Open-source software tools for strategic noise mapping: a case study

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Abstract. Currently, the European Union has adopted a series of measures to combat noise problems, focusing on some key indicators, such as the daily and night level of noise. Among the possible actions to manage environmental noise, there are the creation of noise maps and the adoption of action plans. Noise maps are, usually, produced by modelling and simulating data relating to traffic and various activities of an area. However, in some cases, these input data are not available or it is not possible to include all noise sources in the models used, causing difficulties in the prediction and analysis of the environmental impacts of noise. In this paper, starting from the analysis of open-source software tools for data collection, noise modelling and mapping, i.e. OpenstreetMap, NoiseModelling and QGIS, based on free and public licenses, a methodology for the creation of noise maps will be presented. Finally, the outputs of the application of the methodology to the city centre of the Municipality of Nocera Inferiore, in south Italy, will be the creation of noise maps characterized by the spatial representation of the main standard noise indicators.

1. Introduction

The European Environment Agency recognizes acoustic noise has one of the main hazards for human health in urban areas. It is estimated that more than 100 million people are daily exposed to dangerous noise levels [1]. In 2002, the EU issued the Environmental Noise Directive 2002/49/EC [2] in which, among the others, the countries are obliged to draw strategic noise maps in each city exceeding 250,000 inhabitants, for all major roads which have more than six million vehicle passages a year, major railways airports within their territories. For the purpose of noise management and reduction [3], beside spot noise level measurements to be collected with proper observation time [4, 5], the adoption of predictive software is allowed.

Beside the several statistical models [6], also more advanced techniques can be implemented [7], such as, for instance, stochastic and Poisson processes [8] and cellular automata [9]. Usually, these models require in input several features of the noise sources occurring in the areas, such as road traffic, that is generally considered as the main source in urban zones [10]. These inputs can be provided by means of video processing, both automatic [11] and manually [12, 13], or by statistical analysis [14]. In some application, crowdsourced data can be used to feed the models [15, 16]. The crowdsourcing process has some criticism related to the quality of the data [17, 18] but, when validated with standard measurement processes or with reliable data sources, it becomes a relevant tool for input collection, that can be implemented in geographic information systems (GIS), and can be provided to policy maker for influencing the mitigation actions design and implementation [19, 20].
In this paper, the importance of Open Data License (ODbL) software tools in noise mapping will be discussed, reporting a methodological approach and a case study example. The different input sources will be presented, both crowdsourced and from municipal technical office support. The cleaning of opensource maps will be presented, as well as the import process in a predictive software for environmental noise levels. Finally, the implementation of noise maps in free and open-source GIS platform. Results will show how a correct methodology, based on free-to-access and opensource software tools, can provide reliable noise maps in urban areas, to be used for controlling the existing sources and for designing proper mitigation actions, as well as new transportation infrastructures and other potential noise sources.

2. Material and methods

2.1. Software tools for noise mapping

The software adopted in this paper (OpenStreetmap, NoiseModelling and QuantumGis) for the data acquisition, noise level calculation and creation of noise maps are all open-source and freeware, characterized by Open Data and General Public Licenses.

Open Source Software (OSS), generally, are characterized by licenses with a wide range of capabilities. Their applicability in producing and representing geographic information allows people to participate in the creation of contents, modify data and information, combine data from different sources and produce new ones. These types of tools, based on Volunteered Geographic Information (VGI) acquisition, can be considered an alternative or a support for the validation of maps produced by official bodies or for the creation of updated versions at no cost. Despite the quality and reliability of this kind of information are discussed in [15, 16], the main advantages of the voluntary geographic data are the potential global coverage, their representation in georeferenced maps and their use by groups of citizens and public administrations for the definition of a spatial strategy or vision and the support to public decisions [21, 22].

The georeferenced maps are downloaded from OpenStreetMap® and distributed according to the “Open Data Commons—Open Database License” (ODbL) from the OpenStreetMap Foundation (OSMF). In particular, the license is the “Creative Common Attribution-ShareAlike 2.0 Generic” (CC BY-SA 2.0). OpenStreetMap is a collaborative project, in which the users share, create, adapt and, generally, contribute to the map data, as well as in the wiki and in the forums of the project. The websites and the infrastructure are maintained by a group of volunteers [23]. Maps created by OpenStreeMap contains several information about roads, paths, railway stations and buildings around the world.

The elements of OSM database consist of points (nodes), lines (ways), polygons, described by at least one attribute, and relations, necessary to define complex objects. OSM attributes are known as tags, characterized by the combination of keys and values: for example, a motorway can be tagged in OSM with “highway” for the key and “motorway” for the value (“highway=motorway”), in addition to optional tags related to its intrinsic features, such as its width, number of lanes or maximum speed [22]. The contributors may use the tags listed in [24] or add new values.

The OSM tools allow a simple and functional data collection with the use of smartphone applications or field papers [25] and data exporting using the “Export” button from the OSM homepage [23], the API Overpass [26] and, finally, from other websites whose sources are linked to the main OSM platform, such as GeoFabrik [27] and Planet OSM [28].

In order to produce noise maps, the free and open-source tool, NoiseModelling [29], can be used. It belongs to an integrated platform for the acquisition, modelling and evaluation of environmental noise, called Noise-Planet project [30], designed by two French research teams: the Environmental Acoustics Laboratory (Eiffel University, former IFSTTAR) for environmental noise research and the DECIDE Team (Lab-STICC - CNRS UMR) for GIScience. In this project, the data are collected from the free and open-source Android NoiseCapture application, shared from the OnoM@p Spatial Data
Infrastructure (SDI) [31, 32] and NoiseModelling, allows the design of noise maps based on the CNOSSOS-EU standard method for the noise emission (only road traffic) and propagation. [33].

This GIS plugin is distributed under a free and copyleft general public license (GPL3). In order to handle a large amount of spatial features, it connects to a spatial database H2GIS or PostGIS, which must be hosted by a GeoServer. The communication between the GeoServer and NoiseModelling can be operated from a user-friendly WPSBuilder (Web Processing Services Builder) web interface, based on the creation of graphical process workflows that can be easily executed and reproduced [34].

To compute a noise map, different layers must be uploaded (i.e.: Buildings, Roads, Ground type, Topography and Receivers). Then, it is possible to run the calculation of the noise levels and export the output table, for example, in shp format, that can be read with many GIS tools.

Finally, it is possible to visualize noise maps in a GIS environment. There are several free and open source GIS user interfaces, mostly similar each other. The one used for the applications in this paper is Quantum GIS (QGIS), that is an official project of the Open Source Geospatial Foundation (OSGeo). It runs on Linux, Unix, Mac OSX, Windows and Android and supports numerous vector, raster, and database formats and functionalities. For example, it can display and overlay vectors and rasters of different formats and with different projections, without the need for any format conversion, allows the creation of maps, the analysis of spatial data through the graphical interface that offers a variety of tools, and the publication of the data on the internet using a webserver [35].

2.2. Methodology

In order to create noise maps with the use of open source tools, a methodology, organized in three phases, can be proposed, as shown in figure 1.

Defined the area of interest, the first phase regards the data acquisition, that can be implemented through crowdsourced data collection or official information acquired from public and private entities and technical offices.

Phase 2 is developed in the WPSBuilder platform. It is characterized by two alternative procedures, in relation to the type of available data.

In the first alternative, the database is composed exclusively by the data downloaded from OpenStreetMap platform. For the creation of noise maps, it is necessary to choose the transport map and import it in WPSBuilder, as it contains information related to roads, buildings and ground type. At this point, it is possible to associate the sound power level to the roads, using the Road_Emission_From_Traffic Tool. The output data corresponds to a table called LW_ROADS, that shows the sound power levels on site of a (moving or constant) point source, for different frequency levels and for the different time bands considered. The values obtained are in accordance with the emission laws of the CNOSSOS model [33]. After defining the positions of the points of the receivers, the noise propagation from the source to the receiver is computed using the Noise_Level_From_Source tool. This block generates a receiver grid corresponding to four noise levels: L_{day}, L_{evening}, L_{night} and L_{den}. Specifically, they represent the standard noise descriptors for road, rail and industrial noise, expressed in dBA, i.e. the A-weighted long-term average sound level determined over all the day, evening and night periods of a year (L_{den}), and the day-time (L_{day}), evening-time (L_{evening}) and night-time (L_{night}) noise indicators determined respectively over the day, evening and night periods of a year. Then, it is possible to create a level interpolation between the points of the receiver grid and the result is a map,

In the second procedure of the phase 2 of the methodology, the database is made of official shape files of roads, buildings and ground, suitably modified, and the Digital Elevation Model (DEM), that are, generally, produced by public administrations or other entities. This procedure is similar to the first alternative, except in the first two steps, where the three above mentioned shape files and the DEM are now necessary.

After having exported the results of the phase 2, the third phase consists in their implementation and display in a GIS environment, with the appropriate categorization of the Noise Level and Contouring Noise Maps relating to main noise descriptors.
2.3. Case study

The methodology presented in the previous subsection has been applied to the case study of the city of Nocera Inferiore (south Italy). This city is a medium size municipality, with an overall area of about 20.85 km² and 44,969 inhabitants, according to 2019 census [36]. The geographical position of this city is strategic, since it is located in between Napoli and Salerno, that are the two main cities of Campania Region (figure 2). This position, as well as the presence in downtown of all the major facilities and services (secondary schools, hospital, court and shops), influences the road traffic volume. In particular, downtown is affected by very large traffic volumes, for both for light and heavy vehicles, compared to the city surface. This consideration, together with the high density of population, suggests focusing on the downtown of the city and makes the case study very interesting for noise mapping purposes. For this reason, the simulations have been restricted to the centre of the city, neglecting what happen in the suburbs, that is mainly countryside with agriculture activities.

The municipality local administration funded a field measurement campaign for traffic flows and volumes in critical points of the city downtown, during specific time window. Results are reported in the simulation model described in the Urban Mobility Plan [37]. A map of the measurement points is reported in figure 3. Since only the major roads have been investigated with traffic measurements, local roads volumes have been fixed with standard and reasonable day, evening and night traffic volumes, according to the class of the roads. These datasets have been used in input of the noise predictive software during simulation 2, together with the information coming from OpenStreetMap about roads.
3. Results and discussion

The results of the methodology presented in previous subsections applied to the case study are presented in this section.

The NoiseModelling software automatically produced noise maps of $L_{\text{day}}$, $L_{\text{evening}}$, $L_{\text{night}}$ and $L_{\text{den}}$. As indicated in the previous section, the emission model of the implemented traffic is the CNOSSOS-EU model [33]. For the sake of brevity, in this paper the authors will report only results related to $L_{\text{night}}$ and $L_{\text{den}}$, that are selected as main environmental noise descriptors.

As already mentioned in the methodology subsection, the first simulation is obtained feeding the model with the data coming from OpenStreetMap file. Since data are freely uploaded by different registered users, as vehicles drivers, road hauler, pedestrians who are travelling along the area, it contains several information about roads, paths, railway stations and buildings. Anyway, this information is not fully reliable.

Results for $L_{\text{night}}$ and $L_{\text{den}}$ are reported respectively in figure 4(a) and 4(b). Each map is categorized into 11 classes of different ranges, in dBA, represented on the map with different colors. The lower class refers to values less than 35 dBA and it is graphically represented with the white color. The
higher class is represented in blue and includes values greater than 85 dBA. The other 9 intermediate classes have been defined with an equal width of 5 dBA and the range of colors varies from light green to orange and then to red according to the increasing of the value.

The results for $L_{\text{night}}$ (Fig 4(a)) show that noise emissions along most of the roads in the study area are higher than the night-time guideline value of 45 dBA, recommended by the WHO [38], and most of residents may be experiencing various adverse health effects, for example sleep disturbance, due to high levels of night-time noise exposure. On the map, it is very easy to appreciate immediately the overcoming of the threshold recommended value. Indeed, great part of the area surrounding the city center (in grey) is depicted in orange and blue. Green areas, with low levels, fall in the suburban part of the city far from the main roads and with less density of buildings.

The results for $L_{\text{den}}$ (Fig 4(b)) show how during daytime the general condition gets worse and noise emissions diffusively exceed 55 dBA, that is the EU threshold for excess exposure defined in the Environmental Noise Directive [1]. This indicates that noise emissions in this area are possibly affecting people quality of life.

From the analysis of the results and the comparison between OpenStreetMap data and the information related to critical points of the city reported in the Urban Mobility Plan, various anomalies can be found with reference to the traffic volume in some roads, the heavy vehicles and the characterization of some road pavements. All these differences can influence the results. For this reason, in order to refine results and to achieve a better modelling of the case study, simulation 2 is obtained only implementing the data coming from the official documents recalled in subsection 2.3, i.e. the documents produced during the field measurement campaign of the traffic volumes. Results are reported in figure 5(a) and 5(b). The noise maps are very similar to the ones produced by simulation 1, even if they are more accurate thanks to a more reliable database. It can be appreciated a slight difference in terms of lower values in the second simulation. There is, in fact, a minor density of orange and red areas, due to higher traffic volumes in the first simulation data.

Of course, both these simulations represent an informative tool which can be useful to support the local authority in identifying susceptible areas and to address the noise abatement policies that need to be adopted in a near future, such as noise abatement action plans for the area.

![Figure 4](image-url)  
**Figure 4.** Simulation 1: (a) $L_{\text{night}}$, (b) $L_{\text{den}}$. Values are reported with A-weighting.
4. Conclusions

Starting from an open-source database and with the use of free and public licensed software tools, a methodology for the generation of noise maps was presented in this paper.

After having analyzed three different tools for data collection, noise modelling and mapping (OpenstreetMap, NoiseModelling and QGIS), it was possible to create different noise maps for the city center of the Municipality of Nocera Inferiore (south Italy).

Two simulations were carried out: the first one was based on voluntary geographic data collected by the OpenStreetMap platform and the second simulation was integrated by official data elaborated from local authorities. Since the results of the first simulation showed some anomalies in different critical points, the traffic flows and volume were compared with the official data of the Urban Mobility Plan in those points and, opportunely handled, became the integrated data of the second simulation.

In both cases, the data were processed using the open source WPSBuilder tool, that permitted the creation of noise maps, which were then implemented in the QGIS environment.

From the analysis of the obtained maps, characterized by the spatial representation of the main standard noise indicators, the most suitable interventions could be defined, such as, for example, the use of sound-absorbing floors or the installation of acoustic barriers in places where sound pressure levels remain high over time.

In addition, this study contributed to define indications and suggestions for both data acquisition and sharing. For example, a greater active involvement of volunteers in data acquisition could open interesting prospects for a large number of subjects, including public authorities, which could benefit from the enrichment of their databases. Furthermore, this could lead to a future scenario in which geographic and non-geographic information is continuously updated at no cost. In this scenario it is possible to witness a complete revolution in the role of the planners, who would be able to constantly analyze the available data. Consequently, a continuous support for design, spatial analysis and decision-making could be implemented with significant innovations in urban and regional planning methodologies.

In conclusion, further useful indications for monitoring the acoustic state of an area can be suggested, i.e. to incentivize the use of voluntary geographical maps in order to have the widest possible coverage of the territories, to ensure the presence of protocols for data creation, to encourage the integration of OSM data with official sources in order to have a reliable database and to encourage
public administrations to use open source tools in order to have a continuously updated database available for planning.

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