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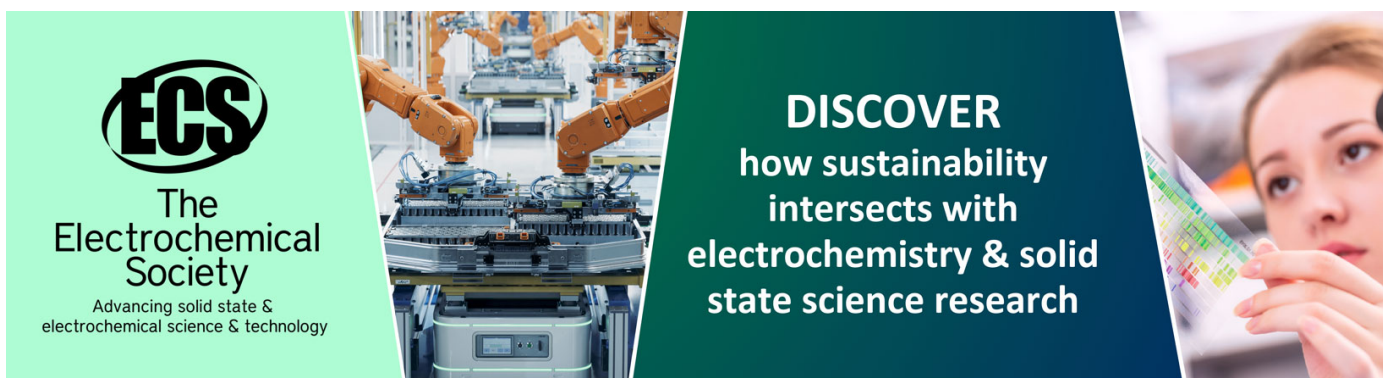
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Analysis of noise annoyance complaints in the city of Milan, Italy

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Abstract. The paper describes the analysis of noise annoyance complaints submitted by citizens to the Municipality of Milan, Italy, from years 2000 to 2015. These complaints have been organized in a database and analysed according to: i) types of noise sources (technical facilities, music, transport infrastructures, etc.), ii) activities (retail and catering businesses, production, service sector, etc.) and iii) outcomes of the complaints inspection by local authorities. In addition, by means of a Geographic Information System (GIS) software, the spatial distribution of complaints has been determined according to the noise source type and activities, including also a geo-statistical representation by complaints density maps. The results show that, despite the dominant noise source in urban areas is mainly the road traffic, the other noises, such as those from industrial facilities, constructions and social activities (parties, fairs and open air markets, residential noise, etc.), are perceived as more disturbing. Since 2007, the number of noise complaints (about 100-150 complaints/year) is almost constant across the years. However, these complaints are expected to increase due to the growing and spreading of leisure activities, malls, exhibition centres and event venues, observed for the years 2014-2015.

1. Introduction

Urban noise is generally regarded as an environmental stressor and the World Health Organization (WHO) declared noise as a pollutant [1], estimating that in the EU countries more than 80 million people are exposed to outdoor noise levels higher than 65 dB(A). In the same decade, the World Soundscape Project, stated the importance of improving the quality of the urban soundscape, due to the negative effects of noise pollution on human health [2]. The European Environmental Agency (EEA) remarked the importance of realizing spaces at low noise pollution (Quiet Areas) in large built-up areas to protect the population. Indeed, epidemiological studies have shown that noise exposure not only produces hearing damages, especially at workplace [3], but it is also related to diseases of the cardiovascular system [4, 5], of the digestive and endocrine systems, including also neural and behavioural disorders. Noise annoyance can have also serious physiological, psychological, and social consequences [6, 7], sleeping disorders being a further impact of noise exposure. All these harmful effects contribute deteriorate the health and quality of life [8, 9]. The concept of soundscape is focused on human experience of the acoustic environment, namely noise perception during daily activities, such as that at leisure-time, at home or at work [10, 11]. Transport noise (road, rail, and air) is the dominant source in



urban areas [6, 7, 12], and to control and predict it dynamic noise mapping and predictive models have been recently introduced [13-17] to provide a prompt tool to plan mitigation actions and a reliable representation of the traffic noise exposure. However, citizens are also exposed to other noise sources such as industrial facilities, construction and social activities [18, 19], once again causing significant effects on residents' health and well-being.

Noise complaints are spontaneous actions, individual or collective, due not only to the noise and the evoked annoyance, but also influenced by socio-economic factors, the person's feeling to have control of the stressor (i.e. noise), as well as the knowledge of an institution to which address the complaint and the expectation of a successful feedback. Complaint data are often used as an index of annoyance, but several studies have shown that only a small percentage of annoyed citizens actually take actions because of the moderating mechanisms between annoyance and complaining. Noise complaints are a very important issue to tackle for national and local policy makers and for all stakeholders involved in planning and management of noise mitigation actions. These data, even if are not so much available in the literature due to their sensitivity and privacy, are very important to infer the people reactions to noise exposure. For this purpose, the temporal and spatial analysis of registered noise complaints reported in the city of Milan by the citizens in the years between 2000 and 2015 have been performed and described in this paper.

2. Database of noise complaints

All the noise complaints data collected from the archive of the Municipality of Milan has been organized in a digital database organized into specific fields (locations of the receiver and the annoying source, details on the source, timeline of the procedure phases, remediation, etc.). Each complaint has been associated with an identity code, referring to the procedure start, for indexing and allow a quick retrieval and making easier the post-processing spatial analysis. The geo-statistical analysis (density maps) focused on the distribution of the complaints according to the type of the annoying source and activity. Considering the difficulty to get all the necessary information on the complaints before 2014, the data analysis for two year intervals (1999-2013 records available on paper; 2014-2015 digital records available) was performed with different degree of detail. The two digital databases (1999-2013 and 2014-2015) allowed performing a spatial analysis of the complaints by means of a geo-referenced software (GIS, Geographic Information System). The spatial analysis for the years 1999-2013, focused on the graphical representation of the distribution of complaints according to the type of annoying source and activity. A more accurate analysis has been performed for the years 2014-2015: in this case, the exact location of both the annoying sources and complainants were available. An analysis through a GIS software allowed to evaluate the spatial distribution of annoying sources and the geo-statistical distribution.

3. Trend of complaints for type of annoying source and activity

The trend of complaints across the years 2000-2015 depending on the type of annoying source is showed in Fig. 1. Most of the complaints are due to noise emissions of technical plants (air conditioning systems, cold store systems, industrial machines, etc.), sound equipment, activities linked to work operations (bays, construction or industrial handling vehicles, etc.). The number of complaints due to anthropic sources is rather limited. However, music and anthropic noises have increased during the last years, mainly because of the upsurge in public commercial establishments (pub, restaurant) with music entertainment in the city of Milan. The yearly trend shows a gradual reduction of the complaints (up to 30-60 complaints/year/source) due to a larger use of noise reduction actions, the displacement of most of annoying activities (such as production activities) from downtown to the suburbs and the entry into force of more restrictive regulations and laws.

Fig. 2 shows the trend of complaints depending on the type of reported annoying activities for the years 2000-2015. Most of the complaints are related to public commercial activities, while industrial activities, crafting and service activities, even if important, do not contribute as much as public commercial ones do. This outcome is due to the displacement of high impact activities from downtown

to the outskirt of the city, encouraged by the Municipality. The number of activities related to “leisure time” shows a slightly increasing trend, most likely due to a greater interest of youngsters in such meeting places. In general, the yearly trend profile shows three stages: an initial one characterized by a limited number of complaints/year in which citizens start to contact the Municipality, an intermediate stage with a growing number of complaints/year, and a more recent one with an almost constant rate.

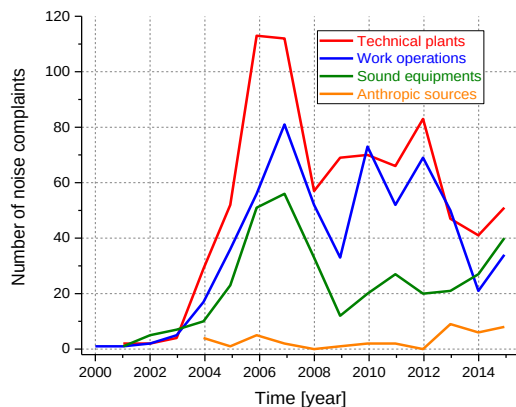


Figure 1: Trend of noise complaints due to the type of noise source.

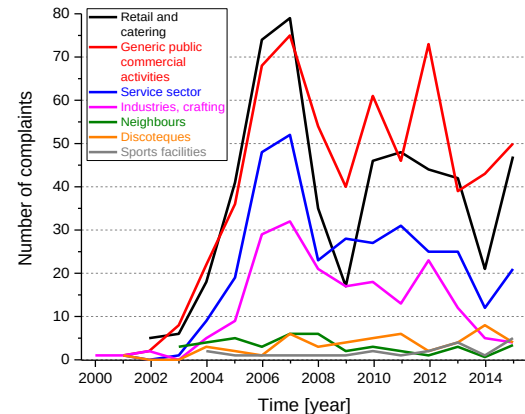


Figure 2: Trend of complaints due to the type of annoying activity (years 2000-2015).

The complaints data for the years 2014-2015 have been analysed also considering the outcome of the inspections by local authorities aimed to check the compliance with the noise limits issued by the Italian legislation. Among the 120 cases available for this analysis, the majority of them (75%) concerned the night-time period (Figure 3). It is interesting to point out that during day-time the noise limits exceedances have been observed in the majority of cases (78%) with windows open, most likely because the disturbing source is outside the annoyed house, while in the night-time the noise limits exceedances are more frequent (58%) with windows closed, most likely because the disturbing source is structurally linked to the annoyed house and/or low frequencies are predominant in the noise immission.

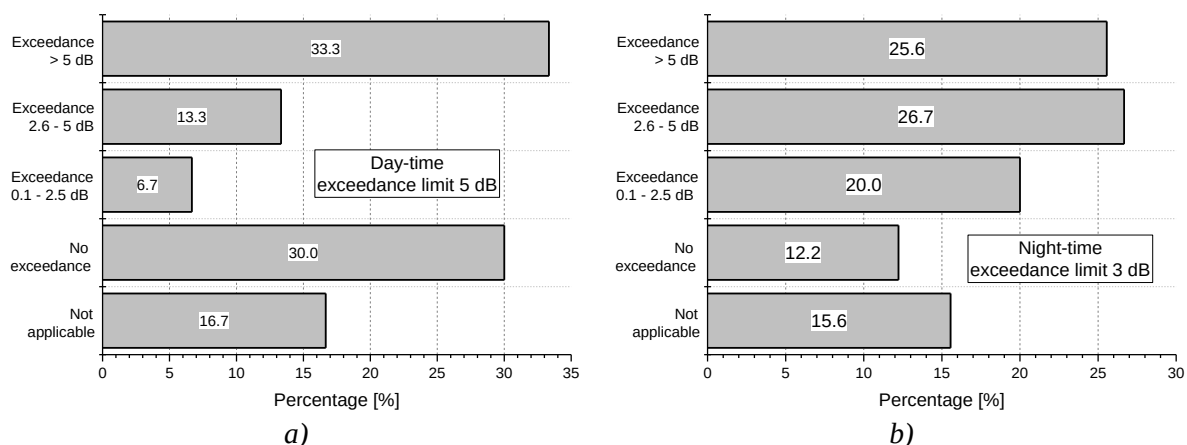


Figure 3: Exceedances of the noise limits resulted from the inspections by local authorities in the day-time a) and night-time b) periods.

4. Spatial Analysis

GIS technology has been used to describe the spatial distribution of the collected complaints through the years 2000-2015 according to the type of source and the noisy activities. Finally, GIS spatial analysis has been applied to calculate density maps, after the assignment of an identification code to each

complaint associated with its address. The most annoying sources, such as working activities, music and technical facilities are widespread within the city and show a spatial distribution in good agreement with the presence of commercial activities such as pubs, cafes, restaurants and shops, mainly concentrated in the central area of Milan. The anthropic noise, with the exception of few areas in the city centre, is mostly annoying in the peripheral areas; this geographical pattern is probably related to the presence of sport centers. Density maps (or hot spot maps) represent the magnitude of a phenomenon throughout the area according to a chromatic scale. Using the number of inhabitants per census area (minimum territorial unity used for census purposes and corresponding to a single district or aggregates) provided by ISTAT (National Institute of Statistics), it has been possible to calculate the density of complaints related to the population density. For the data clustering, a classification into five groups has been performed using the Jenks natural breaks optimization method for non-normal distributions [18 20]. This method identifies class intervals (bins) in the points of discontinuity of a series of values by seeking to minimize each class's average deviation from the class mean, while maximizing each class's deviation from the means of the other groups. In other words, the method seeks to reduce the variance within classes and maximize the variance among classes. Figure 4 shows the complaint density per number of inhabitants per census area (years: 2000-2015) divided into five classes. The range of each class refers to the logarithm of normalized complaints per number of inhabitants per census area. It also shows that the highest density of complaints is observed in the city "old town" centre. Moreover, there are other areas of high density of complaints close to the city's boundaries. For a deeper understanding of the real density distribution of complaints, a spatial analysis based on complainants' addresses has been performed. The map shown in Fig. 4 has been obtained through the use of the "Kernel Density Estimation" (KDE) tool, e.g. a non-parametric way to estimate the probability density function of a random variable and that allows to identify areas with high density of complaints (hot spots) [21, 22]. This geo-statistical technique, implemented in GIS packages, is widely applied in the geographic interpretation of social and economic phenomena, such as the car accidents [23] or the crime mapping [24], and it could be fruitfully used also for the purposes of this study. The KDE algorithm calculates the density of 'occurrences' around a given spatial interval. Therefore, the crucial phase of KDE analysis is the choice of the bandwidth, that is, the reference search radius for the interpretation of spatial correlation between points (complaints, in this case). Equation (1) has been used for the calculation of the Search Radius, SR [20]:

$$SR = 0.9 \cdot \sqrt{\frac{1}{\ln(2)}} \cdot D_m \cdot n^{-0.2} \quad [\text{m}] \quad (1)$$

where D_m is the median distance of all data with respect to the centroid of the statistical sample ($D_m = 676.1$ m) and n is the sample number ($n = 2151$, total number of complaints). The obtained SR was 628.75 m. Furthermore, in order to represent correctly the effective number of citizens affected by a noise source, different weight has been associated with each point: a weight "1" has been attributed to individual complaints, while a weight "2" to collective complaints. Figure 5 illustrates the density map of the noise complaints submitted to the municipality (years 2000-2015). The intervals refer to the number of complaints per unit surface (square km). Here, the results have been divided into 5 classes (density levels), with the exclusion of zero values, according to the Natural Break classification method (the Jenks algorithm) used for non-normal distributions. This method is based on natural groupings inherent in the data. Class breaks are identified that best group similar values and that maximize the differences between classes. This is done by seeking to minimize each class's average deviation from the class mean, while maximizing each class's deviation from the means of the other groups. In other words, the method seeks to reduce the variance within classes and maximize the variance between classes [25, 26]. As is apparent, Fig. 5 presents critical areas (red colour on the map) with two other smaller hot spots characterized by a number of complaints between 114 and 195 per square km. The identified areas are well-known noisy places with a high density of food and entertainment services related mainly to the nightlife. The anthropic night activity in these areas related to social gathering is also known as "movida".

5. Conclusions

The analysis of noise complaints submitted since 2000 allowed identifying the sources and activities indicated by citizens as responsible of noise annoyance, as well as the areas with major noise impact. An interesting result is that the noise from transport infrastructures, though widespread both in time and space, does not represent the main disturbing source perceived by the population in a large city, whereas technical plants, work/anthropic activities result to be the most frequent sources of complaints. Spreading of leisure activities, malls, exhibition centers and venues will likely determine a further increase of complaints in the next future. Thus, municipal authorities have to tackle with the protection of residents from noise exposure on one side, and managing the increasing demands of new activities.

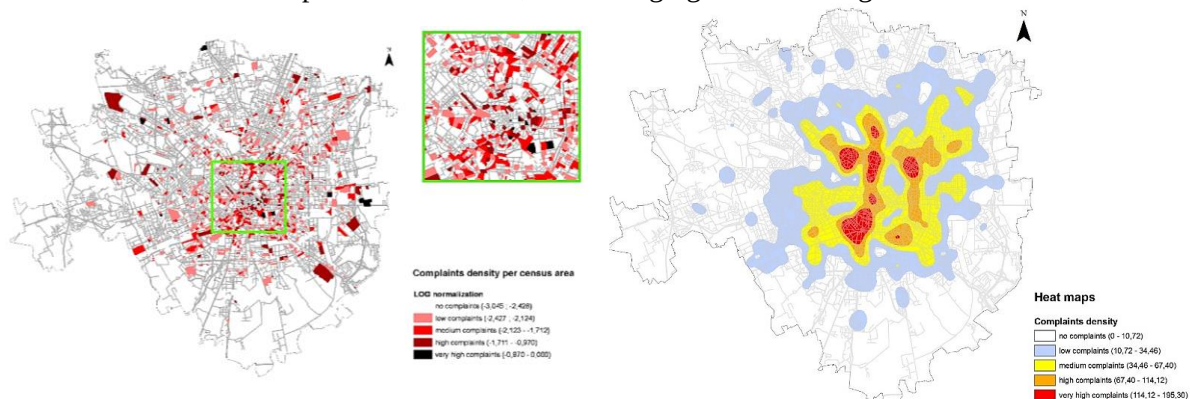


Figure 4: Complaint density per number of inhabitants per census area (years: 2000-2015) submitted to the municipality (years 2000-2015). The range of each class refers to the logarithm of normalized complaints per number of inhabitants per census area.

Figure 5: Density map of the noise complaints submitted to the municipality (years 2000-2015). The intervals refer to the number of complaints per unit surface (square km).

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