The use of VGI in noise mapping

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Abstract

The quality of the soundscape in urban spaces is significant for the total environment of a sustainable city. However, limited attention has been given to the acoustic environment of a city by planners. In Greece, research on this issue and its representation at the city scale has been conducted only in a limited number of large cities whereas in most of the cities and towns there is no available data.

The aim of this paper is to present an overview of a research about the monitoring of the urban acoustic environment affordably and reliably, and investigating the potential of VGI for such applications for typical medium-sized cities. This research is conducted as part of the ongoing Sustainable Urban Mobility Plans project (SUMPs), aiming to improve the urban landscape, increase quality of life and transform cities into more compact urban cores.

Once the urban design characteristics are listed by the experts, audio recordings are collected through crowdsourcing (using smart phones and apps) in several city spots, according to a grid-based sampling methodology. Then, a sound map is created using an Ordinary Kriging technique in GIS, while finally the collected noise data are imported in OpenStreetMap (OSM) by the volunteers. The methodology was tested in two Greek medium-sized city centers (Kozani, and Drama). The soundscape data were then assessed by taking into consideration the European and national legislation about the urban acoustic environment as well as the various characteristics of each case-study area.

As expected, results show that residents are exposed to high sound levels during the day. However, sound levels in car-free zones are considerably lower except from specific streets where motorcycles enter illegally (for delivery or freight purposes).

In overall, this research proved that there is a p[potential of using crowdsourcing technique to collect noise data and monitor the soundscape reliably and affordably. It is crucial for the municipalities to activate citizens in participating to urban renewal projects in main streets as well as in vulnerable city areas (i.e. neighborhoods, school zones) in order to raise awareness about noise maps and create a better acoustic environment. Through these case studies, this paper points out that crowdsourced noise mapping may be utilized as a reliable tool for participatory planning. The paper provides considerations about how the proposed methodology may be further tested and improved.

Keywords

Sustainable mobility, urban planning, acoustic environment, soundscape mapping, ordinary kriging method, Open Street Map, VGI, crowdsourcing.

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1. Considering new technologies for the recording of the sonic environment of the cities

Over 50 years have passed since Murray Schafer studied the influence of the sonic environment on people. However, the term "soundscape", which was used to explain the relation presented above (Rodriguez-Manzo, et.al., 2015 · Schulte-Fortkamp and Jordan, 2016), is still up-to-date. Another up-to-date issue has to do with the transformations of the soundscape. In contrast with the natural and urban environment where the differentiations could be easily understandable through aerial photography techniques of remote sensing and mapping tools, the investigation of the changes that occur in the soundscape (Schaffer, 1993) is not easy due to the fact that, in many areas, mappings of the soundscape are not carried out although they constitute usefulness for the evaluation of buildings and urban areas (Schulte-Fortkamp and Jordan, 2016).

The view of Maffei, et.al. (2012) and Margaritis, et.al.(2015) that the sonic environment did not consist of a significant parameter in the urban planning practice is well-founded even in Greece where the only official mapping of the soundscape has been carried out between 2012-2016 only in specific cities based on the 13586/724/2006 Joint Ministerial Decision (FEK B' 384) that harmonizes the European Directive 2002/49/EC (Vogiatzis and Remy,2017), aimed at confronting high levels of noise in cities using common ways for all the country members (Stoter, et.al., 2008 · Licitra and Memoli, 2008). However, these mapping projects do not constitute a complete representation of the sonic environment but only of the environmental noise [Strategic Noise Maps (S.N.M) and Noise Action Plans(N.A.P.)] (Directive 2002/49/EC), which is only a parameter of the sonic environment according to Rodriguez-Manzo et.al.(2015). The reason for interest in noise has to do with the fact that noise pollution is an essential problem in urban areas (Schweizer, et.al., 2011 · Pödör and Révész, 2014 · Pödör, et.al., 2015 · Rodriguez-Manzo, et.al., 2015 · Poslončec-Petrić, et.al., 2016 · Pödör and Zentai, 2017). Indeed, Vasilev (2017) points out that increase of the levels of noise (0,5-1,0 dBA) in the cities is a reality.

Regarding the measurement and monitoring of noise levels, different methodologies have been occasionally suggested. Such methodologies are noise recordings, population surveys and interviews, soundwalks and noise mapping (Rodriguez-Manzo, et.al., 2015 · Schulte-Fortkamp and Jordan, 2016). Even for individual procedures, different techniques have been proposed. In noise mapping, for instance, different methods and tools could be used (Bennett et al.,2010-Schulte-Fortkamp and Jordan,2016) for data collection and representation. Indeed, according to Schulte-Fortkamp and Jordan (2016), the natural conditions of a soundscape can be measured by using binaural recording devices or microphone arrays. Maps can be created by algorithms that produce maps based on estimations or by using measured data (Cho, et.al., 2007 · Stoter, et.al., 2008). In practice, due to high cost (Schweizer, et.al., 2011), local authorities choose to monitor soundscape by placing sensors in specific indicative points, that usually do not cover the total surface of a city. According to Aiello, et.al. (2016), this particular method is a result of the European Directive 2002/49/EC which requires European countries to monitor noise levels that were produced by specific sources (road traffic, railways, airports and industry). The same researchers (Aiello, et.al., 2016) point out that, due to many deficiencies observed, epidemiological models are occasionally used for estimating noise levels. These models are based on samples of small population or data derived from smartphones or social media, in order to decrease the cost of such researches. The researches of Podor and Revesz (2014), Podor et al. (2015) and Podor and Zentai (2017) converge to the same opinion and argue that is fundamental to use data derived from crowdsensoring and crowdsourcing for monitoring noise levels. That is why, according to the European Directive 2002/49/EC, noise maps must be renewed every 5 years something not easy taking into consideration the economic conditions of certain countries such as Hungary, to which these researches are referred, if the methods used are conventional.

During recent years, the European Commission has financed projects that are based on crowdsourcing in which people have been used as "sensors" (Podor, et.al., 2015). In these projects, people carry their smartphones that are personal devices equipped with applications that provide data without cost (Schweizer, et.al., 2011). According to Schweizer, et.al., 2011 the smartphones constitute ideal platforms for environmental data measurements because, beyond sound levels that are recorded by the microphone which is incorporated in the device, they are also equipped with GPS providing spatial information, at the same time.

The advantages of smartphones can be used in order for researchers to achieve goals like: (a) low-cost data collection process, (b) citizen's participation for improving the quality of urban environment and (c) constant monitoring of the soundscape, when people use applications providing real time data.

From the above, it can be concluded that the participation of people consists of a significant process on which this paper focuses. The reasons are: (a) volunteered participation is a necessary parameter in order to collect data with low-cost budget(Schulte-Fortkamp and Jordan, 2016), (b) volunteered participation has a great additional value as it constitutes a process that increases the geospatial maturity of the society to understand the design procedures and various planning matters (Athanasopoulos and Stratigea, 2015 · Bakogiannis, et.al., 2017) and (c) the participation of people is an example of direct democracy that seals the transparency and the social consensus through a structured dialogue procedure and interaction (Kyriakidis, 2012).

Based on the above, in this paper a methodology is proposed for noise data collection by volunteers who used a specific application in their smartphones. In the next unit, the testing of the proposed method for Kozani and Drama, Greece, is presented, in detail.

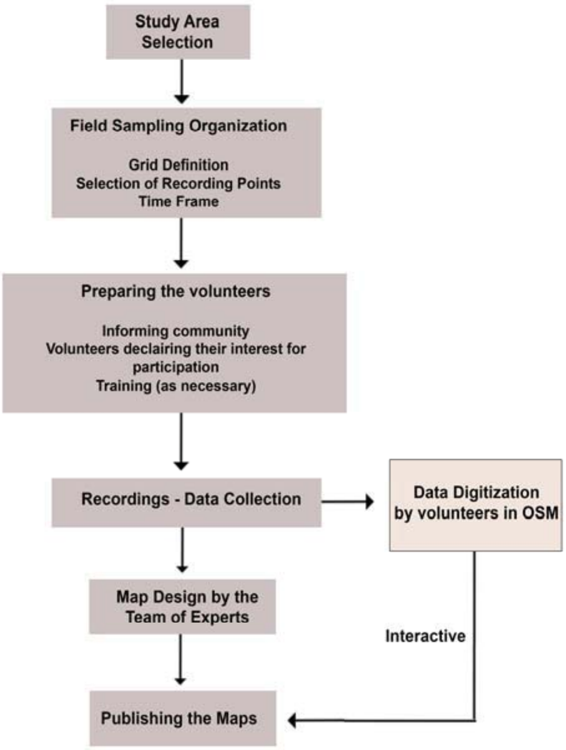

Fig. 1 Block diagram of the proposed methodology

2. Methodology

2.1. Aim and Objectives

Considering that noise mapping is required only for major cities of each EU member country, and considering the lack of financial resources of some EU states (e.g., Greece) to meet this requirement and to expand this practice to other cities (e.g., mid-sized cities), it is worthwhile questioning to what extent crowdsourcing technique could help to create noise maps for mid-sized cities. Thus, the aim of this paper is to develop a methodology for noise monitoring. This methodology should be easily applicable, reliable and cost-effective.

These case studies presented here are for Greece where Sustainable Urban Mobility Plans (SUMP) are implemented. The above research question is well-founded given the fact that the soundscape is essential for the promotion of well-combined urban and transport planning (e.g., reduction of noise levels in areas where it is particularly intense). Moreover, it could be used as an indicator for the SUMP by comparing the previous to the subsequent noise levels.

The main objectives of this study are to:

Examine if the results of surveys carried out by mobile equipment are satisfactory.

Promote the concept of open noise data as far as concerning the cities under study, by uploading them in the Open Street Map (OSM).

2.2. Proposed Methodology

In the literature (Rodriguez-Manzo, et.al., 2015 · Schulte-Fortkamp and Jordan, 2016), there are presented many ways for recording and mapping the cities' soundscape. Such examples are soundwalks, sound recordings and interviews with experts and locals. However, according to current research, participation of citizens consists of a usual process in smart cities' projects (Poslončec-Petrić, et.al., 2016).

This trend is related to the time-consuming process of traditional noise mapping as well as to the cost of its implementation. Indeed, the methodology which is normally used for producing strategic noise maps includes the existence of data-sets such as 3D digital ground models, city traffic models, train traffic models (in case a train station is located in the city under study) and the use of an ideal software for mapping the sound levels (Garai and Fattori, 2009). In many cities of Europe (e.g., most of the Greek cities) there are no available data of such type and their collection is costly. According to the Report "Best Practice in Strategic Noise Mapping" which was drawn up by the subgroup END noise mapping of the CEDR Project Group Road Noise 2 (2013), the cost of noise mapping is significant; an approximate estimation of the average total cost for noise mapping per km mapped is € 604.

In this research which was conducted on Kozani and Drama, a new methodology was used in order for mapping the noise in these two cities. The new methodology is graphically presented in Figure 1. Although this methodology differs from the one that is usually preferred, however, it could be an easily applicable and cost-effective alternative for monitoring noise, mainly in small and mid-sized cities. It is also important that through importing data into OSM it is possible to create an interactive noise map. The next step in this research will be to put in place a dynamic map in which the data collected by the residents through their smartphones will be presented simultaneously on the map. In that way, noise will be constantly monitored.

For the research in Kozani and Drama, the methodology was organized as presented below.

2.2.1. Study areas selection

The cities chosen for this research are medium-sized cities of Greece. Kozani is located in the Region of West Macedonia, Greece; and its population (2011 census) is 41.066 residents. Drama is located in the Region of Eastern Macedonia, Greece and Thrace; and its population (2011 census) is 44.823 residents. They were selected for this paper due to their common characteristics (e.g. they have almost the same population; their central districts have been developed without plan over the centuries; important roads are crossing at their central districts; their central districts mainly display analogous land use dispersion and clustering; Neither S.N.M. nor N.A.P. has been conducted for Kozani and Drama as they are medium-sized cities and there is no obligation to implement them, according to Dir. 2002/49/EC).

The study areas in these two cities involve a number of

central functions and a mix of land uses, with commercial, recreational and administration uses being dominant. These areas are expected to present several land use conflicts due to their functional centrality and the accumulation of high people-concentration especially at peak times.
Considering the above, central districts of Kozani and Drama were selected as study areas for the field research. Due to differences in the geography of these two cities, a different number of recordings has been conducted in each one (Figure 2).

2.2.2. Data collection

The data collection was carried out with the help of volunteers (crowdsourcing), who used their smartphones, following the paradigm of a series of similar surveys (Pödör and Révész, 2014; Garcia-Marti, 2014; Aletta, et.al., 2016). The volunteers participated in the research, upon invitation. Volunteers had no hearing or vision problems.
The chosen method conforms to that of systematic sampling, where sampling points are selected using a grid for selecting points. This method was used as it adequately and easily covers all study areas.
The grid dimensions for the calculation of the points in the two cities were defined as 200 x 200 m. separating the study areas in squares of 200 m. sides, analogous to the research by Margaritis et.al. (2015). The recording points were located at the center of the squares (as shown in Figure 2), where as in cases where measurements at the designated points were not possible due to physical and legal restrictions (e.g., buildings, private space etc.), closest points were selected.
The calculation and assessment process took place at different time periods for the two cities: March 2017 in Kozani and July 2017 in Drama (for one week in both cities). The volunteers (3 volunteers in each city) recorded noise levels (quantitative data) in the various sites for 2 minutes each, using the Sound Meter digital sound recorder, a free smartphone application. This application measures the sound level (or SPL), which is calculated from the following equation (Raymond, n.r.):

$$SPL = 20\log_{10}\left(\frac{P}{Pref}\right)$$

Where the variables stand for:
SPL = sound pressure level, decibels (db)
P = sound wave pressure, newtons/meter2
Pref = reference pressure or hearing threshold, newton/meter2

Duration of recordings was for 3-4 hours/day. The same process was repeated every day for a week. In order to reduce the chance of errors, during the first day of recordings, one member of the team of experts collects the data with the volunteers. Thus, it is possible to answer to any question as far as concerning the recording process. This process consists of a pilot study.
Volunteers also kept a draft calendar in which they reported the type of the sounds they heard (qualitative data) during the recording process.
These data were collected in order for the SUMPs of Kozani and Drama to be implemented. In this paper no reference is made to this data set because it focuses only in noise mapping. It should be noted that measurements were taken during both working and non-working hours. However, the analysis assessed measurements that were taken only in working hours because: (a) cities have more residents and visitors on the move during working hours, and (b) the areas under study are more congested at working hours and therefore noise levels are higher.

2.2.3. Noise maps Production

Upon completion of the field survey, the recordings were mapped using QGIS and ArcGIS software. Different software was used to produce maps in each city, as the cities were studied through different research programs. The maps produced included variables according to: (a) the average

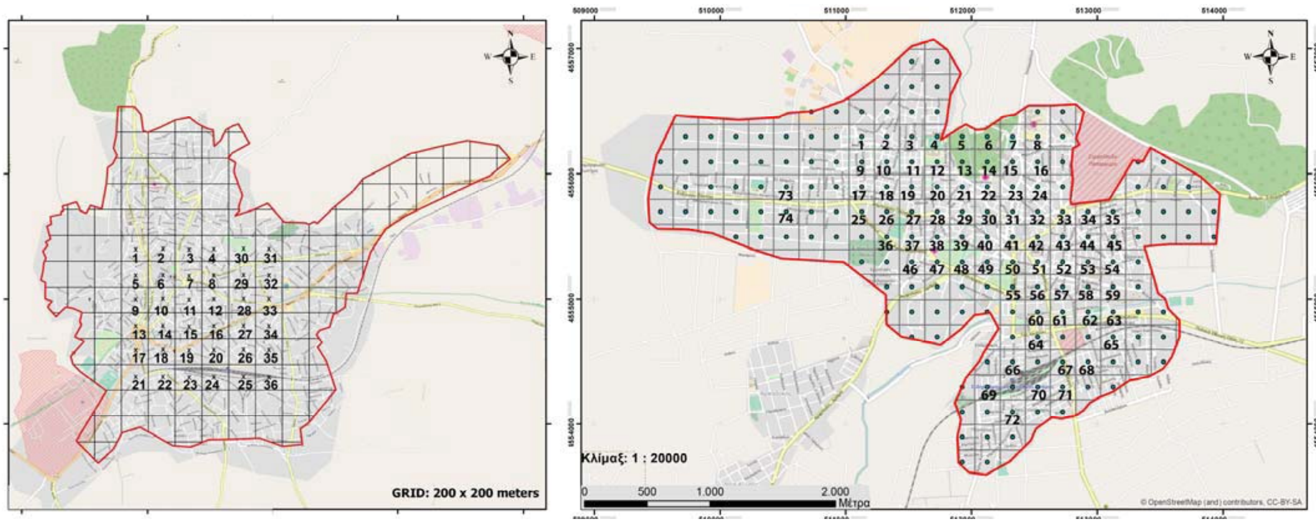

Fig. 2 Field sampling organization: Recording points in the study areas of Kozani (left) and Drama (right).

value of the recorded noise levels; (b) the minimum values; and (c) the peak values for the working hours.

The mapping process is usually implemented by using various interpolation techniques (Margaritis, et.al., 2015). Li and Heap (2008) present 26 interpolation techniques that are quite similar and can be performed for mapping processes. Geymen and Bostanci (2012) support that Inverse Distance Wight Method (IDW), Ordinary Kriging Method (OK) and Redial Basis Functions Method (RBF) are three useful methods for noise mapping, as they have selected these techniques for representation of noise values. Margaritis et.al. (2015) underline that Kriging and IDW techniques are the most widely known in the field of noise mapping. However, through literature review (Geymen and Bostanci, 2012 · Aletta and Kang, 2015 · Margaritis, et.al., 2015), it was concluded that the Kriging technique is a powerful method that is most often used. That was the reason why Kriging methodology was selected for mapping in this study. The 2D raster surfaces were created based on the OK Method considering all the points of each study area. Adobe Photoshop CC14 was also used for improving the aesthetic of the maps. The analysis and mapping process presented above was conducted by the team of experts who were coordinating the data collection process.

Finally, the maps were uploaded by volunteers in the Open Street Map platform in order to provide free access information for anyone interested. Due to the fact that volunteers were people with some technical skills, not much special training was necessary. However, in case volunteers need to be trained, a short training session could be organized in the initial stage of the field research. In this session instructions about the recording process should be given.

2.2.4. Limitations

Research limitations are mainly related to the time frame of the research. The field research has been conducted at different times for each city because each research was a part of SUMPs the time frames and the deadlines of which were different.

As for risk management, a moving vehicle could cause bodily injury and property damage to volunteers and researchers. Moreover, the volunteers had to conduct the research during spring and summer when the temperature is high and they had to be exposed in the sun for many hours a day.

3. Analysis and Results

Although the derived noise data were collected over a one week period in 2017 by volunteers who recorded noise at the street level, they gave us quite rational noise maps, as expected. On that basis, it could be supported that they are reliable enough to draw the conclusions presented below.

Using QGIS and ArcGIS, collected data were presented as a point feature layer. In order to realize where there is a spatial relationship among the values (minimum, maximum and mid values) represented by each point feature, the OK method was used. Figures 3 and 4 depict noise maps for each city studied (Kozani and Drama). The noise maps that were created by taking into account the mid values are the most important because they capture a more in-depth analysis by excluding extreme (min and max) values.

The results for Kozani could be concluded in these points:

- High intensity noise was noticed in Kozani averaging from 39 to 64 dB. As seen in Figure 3b, sounds recorded in a large part of the study area are higher than 55 Db; the noise level defined by the World Health Organization as the limit at which people are at serious health risk.
- Higher intensity sounds were recorded at the northwest region of the study area, due to the following facts: (a) the existence of crucial streets (i.e. Dimokratias Str., Fon Kozani Str., Paulou Mela Str., M. Alexandrou Str.), (b) the concentration of a large number of commercial/ recreation stores and (c) administrative uses and points of high interest.
- Values higher than 84dB (Figure 3c) -sometimes ephemeral- were recorded in a large part of the city. This is a worrying fact, considering that the 87 dB threshold is the limit set by the Greek law (Presidential Decree 149/2006) for a maximum fixed exposure value for a worker in an 8-hour work day.
- Noise levels are relatively high, even in the case of the minimum values (30dB) recorded (Figure 3a), given the fact that levels higher than 23 dB can cause problems in the understanding of speech and thus the communication of people (Anon, n.r.). The intensity of the recorded sounds is higher in the northwest side of the study area, where the concentration of commercial/ recreational land uses is higher, and therefore the higher number of daily discussions is held, especially during working days and hours.
- The north-western part of the study area shows small fluctuations, as shown in Figures 3a-3c. Recorded sounds are mostly high during working hours (Figures 3a-3c). Minor fluctuations in sound intensity are also recorded in areas located in the east of the study area. St. George’s area, the University of West Macedonia campus area and spaces around OSE (inactive train station) are the quietest areas throughout the study area.
- Noise levels are the significant result of the urban environment. In the case of Kozani this is quite evident while observing the noise maps for the semi-pedestrianized city center where the smallest range of peak sound levels is observed, as opposed to the areas near major streets where larger peak sound levels are observed.

Similarly, the results for Drama can be concluded by the following key points:

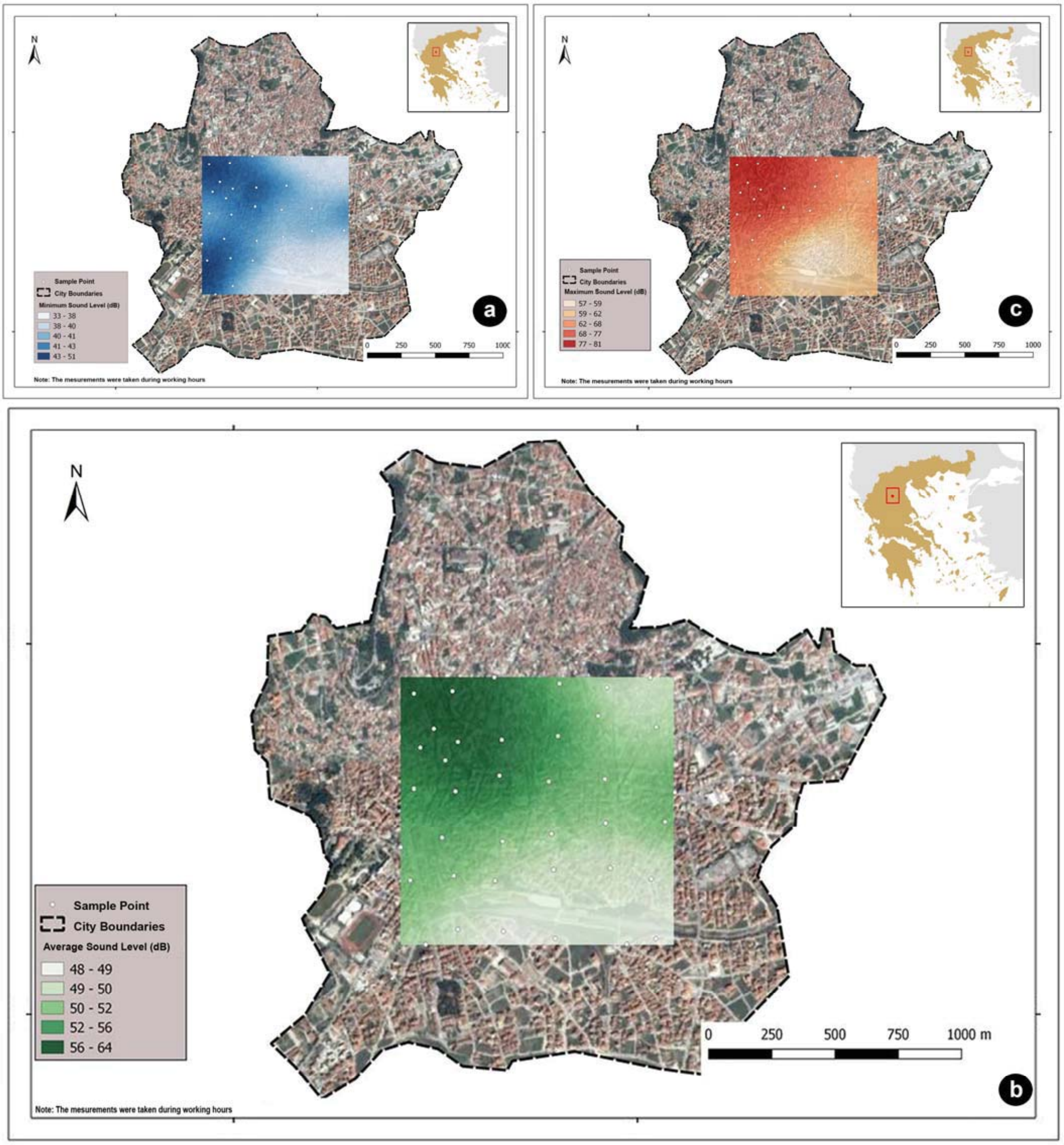

Fig. 3 Noise maps for Kozani.

- Higher volumes were recorded in Drama compared to the city of Kozani. These, on average, range from 59 to 98 dB. Recordings show that the intensity of the recorded noise exceeds the threshold of 55 dB which, as previously noted, is the noise level defined by the World Health Organization as the limit an excess of which places people in a serious risk to their health.
- The 87dB threshold for the continuous 8-hour exposure, as set out in the Greek Legal Framework, is surpassed in much of the city center study area, even momentarily.
- Noise levels in central areas exceed the sound level of 41dB that allows people to communicate properly. As shown in Figure 4a there is no recording of less than 41 dB.

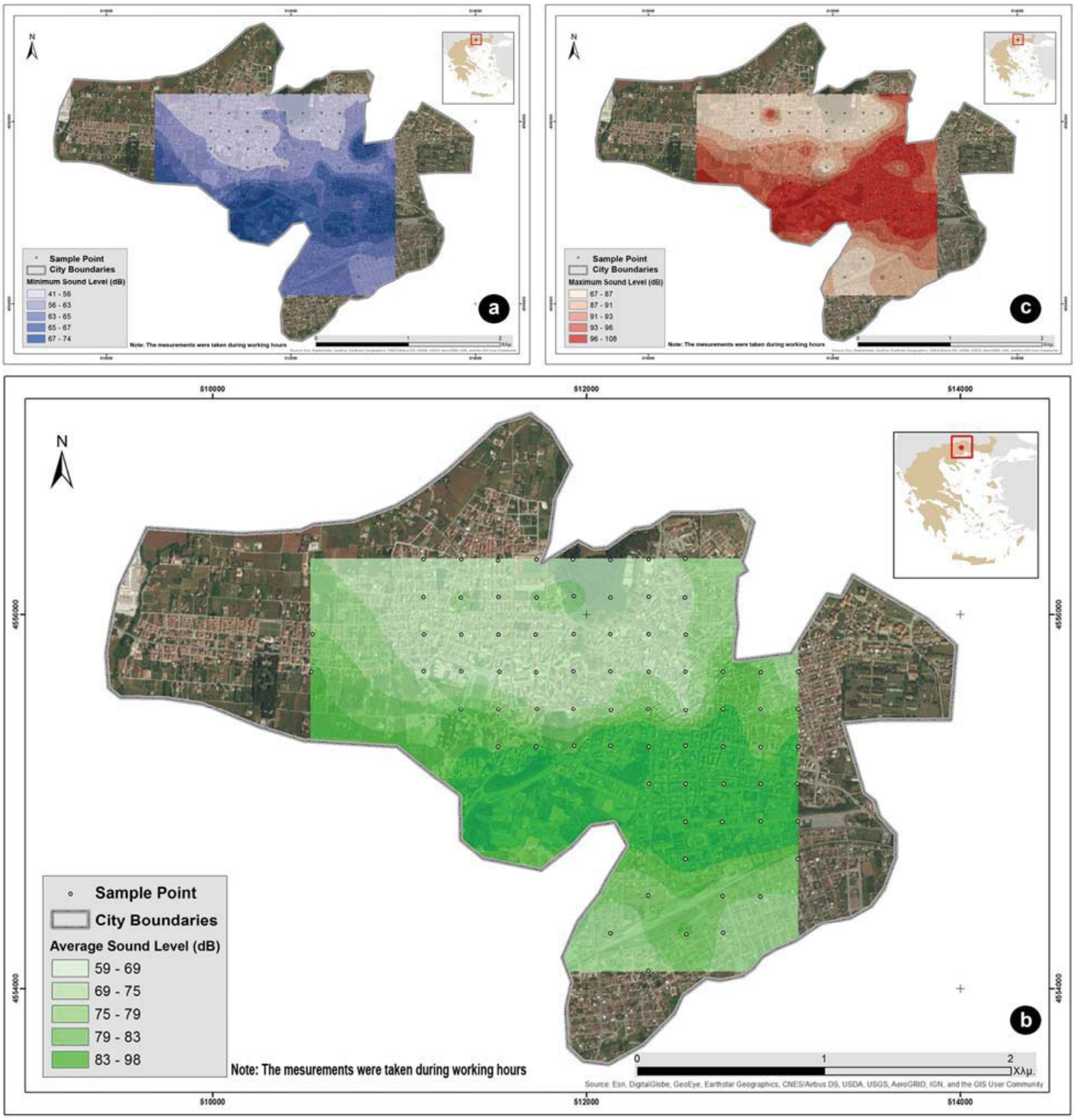

Fig. 4 Noise maps for Drama.

- Highest noise levels were recorded in central areas close to main streets that attract large numbers of motorized vehicles.
- The area around the OSE (inactive train station) appears to have low noise levels, although adverse results were expected. The local maximum levels are lower than those recorded at the center, while the overall highest in the area are relatively low. Overall there are small fluctuations observed in the area.
- As previously noted, the urban environment is significantly associated with noise levels. This is quite obvious in the case of Agia Varvara park, which seems to function as a sound fence for its surroundings. The recorded average high and low sound levels in the vicinity of the park are significantly lower than those recorded throughout the city.

Summarizing the above, both cities encounter issues in terms of noise pollution. Pollution is higher in the city of Drama although there are larger green areas and measurements were taken in the summer period. The greater extent of urban morphology in Kozani, along with the latest pedestrianization projects in the city center, appear to be the two key elements contributing to the maintenance of lower noise levels.

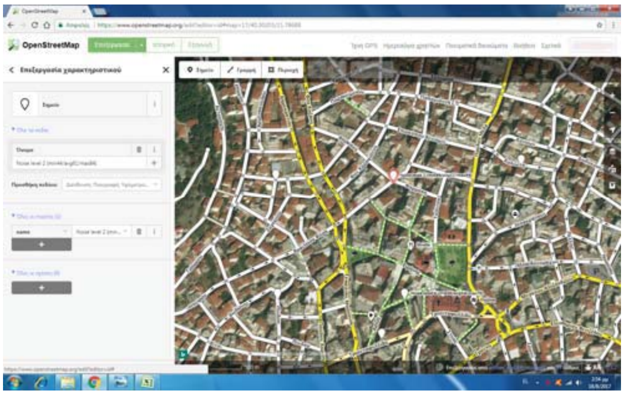

Fig. 4 Noise recordings in Kozani presented in OSM.

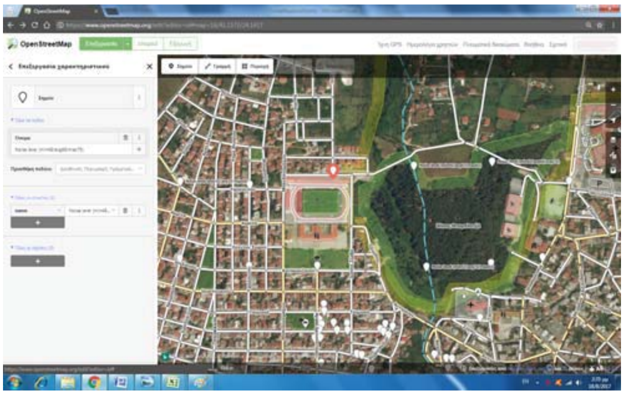

Fig. 5 Noise recordings in Drama presented in OSM

As mentioned before, noise information for these two cities is now available through OSM. Figures 5 and 6 present a part of each city map in OSM, where the noise recordings are presented. Data were digitized by the volunteers who were not trained due to the fact that they were already familiar with the OSM. Instructions about the recording process have been given and a pilot study was also implemented. It should be mentioned that in case volunteers need to be trained, a short training session could be organized, as Figure 1 presents.

4. Conclusions

Noise mapping is a strategy established for monitoring noise levels and protecting human health. Indeed, the European Directive 2002/49/EC proposed plans and maps which had to be implemented for specific cities and transport infrastructures. Through this Directive, a detailed methodology is proposed in which specific indicators should be used. Although the results of this method are accurate, however, this is a time-consuming and costly method. Thus, it is not possible to be applied in medium and small cities for which the compilation of noise studies is not compulsory by the law. In these cases, citizen participation may help in the collection and publishing of the data.

The aim of this paper is to develop a new methodology for noise mapping. This methodology should be easily applicable and cost-effective. Its rationale is based on community engagement and volunteering. The following steps outline a simple and effective strategy for mapping the noise levels in a city:

Organizing the field systematic sampling.

Preparing the volunteers who are responsible for collecting the data and digitizing them in the OSM.

Pilot study.

Collecting the data.

Creating the maps while simultaneously the volunteers are uploading the data in the OSM.

Publishing the maps.

In cases of Kozani and Drama, the above methodology was applied. Three volunteers in each city participated in this project. They collected noise data for one week in each city by using their smartphones. More specifically, they have used one free app, named Sound Meter. These data are differentiated from the data that should be collected according to the Directive 2002/49/EC because: (a) they were collected at the street level, while the Directive imposed that the recording should take place in the height of 4 meters and (b) recordings lasted for approximately 3-4 hours/day while the Directive imposed that the recording should take place 24 hours/day. The first issue is a matter that should be further examined in order to adjust the proposed limits of noise exposure taking into account the height in which the recording are conducted. The second issue can be faced by attracting volunteers in large numbers. The more people participate, the more recordings will be implemented. However, taking into account the fact that there are no available data for many Greek cities (and elsewhere), through this methodology satisfactory information are provided that can be helpful for researchers in order to understand the soundscape of each city.

This has become obvious through the case studies (Kozani and Drama) presented above. Through this methodology, in these cities, transport engineers, planners, decision makers and citizens can understand how important is to use sustainable means of urban transport and to minimize road surfaces within city centers. Indeed, through noise mapping in Kozani and Drama it was found that the street pattern (morphology, geometric characteristics, land use, etc) is related to its soundscape. More specifically, it was found that in semi-pedestrianized areas, the noise levels were lower while the opposite was observed in areas where roads with a high traffic load are located.

It should be noticed that the recorded data are now presented on the OSM and are available (immediately and free of charge) for anyone for whom it is important. OSM functions as an interactive map from which citizens can easily find or transform the existing information which is presented in data point format. However, until now it has not been possible for citizens to look at the noise map produced by the team of experts. This is a problem which needs to be resolved in the next phase of this research. Also, an important step would be to put in place a dynamic map. A dynamic map may be

compiled with data which will be collected by the residents who will provide it by using specific apps through their smartphones by which noise will be constantly monitored. This specific research may play a catalytic role in informing and raising public awareness which is crucial for the compilation of the SUMP of these cities. In the future, it would be crucial to test this methodology in order to realize if it is applicable and provides accurate data.
To sum up, the methodology proposed above has the potential to provide representative data in a cost-effective manner. Moreover, its use is based on community engagement and helps to inform people about the quality of life in their cities and the projects that may take place in the near future. Furthermore, these data are available to everyone through OSM. Finally, there is room for improvement in order for this methodology to be better applicable and readable while it can constantly provide noise information helping in noise monitoring at low cost. Thus, this methodology may be an important tool for planners and researchers as their aim is to contribute to the quality of city life.

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