Journal of Neonatal Surgery
ISSN(Online): 2226-0439
Vol. 12, (2023)
https://www.jneonatalsurg.com

OPEN ACCESS

Integrating GIS in Road Traffic Noise Assessment: A Review of Methods and Applications

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Cite this paper as: Singh Upendrasingh R., Shivendra Kumar Jha, (2023) Integrating GIS in Road Traffic Noise Assessment: A Review of Methods and Applications. *Journal of Neonatal Surgery*, 12, 74-78.

ABSTRACT
Urbanization and increasing vehicular traffic have significantly escalated noise pollution levels, posing health risks and reducing quality of life. Geographic Information Systems (GIS) offer a robust platform for spatial analysis and visualization of noise pollution. This review provides an overview of GIS-based approaches for road traffic noise mapping, focusing on their methodologies, data requirements, modeling techniques, and applications. By analyzing recent studies and tools used in this field, the review highlights the strengths and limitations of current practices and suggests directions for future research to improve accuracy, scalability, and real-time monitoring.

Keywords: *Geographic Information Systems (GIS), visualization, scalability.*

1. INTRODUCTION

1.1 Background

Noise pollution is one of the most significant and growing environmental issues, particularly in large urban areas. Studies indicate that over 20% of the global population lives under unacceptable noise levels, while nearly 60% of the European population is exposed to harmful noise levels during the daytime. This growing issue poses several health risks, including physiological and psychological disorders, hypertension, and ischemic heart diseases.

Various sources contribute to ambient noise in public spaces, such as industrial and construction activities, large machinery, loudspeakers, music systems, vehicular horns, and other mechanical devices. These noise sources negatively impact both the physical health and mental well-being of individuals.

Measuring traffic noise levels and representing them spatially using Geographic Information System (GIS) maps offers a powerful tool for identifying noise sources, analysing their spread, and implementing effective control measures. Road traffic noise is a major contributor to environmental pollution in urban settings. Many countries have set vehicular noise limits and issued guidelines for road traffic noise management. In developing countries like India, where urbanization is accelerating rapidly, vehicular noise is becoming a dominant source of environmental noise pollution. GIS provides a robust framework for collecting, managing, analysing, and visualizing spatial data related to environmental noise. It includes systems for cataloging and metadata management that help track every stage of data processing ranging from input variations and data interpretation to interpolation methods and computational settings. These factors collectively influence the accuracy of the final output.GIS-based tools are particularly useful for visualizing the spatial distribution and intensity of noise pollution. With appropriate software, noise mapping becomes an effective graphical representation of noise levels and their daily fluctuations. Interpolation techniques such as Kriging can be applied to create contour maps that depict noise level variations across a region. This geostatistical method allows for the evaluation of acoustic behaviour in topographical contexts. This review discusses the integration of GIS with noise prediction models, highlighting how GIS-based approaches enable precise and efficient assessments of environmental noise impacts. By offering enhanced visualization and classification of high-noise zones and traffic congestion areas, GIS stands out as a valuable asset in urban noise pollution studies.

GIS as a Tool for Environmental Noise Assessment

Geographic Information Systems (GIS) have become integral to environmental analysis due to their capabilities in managing, analysing and visualizing spatial data. GIS enables the mapping of noise levels across urban landscapes and assists in identifying high-risk zones. It also supports the decision-making process in noise mitigation and urban infrastructure planning.GIS-based noise mapping allows for the graphical representation of noise intensity using spatial data such as traffic volume, road geometry, land use, and building structures. With GIS, various layers of environmental data can be overlaid to understand the correlation between noise sources and affected areas.

2. LITERATURE REVIEW

The integration of Geographic Information Systems (GIS) in environmental noise assessment, particularly for road traffic noise, has received increasing attention over the past two decades. This section reviews key studies that demonstrate how GIS has been used for noise mapping, prediction, and mitigation.

Early Approaches to Noise Mapping:

Initial efforts in noise mapping were largely dependent on manual data collection and statistical methods for noise prediction. Studies such as **Lam and Chan (2000)** evaluated road traffic noise using empirical models but lacked spatial visualization tools. The absence of GIS limited their ability to assess spatial distribution, making results difficult to interpret for urban planning purposes.

Emergence of GIS in Noise Studies

The application of GIS in noise mapping gained momentum in the early 2000s. **Zannin et al. (2002)** demonstrated one of the earliest uses of GIS in mapping urban noise levels in Curitiba, Brazil. Their work highlighted the utility of GIS in combining traffic volume data with urban infrastructure to create noise contour maps. Similarly, **Murphy and King (2006)** applied GIS in Irish cities and emphasized its role in linking spatial noise data with land use planning.

Prediction Models Integrated with GIS

Numerous studies have incorporated standard noise prediction models with GIS platforms for higher accuracy. **RLS-90** (Germany), **FHWA** (USA), and **CNOSSOS-EU** (Europe) are widely used models that estimate noise levels based on traffic volume, speed, and road characteristics. For instance, **Michaud et al. (2008)** integrated FHWA with GIS to predict traffic noise across Canadian urban corridors. Their results revealed the effectiveness of combining deterministic models with spatial data layers.

Spatial Interpolation Techniques

Spatial interpolation methods, particularly Kriging, have been extensively used in GIS-based noise mapping. Ali (2011) used ordinary Kriging to interpolate point-based noise measurements in an urban Indian setting, successfully generating continuous noise maps. Compared to simpler methods like Inverse Distance Weighting (IDW), Kriging provided more accurate results by accounting for spatial autocorrelation.

Applications in Developing Countries

In the context of developing nations, GIS applications are still emerging due to limited data and technical resources. However, some significant contributions exist. Kisku et al. (2006) conducted one of the first GIS-based traffic noise studies in India, mapping noise levels across Varanasi. Their study emphasized the need for standardized protocols and improved data availability. **Banerjee et al. (2008)** also highlighted noise level variations near Indian highways using GIS and stressed its importance in policymaking.

Real-Time Monitoring and IoT Integration

Recent literature has started focusing on the integration of real-time noise sensors and IoT devices with GIS. Gupta and Kumar (2020) developed a prototype system combining low-cost noise sensors and web-based GIS tools for real-time urban noise tracking. This approach allows dynamic visualization of noise data and offers a new direction for smart city applications.

Gaps and Research Needs

While the literature confirms the potential of GIS in noise pollution studies, several gaps remain:

- Most models are based on static data, lacking temporal variation and real-time inputs.
- There is limited integration of socio-economic data, which can enrich public health assessments.
- Machine learning techniques are rarely combined with GIS for predictive analytics.
- Developing countries still face issues with consistent data collection, sensor deployment, and software access.

The reviewed literature underscores that GIS significantly enhances the scope and effectiveness of road traffic noise assessment. From early manual methods to advanced real-time and model-integrated systems, GIS has evolved into a critical tool for urban noise management. However, the full potential of GIS remains underutilized, especially in regions lacking digital infrastructure. Future research must address the current limitations through automation, real-time integration, and the inclusion of AI-driven models to support sustainable urban development and public health planning.

2.1 Noise Propagation Models

Environmental noise modeling is the process of estimating noise levels within a specific area under given environmental and operational conditions. A noise model typically defines the sources of noise, the environmental features that influence sound propagation, and the calculation methodology. Several internationally recognized models are used for environmental noise prediction, each tailored to specific conditions and applications. Some widely used road traffic noise propagation models include ISO 9613:1996, CoRTN88, the Harmonoise Prediction Algorithm, and Nord2000.

ISO 9613:1996

The ISO 9613 standard provides a general method for calculating sound attenuation during outdoor propagation from various sources. It predicts the A-weighted equivalent continuous sound pressure level (LAeq) at a receiver location. This standard accounts for frequency-based loudness perception using A-weighting, including components from lower frequencies that may be less perceptible to human hearing. ISO 9613 is applicable to multiple noise sources including road traffic, industrial operations, construction activities, and railways. It forms the foundation for several other noise propagation models, such as Harmonise, Nord2000, and CoRTN88.

2.1.1 Calculation of Road Traffic Noise

CoRTN88: The CoRTN88 model, developed in the UK, calculates road traffic noise based on indices like L10 (18h) and L10 (1h)—representing noise levels exceeded for 10% of the time during an 18-hour and 1-hour period, respectively. The model takes into account various influencing factors such as average vehicle speed, traffic composition (percentage of heavy vehicles), road geometry (slope, width), low traffic flow conditions, barriers, topographical cuttings, opposite façades, and ground effects. It is particularly useful for assessing noise exposure along highways and urban road networks.

Harmonoise Prediction Algorithm: The Harmonoise model was developed as part of a European research initiative to improve the accuracy of environmental noise predictions. It enhances previous models by incorporating the combined effects of ground characteristics, atmospheric refraction, topographical shielding, and meteorological conditions. Unlike ISO 9613, the Harmonoise model is capable of addressing more complex propagation paths and environmental interactions, offering more detailed attenuation calculations under diverse scenarios.

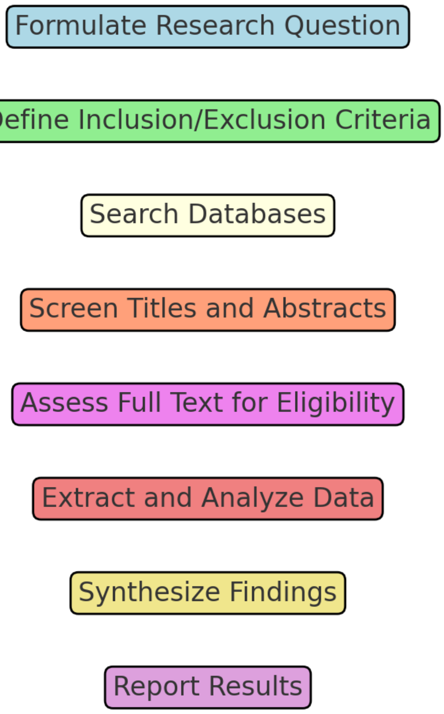
Nord2000:Nord2000, introduced by the Danish Environmental Protection Agency, is a comprehensive noise prediction model designed for strategic noise mapping of both road and railway traffic. It employs a source model based on third-octave frequency bands ranging from 2 Hz to 10 kHz and accommodates up to nine different weather classes to simulate various environmental conditions. Additionally, it considers eight types of ground surfaces, from very soft to very hard, although for practical modeling, only soft and hard ground types are commonly used. Nord2000 provides advanced capabilities for noise simulation in variable weather conditions and complex terrains.

GIS-Based Noise Mapping: Geographic Information Systems (GIS) play a critical role in the spatial representation and analysis of environmental noise. By integrating measured or modeled noise levels with spatial data, GIS can generate noise maps that visually communicate the distribution and intensity of noise across a geographical area. These maps are essential for urban planners, environmental agencies, and public health officials.

One of the most commonly applied GIS techniques in noise mapping is spatial interpolation, particularly the Kriging method. Kriging is a geostatistical tool that estimates noise levels at unmeasured locations based on nearby measured values, while also considering spatial autocorrelation. It is particularly effective in capturing the acoustic behaviour of varied topographies.

Using Kriging, noise contour maps can be generated to display the variation in noise levels throughout different times of the day. Such maps are useful for identifying zones of high noise intensity, traffic hotspots, and noise-sensitive receptors such as schools and hospitals. Additionally, GIS enables multi-layered analysis, allowing researchers to overlay noise data with land use, population density, or health outcome data for a more comprehensive environmental **assessment.**

The process of a systematic review of studies.



2.3 Critical Summary and Conclusion

This review has synthesized the current body of literature on the integration of Geographic Information Systems (GIS) in road traffic noise assessment and mapping. It offers essential clarifications on the definitions and conceptual framework of GIS, noise propagation models, and their relevance to urban noise management. Urban traffic is identified as the predominant source of environmental noise pollution, particularly in rapidly developing cities. Noise pollution not only poses environmental concerns but also significantly affects public health. Documented health impacts include hearing loss, hypertension, ischemic heart disease, heightened annoyance, and sleep disturbances. Therefore, noise mitigation is essential to reduce the adverse impacts on both the environment and human well-being. While numerous noise control methods such as sound insulation, sound absorption, vibration damping, and isolation are known, this paper has focused specifically on noise mapping through GIS. The spatial representation of noise levels using GIS tools enhances understanding and provides an effective platform for analysing, managing, and planning noise control interventions. A critical examination of the literature reveals a significant research gap, particularly in the Indian urban context. There is a lack of comprehensive studies that integrate noise prediction models with GIS for road traffic noise assessments in Indian cities. Furthermore, the development and implementation of 3D noise maps remain largely unexplored. The absence of localized models tailored to Indian traffic conditions and urban morphologies limits the applicability of existing international tools.GIS-based noise mapping provides a powerful approach for visualizing spatial noise disparities, which can aid urban and transportation planners in identifying noise hotspots. Such spatially informed insights are crucial for designing effective mitigation strategies, including green belts and noise barriers. Integrating these spatial tools into the decision-making process can substantially reduce noise exposure and contribute to healthier and more sustainable urban environments.

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