Front. Earth Sci. 2017, 11(2): 214–228
DOI 10.1007/s11707-017-0615-6

RESEARCH ARTICLE

GIS model for identifying urban areas vulnerable to noise pollution: case study

Ştefan BILAŞCO (✉)[1,2], Corina GOVOR[1], Sanda ROŞCA[1], Iuliu VESCAN[1], Sorin FILIP[1], Ioan FODOREAN[1]

1 "Babeş-Bolyai" University, Faculty of Geography, 400006 Cluj-Napoca, Romania
2 Romanian Academy, Cluj-Napoca Subsidiary Geography Section, 9, 400015 Cluj-Napoca, Romania

Abstract The unprecedented expansion of the national car ownership over the last few years has been determined by economic growth and the need for the population and economic agents to reduce travel time in progressively expanding large urban centres. This has led to an increase in the level of road noise and a stronger impact on the quality of the environment. Noise pollution generated by means of transport represents one of the most important types of pollution with negative effects on a population's health in large urban areas. As a consequence, tolerable limits of sound intensity for the comfort of inhabitants have been determined worldwide and the generation of sound maps has been made compulsory in order to identify the vulnerable zones and to make recommendations how to decrease the negative impact on humans. In this context, the present study aims at presenting a GIS spatial analysis model-based methodology for identifying and mapping zones vulnerable to noise pollution. The developed GIS model is based on the analysis of all the components influencing sound propagation, represented as vector databases (points of sound intensity measurements, buildings, lands use, transport infrastructure), raster databases (DEM), and numerical databases (wind direction and speed, sound intensity). Secondly, the hourly changes (for representative hours) were analysed to identify the hotspots characterised by major traffic flows specific to rush hours. The validated results of the model are represented by GIS databases and useful maps for the local public administration to use as a source of information and in the process of making decisions.

Keywords GIS modelling, noise pollution, sound intensity, environmental impact, vulnerability

Received June 13, 2016; accepted September 13, 2016

E-mail: sbilasco@geografie.ubbcluj.ro

1 Introduction and study area

1.1 Introduction

In the present conditions of civilisation, one of the negative factors influencing the daily life of inhabitants is the increased sound intensity which determines the presence of a continuous sound environment. From a physiological point of view, a sound is a sensation affecting the auditory organ, which is produced by the material vibrations of objects and is transmitted via acoustic waves. The human ear generally perceives sounds between the frequencies of 16 Hz and 20 kHz (Olson, 1967), higher levels being uncomfortable (Job, 1999; Pandya, 2003; Baloye and Palamuleni, 2015).

According to various studies, the noise pollution generated by road traffic plays an important role among the environmental factors which lead to illnesses (Teensberg, 1999; Passchier-Vermeer and Passchier, 2000; Babisch, 2004; Bluhm et al., 2004; Babisch, 2006; Maschke and Hecht, 2007; Belojevic et al., 2008; Mihăiescu and Mihăiescu, 2009; European Environment Agency, 2010; Joint Research Centre, 2011; Stansfeld and Clark, 2011; Swain and Goswami, 2013; Dzhambov and Dimitrova, 2014; Quamrul et al., 2015). Specific norms and standards have been determined in most countries in order to monitor and evaluate sound. The European Union adopted the 2002/49/CE Directive of the European Parliament and Council on the 25th of June 2002 concerning the evaluation and mitigation of environmental noise and imposing the existence of noise maps for large cities to use when devising action plans.

In Europe, the main noise sourceis represented by road traffic. Vehicle propulsion noise is the result of the combination given by engine noise and the tyre noise output. (Sternberg, 1999; European Federation for

Transport and Environment, 2008; European Environment Agency, 2014).

The intensity of traffic noise is influenced by car speed, traffic volume, the number of heavy vehicles, and the material of road infrastructure (European Federation for Transport and Environment, 2008).

In the category of negative effects determined by prolonged exposure to noise pollution one can include: decrease of auditory sensitivity, partial or total deafness, symptoms of general tiredness, sleep disturbance, mental health disturbance, high blood pressure, modified breathing and heart rates, and increased risk of heart attack (Konecni, 1975; Mathews and Cannon, 1975; Berglund and Lindvall, 1995; Carter, 1996; Stansfeld and Matheson, 2003; Ising and Kruppa, 2004; Babisch et al., 2005; Stansfeld and Clark, 2011; Anees, et al., 2013; Méline et al., 2013; Dzhambov et al., 2014; Weber et al., 2014; Jazani et al., 2015). In Cluj-Napoca and in the other large cities of Romania, one of the most common effects of excessive noise is auditory tiredness. Among the noise effects on the nervous system, sleep disturbance is the most encountered symptom, as well as irritability. The latter is characterised by a temporary increase of the threshold of auditory perception due to the exposure to the action of an intense noise (Darabont et al., 1983).

In 1999 the World Health Organisation made public a series of recommendations referring to environmental noise (Berglund et al., 1999): to its measurement, its effects on health, threshold values of sound intensity, as well as measures of reducing its negative effects. Protection measures against noise for people working in office buildings or living in residential zones with high noise pollution and prolonged exposure to noise pollution risk were eventually determined and included soundproofing, wall reinforcement with sound-absorbing materials, sound insulation, etc.

As a consequence, the identification of acceptable sound thresholds for different urban zones becomes very important: 60 dB for the city centre (where most of the social and cultural facilities are concentrated); 55 dB for the neighbourhood centres; 50 dB for the residential zones with frequently used social and cultural buildings and facilities such as schools, commercial spaces, medical care facilities; 45 dB for zones of relaxation and resting, protected social and cultural facilities like hospitals, sanatoriums, elder houses, libraries. (European Environmental Protection Agency, 1974; Darabont et al., 1983; Romanian Government Decree, no. 321/2005).

By analysing the threshold values of sound intensity the concept of noise was used as a standard for identifying vulnerability to noise pollution. Environmental noise is defined as "the unwanted or harmful exterior sound generated by human activities, including the sound produced by means of transport, road, rail and air traffic, and industrial establishments." (European Environment Agency, 2014).

According to the 2002/49/CE directive of the European Parliament regarding the assessment and management of environmental noise, one of the main environmental problems in Europe is represented by noise pollution. This directive proposes the establishment of a common method for noise determination as well as threshold values. The noise indicators being used are: Lden – the A-weighted average level of sound pressure for the sum of day time periods over a year being used for the assessment of discomfort during daytime; Lnight- the A-weighted average level of sound pressure for the sum of periods of night time over a year, being used for the assessment of sound disturbance. The two indicators express an average level of sound pressure. Lzsn is the noise indicator for the day, evening and night and it is associated with the general discomfort over 24 hours. The measurements account for the following principles: the daytime has 12 hours, the evening has 4 hours and the night has 8 hours. Thus, the three periods are correspondent to the following time intervals: 7–19, 19–23 and 23–7. The applied methods of calculation are included in the standards ISO 1996/2-08:1995[1)] and ISO 9613-2[2)].

Through this directive, the members of the European Union must create noise maps for: cities with more than 250,000 inhabitants, for the major roads with larger traffic values than 6 million vehicles a year, for railroads with traffic values over 60,000 trains a year, and for major airports. These maps need to be updated every 5 years. In case the limit values are surpassed, the member states must also make action plans including: a description of the agglomeration of the noise sources (roads, railroads, airports), the limit values, the synthesis of the results generated by noise mapping, the assessment of the approximate number of people being exposed to noise, identification of problems and aspects requiring improvement, noise reduction measures, and a long-term strategy assessment.

According the Ministry of the Environment, Water and Forest, the Romanian legislation includes several laws about noise: Romanian Government Decree, no. 152/558/119/532-2008[3)], Romanian Government Decree, no. 321 from April 14th, 2005[4)], Romanian Government Decree,

1) ISO 1996/2-08: standards for the description of noise outdoors in community environments.
2) ISO 9613-2: standards for calculating the attenuation of sound during propagation outdoors in order to predict the levels of environmental noise at a distance from a variety of sources.
3) Romanian Government (2008). 152/558/119/532 Decree no. 152/558/119/532, on the approval of the Guide concerning maximal values for noise in Romanian.
4) Romanian Government, Decree no. 321/2005 for evaluation and environmental noise management, in Romanian.

no.678/1344/915/1397 from 2006[1]. Romanian Government Decree no. 1830/2007[2] for the approval of the Guide for generating, analyzing, and assessing strategic noise map, as well as other similar laws, has as its main purpose and avoidance, prevention, or decrease of negative effects caused by environmental noise, by creating noise maps and taking specific action plans.

Thus, the present work includes maps identifying areas vulnerable to noise pollution which were created by modelling road traffic noise. The study aims at highlighting both the areas with high sound intensity and quiet ones from the centre of Cluj-Napoca city, where the traffic and its corresponding environmental noise are progressively increasing. At the same time, the GIS analysis highlights the differences between the noise pollution being mapped at different representative hours, as well as the integrative analysis of the results based on the cause-effect relationship.

1.2 Study area

The increased territorial and demographic development of Cluj-Napoca Municipality, due to its establishment as the main centre of commercial, cultural, educational and economical attraction, has led to a directly proportional increase in the number of vehicles owned by residents and passing through the city. One of the busiest traffic areas is represented by the Gheorgheni neighbourhood (Fig. 1).

The test area for the present study focused on the Gheorgheni neighbourhood where busy boulevards contrast with green areas. The Gheorgheni neighbourhood is located in the east of Cluj-Napoca Municipality and was built in the 1960s following an urban planning which included many green areas, parks, and recreation zones. The built-up area is represented both by blocks of flats (with 4, 8, or 10 storeys) and houses, and Constantin Brâncuși and Nicolae Titulescu streets represent the main axes of the neighbourhood.

The high traffic intensity of the neighbourhood is the main reason for selecting it as a study area. This intensity is determined by a high number of inhabitants commuting to their workplaces, usually into the surrounding neighbourhoods, by the major arterial roads used for city transit as well as by the presence of schools which act as converging centres of the traffic flows at specific hours.

2 GIS sound modelling, database and methodology

Geographic informational systems prove themselves of great importance in the application of the methodological and scientific endeavour as they optimise the work flow and automate specific calculations, facilitating the user's work.

There are many data types being used for sound modelling, some authors using factors such as the traffic conditions, the configuration of the road network, the category of the road network and the main sound sources (Sheng and Tang, 2011). The utility of the geographic informational systems derives from the fact that they allow the acquisition, the management, the analysis, the modelling, and the highly accurate mapping of the results (Sheng and Tang, 2011).

2.1 GIS sound modelling

There is a variety of software simulating sound propagation using various physical factors which influence it (SoundPlan, LimA, SPreAD-GIS for ArcGIS, Noise-M@ap, etc). The results are highly accurate and allow complex processing as well as export in various forms.

Among the advantages, one must notice the possibility of populating the georeferenced database with attributes, the introduction of noise sources, and, last but not least, the possibility of applying spatial analysis (Kucas et al., 2007; Farcaș and Sivertun, 2009; Tsai et al., 2009; Haq et al. 2012; Garg and Maji, 2014).

For sound monitoring and mapping, the GIS technology enables the generation of a spatial database encompassing the required information in different data types: buildings and their elevation, roads, DEM, sound measurement points etc. Each type of database is organised on thematic layers accompanied by information in the form of attribute tables which is relevant for the process of spatial analysis. The various databases are integrated into corresponding spatial analysis types and the results are represented as maps and databases, both being useful for further analyses by using specialised software or can be disseminated in the virtual environment (digital databases). Visual and interpretative analyses can also be performed for public and informative use (cartographic materials) (Van Blokland and Peeters, 2009; Kephalopoulos and Paviotti, 2013; Licitra, 2013; Licitra and Ascari, 2013).

The evolution of technology has led to an improvement in GIS sound modelling, moving it closer to reality as the generation of different noise reduction scenarios and cost analyses became possible.

2.2 Database and methodology

The digital mapping of areas vulnerable to noise pollution using GIS analysis was performed using the SpreAD-Gis extension (Reed et al., 2012) which operates in ArcGIS.

1) Romanian Government (2006). Decree no. 678/1344/915/1397, on the approval of the Guide concerning noise calculus methods of the industrial, road and ferries and aerial traffic in the airports proximity in Romanian.
2) Romanian Government (2007). Decree no. 1830, on the approval of the Guide concerning analizys and assessment of strategic noise maps in Romanian.

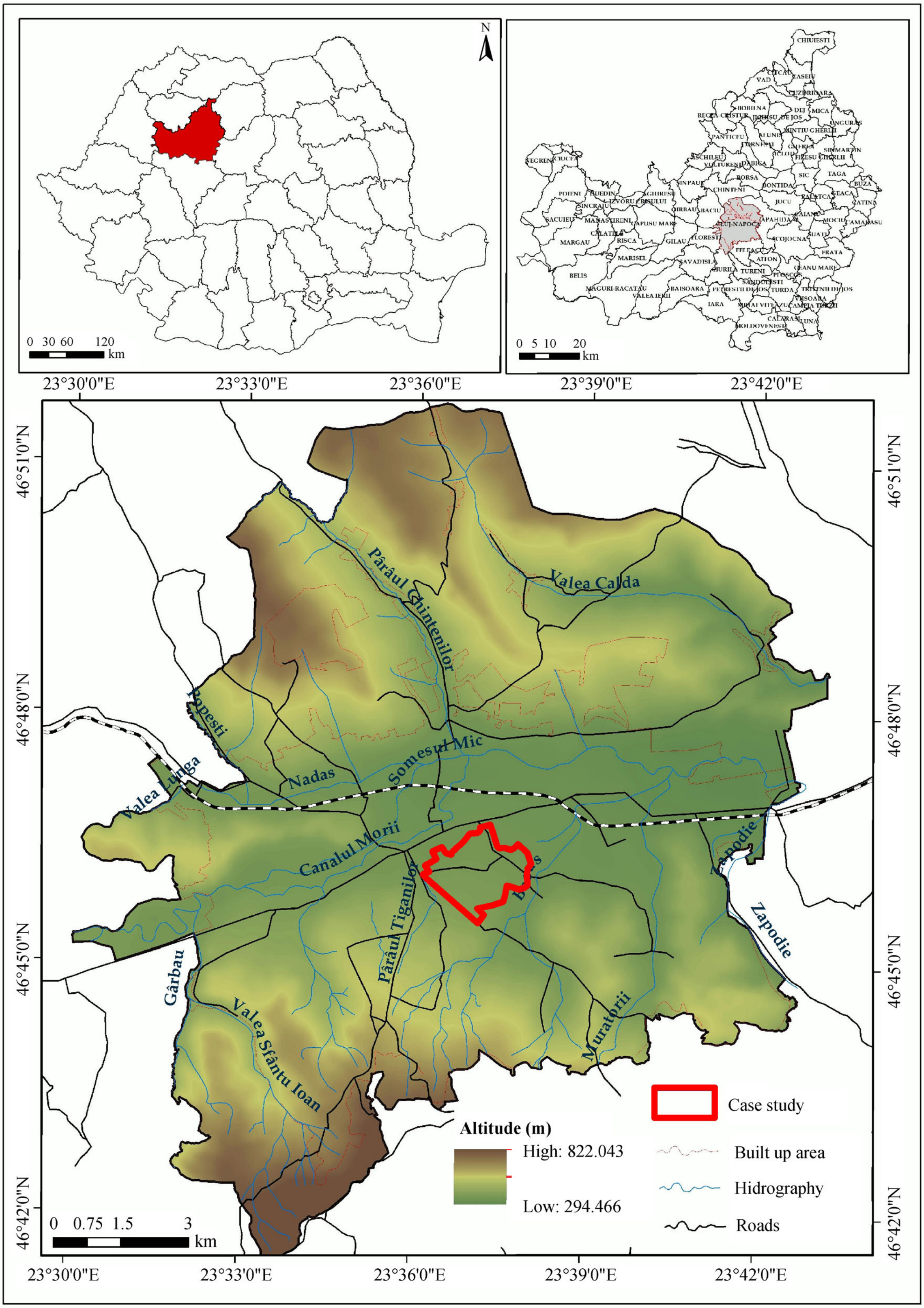

Fig. 1 Geographical position of the study area.

This extension was selected for the study case because it is free to use by all owners of ArcGIS licenses (Romanian public administration) and it enables operations with a multitude of databases both spatial and numeric (measured numerical values of sound intensity, wind speed, and direction for a specific area, general methodological conditions at a specific time, spatial location of sound intensity measurements, etc.) which determine effects on the modelling of sound propagation and the mapping of its specific intervals.

The use of GIS software through spatial modelling for implementing the mapping methodology of the areas vulnerable to sound propagation requires the creation of a specific database and the use of a method which is based on the software and its auxiliary components. The database which was used in the present work includes two main GIS database categories (Fig. 2): numerical databases associated with spatial databases for identification and point measurement of noise level (sound values measured in dB, wind speed, and direction), databases including vector datasets (measurement points, limit of study area, 2-D building contour, land use, traffic systems) as well as databases including raster datasets (digital elevation model, derived digital elevation model) (Table 1).

The sound intensity databases (Table 2) were created through direct point measurements using an SL 5868 digital sound pressure noise level meter device. For enhanced accuracy three measurements were performed per interval in each point. The measurements were done in normal environmental noise conditions at approximately 1.5 m above ground due to the great variety of vehicles (cars, buses, trucks, etc.) which pass through the measurement points.

The choice of the 44 fixed measurement points was made considering their representative position on the road networks and their specific traffic flows, but also due to their statistical dispersion in the analysed territory (Fig. 3).

The time intervals selected for measurements (Table 2)

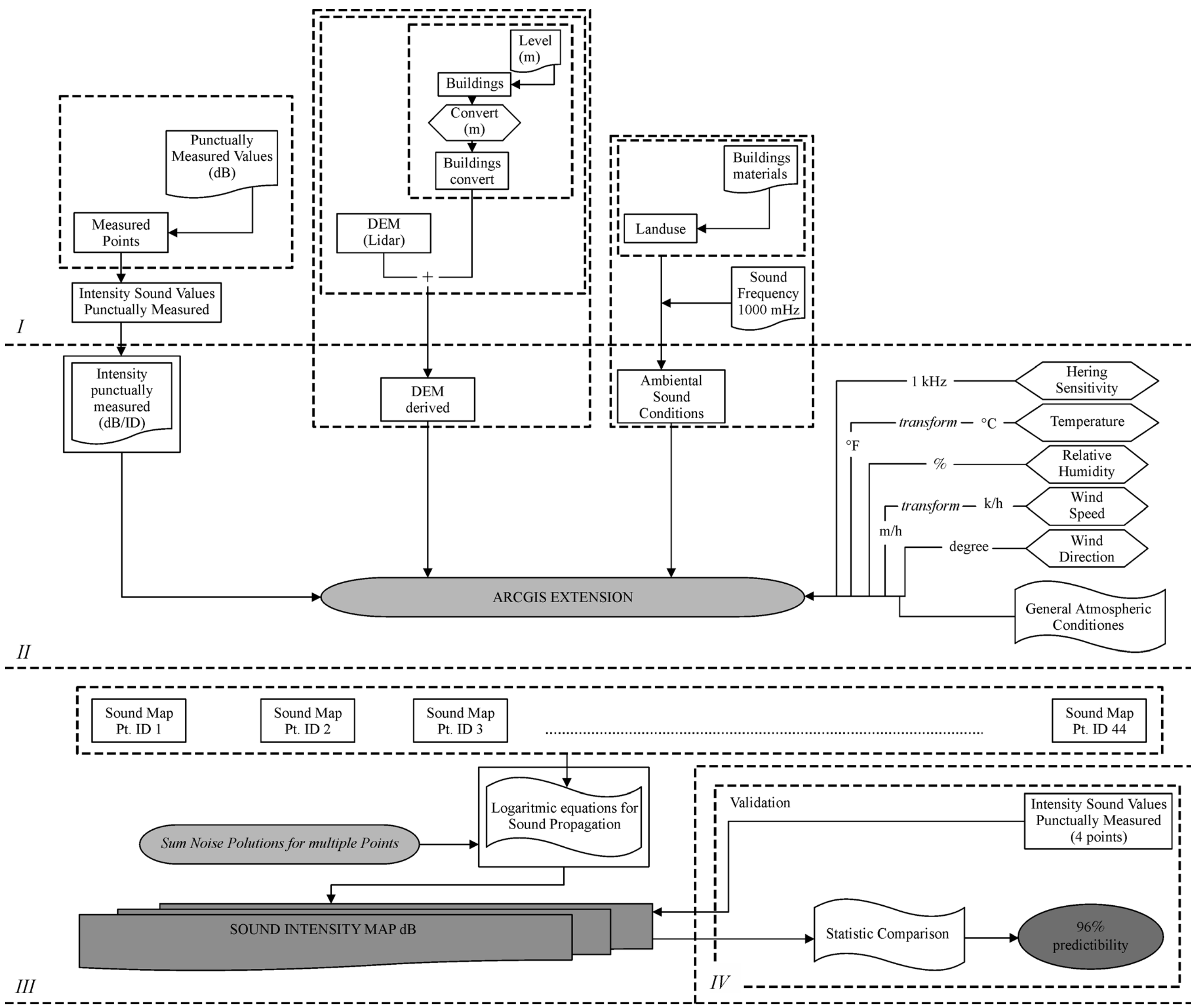

Fig. 2 Methodological flow-chart.

Table 1 Database structure

Database	Structure	Attributes	Type
Limit	Vector-line	-	Primary
Measurement points	Vector-point	Measured value for each interval	Primary
Buildings	Vector-polygon	Z	Primary
Roads	Vector-polygon	Name	Primary
DEM	Raster	Z	Derived
Land use	Raster	Land use type	Primary
Sound propagation maps	Raster	Sound intensity	Modelled

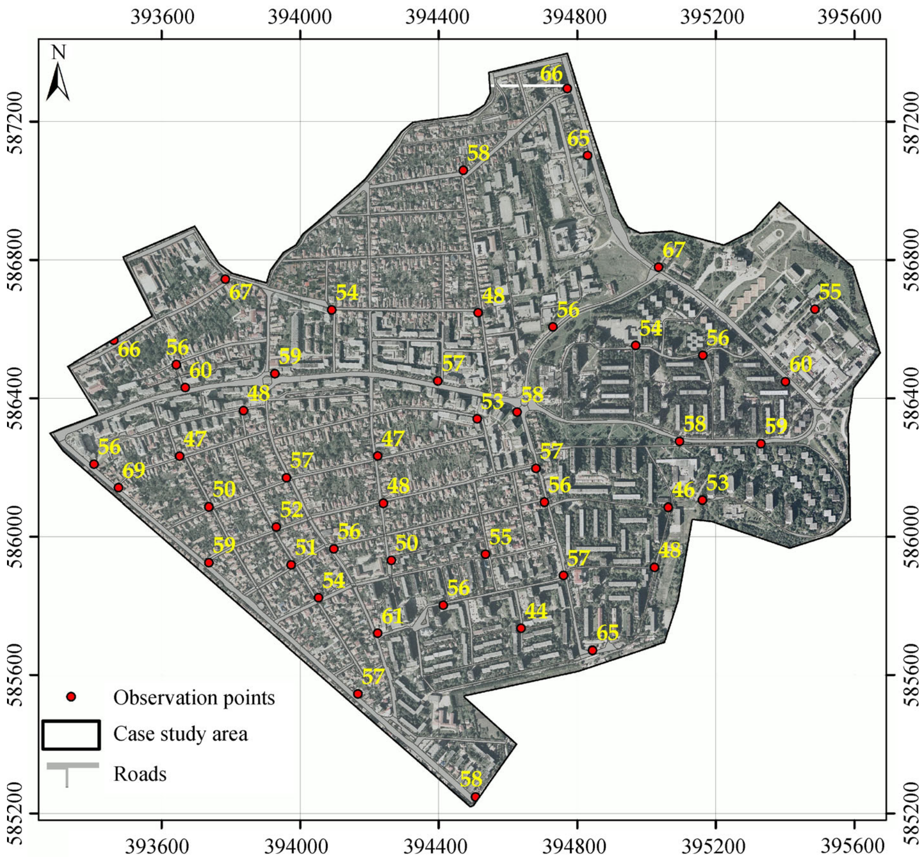

Fig. 3 Map of measurement points.

were: 6–8 (corresponding to morning time and capturing the period in which the inhabitants commute to their work place and/or the time interval in which students go to schools), 12–14 (a representative time interval for two reasons: economical activities are in full progress, reducing noise pollution in residential areas, road traffic is at low levels, and it is a time interval in which students return from school and the schedule of public transport intensifies) and 16–18, which captures the moment in which the inhabitants return to the residential areas or prepare for other activities, thus the increased traffic intensity. Therefore all the three intervals define important moments during a day in which the traffic from Cluj-Napoca and Gheorgheni residential neighbourhood intensifies.

The database representing the built-up area (buildings with different functions) was created as a vector database using recent orthophotoplans. Considering the fact that the height of the building plays an important part in sound propagation and in the modelling process, the spatial database was associated with numerical databases representing the height of each building, varying between 2 m and 35 m.

The land use information was integrated into the model

Table 2 Measured values in each point

No.	Location	Hourly intervals		
		6–8	12–14	16–18
1	Str. Constantin Brâncuşi	56	58	71
2	Str. Constantin Brâncuşi	69	62	66
3	Str. Constantin Brâncuşi	58	61	66
4	Str. Constantin Brâncuşi	59	66	70
5	Str. Constantin Brâncuşi	57	66	69
6	Str. Minerilor	56	58	63
7	Str. General Traian Moşoiu ∩ Str. Aurel Suciu	67	55	69
8	Str. Actorului ∩ Str. Bistriței	48	52	54
9	Str. Aurel Suciu	54	66	69
10	Aleea Băişoara	65	69	61
11	Aleea Slănic	56	53	65
12	Aleea Valeriu Bologa	55	57	66
13	Aleea Slănic ∩ Str. Alexandru Vaida Voievod	67	77	61
14	Str. Baladei ∩ Str. Venus	58	65	63
15	Str. General Traian Moşoiu	66	65	75
16	Aleea Herculane ∩ Aleea Borsec	54	50	58
17	Aleea Herculane ∩ Aleea Snagov	56	62	59
18	Bd Nicolae Titulescu ∩ Str. Liviu Rebreanu	58	62	64
19	Str. Tache Ionescu ∩ Str. Liviu Rebreanu	57	63	64
20	Str. Albac ∩ Str. Liviu Rebreanu	57	69	65
21	Aleea Herculane ∩ Aleea Snagov	56	62	59
22	Bd Nicolae Titulescu ∩ Str. Liviu Rebreanu	58	62	64
23	Str. Tache Ionescu ∩ Str. Liviu Rebreanu	57	63	64
24	Str. Albac ∩ Str. Liviu Rebreanu	57	69	65
25	Str. Heltai Gaspar ∩ Str. Liviu Rebreanu	56	61	63
26	Str. Teodor Mihali	66	68	68
27	Str. Teodor Mihali	65	69	67
28	Str. Alexandru Vaida Voievod	60	62	64
29	Str. Unirii	59	61	62
30	Str. Unirii	58	61	66
31	Aleea Băişoara ∩ Aleea Băița	46	49	50
32	Aleea Băişoara ∩ Aleea Scărişoara	48	50	55
33	Aleea Azuga	44	48	55
34	Str. Albac	56	66	68
35	Str. Albac ∩ Str. Septimiu Albini	61	66	64
36	Aleea Băişoara	53	58	60
37	Str. Constantin Brâncoveanu ∩ Str. Madach Imre	54	55	56
38	Str. Axente Sever ∩ Str. Madach Imre	51	54	53
39	Str. Tache Ionescu ∩ Str. Madach Imre	52	50	56
40	Str. Secerătorilor ∩ Str. Mihai Veliciu	47	49	46
41	Str. Arieşului ∩ Str. Vasile Lupu	47	52	48
42	Str. Arieşului ∩ Str. Buşteni	50	52	54
43	Str. Tache Ionescu ∩ Str. Arieşului	48	44	51
44	Str. Vasile Lupu ∩ Str. Aron Densuşianu	50	52	46

as a spatial database using as criteria the environmental conditions which influence the propagation, absorption or intensification of sound. The database was created mainly based on specific levels represented by materials used in the building and insulation of construction (brick, concrete, polyester) and green areas (parks or green areas with bushes and lawns).

The environmental conditions can be modelled by using a derived GIS model based on the spatial vector land use data. Thus, every land use class received a set of specific attributes depending on its type and its influence on sound propagation. Consequently, for the present work and the frequency of 1000 Hz (a common frequency for an average hearing), specific values have been associated with different types of land use: 40 dB for concrete buildings, 35 dB for brick buildings, 20 dB for parks or green areas with bushes and buildings insulated with polyester, and 24 dB for herbaceous plants or grassland.

Through its configuration, topography plays an important role in blocking the sound propagation by influencing wind speed and direction. As the application used in the present study does not take into consideration the height of buildings as a blocking factor in sound propagation, a digital elevation model was derived from topography and building heights in order to capture this particular aspect.

In order to highlight the blocking effect of buildings for sound propagation a derived DEM was generated with a 10 m resolution which considers the area between buildings to be flat (0 m elevation) and each cell of the built-up area to have a specific elevation. Thus the DEM will represent in the spatial analysis model a double blocking role: a topography barrier and a cumulated topography-building elevation barrier where buildings are present.

In order to complete the spatial analysis model with the extension previously presented, it is necessary to include additional numerical data which influences sound propagation: air temperature, wind speed and direction, the degree of air humidity, hearing sensitivity, and general atmospheric conditions (Table 3).

Table 3 General conditions and numerical databases used in the present work

Parameter	Characteristic value
Air temperature	19°C (66.2°F)
Wind speed	13 km/h (8.08 mph)
Wind direction	SE (120°)
Relative air humidity	28%
General atmospheric conditions	Clear sky, summer day
Hearing sensitivity	1 kHz

The digital mapping of the areas with different sound intensity generated by road traffic was performed by using two functions of the SpreAD-GIS toolbox (Reed et al, 2010): *Calculate noise propagation for one point* considering the environmental conditions, in order to make individual maps for sound intensity corresponding to each sound measurement point and every temporal interval; the result is represented by 144 maps represented by raster databases. The function *sum noise propagation for multiple points* enables the integration of the calculated databases for each individual point in a unitary database for the whole study area, resulting three maps (for specific hours) represented by raster databases (Figs. 3–6).

3 Results, discussion, model validation and conclusions

The analysis of results focused both on the spatial distribution of sound intensity areas in order to highlight the effect of traffic at representative time intervals and on the change in sound intensity between specific hours in order to identify possible causes and issue recommendations for noise pollution mitigation measures.

3.1 Results and discussion

All the resulting rasters were classified so that the intervals corresponded to the intensity of known phenomena, in order to facilitate an interpretation of the resulting levels (according to STAS 10009-88[1)], modified): 0–10 dB corresponding to the sound of swishing leaves; 10.1–12 dB – whispered conversation; 12.1–20 dB–clock ticking; 20.1–30 dB – birds singing; 30.1–40 dB–quiet office; 40.1–50 dB – quiet conversation; 50.1–60 dB–busy office.

The sound intensity values modelled for the 6–8 time interval range from 0 to 49.94 dB (Fig. 4), highlighting two areas with large differences in modelled sound intensity: the first area with values ranging up to 12 dB is located in the space between Bistriței and Arieșului streets. This area is characterised by short buildings with elder inhabitants which keeps the morning traffic at low levels due to the presence of few residents in these zones and the vicinity of the public transportation stations which are located on the main road artery (Nicolae Titulescu Street crosses the neighbourhood).

The quietest zone is located in the north of the neighbourhood. This is due to the presence of tall buildings surrounding the area and acting as a barrier against the noise on the neighbouring boulevards. The second zone is characterised by high levels of sound intensity and is spatially located at the crossroads of the main road arteries. Such hotspots are at the crossroad between Calea Dorobanților and Teodor Mihali streets, which is crossed by the traffic flow from the central zone towards the

1) STAS 10009-88: Building acoustics. Urban zone acoustics. Maximal noise level.

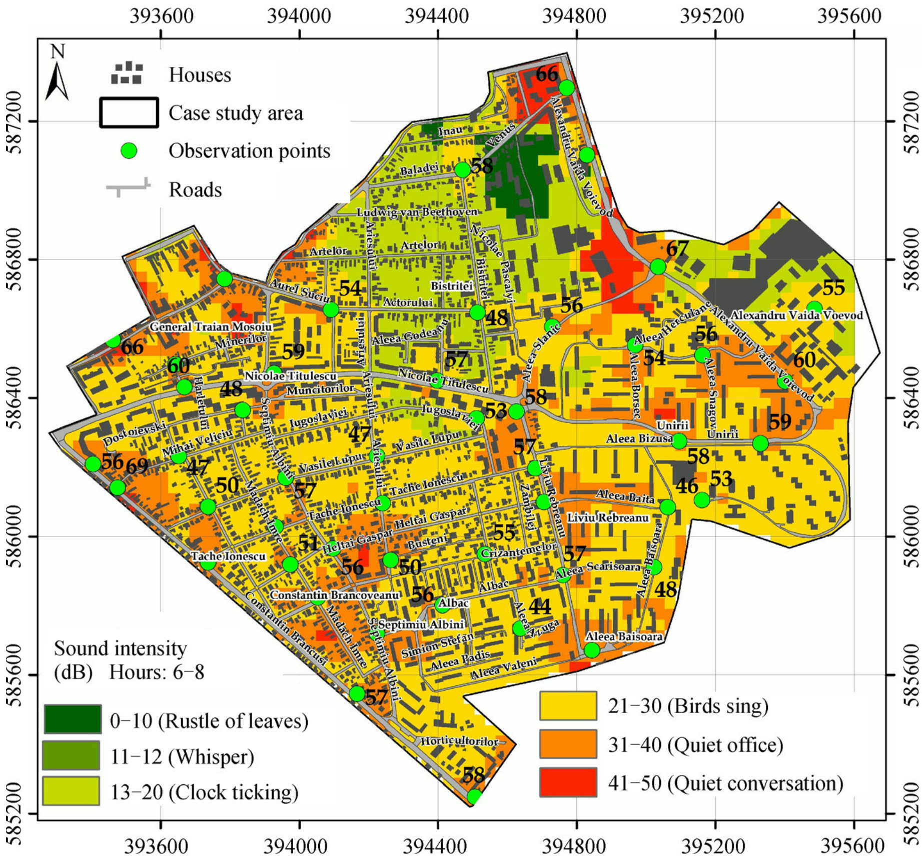

Fig. 4 Sound propagation model for the 6–8 time interval.

Mărăști working neighbourhood as well as by the traffic flow from Gheorgheni neighbourhood towards Mărăști neighbourhood and the eastern city exit. Another important hotspot influenced by traffic flows was identified by the modelling process at the crossroad of the main road arteries passing through the neighbourhood: Nicolae Titulescu Boulevard, Unirii Street, Liviu Rebreanu Street and Aleea Slănic Street. Another cause for this hotspot is the presence of the Interservisan Clinic, which attracts a large number of people. One also must notice Constanti Brâncuși Street as a transit road artery between neighbourhoods negatively influencing the noise pollution of the surrounding areas as it carries a great traffic flow from the new residential neighbourhoods from the southern part of the city towards the city centre. The modelling of high levels of sound intensity and the identification of hotspots negatively influencing the environment is also determined by the presence of administrative buildings of great interest for the population: on Traian Moșoiu Street there is the Military Regional Hospital where the modelled sound values were higher than 30 dB, on Teodor Mihali Street close to the crossroad with Slănic Street where there is the largest building of the Babeș Bolyai University and where most of the students study during the day. In the close vicinity there are also the student dorms and the office buildings where people go every morning to work.

A large number of people going to work and producing noise pollution is what highlights the area of Aleea Herculane and Septimiu Albini streets, the former being characterised only by a large crowding of people, while the latter is also influenced by the existence of main road junctions used as exits from or entrances into the neighbourhood.

In the 12–14 time interval, the sound intensity values vary between 0–58.22 dB (Fig. 5). The maximum values of sound intensity can be identified in almost the same areas exposed to noise pollution during the morning hours but at a lower intensity. One can thus identify a hotspot at the crossroads between Septimiu Albini Street and Nicolae Titulescu Boulevard, which is justified through the intensifying of the traffic flows from the areas close to schools towards the residential zones of the neighbourhood and the city centre.

The vulnerable areas with values of sound intensity over 30 dB are spatially limited: the crossroad between Nicolae Titulescu Boulevard and Septimiu Albini Street, which is usually a crowded point; Unirii Street; the crossroad between Nicolae Titulescu Boulevard and Aleea Slănic

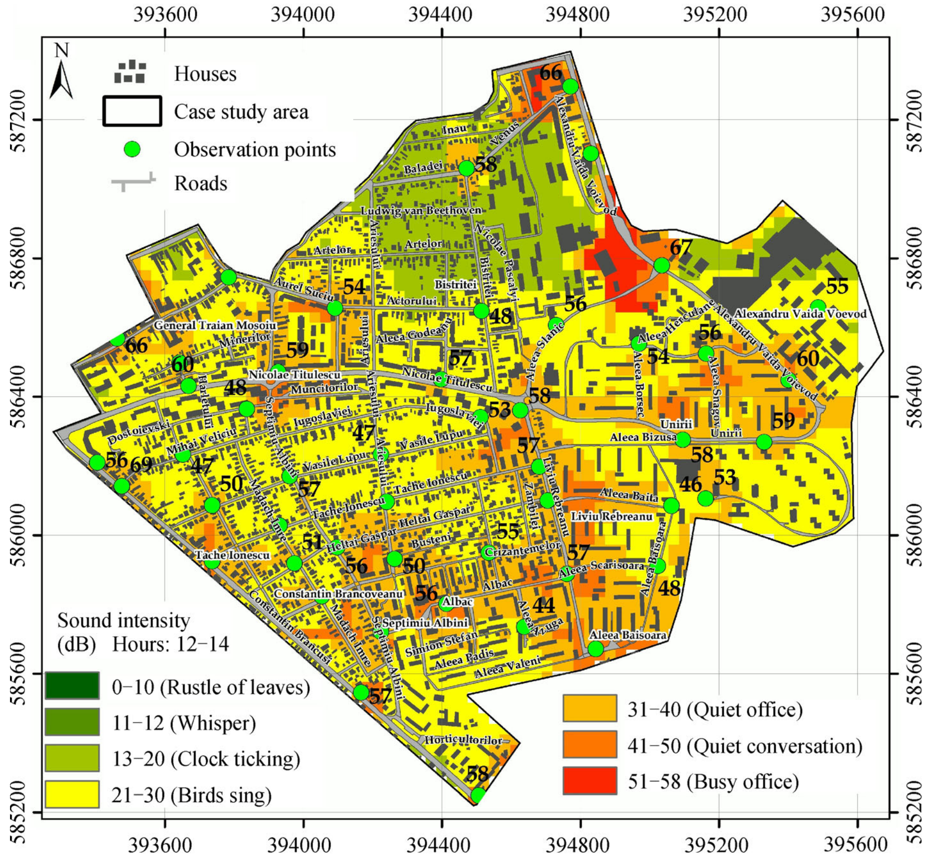

Fig. 5 Sound propagation model for the 12–14 time interval.

Street, as well as Liviu Rebreanu Street. In the daytime, the predominant values range between 20–30 dB. The quiet zone is located in the same area as in the first time interval, however, it has a smaller extension.

An increase in sound intensity can be noticed in the 16–18 time interval up to a maximum value of 54.16 dB, which is also the noisiest period during the day.

The quiet areas shrink even more from the previously analysed time interval or the morning interval, a large part of the quiet areas from the north of the neighbourhood being included in the vulnerable category of high levels of noise. Values ranging between 30–40 dB are predominant. What is different from the first two time intervals is the fact that the highest values (40–50 dB) are found only in small areas, in the access zones towards Mărăşti neighbourhood (Calea Dorobanţilor Street, General Traian Moşoiu Street).

In this context, another hotspot can be identified in the Iulius Mall area which is closely located to the tall blocks of flats from Aleea Herculane Street and the surrounding space but also to the office buildings. One must notice that the hotspot which was previously identified in the area of the UBB building is no longer present in the class of high vulnerability and is included instead in the low vulnerability class with values ranging between 0 and 20 dB. At the same time, the quiet area from the north of the neighbourhood migrates to the east as well, close to Teodor Mihali Street, a fact which indicates the reorientation of the traffic flows from this artery to other road arteries (mainly Nicolae Titulescu Boulevard and Unirii Street) when people return from their work places.

The blocking effect of buildings in sound propagation is clearly reflected by the results. Although the major traffic flows are concentrated on the main arteries which are flanked by tall blocks of flats (8–10 storeys), the sound intensity behind them is included in the category of low vulnerability, while on other segments of the same road arteries which are flanked by short buildings sound travels farther and at a higher intensity. Between tall blocks of flats, there are areas where sound intensity values tend to concentrate, as a result one can identify several grouped small areas with high values (Fig. 6).

In order to highlight the differences between the sound values in the three day time intervals, specific equations of GIS spatial analysis were used based on mathematical operators implemented in ArcGIS software.

When comparing the first two intervals (12–14, 6–8) one notices that the areas which are usually crowded in the morning when the inhabitants go to work are characterised

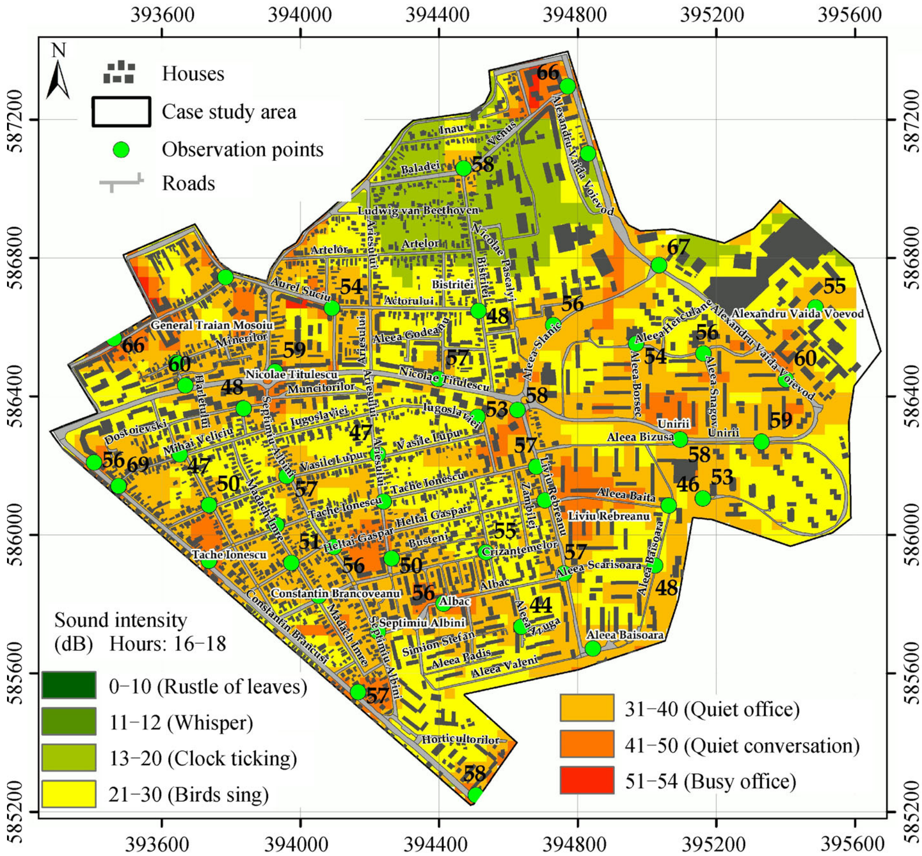

Fig. 6 Sound propagation model for the 16–18 time interval.

by low values at noon. Such situations are encountered at the main crossroads and the access point from Colonia Borhanci. General Traian Moşoiu and Valeriu Branişte streets, which are usually used as shortcuts towards the centre or towards Calea Dorobanţilor Street have lower values. In the last time interval, when people leave work, the values rise again. Hence, these areas get crowded mainly at rush hours.

In the time interval 12–14 (Fig. 7), in the area around Colegiul Energetic the noise is at lower levels than between 6 and 8 o'clock and in the 16–18 time interval (Fig. 8). The main reason for this is that the transport flows are directed towards the school in the morning for the students to get to their courses and in the evening the transport flow brings the students home from school and their parents from their work places to their residential zones.

An important case from one of the hotspots was identified in the first two time intervals and is represented by Albac Street and the crossroad between Albac Street and Diaconu Coresii Street, where there is the Road Police Station. When analysing the changes in sound intensity, one can notice an important decrease in sound intensity between the 16–18 and 12–14 time intervals, as the activity of the station ends and with it the transport flows directed towards it during the day, the remaining noise being generated only by the normal residential traffic.

3.2 Model validation

The validation of the mapping and prediction model for the vulnerable areas to noise pollution was performed using the direct comparison method of the modelling results with samples of manually measured values. For this, four sound intensity measuring stations were placed in four points differently influenced by environmental factors which determine sound propagation (Fig. 9).

The first point of direct measurement was located behind tall blocks of flats which block sound propagation, the second station was placed in the quiet area of the northern part of the neighbourhood, the third point of direct measurements was placed in the vicinity of the main crossroad where traffic flows have high values and the fourth station was placed in the block of flats area close to Septimiu Albini Street, which was modelled as having an average to high sound intensity.

The direct comparison produced the following results (Table 4).

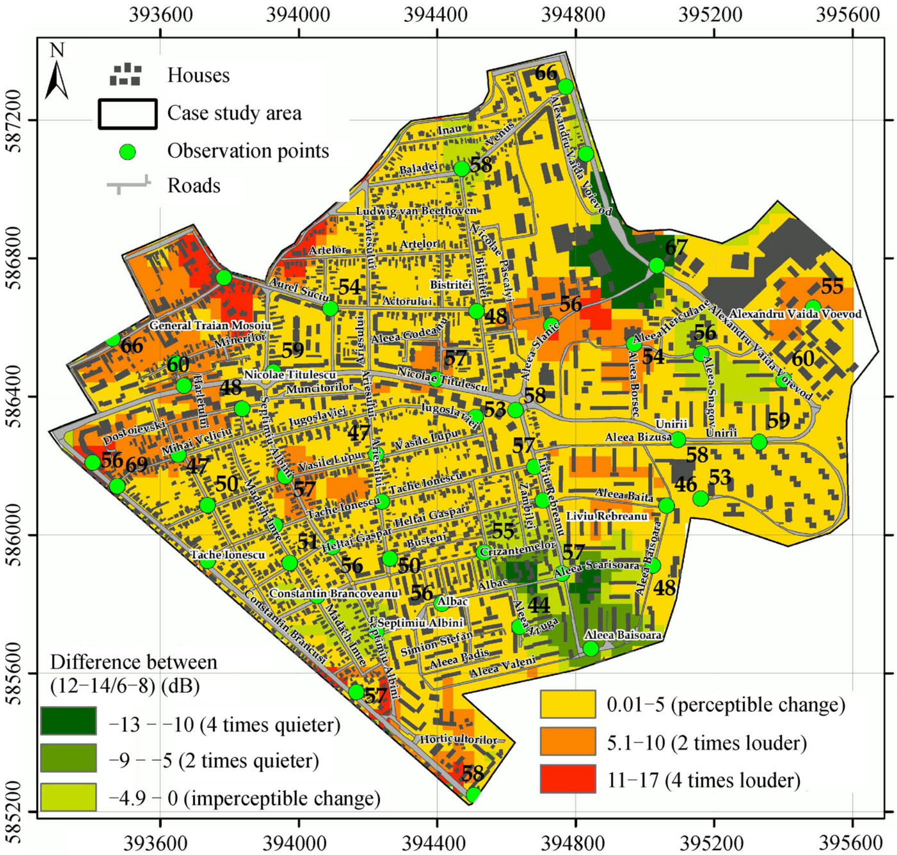

Fig. 7 Difference in sound intensity between 12–14 and 6–8 time intervals.

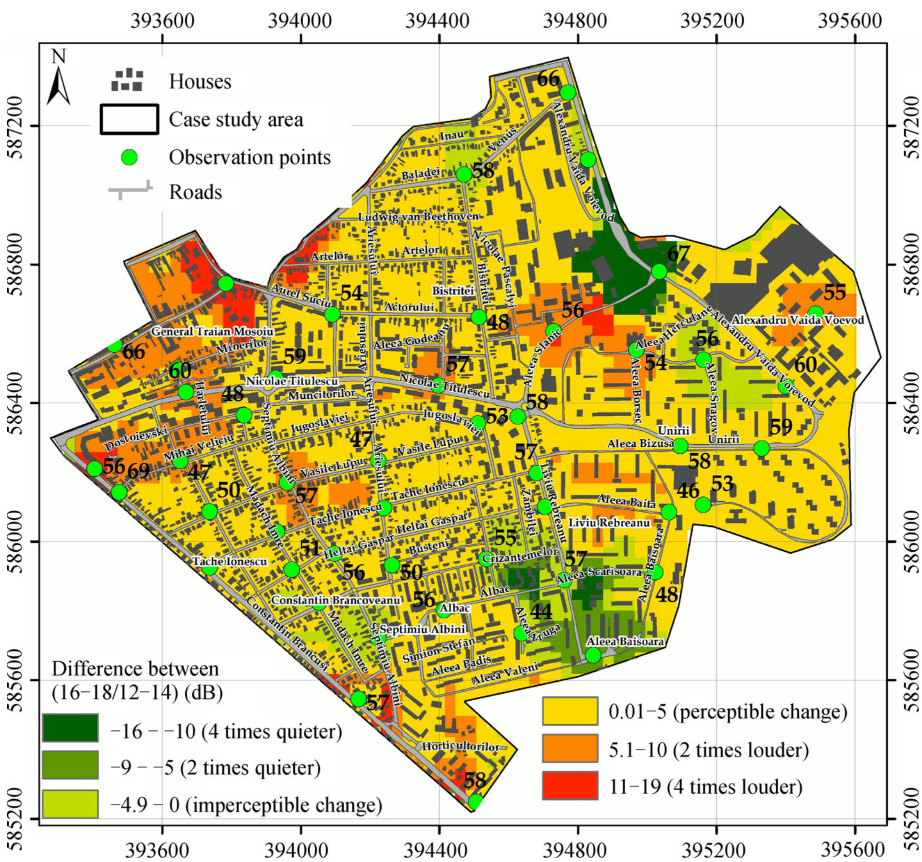

Fig. 8 Difference in sound intensity between 16–18 and 12–14 time intervals.

Table 4 Sound intensity in the validation points

Valitation point	Sound intensity (calculated)	Sound intensity (measured)	Difference
1	32.5 dB	32.4 dB	–0.1 dB (0.30 %)
2	10.3 dB	10.5 dB	0.2 dB (1.90 %)
3	36.6 dB	36.7 dB	0.1 dB (0.27 %)
4	26.1 dB	26.3 dB	0.2 dB (0.76 %)
Validation	*105.5 dB*	*105.9 dB*	*0.4 dB (96 %)*

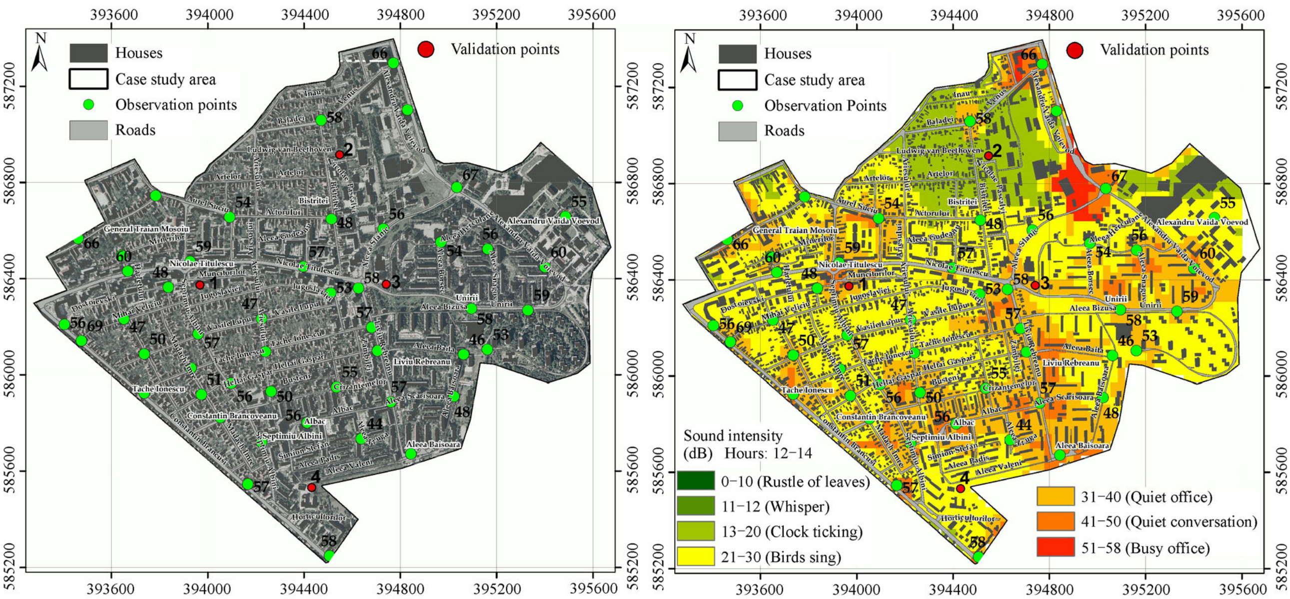

Fig. 9 Position of validation points.

By analysing the direct comparison of the sound intensity, the measured and the modelled values are almost equal, thus the model is validated for the study area. As a result, the model can be successfully applied to urban areas taking into consideration the fact that it fits into the accepted error range (> 95%) and the point values are included in the 0%–5% interval of prediction both for the overestimation and underestimation of the values.

3.3 Conclusions

Environmental noise has become a daily problem in big cities with road traffic as its main cause. Cluj-Napoca Municipality has a progressively growing population and an increasingly intense traffic with many traffic jams and a reduced flow at rush hours. Therefore, it is important to know the current situation of noise in the city and to develop an action plan in the areas where specific thresholds are surpassed. Among the possible measures which could be implemented there are: the limitation of vehicle access on certain streets, reducing the speed limit, and repaving the streets where the surface of the road pavement is of low quality. The Gheorgheni neighbourhood is considered a quiet area of Cluj. However, it has become more of a city zone with many green areas. The building of Iulius Mall shopping centre, the Faculty of Economical Sciences, clinics and office buildings as well as the placement of buildings belonging to the local public administration have led to the increase of road traffic in this neighbourhood.

Traffic jams and areas with high noise pollution can be frequently identified, especially on the main arteries and at the main crossroads: Nicolae Titulescu Boulevard, Unirii Street, Aleea Slănic Street, Teodor Mihali Street.

The implementation of a GIS model in the monitoring and modelling of sound propagation can facilitate the processing and analysis of data and the creation of scenarios with the main purpose of offering solutions for lowering the vulnerability and the risk to noise pollution.

The software and the extensions used for digital mapping and modelling of sound offer impressive results and are characterised by high accuracy, being compatible with various database formats. As a result, they become useful for the local administration and allow the reduction of analysis and decision time.

As possible solutions for reducing noise and its negative effects on humans the present work includes: encouragement of the inhabitants to use public transportation or bicycles in order to reduce traffic, and increasing the number of spaces for parks and green areas which absorb and diffuse sound waves. These actions would have an additional positive effect, reducing both noise and air pollution.

References

Anees M M, Qasim M, Bashir A (2013). Physiological and physical impact of noise pollution on environment. Asian Journal of Environmental and Earth Sciences, 1(1): 25–31

Babisch W (2004). Health aspects of extra-aural noise research. Noise Health, 6(22): 69–81

Babisch W (2006). Transportation noise and cardiovascular risk: updated review and synthesis of epidemiological studies indicate that the evidence has increased. Noise Health, 8(30): 1–29

Babisch W, Beule B, Schust M, Kersten N, Ising H (2005). Traffic noise and risk of myocardial infarction. Epidemiology, 16(1): 33–40

Baloye D O, Palamuleni L G (2015). A comparative land use-based analysis of noise pollution levels in selected urban centers of Nigeria. Int J Environ Res Public Health, 12(10): 12225–12246

Belojevic G, Jakovljevic B, Stojanov V, Paunovic K, Ilic J (2008). Urban road traffic noise and blood pressure and heart rate in preschool children. Environ Int, 34(2): 226–231

Berglund B, Lindvall T, Dietrich H S (1999). Guidelines for community noise. Geneva: World Health Organization

Berglund B, Lindvall T (1995). Community Noise. Stockholm: Center for Sensory Research

Bluhm G, Nordling E, Berglind N (2004). Road traffic noise and annoyance: an increasing environmental health problem. Noise Health, 6: 43–49

Carter N L (1996). Transportation noise, sleep, and possible after-effects. Environ Int, 22(1): 105–116

Darabont A, Iorga I, Ciodaru, M (1983). Noise and vibration measurement in technical domains. Buccharest: Editura Tehnică (in Romanian)

Dzhambov A M, Dimitrova D D (2014). Urban green spaces' effectiveness as a psychological buffer for the negative health impact of noise pollution: a systematic review. Noise Health, 16(70): 157–165

Dzhambov A M, Dimitrova D D, Turnovska T H (2014). Improving traffic noise simulations using space syntax: preliminary results from two roadway systems. Archives of Industrial Hygiene and Toxicology, 65: 259–272

Environmental Protection Agency (1974). Information on levels of environmental noise requisite to protect public health and welfare with an adequate margin of safety. EPA/ONAC Report 550/9-74-004. Washington, DC

European Environment Agency (2010). Good practice guide on noise exposure and potential health effects, EEA Technical report No 11/2010, Copenhagen,

European Environment Agency (2014). Noise in Europe, Report No 10/2014, Copenhagen,

European Federation for Transport and Environment (2008). Can you hear us? Why it is finally time for the EU to tackle the problem of noise from road and rail traffic. Jos Dings, ed. Brussels: T&E

European Parliament (2002). Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise. Official Journal of the European Communities, L(189): 12–25

Farca Fş A, Sivertun (2009). Road Traffic noise: GIS Tools for Noise Mapping and a Case Study of SKANE Region. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 34, Part XXX

Garg N, Maji S (2014). A critical review of principal traffic noise models: strategies and implications. Environmental Impact Assessment Review, 46: 68–81

Haq M A, Islam M M, Ali M S, Haque M F, Akhand M M R (2012). Status of noise pollution in mixed areas of Dhaka City: a GIS approach. Journal of Environmental Science & Natural Resources, 5 (1): 09–17

Ising H, Kruppa B (2004). Health effects caused by noise: evidence from the literature from the past 25 years. Noise Health, 6: 5–13

Jazani R K, Saremi M, Rezapour T, Kavousi A, Shirzad H (2015). Influence of traffic-related noise and air pollution on self-reported fatigue. Int J Occup Saf Ergon, 21(2): 193–200

Job R F S (1999). Noise sensitivity as a factor influencing human reaction to noise. Noise Health, 3: 57–68

Joint Research Centre (2011), Institute for environment and sustainability. Publications office of the European Union, Luxemburg,

Kephalopoulos S, Paviotti M (2013). Noise maps from different national assessment methods: differences, uncertainties, and needs for harmonization. In: Licitra G, ed. Noise Mapping in the EU: Models and Procedures. London: CRC Press

Konecni V J (1975). The mediation of aggressive behavior. arousal level versus anger and cognitive labeling. J Pers Soc Psychol, 32(4): 706–712

Kucas A, Hoej J, Frederiksen R (2007). Efficient Noise Mapping using ArcGIS and detailed Noise Propagation Simulation, In: ESRI European User Conference

Licitra G (2013). Noise Mapping in the EU: Models and Procedures. London: CRC Press

Licitra G, Ascari E (2013). The Good Practice Guide,Version 2'. In: Licitra G, ed. Noise Mapping in the EU: Models and Procedures, London: CRC Press

Maschke C, Hecht K (2007). Stress and noise – the psychological/physiological perspective and current limitations. In: Luxon L, Prasher D, eds. Noise and Its Effects. Chichester: John Wiley & Sons

Mathews K E, Cannon L K (1975). Environmental noise level as a determinant of helpful behavior. J Pers Soc Psychol, 32(4): 571–577

Méline J, Van Hulst A, Thomas F, Karusisi N, Chaix B (2013). Transportation noise and annoyance related to road traffic in the French RECORD study. Int J Health Geogr, 12(1): 44

Mihăiescu T, Mihăiescu R (2009). Traffic noise pollution in urban areas. Case study –Bistrita town. Proenvironment/Promediu, 2: 222–225

Olson H F (1967). Music, Physics and Engineering. Dover Publications

Pandya G H (2003). Assessment of traffic noise and its impact on the community. Int J Environ Stud, 60(6): 595–602

Passchier-Vermeer W, Passchier W F (2000). Noise exposure and public health. Environ Health Perspect, 108(s1 Suppl. 1): 123–131

Quamrul A M, Shahadat H M, Azharul I M (2015). Noise pollution assessment in Jamalpur Municipal Area, Bangladesh, International. Res J Environ Sci, 4(6): 52–58

Reed S E, Boggs J L, Mann J P (2010). SPreAD-GIS: an ArcGIS toolbox for modeling the propagation of engine noise in a wildland setting. Version 2.0. The Wilderness Society, San Francisco, CA

Reed S E, Boggs J L, Mann J P (2012). A GIS tool for modeling anthropogenic noise propagation in natural ecosystems. Environ Model Softw, 37: 1–5

Sheng N, Tang U W (2011). Spatial analysis of urban form and pedestrian exposure to traffic noise. Int J Environ Res Public Health, 8(12): 1977–1990

Stansfeld S A, Matheson M P (2003). Noise pollution: non-auditory effects on health. Br Med Bull, 68(1): 243–257

Stansfeld S, Clark C (2011). Outcomes of the European network on noise and health (ENNAH). In: 40th International Congress and Exposition on Noise Control Engineering, Proceedings of INTERNOISE 2011. Osaka, 25–29

Sternberg R J (1999). Handbook of Creativity. Cambridge University Press

Swain B K, Goswami S (2013). Integration and comparison of assessment and modeling of road traffic noise in Baripada town, India. International Journal of Energy and Environment, 4(2): 303–310

Tsai K T, Lin M D, Chen Y H (2009). Noise mapping in urban environments: a Taiwan study. Appl Acoust, 70(7): 964–972

Van Blokland G, Peeters B (2009). Modelling the noise emission of road vehicles and results of recent experiments. Internoise, Ottawa

Weber N, Haase D, Franck U (2014). Assessing modelled outdoor traffic-induced noise and air pollution around urban structures using the concept of landscape metrics. Landsc Urban Plan, 125: 105–116