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Simulation-Based Assessment of Traffic Noise Mitigation Strategies in Tripoli

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Index Terms
Traffic noise pollution, noise levels simulation, mitigation strategies, noise barriers.

Abstract
Noise pollution constitutes a significant concern in urban areas, exerting far-reaching impacts on public health and social well-being. Building on a previous publication on noise pollution levels within the city of Tripoli, Libya, in which noise levels were measured in six distinct highly populated locations, during working days and weekends, and encompassing morning, afternoon, and evening, this analysis is concentrated on only one location–the highway. As expected, the 2nd ring road highway exhibited the highest noise levels among the locations surveyed. These elevated levels underscore the need for targeted noise control measures, particularly the deployment of noise barriers. Consequently, simulation analyzes were performed for different scenarios with noise barrier implementation. The results obtained indicate that the application of these mitigation measures could achieve a significant reduction in noise levels. Noise barriers can effectively reduce noise levels, but depend not only on horizontal distance from the source to the receiver, but also on the receiver’s elevation. Collectively, these findings highlight the critical importance of improving public awareness regarding urban noise pollution, its adverse effects on communities, and the range of applicable mitigation strategies.

محاكاة لاستراتيجيات تقليل الضوضاء الناتجة عن حركة المرور في طرابلس

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الكلمات المفتاحية
تلوث الضوضاء المرورية، محاكاة مستويات الضوضاء، استراتيجيات التخفيف، حواجز الضوضاء.

الملخص
يشكل التلوث الضوضائي أهمية كبيرة في المناطق الحضرية، حيث له تأثيرات واسعة النطاق على الصحة العامة والرفاه الاجتماعي. استنادًا إلى ورقة منشورة سابقا حول مستويات تلوث الضجيج داخل مدينة طرابلس، حيث تم قياس مستويات الضجيج في ستة مواقع عالية الكثافة السكانية، وخلال أيام العمل وعطلة نهاية الأسبوع، وثم تغطية فترتي الصباح والظهيرة والمساء، تركز الدراسة الحالية على موقع واحد فقط - الطريق الدائري الثاني. كما كان متوقعًا، سجل الطريق الدائري الثاني أعلى مستويات للضجيج بين المواقع الستة. تؤكد هذه المستويات المرتفعة على ضرورة اتخاذ تدابير للتقليل من الضوضاء. بناءً على ذلك، تم في هذه الدراسة إجراء تحليلات المحاكاة لسيناريوهات مختلفة لاستخدامات حواجز الضوضاء. تشير النتائج المتحصل عليها إلى أن تطبيق هذه الإجراءات يمكن أن يحقق تقليلًا في مستويات الضوضاء. يمكن لهذه الحواجز تقليل مستويات الضوضاء بفعالية، وهي تعتمد ليس فقط على المسافة الأفقية بين المصدر والمستقبل ولكن أيضًا على ارتفاع المستقبل. تسلط هذه النتائج الضوء على أهمية تعزيز الوعي العام بشأن التلوث الضوضائي في المناطق الحضرية، وتأثيراته السلبية على المجتمعات، ومجموعة من استراتيجيات التخفيف المناسبة.

I. Introduction

Urban noise pollution arises primarily from transportation, industrial activities, and human interactions. In the city of Tripoli, traffic noise is the most prominent source of noise, where roads are significant contributors, generating high levels of noise that can adversely affect nearby residential areas. Prolonged exposure to high levels of noise is linked to various health problems, as mentioned by the World Health Organization [1], including stress, sleep disturbances, and cardiovascular disease [2,3,4]. In addition to that, urban noise pollution affects the quality of life of people residing near motorways. Previous studies have demonstrated the substantial impact of noise pollution on both human well-being and the quality of urban environments. References [5,6] report that elevated exposure to noise adversely affects self-perceived health, happiness, and life satisfaction, while also contributing to increased levels of annoyance and stress. Furthermore, [7] emphasize the need to advance knowledge on urban noise dynamics and to formulate effective mitigation strategies.

Regarding the limits for noise exposure, the 1974 U.S. Environmental Protection Agency (EPA) guidelines recommend average exposure limits of 70 dB over 24 h (75 dB over 8 h), with maximum allowed averages of 55 dB outdoors and 45 dB indoors for normal activities [8]. The US Occupational Safety and Health Administration (OSHA) mandates engineering controls above 90 dB(A) for an 8 hours workday and additional protective measures beyond 85 dB(A). The WHO thresholds advise limiting exposure to < 70 dB(A) over 24 h and < 85 dB(A) over 1 h to prevent hearing impairment [9,10].

An efficient method to reduce traffic noise on motorways is the use of noise barriers. The use of noise barriers is a well-documented and effective strategy to mitigate traffic noise, particularly along highways and busy roads. They are made of different shapes and materials, can be either solid or porous, and can significantly reduce noise levels. Traditional noise barriers are typically constructed from materials such as concrete, metal, or earth mounds. Reference [11] emphasizes the utility of noise barriers, which are implemented globally in residential neighborhoods adjacent to major highways. Reference [12] mentions the economic optimization of designing low-cost barriers that are still effective.

Several parameters can affect traffic noise attenuation, such as the number and type of vehicles, the condition of the road, the speed of the vehicle, and the distance between the source and receiver. These parameters could make road traffic noise modeling a little complicated to do properly; hence, noise reduction strategies a bit difficult. These parameters are investigated by [13]. Furthermore, [14] supports the idea that higher barriers generally provide better sound insulation; nevertheless, the height of the barrier can lead to other issues, such as visual obstruction and potential radio interference. This understanding could be critical in designing effective barriers that do not compromise the visual or environmental quality of the area.

In addition to physical barriers, the choice of pavement materials can also contribute to noise reduction. Innovations in road surface materials, such as porous asphalt or rubberized concrete, have shown promise in reducing the sound emitted by vehicle tires [15,16]; however, these approaches are beyond the scope of this article. Kacker et al. [17] provides a review on innovative methods utilized in traffic noise mitigation through pavement solutions, focusing on pavement technologies like porous asphalt overlays and tire-road interaction. In addition, Guarnaccia et al. [18] published a review on recent strategies for modelling of road traffic noise emission.

Based on the findings reported in [19], the traffic noise levels measured in the city of Tripoli exceed the WHO guidelines in certain areas, namely the 2nd ring road highway. The current study is a continuation of these findings and it investigates practical mitigation strategies for identified hotspots, that is, the second ring road highway. These high noise levels highlight the need for targeted control measures, such as the installation of noise barriers. Simulations are carried out to compare scenarios with and without these measures. The previous measurements collected by [19] are used as references to compare with. It is important to mention that up to the date of writing this paper, very few, if not none, traffic noise assessment data have been collected for the 2nd ring road in Tripoli. More studies are highly recommended to create databases as valuable references for urban planners and policy makers.

II. Previous Results

The study was carried out in Tripoli, located in the northwest of Libya, with a population of approximately 2.0 million (2021 est.), covering an area of approximately 1507 km2, characterized by a mixture of residential, commercial, industrial, and recreational areas, and has a wide mixture of road types. More than 2 million vehicles travel the city roads, according to the World Bank's World Development Indicators. The reason for this high number of trafficking vehicles is the lack of an appropriate public transportation system. A Bruel & Kjaer 2232 precision sound level meter was used to collect measurements, and a Web-based noise mapping tool from dBmap.net was used. This software is a specialized web application used for modeling external sound propagation. It is primarily used to calculate decibel levels from noise sources while accounting for the screening effects of buildings and barriers. It is based on the implementation of ISO-9613 calculations to predict how noise propagates across a site.

All obtained results have been published by [19], and, as expected, the working days resulted in higher noise levels. The maxima SPL of the three intervals–morning, afternoon, and evening–are shown in Table 1 for all investigated regions. The second ring road highway recorded the highest level among all, registering 94.5 dB(A).

TABLE I. Maximum Noise Levels Measured During Working Days.

Location	Maximum Noise Level, dB(A)
Al-Jalaa hospital	76.57
Martyr's Square	82.30
Algeria square	87.50
UoT hospital	68.20
Al-Dehmani park	88.10
Sooq Althulatha park	86.70
2nd ring road highway	94.50

Comparing the results obtained, namely for the 2nd ring road highway, it definitely exceeds the recommended noise exposure limits, mentioned earlier, of 85 dB(A) if exposed for more than one hour. This could directly affect the residents close to the 2nd ring road highway, and thus needs to be reduced.

III. Approaches to Noise Mitigation

Recent studies in noise monitoring and research have consistently underscored the critical need to employ effective noise abatement strategies. These studies collectively emphasize that noise pollution is a major environmental contaminant, with various negative effects on human health and overall well-being. Noise control methodologies are generally categorized into three main approaches: attenuation at the source, modification of the transmission path between the source and receiver, and protection of the receiver environment. In Tripoli, road traffic constitutes the predominant source of noise, which is mainly related to the absence of significant industrial infrastructures. Although mitigating the noise of road traffic is somehow impractical, it could still be accomplished by acquiring advanced acoustic engineering for vehicular powertrains, which is beyond the scope of this paper.

The other approach to protecting the receiver environment, rather than altering the source, aims to protect or insulate the receiver, for example, residential, institutional, or recreational, from incoming high noise levels [20, 21]. This is usually accomplished through architectural, spatial and material interventions, such as enhancements to the building envelope, spatial planning and zoning, landscape modifications and indoor acoustic treatment to reduce noise. This approach also lies beyond the scope of this paper. Other mitigation procedures suggest the construction of low-noise roads and road maintenance, the use of low-noise tires that contribute to a range of approximately 10 dB [22], and traffic management to avoid traffic congestion.

The remaining strategy–changing the route of the noise transmission path between source and receiver–emerges as the most viable mitigation approach for the 2nd ring road highway. Two primary solutions are applicable in this case:

1. strategic positioning sound barriers between opposing lanes of the highway.
2. sound barriers installed along the sides that separate the highway from adjacent residential areas.

The effectiveness of these barriers depends on four key parameters: the source of distance from the noise to the barrier, the height of the barrier, the distance from the barrier to the receiver, and the overall length of the barrier [8]. Barriers may be artificial or natural, for example, planting trees along the sides of the 2nd ring road highway to buffer nearby residential zones. Reduction of noise levels is achieved when these barriers intercept, deflect, or absorb some of the sound waves. The next section explores a few scenarios using this approach, with simulations conducted to evaluate different configurations.

IV. Simulation of Noise Barriers for the 2nd Ring Road Highway

The highest noise level recorded on the 2nd ring road was 94.5 dB(A). This case has been modeled using the dBmap software. The 2nd ring road highway comprises dual motorways, each consisting of two lanes per direction, with an approximate width of 10 m per side, and a central median strip measuring approximately 2m. Two simulation scenarios are evaluated:

1. a baseline scenario without any noise barriers.
2. a mitigation scenario involving the installation of barriers at two strategic locations–within the central median strip between opposing lanes, and alongside the outer edges adjacent to both motorways.

In the second scenario, two types of barriers are present and modeled: a barrier on the central median strip that stands 1.5 meters high, and another barrier along the outer edges adjacent to the motorways. The latter barrier is modeled at two heights: 1.5 m and 7.0 m. The 7.0 m high barrier is not the usual noise reduction barrier, but in fact represents the case of planting tall dense trees, as trees are commonly used as noise barriers on high-traffic roads [8]. All barriers used in our model have a reflection coefficient of 0.9, assuming typical weather conditions of 20°C temperature and 70% humidity.

The model incorporates four point-sources of noise, each emitting 94.5 dB(A), representing moving vehicles. Each couple of these sources is positioned along one direction of the highway to simulate vehicular noise emission. In these models, two buildings are considered for the sake of simulation, present on one side of the highway, about 10 m away. Each building has about 20 m front, where building-1 is 9.0 m high and building-2 is 5.0 m high. The general setup is as shown in Figure 1. This figure is not to scale but for reference only.

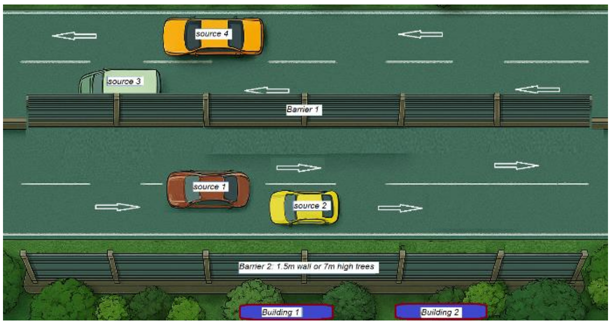

Figure 1. General setup of the simulated scenarios.

For all these models, noise mapping is modeled, and noise levels are strictly calculated, simulating two receivers located in front of the two buildings. Noise mapping is predicted at different heights, namely at 1.0 m, 4.0 m, 9.0 m, and 12.0 m.

A. Baseline Scenario: Scenario 1 (no barriers)

In this first scenario, barriers are considered, neither between lanes nor along the road (between the road and surrounding buildings). Sound pressure levels (SPL) are calculated in all areas near the noise sources, at octave frequency bands, as shown in Figure 2. Note that higher levels are observed at 1 kHz, as the human ear is more sensitive at and near this frequency.

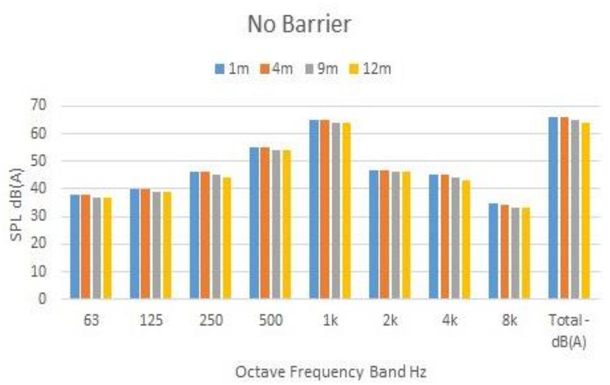

Figure 2. SPL calculated at different heights: scenario 1.

Figures 3-6 illustrate a visual representation of the mapping of these simulated noise levels. These noise level values are higher at 1 m above ground, as the point sources are located at 1.0 m high, and lower at higher levels above ground, as expected. When calculated at heights above 5.0 m, it extrapolates building #2 and is spread to the surroundings, but with SPL below 64 dB(A).

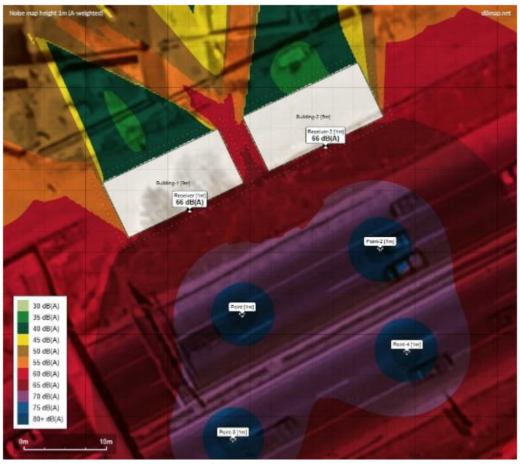

Figure 3. Noise level map for scenario 1: the source height is 1m; receiver height is 1m.

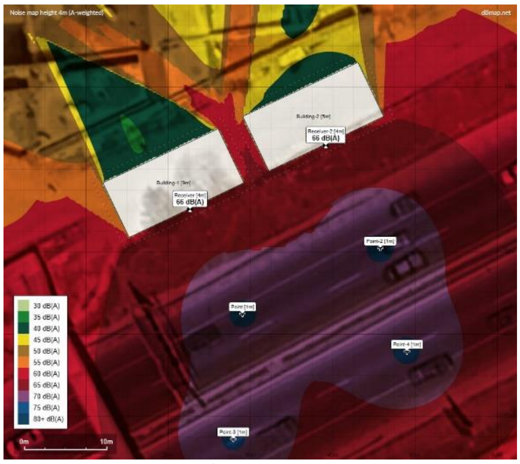

Figure 4. Noise level map for scenario 1: the source height is 1m; receiver height is 4m.

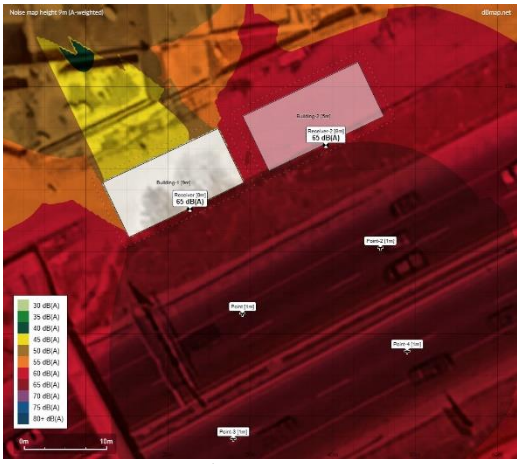

Figure 5. Noise level map for scenario 1: the source height is 1m; receiver height is 9m.

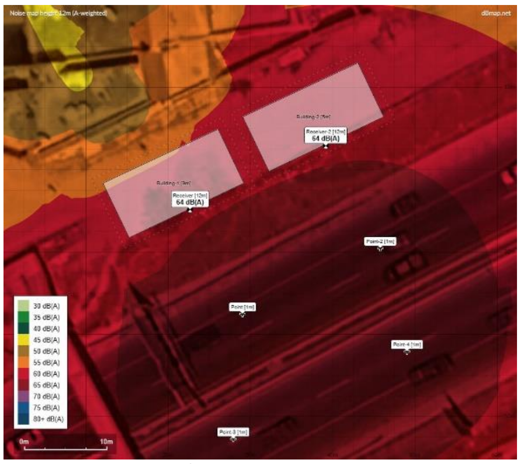

Figure 6. Noise level map for Scenario 1: source height is 1m; receiver height is 12 m.

B. Noise Mitigation Scenario: Scenario 2 (with barriers)

In this second scenario, sound pressure levels (SPL) are calculated with two barriers installed simultaneously:

i. **Scenario 2.1:** 1.5m high barriers in the central median between opposing highway lanes, plus 1.5m-high barriers along the outer edges separating the highway from adjacent residential areas. The barrier setup used in this scenario is as shown in Figure 7.

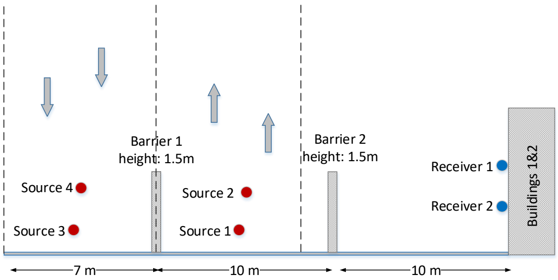

Figure 7. Setup of barriers positions for Scenario 2.1 on the 2nd ring road.

i. **Scenario 2.2:** 1.5m high barriers in the central median between opposing highway lanes, plus 7m-high barriers along the outer edges separating the highway from adjacent residential areas. The 7m high barriers represent tall, dense trees, known as green acoustic screens. The barrier setup used in this scenario is as shown in Figure 8.

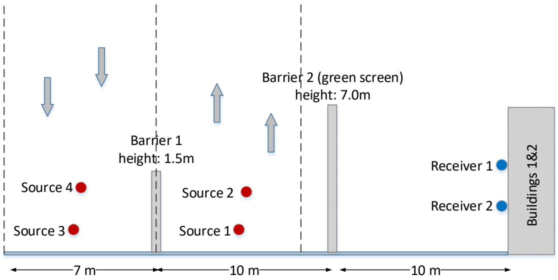

Figure 8. Setup of barriers positions for Scenario 2.2 on the 2nd ring road.

It is observed that the use of a 1.5m high barrier affected the noise levels in front of the two buildings measured at 1 m height, decreasing its total from 66 dB(A) when no barriers exist, to 58 dB(A) with a 1.5m high barrier, as shown in Figure 9. However, using a 7m high barrier helped decrease noise significantly to 43 dB(A), as would be expected, as shown in Figure 10.

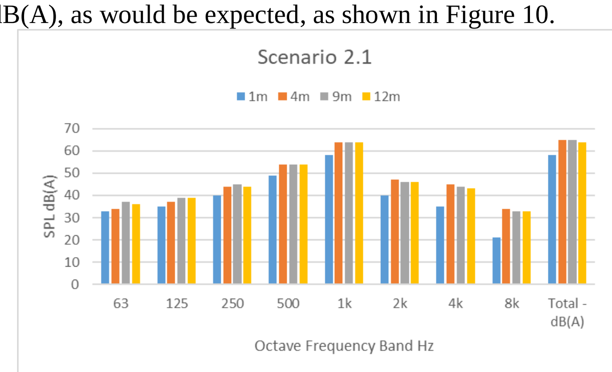

Figure 9. SPL calculated in Scenario 2.1.

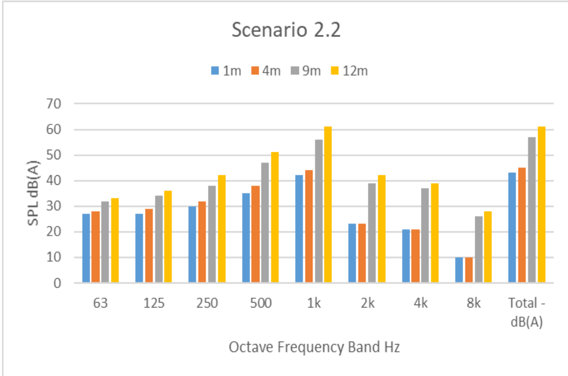

Figure 10. SPL calculated in Scenario 2.2.

The visual mapping of scenarios 2.1 and 2.2 are demonstrated in Figures 11-14 and Figures 15-18, respectively. Observe that these noise levels are higher at 1m above ground, as the point sources are located at 1 m high, and lower at higher levels above ground.

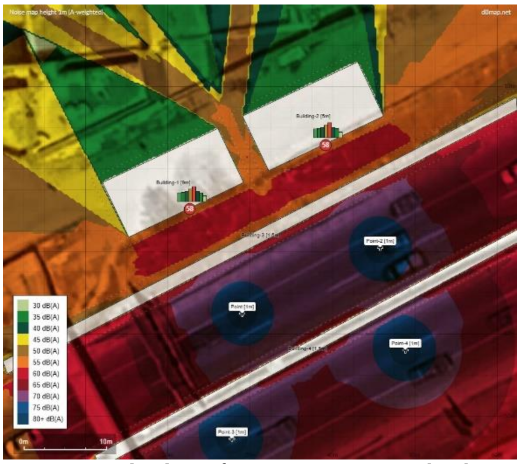

Figure 11. Noise level map for Scenario 2.1: source height is 1m; receiver height is 1m.

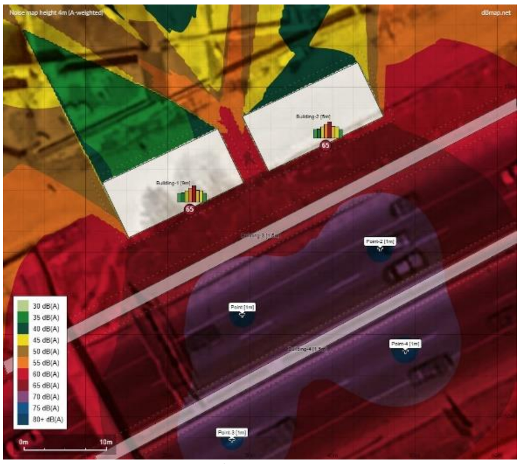

Figure 12. Noise level map for Scenario 2.1: source height is 1m; receiver height is 4m.

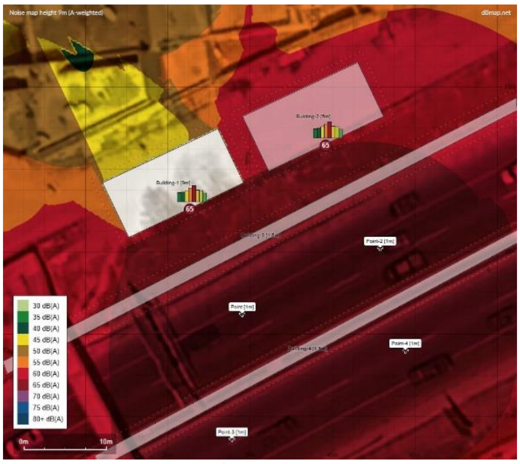
Figure 13. Noise level map for Scenario 2.1: source height is 1m; receiver height is 9m.

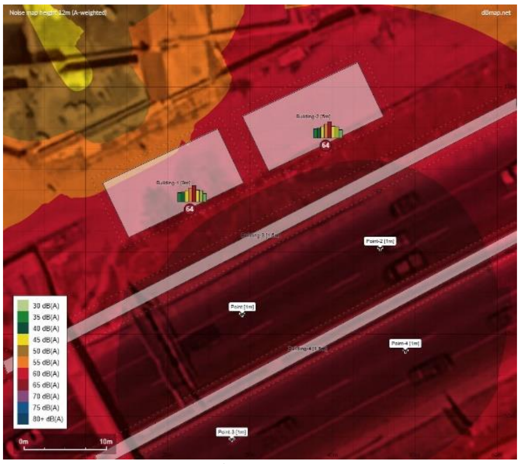
Figure 14. Noise level map for Scenario 2.1: source height is 1m; receiver height is 12m.

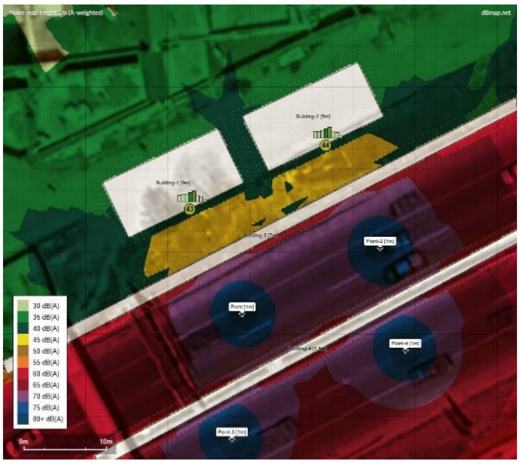
Figure 15. Noise level map for Scenario 2.2: source height is 1m; receiver height is 1m.

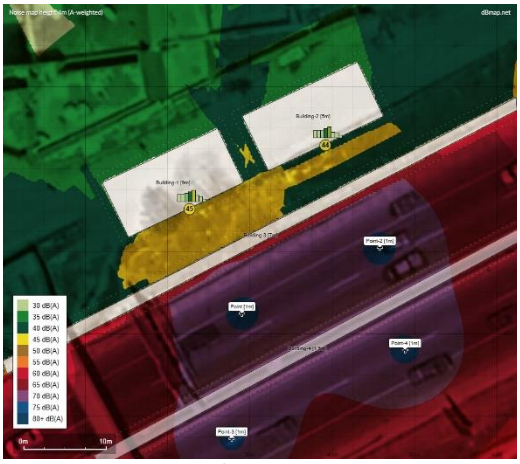
Figure 16. Noise level map for Scenario 2.2: source height is 1m; receiver height is 4m.

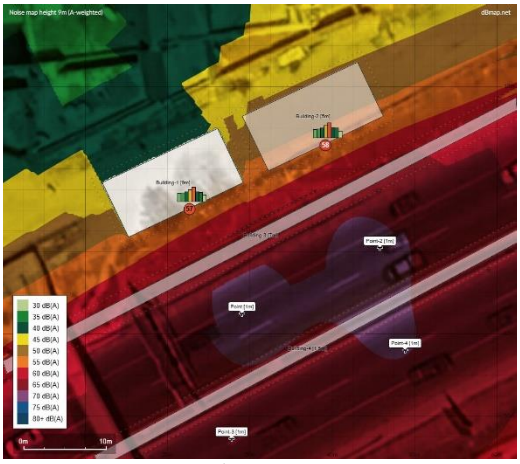
Figure 17. Noise level map for Scenario 2.2: source height is 1m; receiver height is 9m.

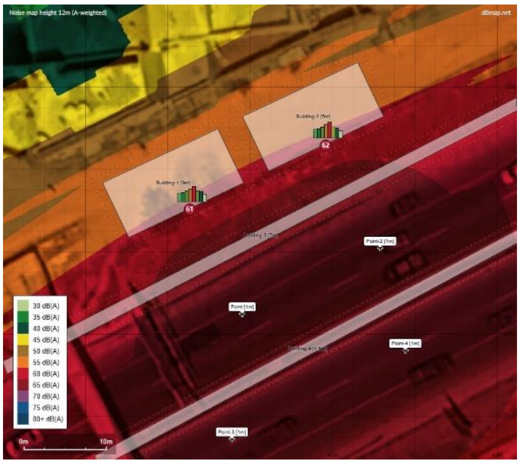
Figure 18. Noise level map for Scenario 2.2: source height is 1m; receiver height is 12m.

Noise barriers can effectively reduce noise levels, but their effectiveness depends not only on the horizontal distance from the highway, but also on the receiver's elevation of the receiver [23,24]. This is clearly demonstrated in Figure 19. The noise barrier tries to block the direct line of sight between the noise source (vehicles) and the receiver (adjacent buildings), forcing sound to diffract at the top of the barrier. This is clearly observed, for example, in Scenario 2.2, where the noise level is reduced from 66 dB(A) at the source to 43 dB(A) at 1m-high receiver. Then it starts to increase to 45, 57, and 61 dB(A) at a 12m high receiver. Therefore, at higher floors of adjacent buildings, the attenuation of noise can drop significantly, that is, to 3dB(A) at 12m high. Scenario 2.1 shows a similar effect, but with lower attenuation.

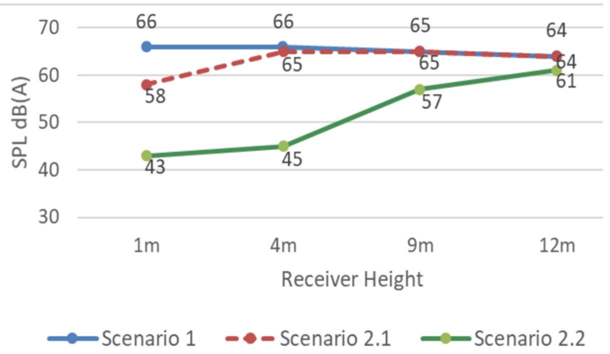

Figure 19. Noise levels comparison for the three scenarios.

The case of using a 7m high barrier simulates planting tall, dense trees along the 2nd ring road highway. Previous studies have demonstrated that tree noise attenuation can be improved if trees are arranged in a periodic lattice configuration, in what are called green acoustic screens [25]. The other affecting factor is to have the foliage dense enough for proper attenuation to occur [26]. Keep in mind that these are simulations and accurate measurements are necessary to conduct during noise abatement projects using noise barriers.

V. CONCLUSIONS

This numerical study evaluated the reduction of noise along the 2nd ring road highway in Tripoli, which was identified in a previous research as the city's loudest site among other regions. The study was carried out by simulating the installation of road noise barriers under two height configurations. Two scenarios were analyzed, differing only in noise barrier height. The optimal scenario combined 1.5m-high barriers between opposing lanes with 7m-tall dense tree planting, demonstrating what is known as the green acoustic screens. This scenario achieved a reduction of up to 16 dB (A) in noise level at lower elevations. This outcome emphasizes that the effectiveness of the barrier depends not only on the horizontal distance from the source but also on the elevation of the receiver. The results obtained demonstrate that integrating green barriers with conventional noise barriers substantially improved noise attenuation in areas adjacent to the highway. On the other hand, the reported findings highlight the importance of enhancing public awareness of urban noise pollution and its adverse effects on communities. State authorities are advised to maintain noise pollution records, along with GIS data, for future comparisons and to maintain the well-being of residents.

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