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# NOISE POLLUTION: A GIS-BASED APPROACH TO MAPPING AND ASSESSMENT

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***Abstract***

*Monitoring noise pollution is crucial for protecting public health and the environment. It provides data and information needed to understand the sources and distribution of noise levels. This paper presents a GIS-based study of noise pollution for an area located in the southwest part of Bucharest, between Mihail Sebastian, Calea 13 Septembrie and Drumul Sării streets. The values of noise have been recorded by using the Sound Level Meter Lutron - Model SL-4012, in September 2022, for 3 different moments: in the morning, at midday, and in the evening. The results of the analysis have been then used to produce noise maps for each of the three locations. The results showed significant differences in noise levels across different times of the day, with peak levels occurring during daytime hours and early evening in different locations. The study's noise maps provided a clear visual representation of the distribution of noise levels, highlighting areas of concern. The study presents the importance of considering temporal factors in noise mapping and assessment, and the benefits of using GIS tools for this type of analysis.*

***Key words**: GIS-based mapping, noise pollution, road traffic noise, SLM-Sound Level Meter.*

## INTRODUCTION

Noise pollution refers to excessive or annoying sound that can have an adverse effect on human health and the environment. Noise pollution is a growing concern in many urban areas, affecting the physical and mental health of millions of people worldwide (Ertugrul E. & Sercan E., 2021).

Sources of noise pollution can include traffic, construction sites, industrial machinery, loud music, and other human activities.

Even though noise is a consequence of numerous human activities, the main source of environmental noise is urban traffic. Urban traffic noise is regarded as the 2nd most important environmental source of health concerns in Europe, after fine particle pollution (Hänninen et al., 2014). Ambient noise levels in a large city tend to be higher when traffic is heavier (Alves, J.A. et al., 2015).

Despite new vehicle models becoming quieter, the increasing volume of road traffic increases the noise emitted. Many central city streets have reached traffic saturation, congested almost daily and with lower speeds throughout the day (Fan S., 2022).

Urbanization generates significant environmental issues like air pollution (Yuan Song et al., 2014), loss of biodiversity (Cardinale et al., 2012), soil pollution (Sandu, 2013) and noise levels exceeding permissible limits (Halonen et al., 2016).

EEA (2019) & ETC/ATNI (2019) shows that most countries have more than 50% of urban dwellers exposed to road noise levels of 55 dB Lden or higher during the day-evening-night period. Excessive exposure to noise pollution can lead to heart disease, high blood pressure, hearing loss and even cognitive impairment (Cueto et al., 2017; Majidi & Khosravi, 2016; WHO, 2018).

Environmental noise is one of the issues that is attracting more and more attention worldwide and is regulated by an increasingly demanding legal framework, because its effects on the population are really worrying (Titu et al., 2022). Noise pollution remains a major environmental health problem in Europe (EEA, 2017). Romania also has a considerable number of urban areas within territories, with a high percentage of people exposed to noise levels above the Environmental Noise Directive in Europe thresholds (Table 1).

Tabel 1. Number of people exposed in Romania to high levels of noise above the EU reporting thresholds (https://www.eea.europa.eu/themes/human/noise/noise-fact-sheets/noise-country-fact-sheets-2021/romania)

| | **Lden > = 55 dB** | | | **Lnight > = 50 dB** | | |
|---|---|---|---|---|---|---|
| | **2007** | **2012** | **2017** | **2007** | **2012** | **2017** |
| Road | 2.897.000 | 2.511.100 | 2.752.700 | 2.056.500 | 2.090.900 | 1.956.700 |
| Rail | 273.100 | 275.400 | 96.700 | 206.000 | 241.600 | 93.500 |
| Air | 25.800 | 44.300 | 3.500 | 27.700 | 27.400 | 13.300 |
| Industry | 90.400 | 230.700 | 15.800 | 50.400 | 64.000 | 7.100 |

A Geographic Information System (GIS) - based approach for noise monitoring can address several problems associated with traditional noise monitoring methods, providing a more comprehensive and spatially explicit understanding of noise pollution. GIS allows the collection, storage, manipulation, and analysis of spatial data, providing a comprehensive understanding of the distribution and intensity of noise pollution.

Traditional noise monitoring methods often provide only point measurements of noise levels, which do not capture the spatial distribution of noise pollution. GIS-based approaches, on the other hand, can provide a spatially explicit understanding of noise pollution by mapping noise levels across different locations.

On the other hand, by combining GIS with noise measurement devices, it is possible to create accurate noise maps that can help identify high-risk areas and inform urban planning and environmental policies.

While the use of GIS for noise mapping is a relatively new field, researchers have made significant strides in understanding the complexities of noise pollution and developing effective solutions using GIS techniques (Alvarado, R.A. & Parra, C.M., 2019; Baskaran, R. & Ravindran, D., 2018; Castillo-Salazar, J.A. et al., 2020; Cheng, M., Lu, X. & Du, W., 2017; Eftekhari, M. et al., 2020).

In their studies, the specialists have found that the use of GIS-based noise monitoring can provide a more accurate and comprehensive picture of noise pollution levels in each area. The researchers, including L. Maffei and A. Zambon, conducted their study in the city of Padua, Italy and concluded that GIS-based noise monitoring can help identify noise hotspots and support effective noise control strategies (Maffei, L. & Zambon, A., 2012). Another study focused on the use of GIS and noise modeling to assess the impact of urbanization on noise pollution in the city of Chandigarh, India. The researchers, including S. K. Saha and S. Kumar, found that GIS-based noise modeling can provide valuable insights into the sources and levels of noise pollution in urban areas, as well as help identify areas where noise reduction measures are needed (Saha, S. K. & Kumar, S., 2019).

E. McKeogh and D. Robinson, examined the use of GIS-based noise mapping to support urban planning and land-use management in the city of Dublin, Ireland. The researchers found in their study that a GIS-based noise mapping can help identify areas with high noise pollution levels and inform decisions on land-use planning and development (McKeogh, E. & Robinson, D., 2004).

GIS-based noise monitoring is an important tool for this task as it allows for a more accurate and comprehensive assessment of noise pollution levels in each area. GIS technology enables the integration of different types of data, including noise measurements, land use patterns, and demographic information, which can be used to identify noise hotspots and develop targeted noise control strategies.

In summary, the use of GIS-based noise monitoring is essential for effective noise pollution management and can help improve the quality of life in urban areas. It is therefore important for policymakers and urban planners to consider the benefits of this technology when developing noise control policies and strategies.

## MATERIALS AND METHODS

Bucharest, Romania's capital city, is facing a growing problem with noise pollution (Albu, C. et al., 2019; Boboc, M.C. et al., 2018; Chiriac, C.R. et al., 2017; Deaconu, S. & Cioca, L.I., 2019; Rusu, C.M. et al., 2015; Soreanu, G., & Dumitru, D., 2015; Tăranu, N. & Ioniță, I., 2019; WHO, 2018). The city's rapid urbanization, increasing population, and high levels of traffic are some of the main causes of noise pollution in the area. The effects of noise pollution in Bucharest can be particularly harmful to public health, including hearing loss, cardiovascular disease, and sleep disturbances. Noise pollution can also negatively impact the environment and quality of life in urban areas.

Some places in Bucharest that are particularly noisy include busy intersections, construction sites, and public transportation hubs. The city's nightlife scene, which includes numerous bars and nightclubs, can also contribute to high levels of noise pollution in certain areas. The paper "Assessment of urban noise pollution in Bucharest, Romania", published in the Journal of Environmental Protection and Ecology in 2015, found that noise pollution levels in Bucharest exceed World Health Organization guidelines and pose a significant health risk to residents. This study provides an assessment of urban noise pollution in Bucharest, with a focus on traffic noise. The authors used measurements from 48 monitoring stations throughout the city to assess noise levels and found that levels exceeded World Health Organization guidelines in many areas. The study also highlights the health risks associated with high levels of noise pollution, including hearing loss, cardiovascular disease, and sleep disturbances (Rusu, C.M. et al., 2015).

The study "Mapping noise pollution in Bucharest using GIS technology", published in the Environmental Engineering and Management Journal in 2019, conducted by Nicoleta Tăranu and Ion Ioniță aimed to map the noise pollution levels in Bucharest, using GIS technology. The authors collected noise data from 34 measurement points across the city over a 24-hour period. They also collected data on various noise sources, such as road traffic, trains, and planes.

The noise pollution thresholds in Bucharest vary depending on the location and time of day. According to a study published in the Environmental Engineering and Management Journal in 2019 (Tăranu, N. & Ioniță, I., 2019), the average noise level in Bucharest is estimated at 70 decibels (dB). However, in congested areas with heavy traffic or in the vicinity of airports and train stations, noise levels can reach over 80 dB.

Furthermore, the study found that noise levels in residential areas during the day ranged between 55-70 dB, which is above the recommended threshold by the World Health Organization - WHO (WHO, 2018) of 55 dB. At night, the noise levels in residential areas ranged between 45-60 dB, which is also above the recommended threshold by the WHO (2018) of 40 dB. Overall, the study highlights the need for effective noise reduction strategies and policies to address the significant impact of noise pollution on public health and well-being in Bucharest.

Using GIS technology, the authors created noise pollution maps of Bucharest, showing the noise levels in different areas of the city. They found that the noise pollution levels were highest in areas with heavy road traffic and in areas close to airports and train stations. The authors also analyzed the impact of noise pollution on human health and found that prolonged exposure to high levels of noise can lead to various health problems, including hearing loss, cardiovascular diseases, and stress.

The study concluded that GIS technology is an effective tool for mapping noise pollution in urban areas and can be used to develop noise reduction strategies and policies to improve public health and well-being.

To address the issue of noise pollution, policymakers and urban planners in Bucharest can use GIS-based noise monitoring to identify areas with high levels of noise pollution and implement targeted noise reduction measures. These may include noise barriers, traffic management strategies, and building design modifications. By taking proactive steps to reduce noise pollution levels, Bucharest can protect public health and improve the quality of life for its residents.

The studied area is located in the southwest part of Bucharest, between Mihail Sebastian, Calea 13 Septembrie and Drumul Sarii streets.

It is a mixed area consisting of residential buildings, both blocks of flats and houses, shops, commercial spaces, restaurants, playgrounds for children, office buildings, the Ion Barbu theoretical high school, various institutions, as well as thoroughfares with heavy traffic as well as pedestrian streets and alleys. It is a very crowded area in the city with a high level of noise pollution due to heavy traffic, proximity to office buildings and other areas of activity.

The period chosen for the analysis is 2022 September month. This month is the moment when economic activity resumes, and road traffic is more intense in the area. This could lead to an increase in noise levels and makes this period relevant for noise pollution analysis.

The measurements the measurements were carried out in September 2022, three times a day at 07:00 A.M., 12:00 P.M and 9:00 P.M.

The data were taken from the sidewalk in the immediate vicinity of the mentioned intersections, at a height of 1 meter above the ground. The temperatures on the date of the measurements were on average between 15 and 28 degrees Celsius, the wind speed was generally between 1 and 30 km/h, generally clear sky and with a low level of precipitation, between 0 and 8 mm.

GPS coordinates were recorded for each analyzed location. These are represented in Figure 1.

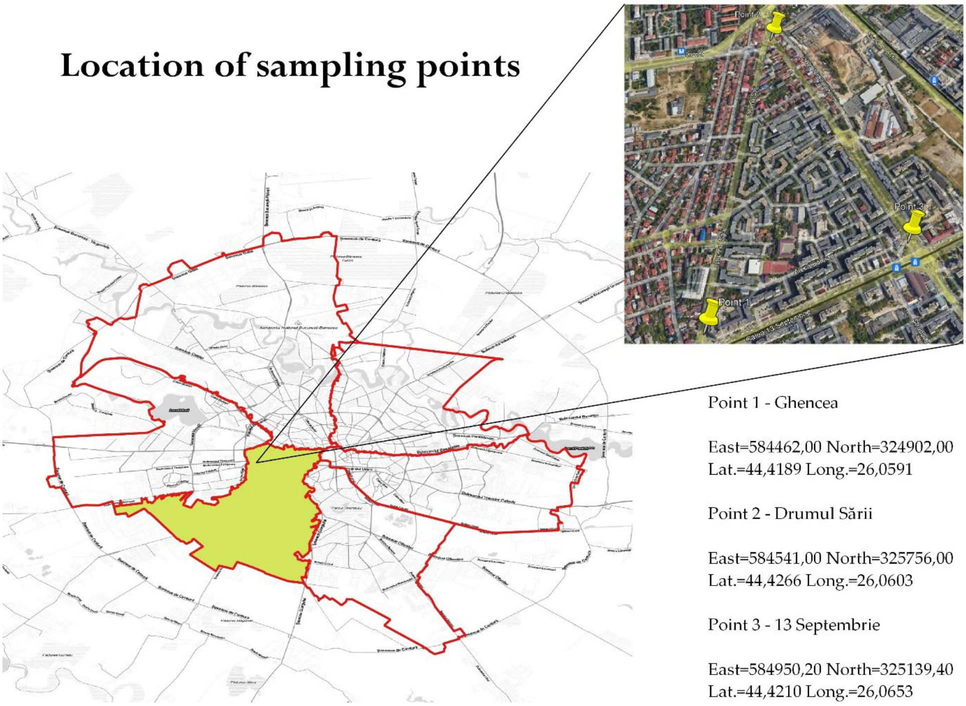


Figure 1. Sampling points locations map

The first location, named generically "Ghencea" is located at the intersection of Calea 13 Septembrie and Drumul Sării; the measurements were made from the sidewalk related to the intersection located approximately 30 m away from the Calea 13 Septembrie road and approximately 2 m from the Drumul Sării road. The coordinates in the 1970 Stereographic System are: East = 584462.00 and North = 324902.00 (Latitude = 44.4189 and Longitude = 26.0591).

The second site named generically "Drumul Sării" is located at the intersection between Drumul Sării and Mihail Sebastian Street; the measurements were made from the sidewalk related to the intersection, located approximately 5 m from Drumul Sării road and approximately 5 m from Mihail Sebastian Street Road. The coordinates in the 1970 Stereographic System are: East = 584541.00 and North = 325756.00 (Latitude = 44.4266 and Longitude = 26.0603).

The third and last location named generically "13 Septembrie" was established at the intersection between Mihail Sebastian Street and Calea 13 Septembrie; the measurements were carried out from the sidewalk related to the intersection, located approximately 30 m away from the Calea 13 Septembrie road and approximately 5 m from the Mihail Sebastian Street Road. The coordinates in the 1970 Stereographic System are: East = 584950.20 and North = 325139.40 (Latitude = 44.4210 and Longitude = 26.0653).

The sound values were recorded using the sound level meter Lutron - Model SL-4012 (Figure 2). This is a high-precision digital sound-level meter, accuracy class 2 according to IEC 61672, A & C frequency weighting, high accuracy condenser microphone and measurement range from 30 to 130 dB.


Figure 2. Sound Level Meter Lutron - Model SL-4012 used for measurements

The device is designed for neighborhoods noise monitoring, construction site noise control and road traffic noise monitoring.

The measurements are carried out according to specific requirements for the road noise measurements in the immediate vicinity of the currents of vehicles from the intersections with the microphone pointing toward the main noise source (SR ISO 1996-1 regulation).

In many cases, noise data can only be collected at a few locations, making it difficult to estimate noise levels at unknown locations. In such cases, data interpolation can be used to estimate noise values at these unknown locations.

Interpolation is an important process in spatial data analysis that involves estimating values at unknown locations based on known values from adjacent or neighboring locations.

In this paper, we used the interpolation tool from QGIS software to determine values for the entire area of interest.

We chose to apply the IDW (Inverse Distance Weighting) method, which considers the values of the three points to estimate the unknown value. Thus, we obtained maps of the interpolation results, which shows the distribution of noise around interest. We checked and adjusted the interpolation settings to obtain the best possible result.

This analysis contributes to a better-informed decision regarding the impact of noise on the area and can aid in the development of effective strategies to mitigate or manage noise levels in the affected areas.

## RESULTS AND DISCUSSIONS

This preliminary study was conducted in a small area to provide an initial assessment of noise pollution levels and distribution. By conducting this preliminary study, we have identified key areas where noise pollution is particularly high, which can be targeted for further research and intervention.

The noise pollution maps, generated by using the calculated average noise values of the measurements taken during September month, is given in Figures 3, 4 and 5.

In the maps the red color indicates the higher noise level, yellow indicate medium level of noise while the blue color indicates the lowest values of noise.

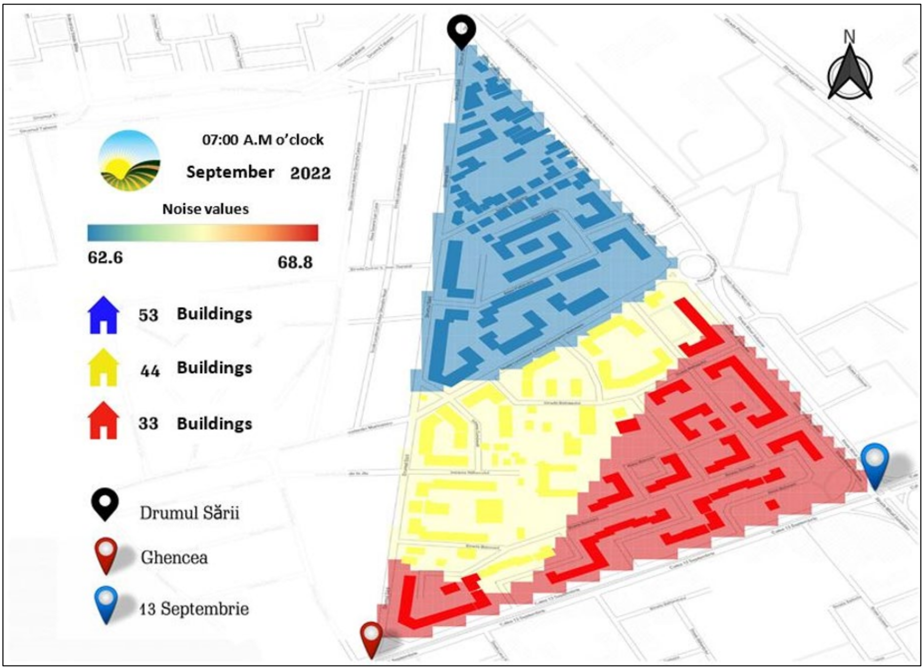


Figure 3. Interpolation of average values of noise at 07:00 A.M o'clock

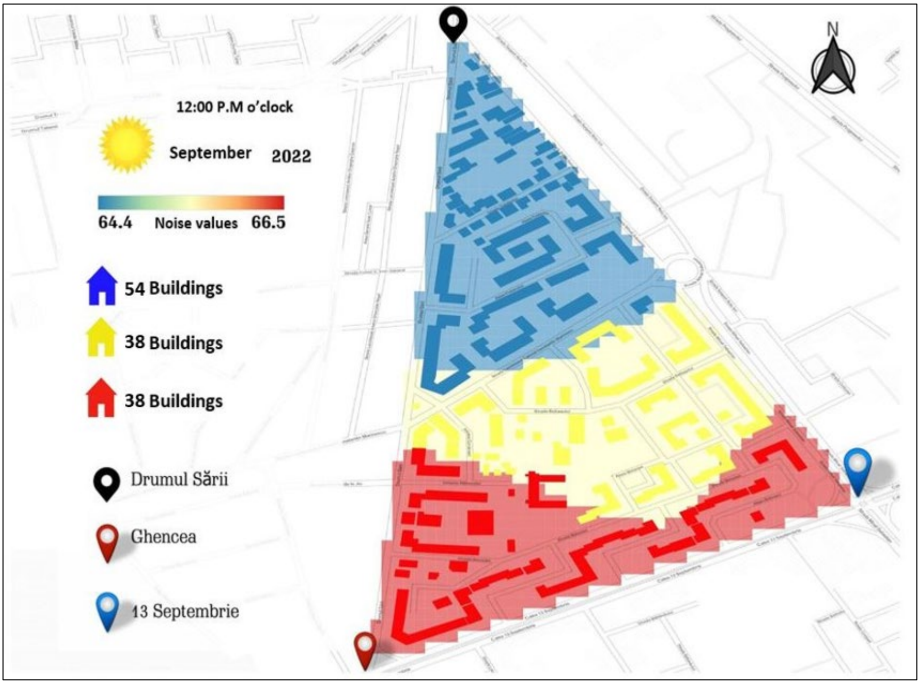


Figure 4. Interpolation of average values of noise at 12:00 P.M o'clock

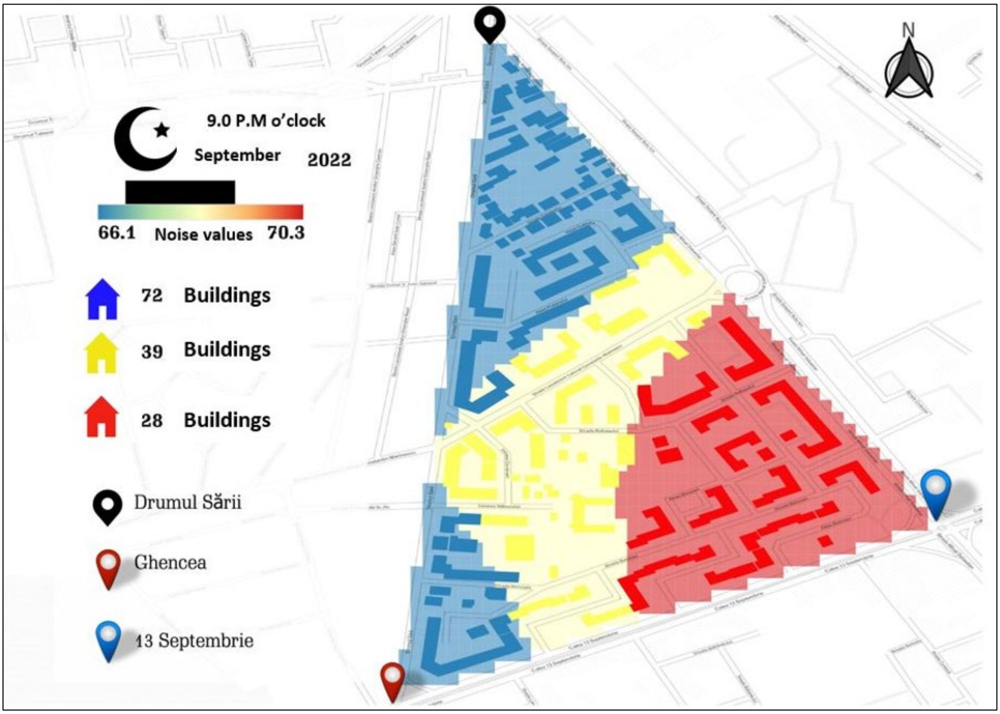


Figure 5. Interpolation of average values of noise at 09:00 P.M o'clock

The GIS-based mapping and assessment of noise pollution revealed that the recorded noise values varied in the three locations depending on the time of day.

According to the Figures 3, 4 and 5, the higher levels of noise pollution have been recorded in the Point 1 - Ghencea and in the Point 3 - 13 Septembrie while the lowest noise values are recorded in the Point 2 - Drumul Sării.

By analyzing the noise values recorded in September, Figures 6, 7 and 8 the following classifications were made:

By time, in the morning, at 07:AM, the lowest noise values were recorded in Point 2 - Drumul Sării, with values between 56.9 dB and 70.4 dB, while the highest values were recorded in Point 3 - 13 Septembrie with values between 65.5 dB and 71.5 dB.

At the midday, at 12:00 P.M the lowest noise values were recorded in Point 2 - Drumul Sării, with values between 55.7 dB and 70.2 dB. At the same time, the Point 1 - Ghencea recorded the highest noise trend with values between 62.9 dB and 70.2 dB.

In the evening, a trend like the one recorded in the morning was registered, namely, the trend with the lowest noise values was recorded in the location Drumul Sării with values between 60.1 dB and 70.1 dB. At the same time, the trend with the highest noise values was recorded in the location 13 Septembrie, with values between 68.9 dB and 72.5 dB.

The lowest value recorded for the entire analyzed period was 55.7 dB (recorded in Drumul Sării location) while the highest value was 71.5 dB (recorded in 13 Septembrie location).

Furthermore, from the analysis of the collected values, it was observed that there are some gaps in the noise values recorded on weekend days. This observation suggests that noise levels may be lower on weekend days, which may be explained by a reduced road traffic.

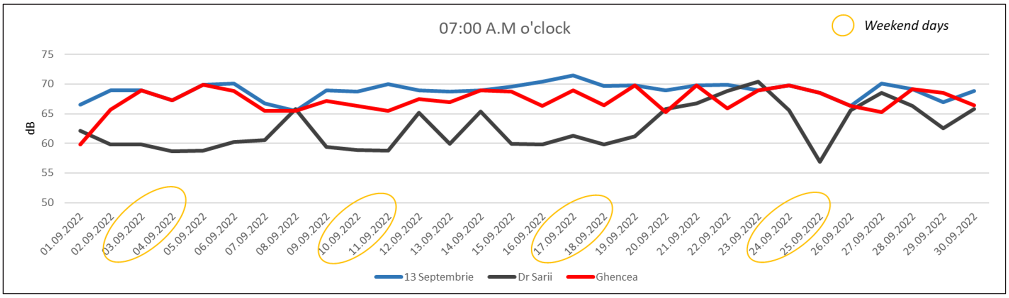


Figure 6. Distribution of the Noise Values Recorded in the three locations at 07:00 A.M o'clock

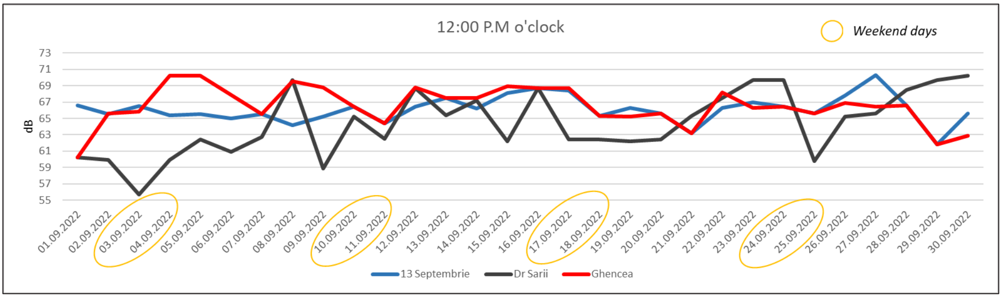


Figure 7. Distribution of the Noise Values Recorded in the three locations at 12:00 P.M o'clock

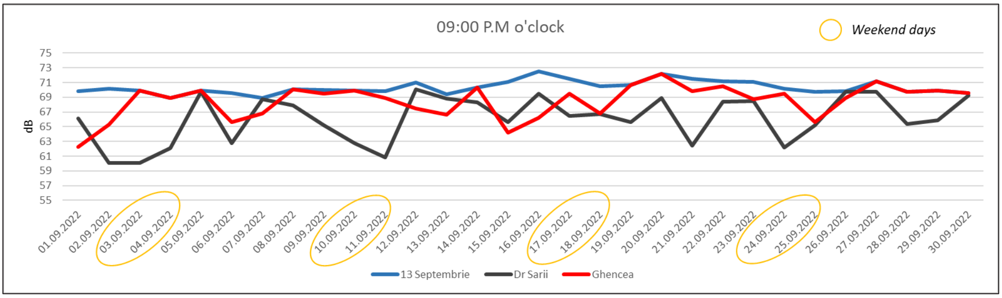


Figure 8. Distribution of the Noise Values Recorded in the three locations at 09:00 P.M o'clock

## CONCLUSIONS

Noise pollution is a widespread problem in urban areas, with high levels of noise exposure affecting large numbers of people. In conclusion, the tested GIS interpolation variant has shown promising results in the analysis of noise values during the preliminary study. Conclusions that can be drawn from this study include the effectiveness of interpolation, the establishment of a noise value analysis methodology, the need for further research, and the importance of using GIS in noise value analysis.

The distribution of noise pollution is not uniform, with certain areas experiencing higher levels of noise than others. GIS-based noise pollution analysis is proper to identify areas with diverse levels of noise pollution. Interpolation in GIS is extremely useful, especially where there is no noise data, it can be said that its use allows making estimates of the noise level in areas without data, by extrapolating existing values in adjacent areas. Interpolation can also create a coherent picture of the distribution of noise levels. Therefore, interpolation in GIS is an effective method to estimate the noise level in areas where no noise data exists, making it a valuable technique for assessing the impact of noise in the urban environment.

In Bucharest, the ambient noise limit values are set by Government Decision No. 944/2003 regarding the noise produced by fixed and mobile sources, with subsequent amendments and additions. This decision was issued in accordance with the provisions of Law no. 349/2002 regarding the prevention and combating of pollution.

According to this decision, for mixed-use areas, the limit values for noise produced by fixed sources are 70 dB during the day and 60 dB during the night. After our analysis, the average values recorded in September 2022 in the three locations fall within the official limits.

Of the four possible sources of environmental noise - road traffic, rail traffic, air traffic and industrial activity - the only cause of exceeding the limit values in Bucharest can be road traffic, as there is no industry in residential areas, the railway and the airport are far from residential areas. Therefore, given that the only source of noise exceeding the limit levels set by European legislation (ECD, 2002/49/EC; Xu, H. & Zhao, G., 2021) is road traffic, reducing environmental noise can only be achieved by reducing road noise, both at the source (emitted noise) and at the receiver (mixed noise-perceived by residents).

It is important to note that this preliminary study was conducted in a limited area, which may limit the ability to draw clear conclusions. There is also the opportunity to continue the study, expanding the analyzed area and applying various analysis methods and techniques, integrating noise data in the context of other geospatial data, such as land use, traffic, transportation, population density maps and others. So that a more detailed and accurate understanding of the noise level and the factors that influence it in those areas can be obtained.

## REFERENCES

Albu, C., Olaru, M., & Gavrilă, A.G. (2019). Noise pollution in Bucharest: A case study. In Proceedings of the International Conference on Noise and Vibration Engineering (pp. 1969-1976).

Alvarado, R.A., & Parra, C.M. (2019). Noise pollution mapping and modelling using GIS and mobile monitoring devices: a case study in a Colombian city. *Applied Acoustics*, 149, 212-222.

Alves, J.A.; Silva, L.T.; Remoaldo, P.C.C. (2015). The Influence of Low-Frequency Noise Pollution on the Quality of Life and Place in Sustainable Cities: A Case Study from Northern Portugal. *Sustainability,* 7, 13920–13946.

Baskaran, R., & Ravindran, D. (2018). Spatial mapping and analysis of noise pollution using GIS: A case study of Chennai city, India. *Sustainable Cities and Society*, 38, 413-424.

Boboc, M.C., Ionel, I., & Ene, A. (2018). Environmental noise pollution in Bucharest, Romania. *Journal of Environmental Protection and Ecology*, 19(3), 1228-1236.

Cardinale, B. J., Duffy, J. E., Gonzalez, A., Hooper, D. U., Perrings, C., Venail, P. (2012). Biodiversity loss and its impact on humanity. Nature, 486, 59–67.

Castillo-Salazar, J.A., Cañete-Medinilla, A., & Vidal-Barrero, F. (2020). Noise pollution modeling and mapping in urban areas using GIS and regression analysis. *Journal of Environmental Management*, 257, 109976.

Cheng, M., Lu, X., & Du, W. (2017). Spatial mapping and analysis of noise pollution in urban areas: A case study in Harbin, China. *Applied Geography*, 79, 89-98.

Chiriac, C.R., Chiriac, A.E., & Popa, V. (2017). Environmental noise monitoring in Bucharest using GIS technology. Energy Procedia, 111, 553-562.

Cueto, J. L., Petrovici, A. M., Hernández, R., & Fernández, F. (2017). Analysis of the impact of bus signal priority on urban noise. *Acta Acustica United Acustica*, 103(4), 561–573. https://doi.org/10.3813/AAA.919085.

Deaconu, S., & Cioca, L.I. (2019). Noise pollution and urban planning in Bucharest, Romania. In Proceedings of the 16th International Multidisciplinary Scientific GeoConference SGEM, pp. 63-70.

EEA Report (2019). Environmental noise in Europe - 2020, No 22/2019, ISBN 978-92-9480-209-5, ISSN 1977-8449, doi:10.2800/686249

EEA (2017). Managing exposure to noise in Europe. EEA_briefing 2017-blue.pdf

EEA (2019). 'Reported data on noise exposure covered by Directive 2002/49/EC', European Environment Agency. Available online: https://www.eea.europa.eu/data-and-maps/data/data-on-noise-exposure-7

Eftekhari, M., Sarafi, M., Akhavan, S., Motlagh, M. M. (2020). Noise pollution mapping in the city of Tehran, Iran: Application of GIS and machine learning techniques. *Environmental Pollution*, 259, 113862.

Ertugrul E., Sercan E. (2021). GIS-based mapping and assessment of noise pollution in Safranbolu, Karabuk, Turkey. Environment, Development and *Sustainability* 23:15413–15431

ETC/ATNI (2019). Noise indicators under the Environmental Noise Directive. Methodology for estimating missing data, Eionet Report ETC/ATNI No 1/2019, European Topic Centre on Air Pollution, Transport, Noise and Industrial Pollution. Available online: https://www.eionet.europa.eu/etcs/etc-atni/products/etc-atni-reports/noise-indicators-under-the-environmental-noise directive methodology-for-estimating-missing-data.

European Commission 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. Available online: https://publications.europa.eu/en/publication-detail/-/publication/27d1a64e-08f0-4665-a258-96f16c7af072/language-en

Fan, S., Li, J., Li, L., Chu, Z. (2022). Noise Annoyance Prediction of Urban Substation Based on Transfer Learning and Convolutional Neural Network. *Energies*, 15, 749.

Halonen, J. I., Dehbi, H. M., Hansell, A. L., Gulliver, J., Fecht, D., Blangiardo, M. (2016). Associations of night-time road traffic noise with carotid intima-media thickness and blood pressure: The Whitehall II and SABRE study cohorts. *Environment International*, 98, 54.

Hänninen, O. (2014). Environmental burden of disease in Europe: assessing nine risk factors in six countries, *Environmental Health Perspectives* 122(5), pp. 439-446 DOI: https://doi.org/10.1289/ehp.1206154.

https://www.eea.europa.eu/themes/human/noise/noise-fact-sheets/noise-country-fact-sheets-2021/romania

Maffei, L. and Zambon, A. (2012). GIS-based noise monitoring: a case study in Padua, Italy. *International Journal of Environmental Research and Public Health*, 9(9), 3247–3265.

Majidi, F., & Khosravi, Y. (2016). Noise pollution evaluation of City Center of Zanjan by geographic information system (GIS). *Iranian Journal of Health and Environment*, 9(1), 91–102.

McKeogh, E. and Robinson, D. (2004). GIS-based noise mapping as a tool for implementing European environmental noise directive in Dublin, Ireland. *Applied Acoustics*, 65(9), 887-904.

Rusu, C.M., Roșu, E., & Georgescu, L.P. (2015). Assessment of urban noise pollution in Bucharest, Romania. *Journal of Environmental Protection and Ecology*, 16(3), 1293-1303.

Saha, S.K. and Kumar, S. (2019). GIS-based noise modeling to assess the impact of urbanization on noise pollution: a case study of Chandigarh, India. *Environmental Monitoring and Assessment*, 191(5), 293.

Sandu M.A., Bica I., Virsta A., Preda M. (2013). Human health risk of contamination by polychlorinated biphenyls in the area of Bucharest city International Multidisciplinary Scientific GeoConference SGEM; Sofia: 545-552. Sofia: Surveying Geology & Mining Ecology Management (SGEM).

Soreanu, G., & Dumitru, D. (2015). Noise pollution in Bucharest, Romania. *Revista de Chimie*, 66(9), 1373-1377.

Sound Level Meter - Model: SL-4012. Technical Reference Manual. Available online: http://lutron1976.myqnapcloud.com/database/pdf/SL-4012.PDF

SR 10009:2017 Acoustics. Permissible limits of ambient noise level, www.asro.ro

Tăranu, N., & Ioniță, I., (2019). Mapping noise pollution in Bucharest using GIS technology. *Environmental Engineering and Management Journal*, 18(11), 2593-2601.

Titu, A.M., Boroiu, A.A., Mihailescu, S., Pop, A.B., Boroiu, A. (2022). Assessment of Road Noise Pollution in Urban Residential Areas - A Case Study in Pitesti, Romania. *Appl. Sci.*, 12, 4053. https://doi.org/ 10.3390/app12084053.

World Health Organization - WHO (2018). Environmental noise guidelines for the European region, WHO Regional Office for Europe, Copenhagen, Available online: http://www.euro.who.int/en/health-topics/environment-and-health/noise/publications/2018/environmental-noise-guidelines-for the-european-region-2018.

Xu, H. & Zhao, G. (2021). Assessing the Value of Urban Green Infrastructure Ecosystem Services for High-Density Urban Management and Development: Case from the Capital Core Area of Beijing, China. *Sustainability*, 13, 12115.

Yuan, M., Song, Y., Huang, Y., Hong, S., Huang, L. (2017). Exploring the association between urban form and air quality in China. *Journal of Planning Education and Research* 0739456X1771151.