From regional “strategic” maps to microscopic scale models: multi-scales approaches to improve the assessment of the exposure to pollutants associated with transportation.

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Summary

Because land transportation remains the first source of noise in urban environment, lots of efforts have been put into the development of computational tools for the prediction of traffic noise and air pollutions. Strategic noise maps are well suited for global assessment of noise levels. However, when accurate exposure estimation is required, at infra-communal level, improved modeling methods should be considered, such as: coupling between microscopic traffic modeling and noise or pollutants imissions prediction, computation of temporal, statistical or dynamical indicators, better knowledge of population mobility behavior.

On the basis of real experiments performed in the Rhône-Alpes Region, this paper outlines the interest of using coherent multi-scale approaches, with the view to better qualify and quantify exposure to environmental pollutions (noise and air).

1. Introduction

A recent national survey (IFOP, 2014) reiterates the concern of the French people regarding noise in their environment. This survey confirms a growing awareness of the link that exists between health and exposure to noise, and with it the need for quality information on their exposure. This information is also a key point for policy makers when working out transport or land use plans.

Through the strategic noise maps required by the Environmental Noise Directive 2002/49 / EC, the access to noise information has been generalized. These maps, revealing noise issues due to transport infrastructure and industries, help to quantify population exposure, and they are used as a starting point for diagnosis and prevention and action plans. However, this first analysis often deserves thorough analysis in order to take local scale specifies into account or to be included in a more systemic approach.

Throughout recent experiments and projects, carried out on the Rhône-Alpes region these last few years, several areas for improving the valuation of nuisances such as ambient noise or air pollution are discussed in this paper. A “Russian doll” approach is adopted to show the complementarities of the methodologies, and tools used at each geographical scale.

The main motivations for these works can be summarized in two key points:

- Noise and air pollution are among the main determinants of public health and there is a need for developing efficient decision-tools and comprehensible information for policy-makers. With this aim, an environmental data platform mutualizing information and proposing alternative indexes to decode noise issues is introduced.
- Environmental data are an essential input to health studies provided that the information they carry are suited to effects. This raises the difficult question of assessing or modeling a realistic human exposure. Taking into account the behavior of the population regarding its mobility, and fine temporal modeling of pollution, have been tested on small areas and are discussed in the following.

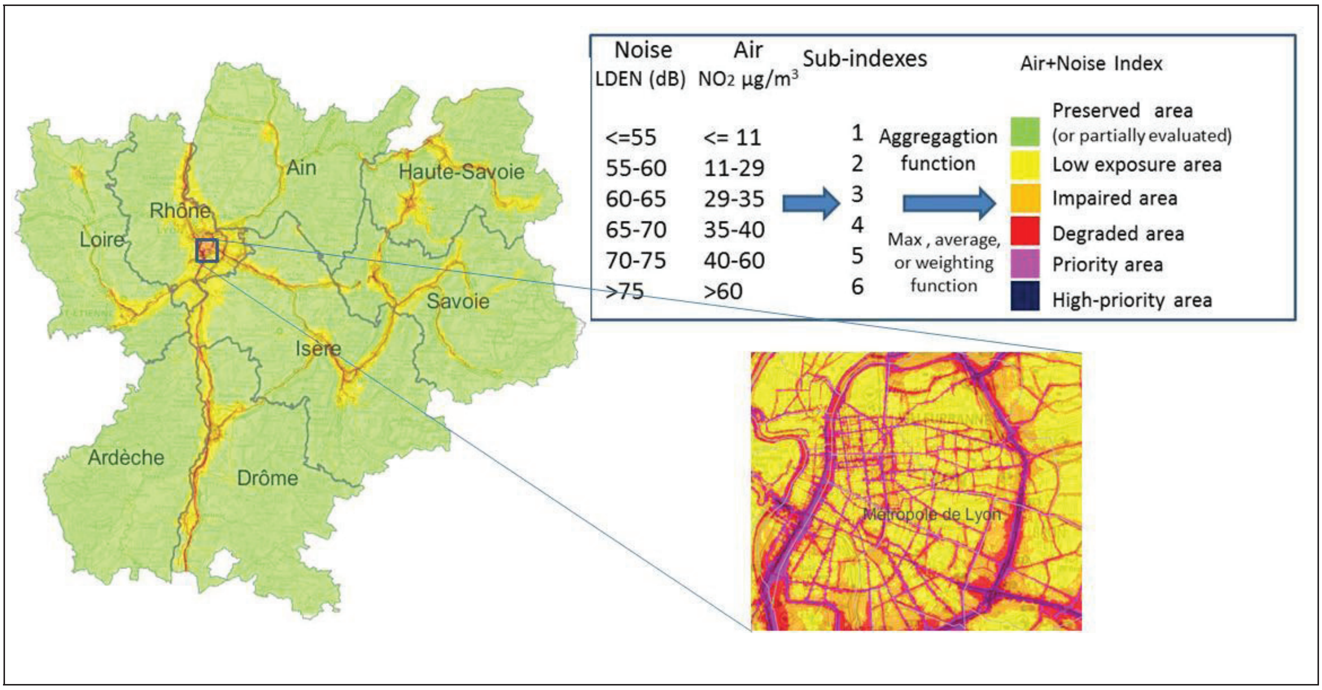

Figure 1. "Air+Noise" co-exposure index mapping computed over Région Rhône-Alpes including road traffic emissions (LDEN+NO2 concentrations). Here the co-exposure index computed on a 10X10m² resolution grid, is the average of both noise and air sub-indexes.

2. Joint "Air and Noise" strategic maps

Many efforts have been made by the European Union member states to produce strategic noise maps of the most emitting transport infrastructure and industries. Even if noise annoyance are mainly perceived at a very local level, the resulting acoustic environment is also closely related to the public policy implementation related to the planning, development of transport networks. The spatial scales involved are significantly larger and there is a need for reliable and homogeneous information at each relevant level.

In addition, assessing the quality of the life needs to account for the priority environmental burdens that can interact with each other. Beyond noise issue, transport is for instance, inseparable from air pollution. That's why diagnosis and land planning tools should contribute to the overall assessment using a systemic approach.

Since 2010, as part of Regional Health and Environment Program of the Rhône-Alpes region, an integrated data platform, called "ORHANE" (RHône-Alpine Observatory of Environmental Nuisances), is being worked out.

The first initial objective of the project was to bring together all geographic thematic layers needed to compute noise and air pollution maps. These layers refer to transportation sources characteristics: geometry, traffic (flow, speed, heavy trucks' ratio…), and nature of road surfaces; the description of the 3D environment (topography, land cover, buildings, noise barriers…); population distributed in the building thematic layer. Meteorological data have also been included for pollutant dispersion modeling purpose.

A collaborative work, conducted with local and state authorities, infrastructure managers, has led to the collection and standardization of data on the whole territory (43,698 km² and 6,341,000 inhabitants). Consistent noise and air pollution maps were finally computed using exactly the same emission sources. The methodology used is fully compatible with the European Directives requirements (Miège, et al., 2012).

The second objective of ORHANE is to address the question of co-exposure to both air and noise pollution. Involved in cardiovascular, respiratory diseases or lung cancer (WHO, 2013), air pollution is a major environmental risk to health. The extra-auditory effects of long-term noise exposure are also well established and beyond annoyance and sleep disturbance, ambient noise even at moderate level, can increase the risk of cardiovascular diseases. In a recent paper, the

World Health Organization (WHO, 2011), suggests the use of exposure-response relationships for "assisting policy-makers in quantifying the health impacts of environmental noise".

It is a fact that societal concern for multiple exposures to physical and chemical agents is growing with health and environmental awareness. Spotting most impaired area is therefore a first step while evaluating and prioritizing mitigation actions. Another challenge is to improved knowledge of combined health effects of air and noise pollution. Recent reviews and studies (Laszlo, et al., 2012) (Sorensen, et al., 2014) have shown that cumulative or synergistic risks may exist regarding cardiovascular disease or (ischemic) stroke, but evidence needs to be confirmed and long-term quality environmental data can help to reduce statistical bias used in cohort studies.

Keeping this goal in mind, but with no intention to prematurely propose a "composite health index", air and noise maps computed in ORHANE have been mixed together to produce a co-exposure index. The first step was to mark, noise levels and pollutants concentrations onto a high-resolution common grid (10X10m²). This size is considered as "reasonable" regarding both models uncertainties and still compatible with the aim of detecting air plus noise black spots. It can be noticed that the noise modeling program used in ORHANE (Mithra-SIG, http://www.cstb.fr/), allows the computation noise levels at higher resolution and on building facades. These data are saved in specific geographical layers for further analysis or detailed investigations (see §3).

The construction of the current co-exposure index is based on the conversion of noise indicators (L_{den}) and pollutant concentrations on a common 6-step value scale. This operation leads to two thematic maps of sub-indexes (fig. 1). The closed scale goes from "very low exposure (or not evaluated)" to "High priority area". The middle class "degraded area" is based on the regulatory values: 40 µg/m3 is the limit value for the annual dioxide nitrogen concentration, and 68 dB(A) being the limit value for noise. Note that the 5 dB(A) classes for noise is used to keep coherency with strategic noise maps.

Moreover, the acoustic model is not able to estimate low noise levels with accuracy as background noise is not accounted for. That's why the first class of the noise sub-index gathers L_{DEN} standing below 55 dB(A) and non-computed values. As regards NO_2 pollutant, a background concentration is added all over the region.

Finally the co-exposure index is computed by aggregating air and noise sub-indexes. This is the tricky part of method since the aggregate function can strongly influence the weight given to one nuisance or another and consequently the reading of environmental issues. For instance, using a max function, as it is done with Air Pollution Indexes (API), will enlighten most impaired areas for one pollution, whereas averaging indexes will give more weight to bi-exposed zones.

It was decided, at this stage, not to differently weight sub-indexes with health considerations, introducing, for instance, DALY (disability-adjusted life year). The two main reasons have guided this choice: first, it is a way to keep attention of final users (policy-makers, scientists,…) on both air and noise topics; second, in the current state of knowledge regarding combined health effects, weighting could prejudge of potential (or absence of) interactions.

This is why the results should be interpreted as a first "strategic" representation of territorial issues more than a direct mean to estimate of health risks. However, this kind of mapping can be advantageously used to guide finer health studies trying to objectify the effects of co-exposure.

Thanks to this new representation, local actors benefit from an enriched information, providing an additional level of contrast between the mono- and bi-exposed areas. Nevertheless for the diagnosis to be more comprehensible, secondary decision-tools deserve to be derived from these big-data mapping.

3. Alternate indexes for from statistical map analysis

In order to synthesize the large amount of data produced with ORHANE, on a conurbation such as the Metropolis of Lyon, new indexes have been proposed at the city scale. On the basis of the strategic maps presented below, and reduced here to noise topic, and using a statistical analysis, three kind of acoustical indexes have been built and estimated for each township. All the three indexes are homogeneous to noise level and reported on a five-step value scale going from <50 dB(A) to >65 dB(A) per 5 dB(A).

The first statistical index is elaborated from the average surface noise levels on each municipality (fig. 2). This index mapping underlines the density and intensity of the sources in sub-areas. The very center of Lyon, the Presqu'île district and the Rhone-Saone Confluence sectors to the west are clearly distinguished from peripheral areas on which the transport infrastructure network is significantly less dense. This first index can be read as a macroscopic indicator of quietest areas density (reduced to traffic noise considerations here).

For the second index, the average of noise levels computed on residential building facades is depicted (fig. 2). The resulting map highlights (in red and purple) situations of proximity between the townships and the built environment. This is particularly the case for the boroughs of the city of Lyon and the surrounding municipalities with dense urbanism. The index 2 can also be used to estimate the macroscopic sound insulation costs according to the average exposure noise levels.

Adding the population criterion (index 3), provides an additional level of contrast and it highlights territories sharing important sound sources, high building and population densities (see fig. 4): the vertical density of residential buildings from in the center of Lyon and surrounding towns, such as Villeurbanne and Bron, leads to higher indexes, greater than 65dB(A) per inhabitant.

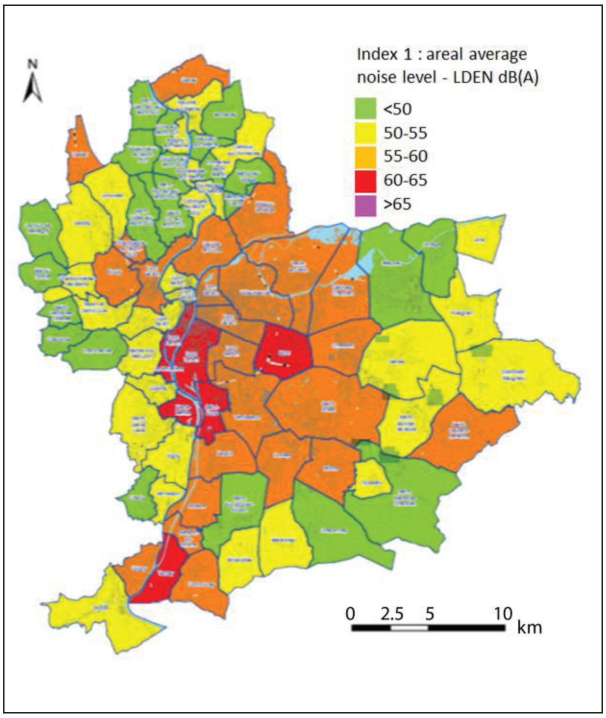

Figure 2. "Surfacic noise index" computed for the 59 townships of the Metropolis of Lyon.

From a refine statistical analysis of all the territories, it is possible to classify the conurbation in different key pointers for analyzing the situations. For example, considering 58 towns or districts in the test area, it appears that 25 of them can claim for residential buildings and people exposed to noise levels below 30 dB(A). Conversely, other municipalities lack habitat or population in very quiet areas. Such classifications can be a valuable decision support and help to prioritize actions.

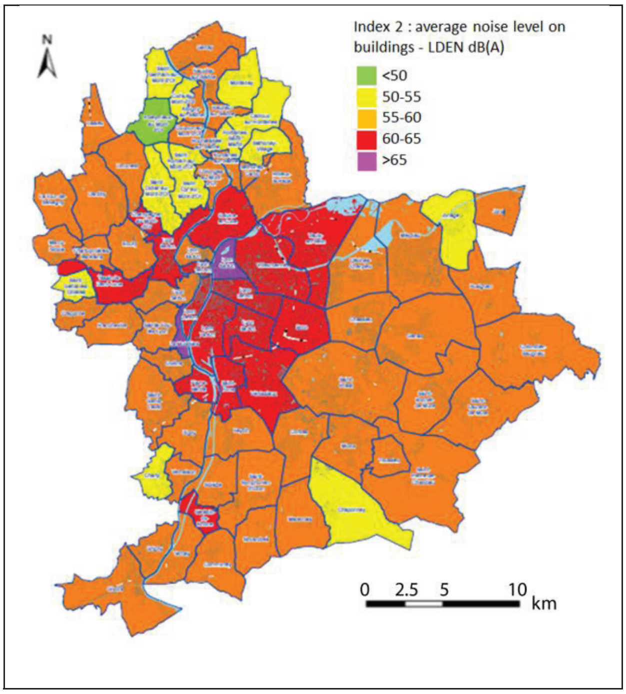

Figure 3. "Noise level per building index"

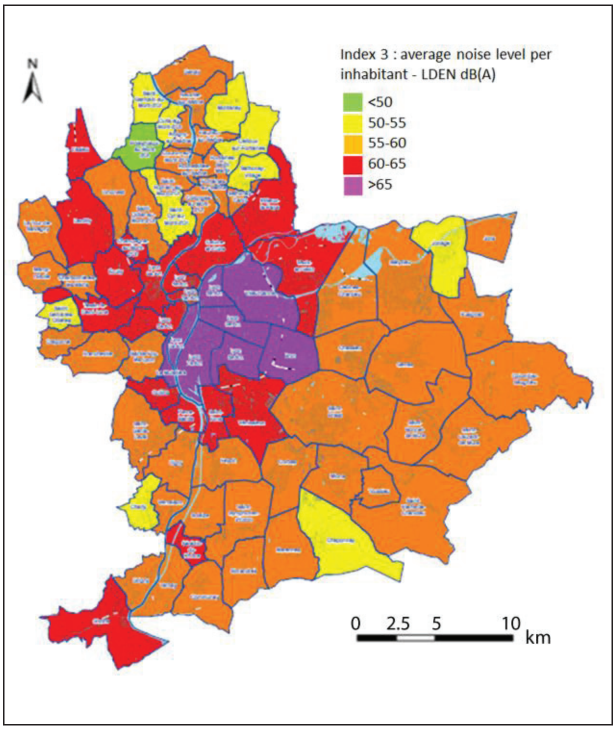

Figure 4. "Noise level per inhabitant" index computed

4. Population mobility and exposure

Strategic mapping is generally associated with a "static" representation of the environment: sources are described from their annual average daily emission properties (traffic in our case) and the population is located hundred percent of the time in housing. In an attempt to approach a more accurate estimation of exposure an experiment based on the use of the 2006 household travel survey of the Grand Lyon was conducted (Golay *et al*., 2014). Hourly dynamic population density maps, characterizing the mobility of people on a representative week have been built (CERTU/CETE DE LYON, 2013). From these density maps people were statistically reallocated in dwellings and their hourly exposure to air pollution was estimated. For this study, the data crossing was done with nitrogen dioxide and fine particulate matter (PM10) concentrations modeled with an hourly time step reported on a 10x10m² mesh covering a 900 km² area. Contrary to ambient noise, air pollution phenomenon is very sensitive to atmospheric conditions and pollutant emissions and concentrations may strongly vary over the day and from one day to another.

The results showed that for certain sub-areas, the results from the static and dynamic approaches differ greatly. The conjunction of increased road traffic and population in some areas during the day (commercial or business poles) can lead to underestimate a pollutionXpopulation indicator by a factor of 3. The same exercise could be done with ambient noise, using for instance the calculated sound levels on the day-evening and night periods.

This kind of study is especially interesting when dealing with environmental evaluation of transport or land plans. It can bring valuation indicators on the consequences of urban sprawl, and guide the development of efficient intermodal transport strategies taking into account environmental and health concerns.

5. Microscopic modeling

Once the "strategic" diagnosis, as presented above has been achieved, it is necessary to get down to a more "local" level to refine exposure assessment and mitigations measures. This downscaling process may deal with both spatial and temporal scale. This last dimension is especially important in urban areas when noise abatement strategies are based on the modification of traffic conditions (regulation) such as: change of speed limit, modified road network capacity, sharing of urban roadways among the various transport modes,…

These actions have direct impacts on the acoustic emissions that are not always easily assessed with regulatory models and indicators (L_{den}, L_{Aeq}).

For instance, changes in fire cycles can significantly affect the dynamics and perception of the ambient noise, without significantly altering the L_{Aeq} over a period of several hours (Leclercq, et al., 2008). In this case microscopic dynamic traffic modeling, coupled with an acoustic model can be advantageously used to objectify and predict these effects (Can, Leclercq, & Lelong, 2008). It is then possible to simulate the characteristics of cycles the flow of traffic and events, which are all factors that influence the perception and appreciation of the environment.

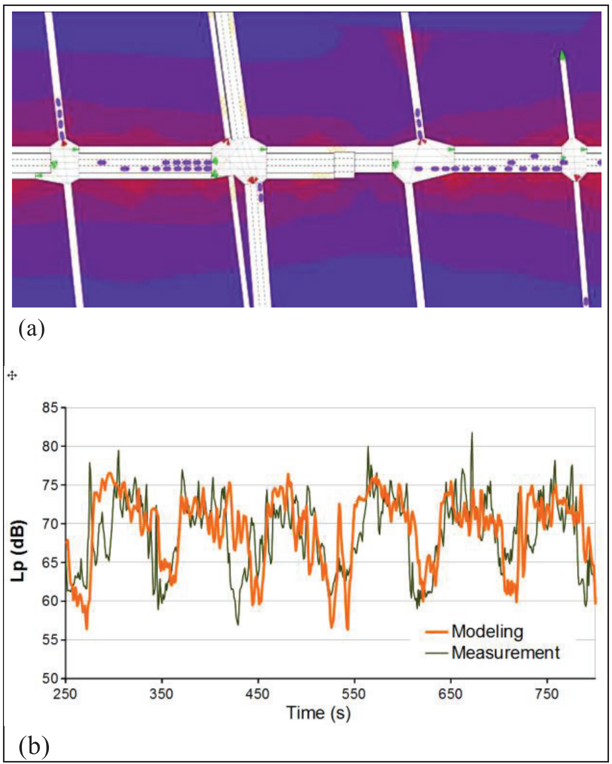

Figure 5. (a) Screenshot of a dynamic noise modeling (Leclercq, et al., 2008); (b) Comparison between computed and measured noise levels (1s time step)

The relative complexity of dynamic traffic modeling and the amount of data to interpret limit the use of these methods to neighborhoods or in the vicinity of structuring roads. However, the information obtained occasionally considerably enriched the analysis of the acoustic environment and contributes to better communication on the resulting ambient noise. Figure 5 (b) shows compared modeling and measurements obtained

on a structuring axis of Lyon (Cours Lafayette) using SYMUBRUIT (ENTPE/IFSTTAR) for the traffic model, and OASIS® (CSTB) for the emission and propagation models. The noise simulation results from the individual emissions of vehicles modeled as moving sources and are subject to traffic conditions (fires, congestions…).
The model is able to catch the main acoustic periodicities of events (stop and go due to fire cycles), and statistic noise indicators such as L_{10} or L_{90} (10 and 90 percent exceeded levels) were estimated, in this case, with an accuracy close to 2 dB(A).
Beyond urban planning aspects, this kind of modeling could be of real interest for improving the knowledge of relationships between noise and health effects.

6. Conclusion

To understand the complex links between transport, environmental pollution and health, it appears necessary to have a set of tools, and indicators for each geographic scale and each end-user (policy-makers, scientific community…). Through the examples presented in this paper, the interest to develop a multi-disciplinary "air-noise" approach was highlighted, as well as the opportunity to improve the knowledge of exposure by adding the temporal dimensions (mobility of people or fine modeling of noise levels).

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