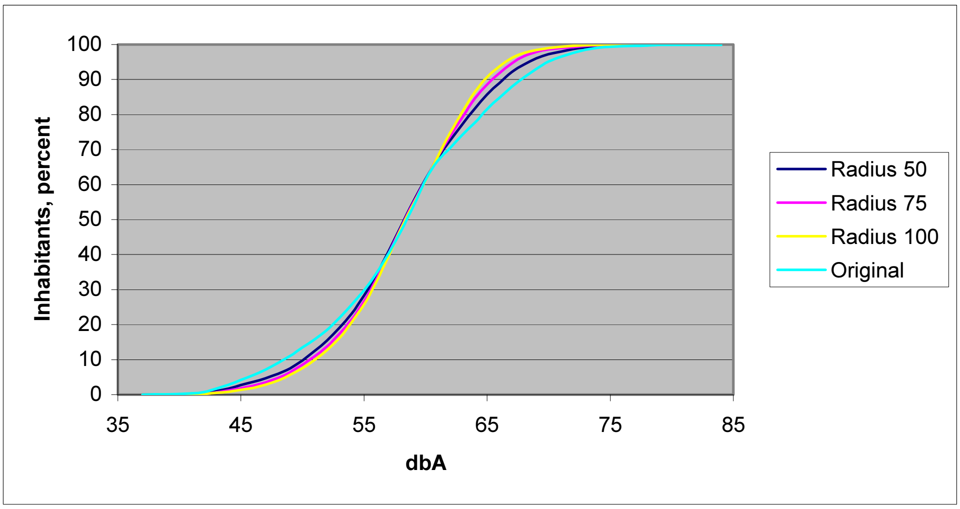


Source: Statistics Norway
Map source: Statistics Norway and The Norwegian Mapping Authority LKS 82003-596

The method is visualized in figure 2. Part A shows the situation with graduated colours based on the noise level at each dwelling. Part B shows the situation with graduated colours based on the neighbourhood noise level L_{neigh} at each dwelling. The circle defines the neighbourhood (such a circle is constructed around each dwelling in the calculations).

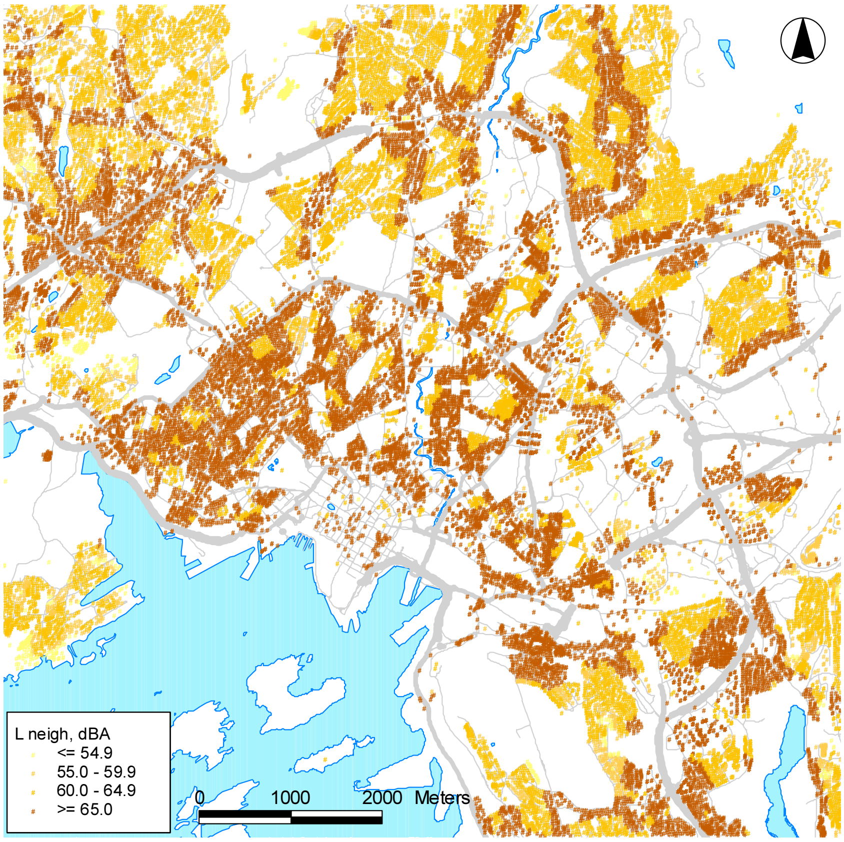
Figure 3 shows the cumulative proportion of inhabitants exposed to different levels of neighbourhood noise for some alternative choices of the size of the neighbourhood radius. As the radius increases, the range of L_{neigh} values gets narrower.

Figure 3.Cumulative number of Inhabitants by neighbourhood noise level. Separate relationships for neighbourhoods having 50, 75 and 100 m radius. Oslo



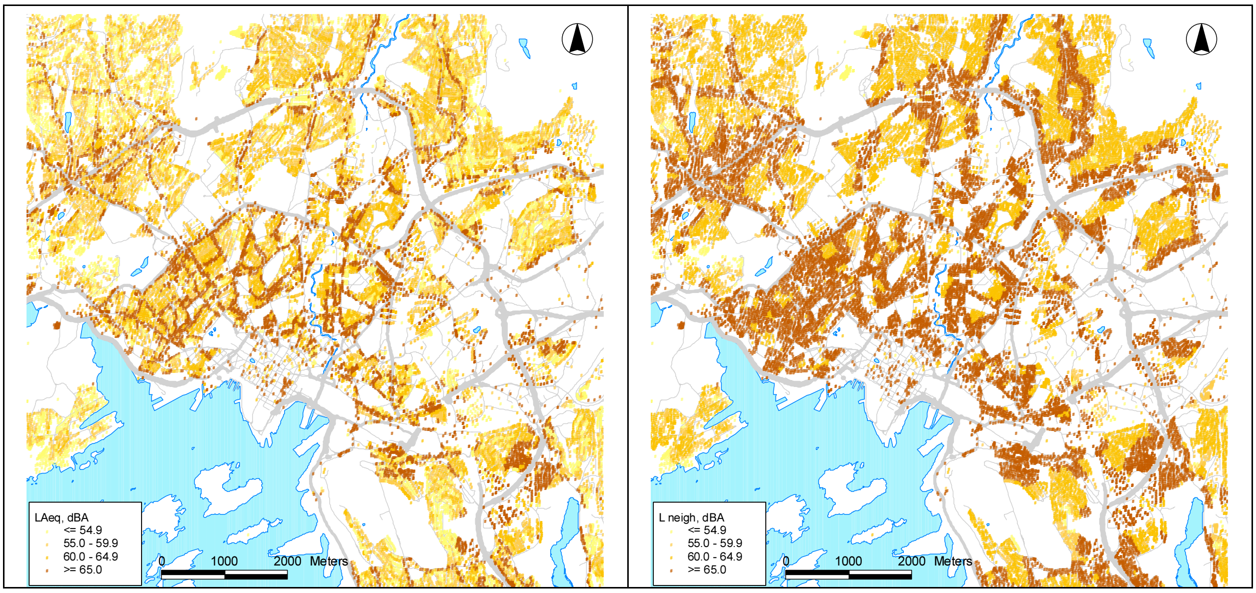
In figure 4 the neighbourhood noise levels for case area Oslo is visualized. The neighbourhood is set to radius 75 meters.

Figure 4. Neighbourhood (road traffic) noise level (L_{neigh}) at dwelling. Oslo. Neighbourhood 75 m.



Source: Statistics Norway
Map source: Statistics Norway and The Norwegian Mapping Authority LKS 82003-596

Figure 5. Comparison of L_{eq} (figure 1) and L_{neigh} (figure 4). Oslo

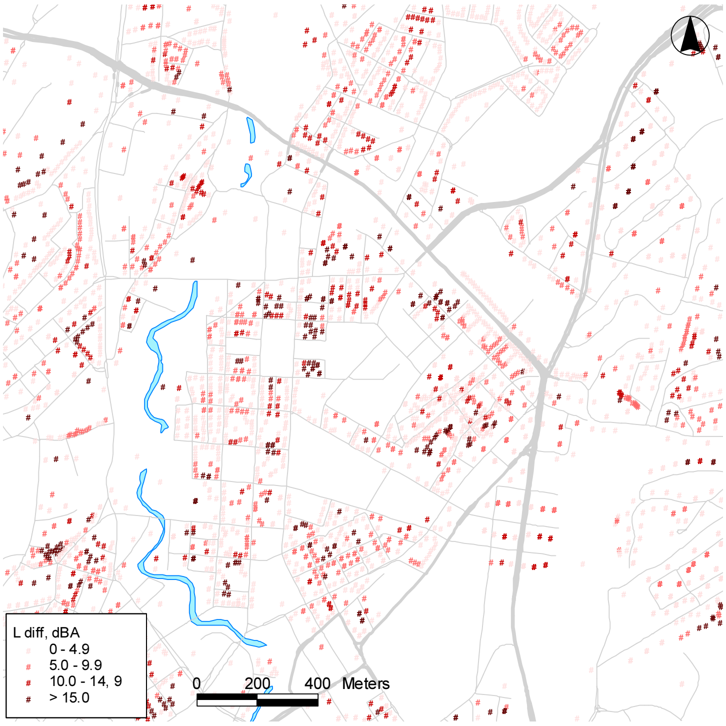


4.3 Difference indicator (L_{diff})

In order to differentiate between the impact of the noise level at the apartment and the additional road traffic noise load from the neighbourhood, (Klæboe et al. 2004) calculated the difference indicator L_{diff}. This indicator is simply the number of decibels that the neighbourhood soundscape noisiness indicator exceeds the noise exposure level at the dwelling.

$$L_{diff} = L_{neigh} - L_{eq}$$

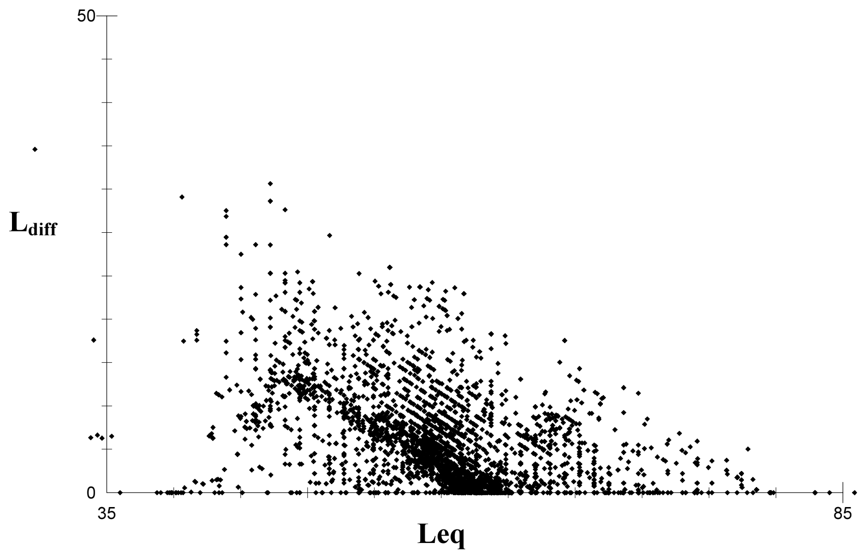
Figure 6. The neighbourhood difference indicator, $L_{diff,}$ at dwellings. Oslo



Source: Statistics Norway
Map source: Statistics Norway and The Norwegian Mapping Authority LKS 82003-596

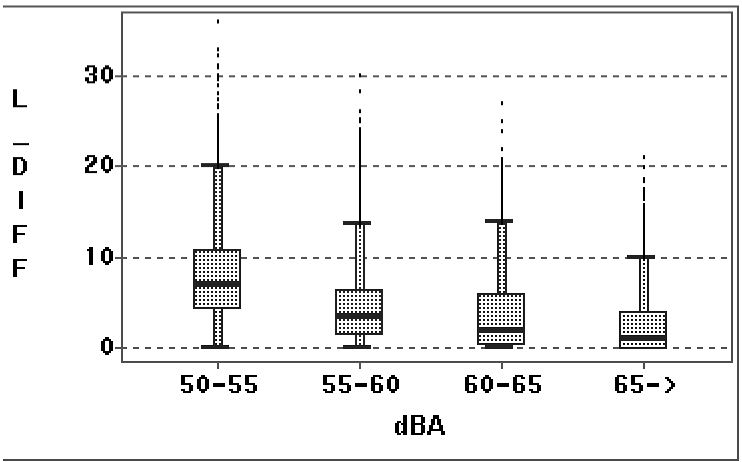
We implemented the L_{diff} calculation on our Oslo data. Figure 6 shows the geographical distribution of L_{diff} in a part of Oslo. The highest values are found along second row houses or back yards facing away from major streets.

Figure 7. The difference indicator by equivalent noise level. Oslo



When plotting the L_{diff} values by equivalent noise level (figure 7), the variation in the neighbourhood noisiness appears. The difference is largest for dwellings exposed to the lower equivalent noise levels. The same data is aggregated and presented as box-plot in figure 8. The figures portray the same overall trend as observed by (Klæboe et al. 2003) from five socio-acoustic surveys.

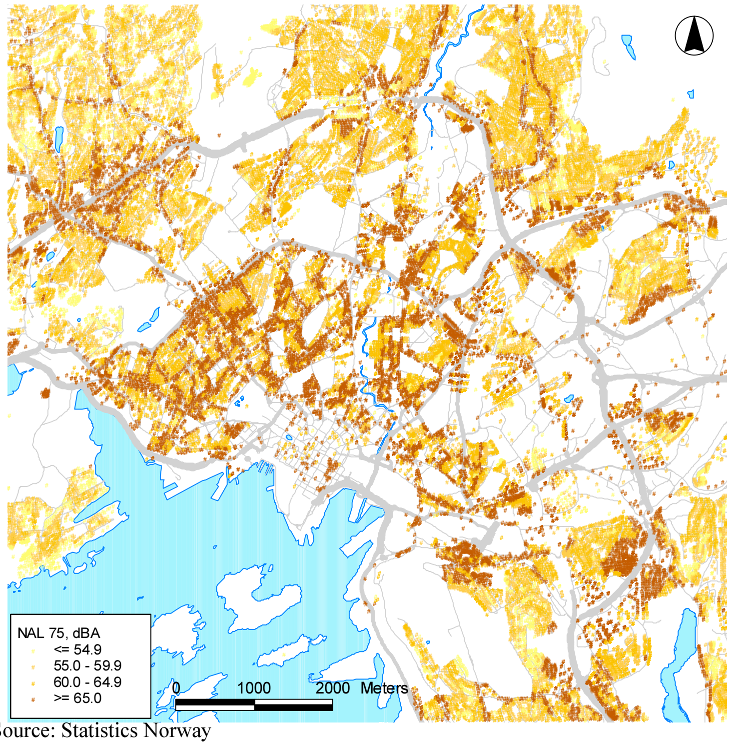
Figure 8. Box-plot of the difference indicator by equivalent noise level class (N=70 489)



4.4 Neighbourhood adjusted noise level, NAL

Klæboe et al. (2004) estimated the effect size of the neighbourhood difference indicator L_{diff} to about 40 percent that of the noise level L_{den} at the most exposed façade. They exemplified this with a dwelling exposed to L_{den} = 50 db and L_{diff} = 12 db would induce about the same degrees of annoyance as a dwelling exposed to L_{den}= 55 and L_{diff} = 0 db. When adjusting L_{den} with 40 percent of L_{diff} we obtain the neighbourhood adjusted noise level NAL. (In our study we have calculated the NAL with basis in L_{eq} not $L_{den.}$) Figure 9 shows the dwellings with graduated colour based on the NAL. The NAL is the context dependent resulting noise impact indicator that serves as the dwelling attribute, that in the second part of our work serves as basis for modelling the neighbourhood sonoscapes where dwellings having similar noise impacts are merged into contiguous areas.

Figure 9. Neighbourhood (road traffic) noise level at dwellings (NAL). Oslo. Neighbourhood 75 m



Source: Statistics Norway
Map source: Statistics Norway and The Norwegian Mapping Authority LKS 82003-596

4.5 The delimitation of neighbourhood sonoscapes

The methodology, based on buffering, merging and smoothening of outlines of polygons developed for constructions of settlement boundaries (Dysterud et al. 1999) and land use areas (Engelien and Schøning 2000) in Statistics Norway, can also be used for aggregation of noise neighbourhood areas.

The methodology of utilising similar units in the immediate vicinity as a basis for contextual information can be utilised as a basis for determining the homogeneity or heterogeneity of an area with respect to a given indicator. The methodology of building contiguous areas is not limited to noise impact assessment, but should be generally applicable to situations where a population within an area can be assigned to different classes on the basis of a given attribute.

The procedure comprises 4 steps as follows:

1. From a starting point with sites and centre points of buildings compiled in one layer in GIS, this layer is split into separate layers for each noise level category (figure 10).
2. For each separate layer of noise level category the sites that are positioned close to each other are merged. The criteria for distance is based on empirical experience yielded during the project period. The technical merging of sites to larger polygons is done in ARCINFO. These buffer areas cover a larger area than the dwellings they are based upon.
3. A buffer with negative prefix is utilised to confine the buffer regions to the immediate vicinity of the dwellings (figure 11).
4. Finally all the separate layers each with merged larger areas of homogenous perceived noise levels are overlaid, assigned a class membership and merged to one layer (figure 12). Overlap of areas will occur i.e. that the same area can be classified with two or more noise level classes. In order not to doubly classify the areas, it is chosen to assign the final noise level classes to the overlapping areas according to the following priority: 1.High noise impact, 2.Low noise impact.

The method also gives the possibility of deriving statistics for the size, shape and geographical distribution of areas, as well as accumulating the impacts for each neighbourhood sonoscape.

Figure 10. Selection (A) and modelling (B) of neighbourhood areas in separate layers

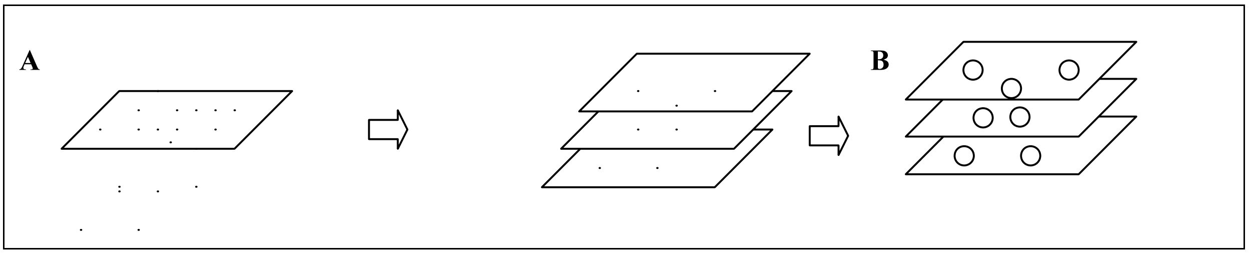


Figure 11. Merging of sites to larger areas by expansion and contraction

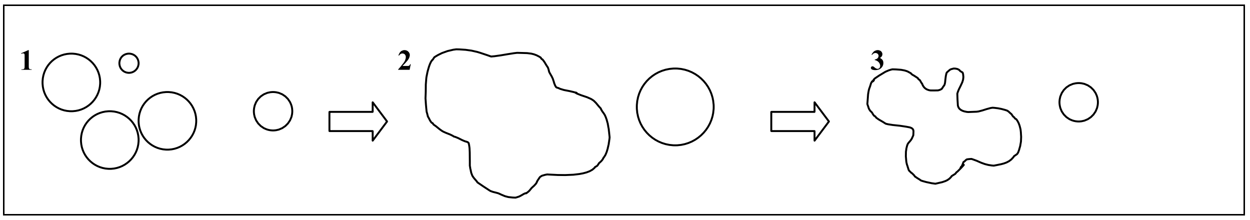
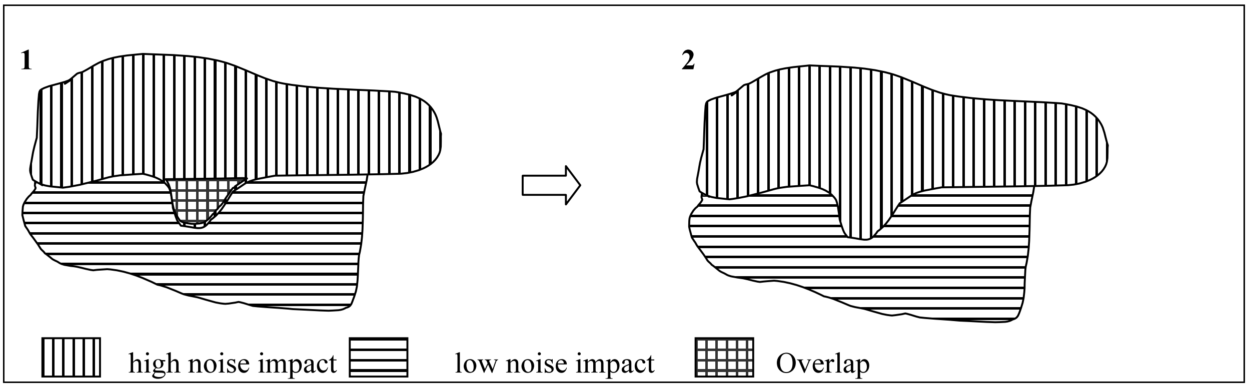


Figure 12. Classification of areas with overlap - based on a preliminary system of priority



The method for aggregation of sites into larger homogenous areas is sensitive to the selected distance criteria for merging.

At present the positive buffer radius is set to 50 metres and the negative buffer radius is 40 metres. This ensures geographical connection and continuity while keeping the actual neighbourhood soundscapes limited to the vicinity of dwellings. The development of methodology for aggregation of *areas* within the urban settlements is an ongoing process. Final distance criteria can be finally decided upon when more empirical work/practical experience is yielded.

The method and effects for neighbourhood delimitation

The method can be regarded as elements of generalisation. Usually the purpose of generalisation of maps is 1) make spatial analyses more effective (model generalisation) or 2) improve visual communication (cartographic generalisation) Gjertsen og Moum (1999). The main purpose of delimitating sonoscapes, fall in to both these categories. The aim of delimitating sonoscapes, are to make other spatial analyses possible and to do visual communication. The method consists of cartographic generalisation, and bias is introduced along with elimination compared to the data source.

The cartographic generalisation and its effects must be seen in the light of the purpose of this work. The data source does not allow for the establishment of a complete classification of the urban settlements, but delimitation and classification of the populated areas.

The method requires that some choices to be made which effects the delimitation. Especially three aspects are important: Choice of minimum meaningful neighbourhood impact class area, choice of distance criteria and choice regarding overlapping areas.

The choice of least minimum meaningful neighbourhood impact class area has significance for which areas that will be considered as areas of their own and how large elements of other classes that can be accepted before this are divided as separate areas (dependent on which methodology is chosen for overlapping areas). Choice of least minimum meaningful neighbourhood impact class area, are also deciding for the percentage of the dwellings being classified to areas. In the above described methodology 0,5 hectares are used as a minimum neighbourhood area size. This could be reconsidered after more experience and one may eventually choose to omit the least area criterion entirely.

In the described methodology all areas are forced in to one plane. As a result, each point in the delimitated areas is classified to one class only. One could, however, treat the different classes separately without merging in to one plane. This would lead to delimitations following the original, generalised borders. One dwelling (point) would in this way be classified to more than one sonoscape neighbourhood. The merging process could also take into account the number of dwellings within each neighbourhood noise impact buffer area. A hierarchy of classes as we have chosen here, however, leads to mutual exclusive areas.

After the delimitation process, parts of the urban settlement will still remain unclassified. This is natural since the aim is to classify and delimitate dwelling areas only, but some dwellings may be included in the unclassified areas. Especially in areas characterized by few and large buildings with spacious outdoor grounds, dwellings may be omitted from being delimitated. The distance criteria are however chosen in order to include most of these areas as well. Crucial for the distance criteria is the urban fabric; the urban landscape.

Delimitation of sonoscapes with basis in urban landscapes

When analysing urban settlements with land use modelling in mind (Bloch 2002), one can divide the urban settlement into central areas in the core of the city/town and the periphery. The landscape elements, which is used in defining an area is mainly buildings and roads. These built up areas is what makes up the matrix or the majority of the urban landscape. Fabric in this matrix can give guidance in deciding distance criteria also for delimitation of sonoscapes.

The central part of urban settlements are the most intensely built up. Especially in older districts with blocks of houses where the buildings are situated right up to the roads. The road may be narrow and sometimes without sidewalk. In these instances it is sufficient to use short distance criteria to obtain continuous areas.

In the fringe districts of the urban settlements, buildings are usually more scattered. Most of the buildings are for dwelling purposes. The challenge then is to make continuous areas in these districts without causing too much overlap in the central parts of the urban settlement. Bloch (2002) set the distance criteria based on average size (of buildings and property) and distance in dwelling areas of the settlement, and practical experiments. The distance criteria used in sonoscape delimitation are somewhat longer (50/ 40 metres) than used in the land use modelling (30/ 15 metres). This is because noise impact classes are less sensitive to overlap than land use classes, and hence the criteria can be enlarged in order to obtain continuous areas.

5. Results

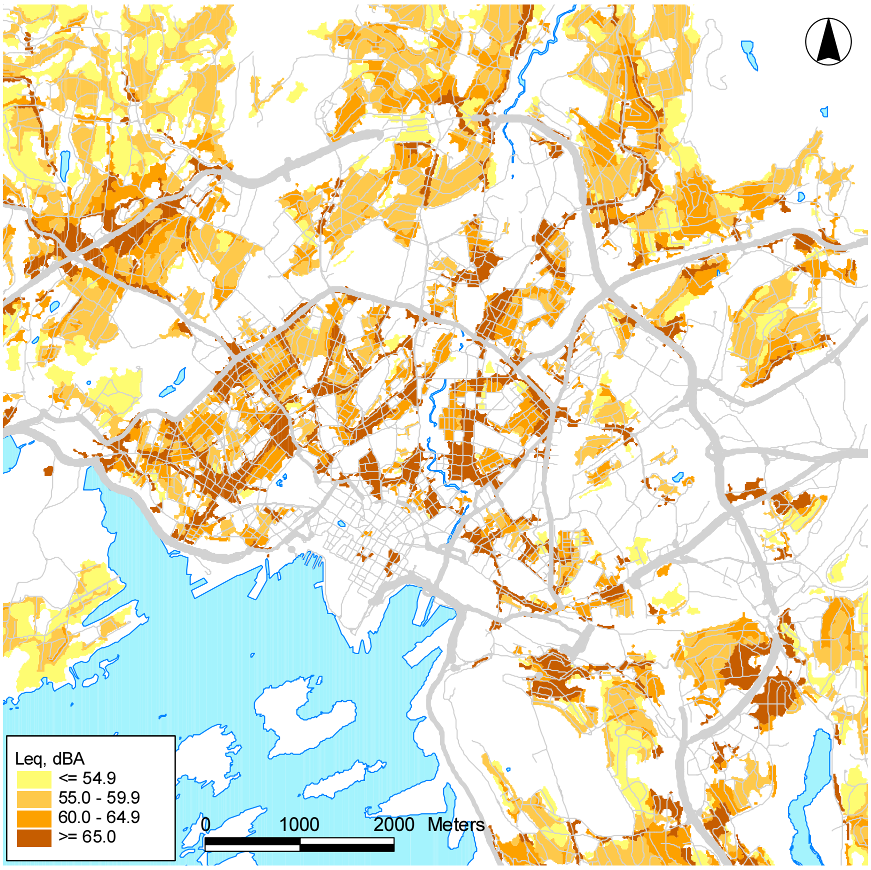
In this chapter we present the results of the above described modelling. First we make neighbourhood soundscape areas based on the $L_{Aeq,24h}$ values and then the results with different neighbourhood sizes[3] are displayed for a central part of Oslo. Finally results from some other municipalities are presented (with the neighbourhood fixed at 75 metres.)

5.1 Oslo

Effects of using neighbourhood adjustment

Comparing neighbourhood sonoscapes based on $L_{Aeq,24h}$ (figure 13) and NAL (figure 14) show that sonoscapes with low annoyance score (yellow areas) becomes more extensive when using NAL. Similarly the areas with high annoyance score (dark areas) along main roads, becomes somewhat larger. This means that adjusting for the impact of the neighbourhood soundscape results in a crisper delimitation of urban sonoscapes, allowing for a more targeted approach for local noise abatement measures.

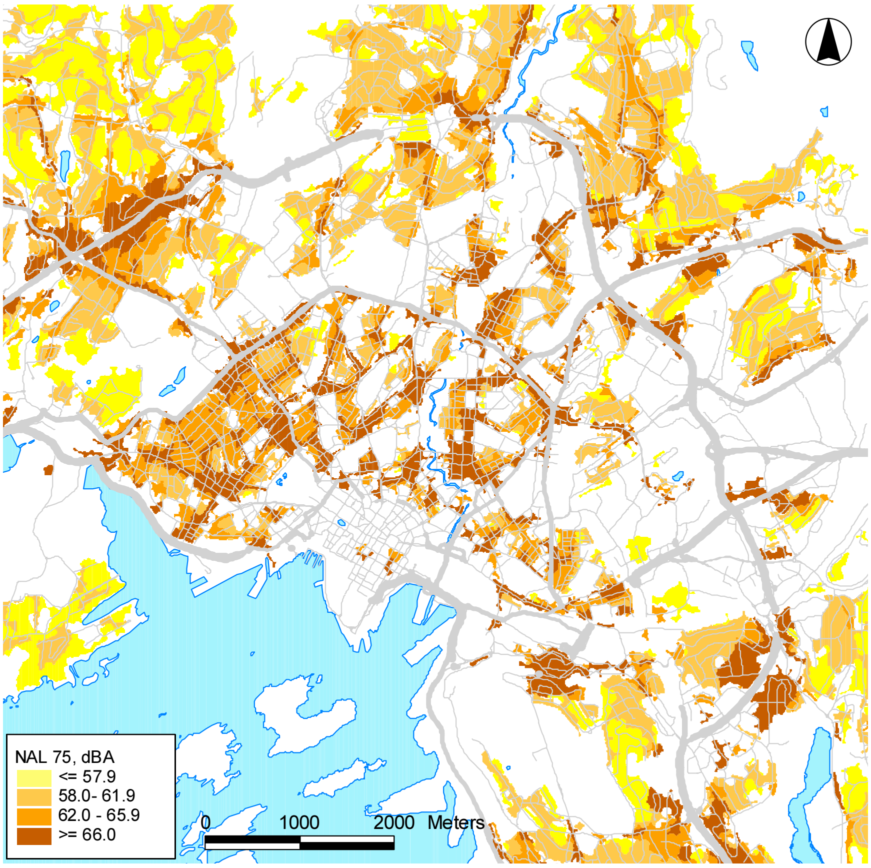
Figure 13. Reclassification and modelling of areas. Oslo. L_{ekv}. 4 classes



Source: Statistics Norway
Map source: Statistics Norway and The Norwegian Mapping Authority LKS 82003-596

[3] As the parameter values for the impact of the neighbourhood soundscape have been extracted from dwellings within 75, choosing a different radius will also mean that the parameter might need adjusting.

Figure 14. Reclassification and modelling of areas. Oslo. NAL_{ekv} 75 m. 4 classes

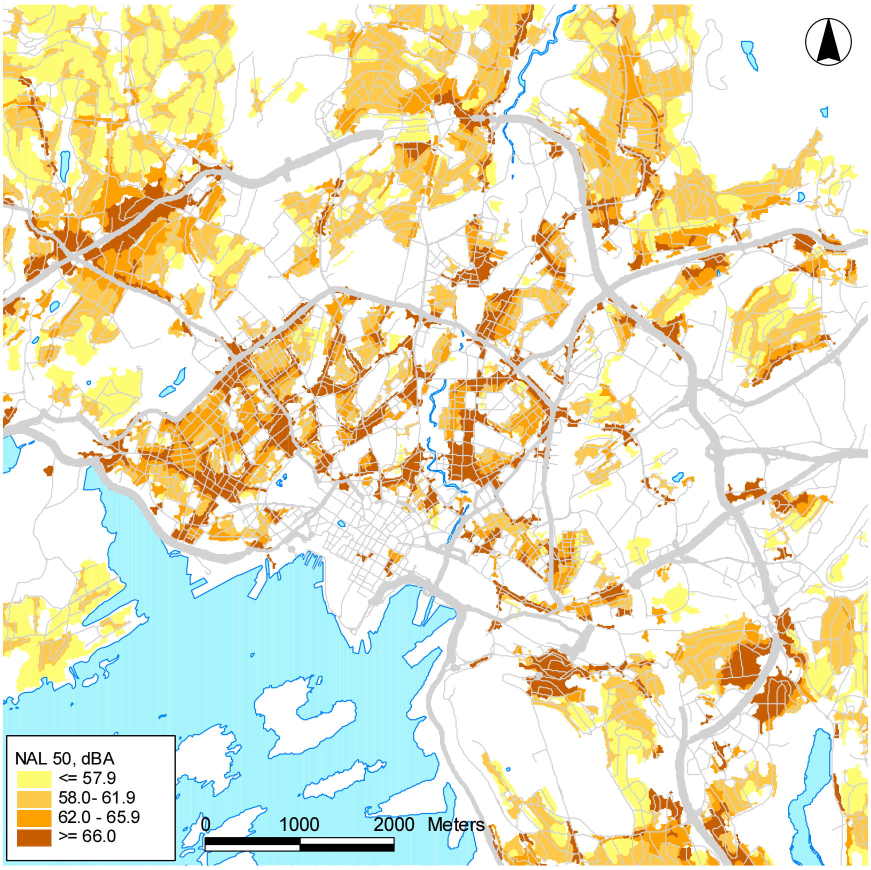


Source: Statistics Norway
Map source: Statistics Norway and The Norwegian Mapping Authority LKS 82003-596

Effects of changing the size of the neighbourhood

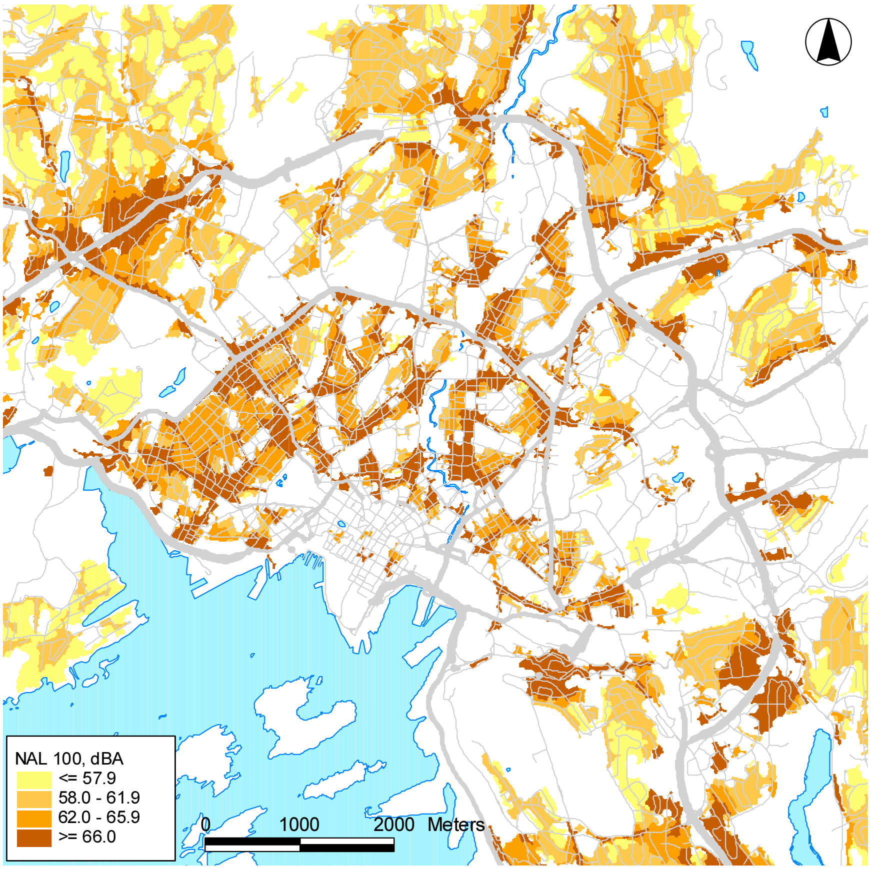
The method has been tested for several sizes of neighbourhoods, differing in radius from 50 to 150 meters (figures 15 through 17). When comparing the results of these approaches we see that an increase in neighbourhood size leads to an increase in the overall classified area. As the neighbourhood size increases more of the area is classified to higher noise impact, while there is a decrease in lower impact areas (figure 18). When it comes to number of areas, the overall trend is a decrease in number of areas, especially this is valid for the lower noise impact areas while in the highest noise impact areas, the number of areas are more stable (figure 19). An increase of the neighbourhood-size thus leads to larger and more homogeneous areas.

Figure 15. Reclassification and modelling of areas. Oslo. NAL_{ekv} 50 m. 4 classes



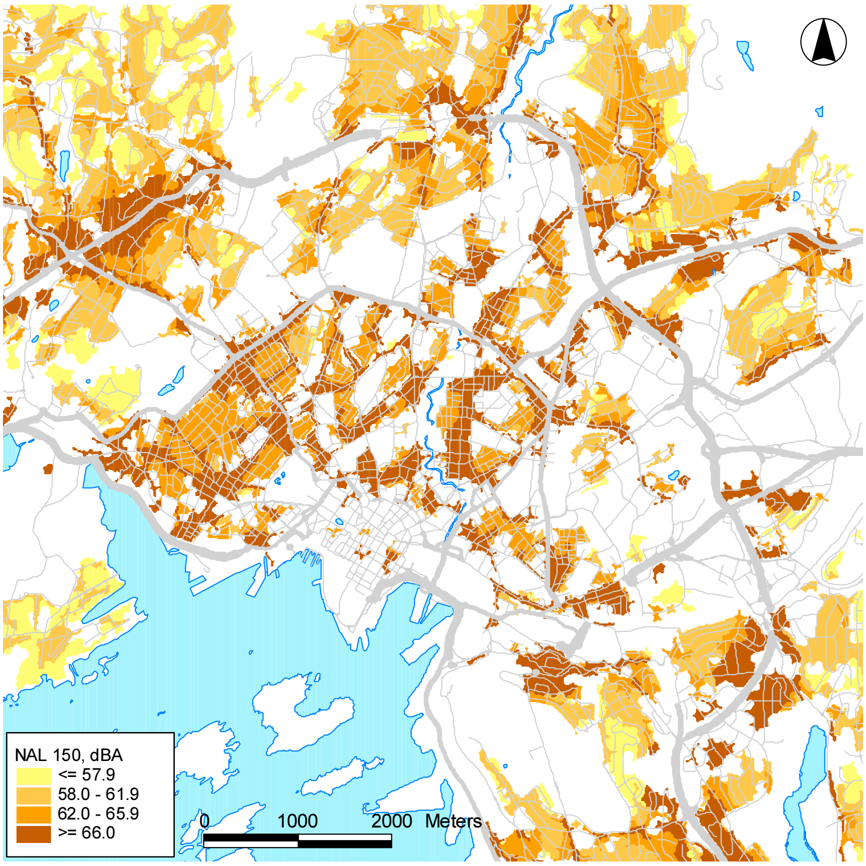
Source: Statistics Norway
Map source: Statistics Norway and The Norwegian Mapping Authority LKS 82003-596

Figure16. Reclassification and modelling of areas. Oslo. NAL_{ekv} 100 m. 4 classes



Source: Statistics Norway
Map source: Statistics Norway and The Norwegian Mapping Authority LKS 82003-596

Figure 17. Reclassification and modelling of areas. Oslo. NAL_{ekv} 150 m. 4 classes



Source: Statistics Norway
Map source: Statistics Norway and The Norwegian Mapping Authority LKS 82003-596

We do not base the definition of neighbourhood just on exposure, but from the area close to the dwelling used by the inhabitants (with high probability). The activity pattern is to a large extent deciding for the size of the neighbourhood. Ideally one should know more about the actual use of the neighbourhood. Some people are very active and make use of a wider neighbourhood, while others do not. Likewise, some people make frequent use of the city centre, parks and nearby facilities, while others tend to spend more time indoors at home.

Figure 18. Area of neighbourhood sonoscapes. No neighbourhood adjustment (L_{eq}) and neighbourhood-sizes 50-150 meters.

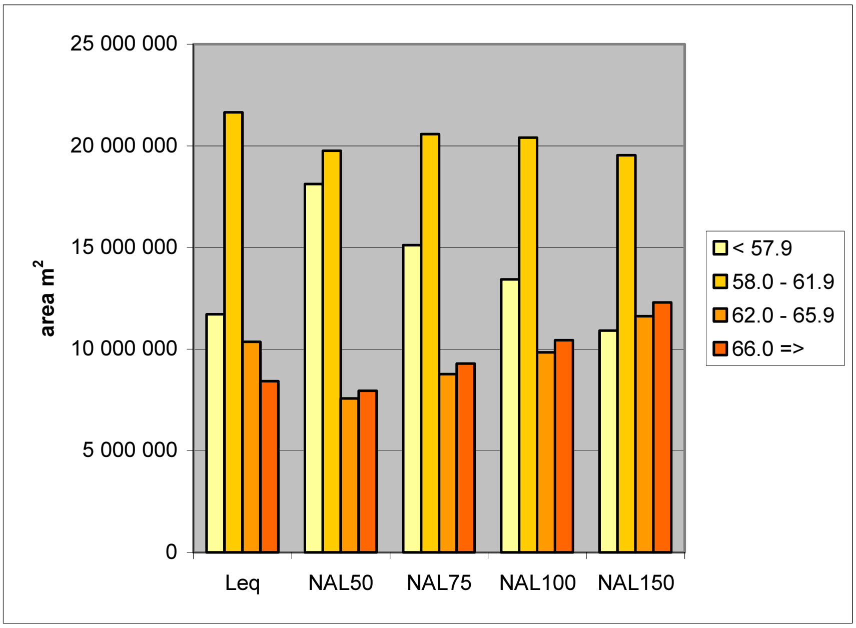
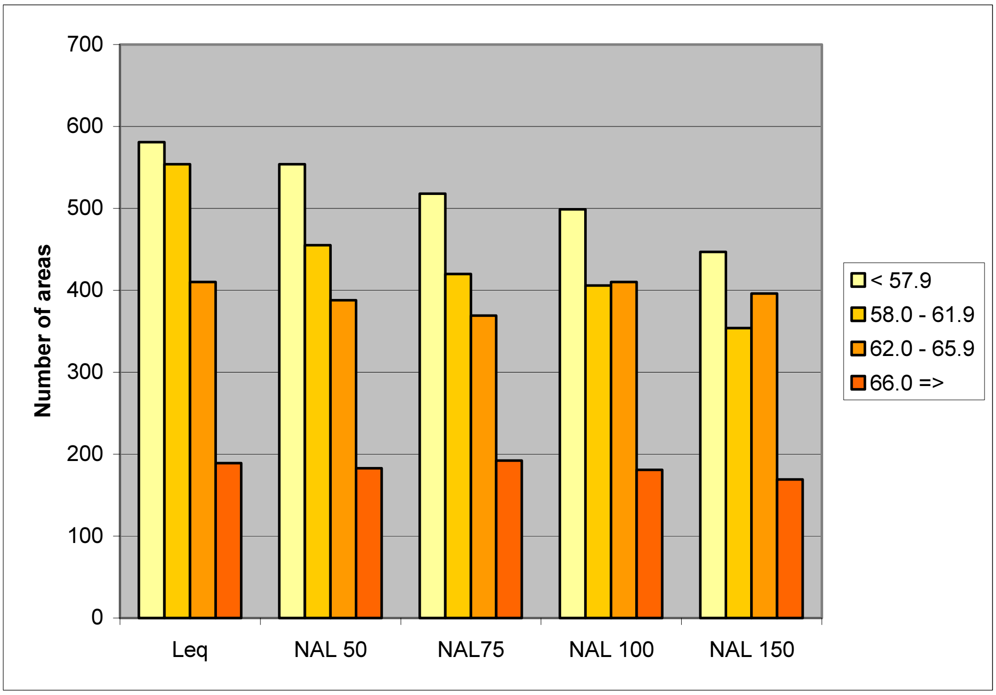


Figure 19. Number of neighbourhood sonoscapes. No neighbourhood adjustment (L_{eq}) and neighbourhood-sizes 50-150 meters.

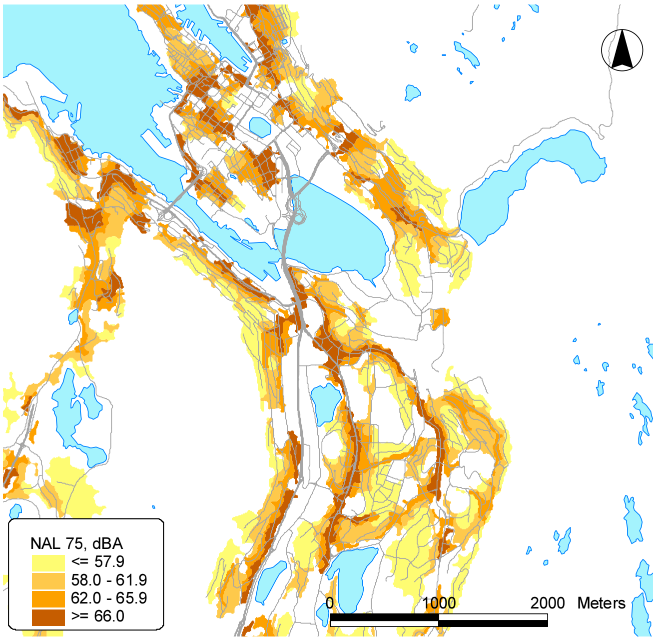


The use of the neighbourhood or the size of the neighbourhood may also differ in different parts of the city. By using a wide neighbourhood definition the probability of including areas which are seldom used, increases. Representing the neighbourhood as a circular area is an obvious simplification, and in lack of empirical data deciding on the radius is an assessment. In the test results presented we have adopted the 75 m criteria as used by Klæboe et al. 2004.

5.2 Examples from other Norwegian cities

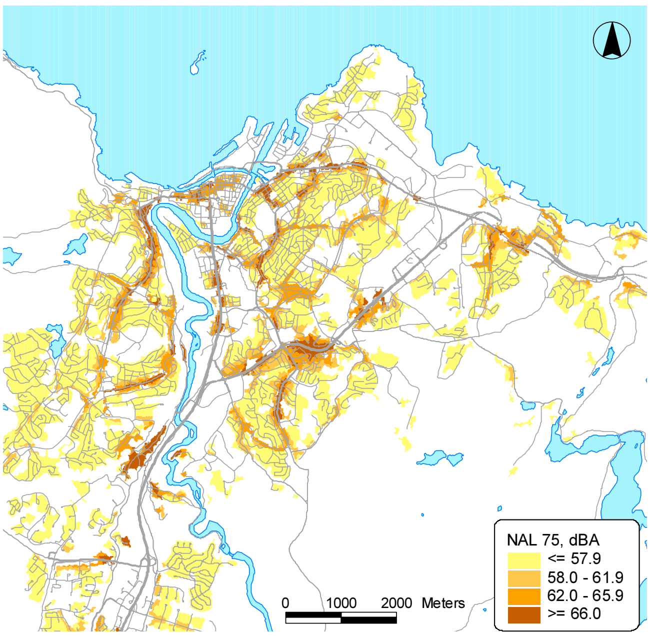
This chapter presents results from some other major city centres in Norway (Bergen and Trondheim) along with an example from a small town (Kongsvinger).

Figure 20. Reclassification and modelling of neighbourhood sonoscapes . Bergen. NAL_{ekv} 75 m. 4 classes



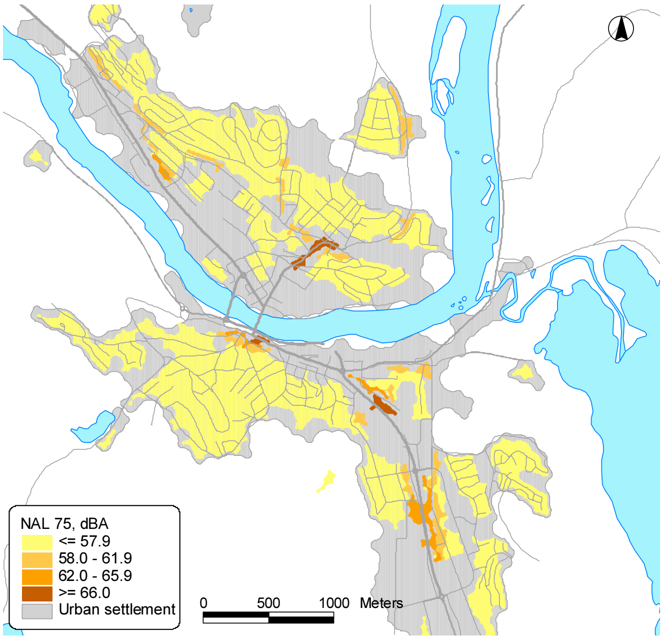
Source: Statistics Norway
Map source: Statistics Norway and The Norwegian Mapping Authority LKS 82003-596

Figure 21. Reclassification and modelling of neighbourhood sonoscapes. Trondheim. NAL_{ekv} 75 m. 4 classes



Source: Statistics Norway
Map source: Statistics Norway and The Norwegian Mapping Authority LKS 82003-596

Figure 22. Reclassification and modelling of neighbourhood sonoscapes. Kongsvinger. NAL_{ekv} 75 m. 4 classes



Source: Statistics Norway
Map source: Statistics Norway and The Norwegian Mapping Authority LKS 82003-596

5.3 National statistics of sonoscapes

Most importantly, the results from sonoscape modelling, will serve as a basis for stratification for noise annoyance surveys, targeting noise abatement measures and a simple introduction for the local government planner, along with implementation in the national noise annoyance calculations.

The results are part of a research project and there are no intentions to produce statistics at the present stage. When or if the results of Klæboe et al. (2004) are incorporated in to the national calculations of noise annoyance, the production of statistics should be explored further. However, a first national statistics could summarize population and area in sonoscape classes. Statistics could be produced for counties or even municipalities and thus give an alternative characterization of quality of the dwelling areas. Appropriate class labels and adjustment of the classification, must be undertaken before such statistics are produced.

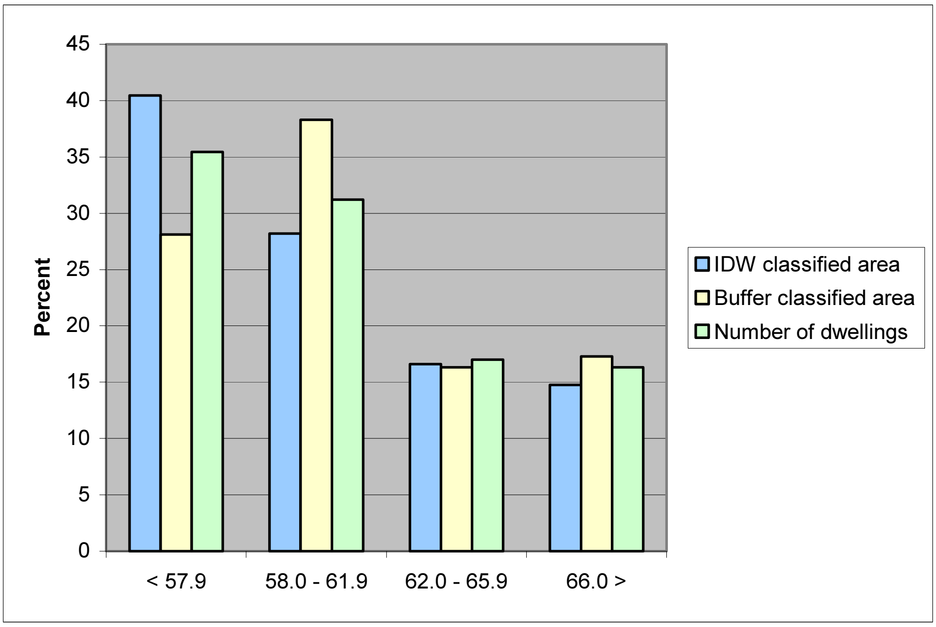
6. Other techniques tested in the project

We have tested different delimitation techniques, in addition to the preferred buffer methodology. One other vector technique has been tested (thiessen), but the primary opponent to the buffer method, are raster based interpolation techniques. By using raster, one divides the world into grid cells of fixed square size. By using the values of points in the vicinity of each grid cell, interpolated values can be assigned to the cell. The raster approach can once again be divided in to steps.

1. Interpolation to raster from estimated perceived noise annoyance at each dwelling (numerical value)
2. Reclassification to perceived noise annoyance classes

The result from such an exercise is dependant on cell size, but also the search radius and other parameters. We have chosen inverse distance weighting with standard (2) exponent of distance, which controls the significance of surrounding points upon the interpolated value. (A higher power would result in less influence from distant points.) Furthermore, we have used search distance of 50 metres and cell size 10*10 meters. Results from the modelling, is shown in figures 24 (from Leq) and 25 (from NAL) while a comparison of the resultant area is illustrated in figure 23.

Figure 23. Area (IDW and buffer) and number (dwellings) by perceived annoyance class. Percent of classified area (and percent of total number of dwellings)



The total classified area is considerably higher by IDW (90.14 km^2) compared to the buffer methodology (53.75 km^2). The IDW method leads to a classification of all cells within 50 metres from all dwellings. The buffer methodology, on the other hand, classifies only areas within 10 metres from the dwellings. This is the main explanation for differences in total classified area. In addition, the buffer methodology incorporates a minimum area criterion, which excludes small isolated areas. The small isolated areas occur, for the most part, in the sparsely built up districts in the urban periphery. Theoretically, each dwelling in these districts could result in 0,79 hectares (50^2 * pi m^2) of IDW-classified area, while being omitted in the buffer approach because of the minimum area criterion. These districts are located farther away from main roads and are thus less exposed to noise and fall into the lowest annoyance class. The buffer methodology bind areas with the same quality together, while the IDW methodology only interpolate values from nearby points. As a result, interconnecting areas made by the buffer method can be classified differently with IDW. Differences are also due to the implemented order of priority in the buffer methodology.

One advantage of using the buffer methodology is that it is simple and will keep all processing within the vector-GIS environment, and automation and integration with the national noise mapping system is easy. If one chooses to implement IDW, additional studies regarding various parameter adjustments must be undertaken. However, the two methodologies represent two fundamentally different approaches. Whereas the buffer methodology reclassify and make interconnected areas of the same class, the IDW methodology interpolates a "surface" and then reclassify regardless of dwelling configuration. Strong emphasis on the configuration or context of adjacent dwellings of the same class in the delimitation process, are one of the advantages of the buffer methodology. The buffer methodology is sensitive to the maximum distance chosen. In certain (densely built up) districts the distance can be too wide, giving rise to, in part, erroneously classified areas. In these instances, overlap with other classes will occur, causing a shift towards the higher annoyance classes. In the end, the decision between methodologies is an assessment, since no "ground truth" exists.

To illustrate effects of the two methods, we have compared the soundscape class with the corresponding sonoscape class at each dwelling. This has been done both for the buffer results (table 1) and the IDW results (table 2).

Table 1. Soundscape class and sonoscape class at each dwelling. Buffer methodology

	Buffer sonoscape class				
Soundscape class	0	< 57.9	58.0 - 61.9	62.0 - 65.9	66 =>
< 58	1 379	16 546	4 338	430	111
58 - 62	1 517	189	17 281	1 369	341
62 - 66	1 484	31	272	8 255	1 144
66 =>	1 092	3	45	130	9 577

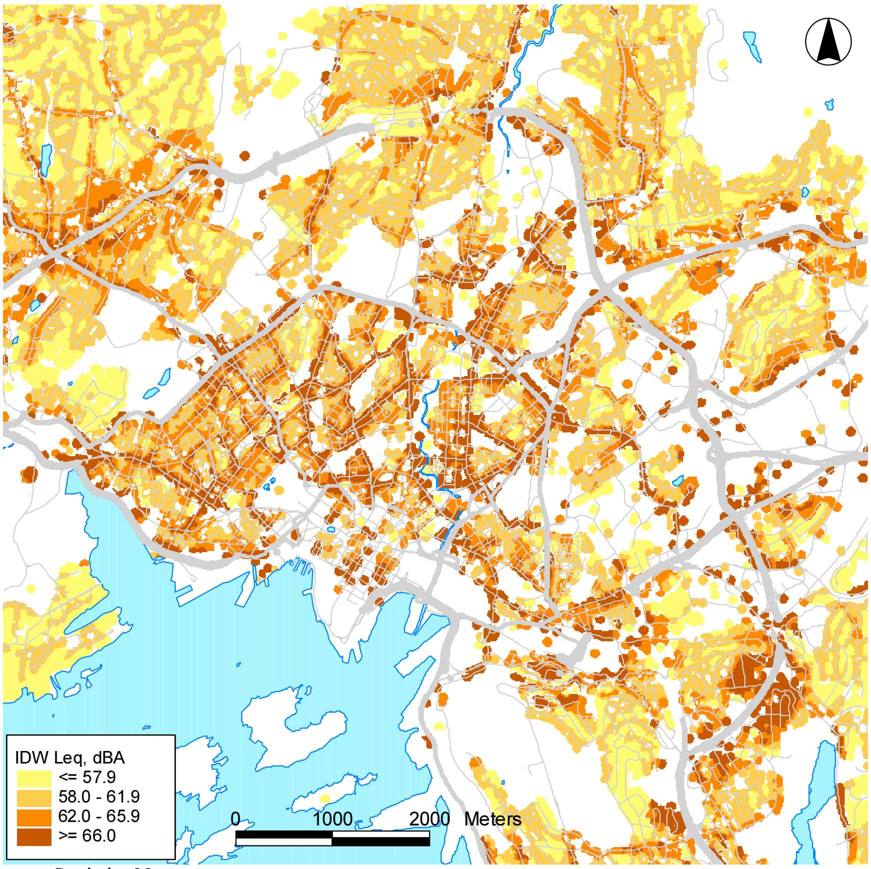
Some of the dwellings will not be classified to any sonoscape class using the buffer methodology, as they do not belong to any continuous neighbourhood. These dwellings are designated "0" in figure 24. One can observe a shift from lower soundscape classes to higher sonoscape classes. The shift towards higher classes must stem from the priority criterion, or at least partly so. Heterogeneous dwelling areas with respect to soundscape class, will lead to dwellings being incorporated into other sonoscape classes. The high number of dwellings being shifted towards higher sonoscape classes indicates that we should reconsider the distance criteria. Making the distance criteria narrower, more in line with the land use distance considerations, should be tested.

Table 2. Soundscape class and sonoscape class at each dwelling. IDW methodology

	IDW sonoscape class			
Soundscape class	< 57.9	58.0 - 61.9	62.0 - 65.9	66.0 =>
< 58	22 736	66	2	0
58 - 62	3 101	17 555	39	2
62 - 66	0	2 108	9 043	35
66 =>	0	1	1 611	9 235

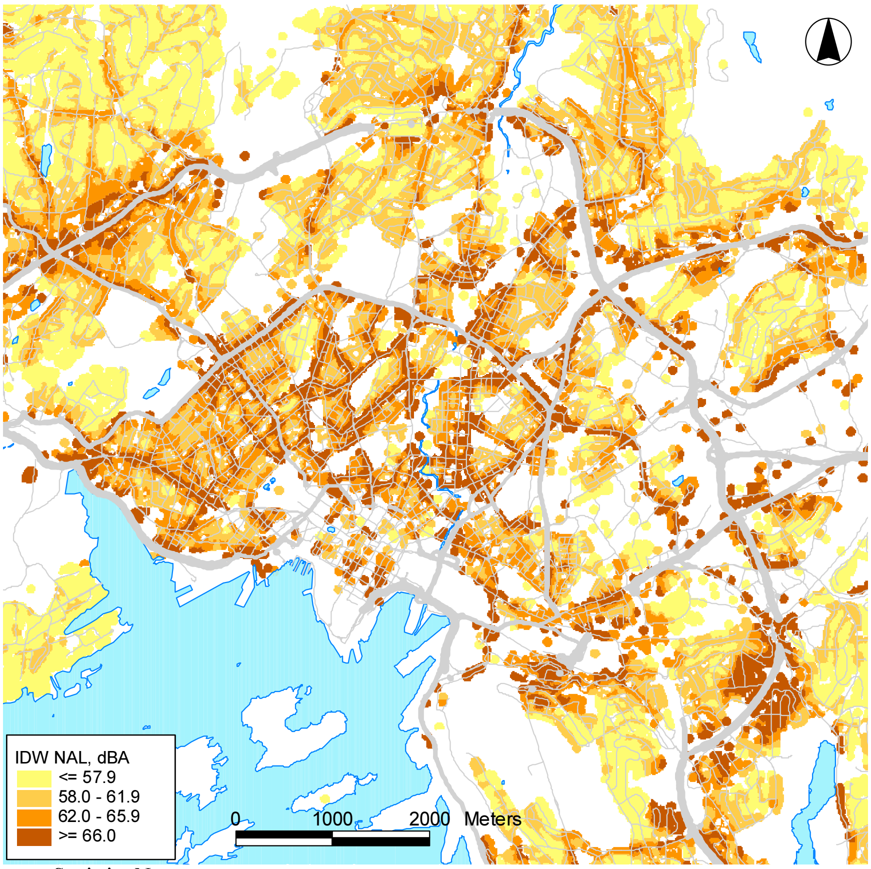
In the IDW-methodology, all dwellings are classified to a sonoscape class. Contrary to the results from the buffer methodology, IDW leads to a shift towards lower sonoscape classes. Few or no dwellings end up in the most distant sonoscape classes.

Figure 24. Neighbourhood sonoscapes. Oslo. Modelled by the interpolation method Inverse Distance Weighting (IDW) with basis in noise level at each dwelling



Source: Statistics Norway
Map source: Statistics Norway and The Norwegian Mapping Authority LKS 82003-596

Figure 25. Neighbourhood sonoscapes. Oslo. Modelled by the interpolation method Inverse Distance Weighting (IDW) with basis in neighbourhood adjusted noise level



Source: Statistics Norway
Map source: Statistics Norway and The Norwegian Mapping Authority LKS 82003-596

7. Conclusions and further work

Maps of urban neighbourhood sonoscapes on the basis of SSB’s national noise exposure mapping efforts and SSB’s spatial buffering routines are developed. These maps serve as an initial environmental labeling of neighbourhood soundscape quality and provide information to consumers and planners.

Results from a methodological evaluation (chapter 6), indicates that somewhat narrower distance criteria should be implemented. When finalised, the project results can easily be extended to, and implemented in, the national mapping of noise annoyance also taking multi source situations into account. Characterizing all dwellings could make it possible to do stratifications by neighbourhood sonoscape quality. The advantage of such stratification is that the whole population is allocated to distinct contiguous areas.

Most importantly, the results from sonoscape modelling, will serve as a basis for stratification for noise annoyance surveys, targeting noise abatement measures and a simple introduction for the local government planner, along with implementation in the national mapping of noise annoyance.

The results are part of a research project and there are no intentions to produce statistics at the present stage. When or if the results of Klæboe et al. (2004) are incorporated in to the national calculations of noise annoyance, the production of statistics should be explored further.

The methodology of utilising similar units in the immediate vicinity as a basis for contextual information can be utilised as a basis for determining the homogeneity or heterogeneity of an area with respect to a given indicator. The methodology of building contiguous areas is not limited to noise impact assessment, but should be generally applicable to situations where a population within an area can be assigned to different classes on the basis of a given attribute. Provided a monetary value can be assigned to different types of impacts, such a classification could well be the accumulated costs associated with the environmental exposures.

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