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Noise Environmental Impact Assessment

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ملخص: يمثل مؤشـر التلوث البيئي أحد أهم عوامل جودة الحياة بالمدن. وتعد الضـوضـاء أحد أهم مجالات اهتمام الباحثين من مختلف المجالات المتعلقة بالعمران والفراغات العامة. ومع تطور نظم المواصـلات والاتصـالات ازدادت مخاطر تعرض المستخدمين في الأماكن العامة للمخاطر الناجمة عن التلوث السمعي، حيث يعانى مستخدمي بعض الأماكن العامة خاصة المغلقة التي تتداخل فيها أنشطة المشاة مع وسائل ونظم النقل والتهوية المختلفة من التعرض لمستويات من الضجيج قد تؤثر عليهم صحيا. كما أنهم قد يتعرضون لها لفترات زمنية قد تسـبب لهم ضـررا جسـمانيا دائما. من أهم أمثلة تلك الفراغات محطات المترو ومواقف السيارات المتعددة الطوابق وأنفاق السيارات حيث تختلط فيها حركة المشاة مع المركبات. وتقدم هذه الدراسة نموذجا لتقييم وإدارة الفراغات العامة ذات مخاطر التلوث بالضـوضـاء وآلية التعامل مع مثل تلك الفراغات وذلك من خلال عمل دراسة تحليله لمثال تطبيقي، وللوصول لاهداف الدراسة تم اتباع منهج وصفي تحليل يتم من خلاله عمل مسح ادبي لمخاطر الضوضاء ومستوياتها والحدود القصوى للتعرض لها كما تم من عمل دراسة تطبيقية أمكن من خلالها دراسة الأنشطة المختلفة وتمييز فئات المستخدمين وأزمنة تعرضهم لمستويات الضـوضـاء المختلفة وتحديد الفراغات التي تتم فيها الأنشطة ومن ثم دراسة مصادر وأنواع

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ومستويات الضوضاء داخل الفراغ موضع الدراسة كما أمكن من خلال ذلك تحديد الفئات الأكثر تعرضا للمخاطر وأماكن تعرضهم وطبيعة انشطتهم. وقد خلص البحث إلى وضع توصيات لتقليل مستويات الضوضاء البيئية داخل النفق وكذلك تقليل زمن تعرض للفئات المعرضة للمخاطر.

Abstract: Pedestrian activities interfere with vehicles in semi-closed spaces like underground metro stations, multi-story parking structures, and dual-use tunnels. Users of these public spaces are subject to different types of noise. When pedestrians' activities are mixed with various means of traffic and machinery noise, they suffer from exposure to levels of noise that may affect their health and, in some cases, cause permanent harm both sociologically and physically. International health and professional organizations worldwide defined the levels and periods of exposure to noise levels. The Al-Souk Al-Sgheer Tunnel beneath the Grand Mosque plaza in Mekkah is an example of these places where pedestrians are exposed to very high noise levels and where pedestrian traffic mixes with cars**.** This study presents an analytical approach to evaluating the hazard risk in such spaces. To achieve its objectives, users' activities were recorded in terms of location and periods, and noise levels were recorded within these spaces. Three contour maps for activities, periods, and noise levels were created. These contour maps allowed for comparing pedestrian activities with noise levels in the main and sub-zones within the tunnel. Locations with high noise levels and users' exposure periods were identified. Depending on such assessment, good and effective solutions became possible. Through the research, a case study was evaluated using the previous process. The evaluation is followed by analysis. The research concluded with general recommendations for urban designers and decision-makers of such public places, and specific recommendations for the case study were given to reduce the noise of exposure to the most vulnerable groups of users in the long and short term.

Keywords: Urban management, Environmental Pollution, Noise control, Public spaces.

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1. Introduction:

Environmental noise is one of the most severe manifestations of pollution affecting humans. Mixed-use public spaces where users' activities mix with vehicles are factors that multiply the impact of noise on users of these spaces.

The small market tunnel represents one of the main axes of movement and connection to the central area, in addition to representing one of the axes of access to the courtyards of the Grand Mosque. The visitor to this tunnel notices the high noise level, which causes inconvenience, which is a good model for such a disturbance.

1.1.Research objective: The research aims to develop a strategy and implement the risks of exposure to environmental noise within public spaces.

1.2. Research Methodology: The research follows a descriptive-analytical approach through which noise types, exposure levels, and durations are reviewed. An analytical approach was followed to investigate a case study, field measurements were collected, and exposure levels were compared to benchmarks. Recommendations were concluded to reduce noise impact on space users. Figure 1 presnts the research methodology..

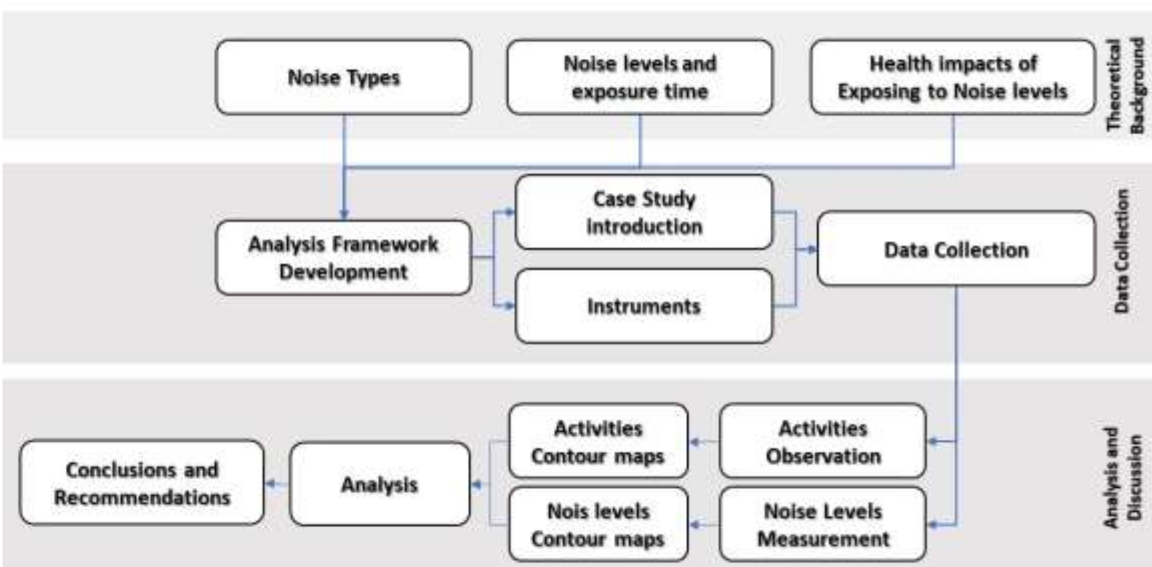

Figure ١ : Methodology Framework

1.3. Definitions and Acronyms:

Noise: Noise is defined as any sound in a headset that does not contain helpful or unwanted meaning or information [1].

Environmental Noise: The Noise a person is exposed to while practicing daily activities within the built environment.

Types of Noise: When measuring noise levels, the quality of the noise in the vacuum must be determined, and thus, the indicators of that type and the necessary devices and appropriate measurement methods can be determined [2, 3]. Environmental noise is divided into:

Continuous noise is caused by non-stop equipment such as water motors, air conditioners, etc. Such noise can be measured for several minutes and with manual measuring devices.

Intermittent Noise: Motors operate at intervals during which noise levels increase and decrease. This type of noise can be measured with the same devices that can measure continuous noise, but the time range of noise surge cycles must be documented.

Sudden Noise (Impulsive Noise): Occurs over a small period, has a very high sound intensity, and is one of the most annoying types of noise. It is measured by recording the difference between fast and slow reaction measurements and the repetition rate in time.

Melodic Noise (TONES): The presence of melodic noise is distinguished by the naked ear, as it can. Two primary sources cause this type of noise:

1. Motor parts that rotate, propellers or gearboxes attached to motors.
2. Air flows inside the ducts of mechanical ventilation devices, or water flows inside the pipes.

Low-frequency noise: Enormous sound energy with a frequency between 8 and 10 hertz, and the difference between the level of medium sound pressure (a) and medium sound pressure (C) is a good indicator of a problem of low-frequency Noise. Frequencies below 20 hertz affect humans as sound energy; although they are not heard, their effects are still under research, and there are no international rates of their levels [2]

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3. Literature Review:

3.1. Noise indicators

Researchers and practitioners worldwide have been interested in defining the noise exposure levels, their time rates, and the nature of the risks resulting from exceeding those rates and levels. Meanwhile, many health organizations and standard bodies have developed several indicators to predict noise levels. Selecting noise indicators is based on their suitability to estimate the effect of interest. However, several other social and political criteria affect indicator selection. The most used noise indicators are *L*den and *L*night. They are based on their components (*L*day, *L*evening, *L*night, and the duration in hours of *L*night) and measured at the most exposed areas. These indicators are widely used by authorities and health and administration studies to assess the effect of noise exposure on health [4]. A European Quality of Life survey revealed that 32% of more than 30,000 European participants suffered from neighborhood noise issues. The WHO European Region adopted the following noise indicators for noise monitoring and exposure assessment that can be followed elsewhere: [5].

- L_{den} is the average sound pressure level over all time.
- L_{night} is the equivalent continuous sound pressure level with time intervals.

The L_{Aeq} indicator is used to measure noise related to leisure activities.

- L_{Aeq} is the A-weighted equivalent continuous sound pressure level between starting time t1 and ending time t2 in decibels (dB).

These indicators are tested and measured at a particular location.

3.2. Noise Health Impacts:

The type and intensity of noise and exposure duration are factors related to noise sources and conditions influencing the community population's health. Other factors related to population, like demographics, genetics, and behavior, can affect noise exposure impacts on public space users [1]. Korver et al. cited Feifan et al., who reported that noise exposure over 85 dBA for longer than 8 hours a day over a long time has been considered the most critical risk factor for noise-induced hearing loss (NIHL). [6]. Based on population, exposure, comparator, confounder, outcome, and study (PECCOS), a scheme of critical health outcomes for exposure to road traffic noise revealed that the average noise exposure to cardiovascular disease, annoyance, cognitive impairment, hearing impairment, and tinnitus, adverse birth outcomes quality of life, well-being, and mental health, and metabolic outcomes [4]. A literature review study by the WHO Regional Office for Europe reported the following traffic noise impacts on community health: Ischaemic heart disease (IHD), hypertension, stroke, high blood pressure, annoyance, cognitive impairment, hearing impairment, and tinnitus and sleep disturbance [4, 7, 8],

3.3. Allowed exposure levels:

The WHO European recommended a threshold of maximum noise exposure of 53 dB L_{den} for road traffic and 45 dB for air turbine noise and exposure less than 70 dB Laeq for 24 hours throughout the year. Moreover, a weekly exposure of less than 80 dB for two hours a week from leisure sources and a maximum of 15 minutes of exposure for 199 dB L_{eq} [5]. The World Health Organization has determined that 70 dB LAeq is the highest external noise level that members of society can be exposed to. Road traffic noise level is associated with unfavorable health effects. The WHO Guideline Development Group (GDG) recommended a maximum average road traffic noise level to be reduced below 53 dB *L*den [1, 9, 10]. OSHA anticipated that 25% of the workers exposed for a 20-year to 90 dBA PEL are at risk of noise-induced hearing loss (NIHL) [11]. The European standard ISO R532 1999 also stipulated that to protect the vast majority of the public in public areas from disturbance; the general noise rate must not exceed 55 dB LAeq [11].

3.4.Negative impacts of noise levels on personal health:

Reduce the ability to receive audible frequency range: The audible field ranges between 20 Hz and 20 KHz. Exposure to that noise level could cause hearing loss of some frequencies, which may be temporary or permanent.

Vocal impairment: It is caused by exposure to frequencies between 3 and 6 kHz. This can cause hearing impairment based on the duration of exposure and the level of exposure. The limit of hearing impairment has been set at 140 dB as the maximum value of the Peak Sound measurement for adults and 120 dB for children [4].

Vocal communication disability: The vocal energy required to communicate in a quiet environment is 50 decibels. Noise levels with differences of about 35 decibels would obstruct sharing conversations.

Hindered sleep: A quiet environment is necessary for sleep. The noise levels for such an environment should range between 30 and 45 decibels. Any rise above this level may hinder the user's sleep.

Impacting personal behavior: It has been proven that a noise level greater than 80 decibels LAeq for any length of time reduces feelings of helping others and increases the feeling of aggression towards others.

Intellectual ability impairment: Noise can impact intellectual abilities and negatively influence performance [1, 5, 10, 12].

The framework presented in Figure 2 is developed based on reviewing several studies to evaluate the noise environmental impact of particular public spaces. The framework has three consequence stages; the first is composed of elementary assessment and data collection of the space characteristics, noise sources, and space users. The second stage is related to analyzing noise impacts on users, while the third stage covers recommendations and monitoring and assessment plans of taken actions to mitigate the noise issues [13-16].

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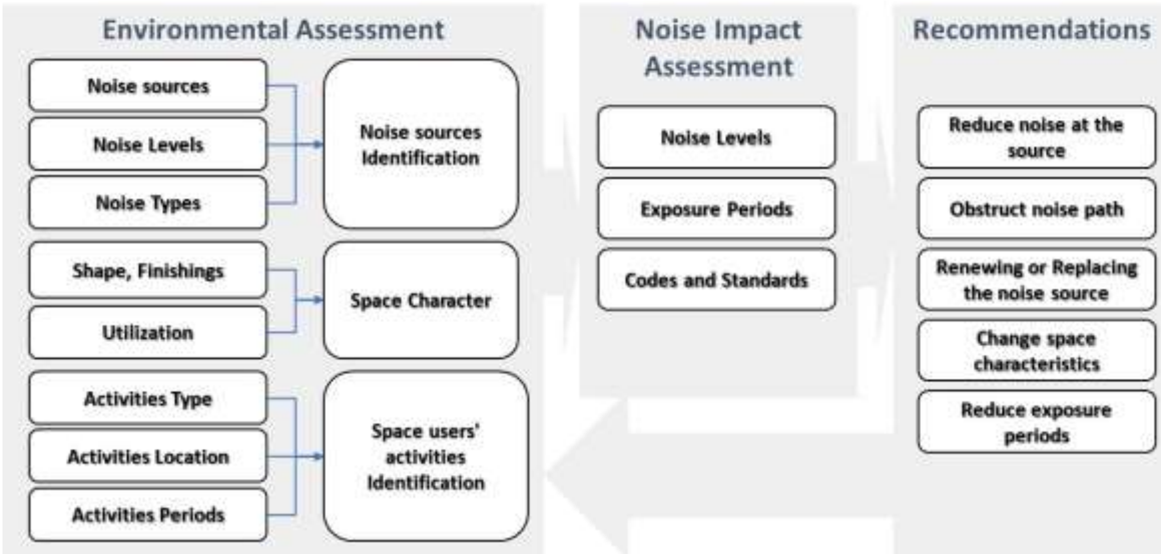

Figure ٢ Framework for Noise Environmental Impact Assessment

4. Case Study:

Makkah is a city with many tunnels due to its topology. The map in Figure 3 illustrates the Makkah tunneling system. Some of these tunnels are dedicated to vehicle traffic, and others are dedicated to pedestrian movement. All the tunnels are ventilated through propellant fans. And even some of them are equipped with mechanical movers. Some of these tunnels have mixed use during seasons or all year.

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Figure ٣ : Tunneling system for road network in Makkah City.

Sampling Strategy: The selected sample fulfills the following characteristics:

- Public space.
- High-density activities and large numbers of participants.
- Extended periods of activities.
- Mixed use of users and machines.
- Presents different types of noise sources.

Study Sample :

One of these tunnels runs under the Grand Mosque, where high traffic runs through most of the year during day and night. This tunnel represents one of the main axes of movement connecting the Grand Mosque to other city districts. It is one of the main routes that connect the Grand Mosque to other urban areas to the east and west of the city. This tunnel has several pickup and drop-off areas. Each one of these areas has a waiting plaza served with escalators and staircases. These staircases lead directly to the Grand Mosque plazas [17]. Hundreds of thousands of worshippers use the tunnel to get their transportation home; this exposes them to high noise levels for extended periods, especially when leaving after performing night prayers. It is evident that the commuters'

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density and exposure to an environment full of noise sources. The aerial photo in Figure 4 showing the central area, the location of the tunnel, and its relationship to the courtyards of the Grand Mosque structure and plaza.

Figure ٤ : Shape and location of the study area.

4.1. Space Description:

The tunnel consists of a rectangular concrete body section with a width of about 22 meters and a height of five and a quarter meters; the tunnel includes two parallel tracks for cars, each consisting of three longitudinal lanes, and the tunnel includes longitudinal concrete walls separating passenger stations from the rest of the tunnel body. Figure 5 shows a plan of the inner space of the tunnel with its ramps and the four drop-off areas (passengers' stations). Each has two parking lanes for loading and unloading [17]. Drop-off areas are separated from the main road by a concrete wall, as illustrated in Figure 6.

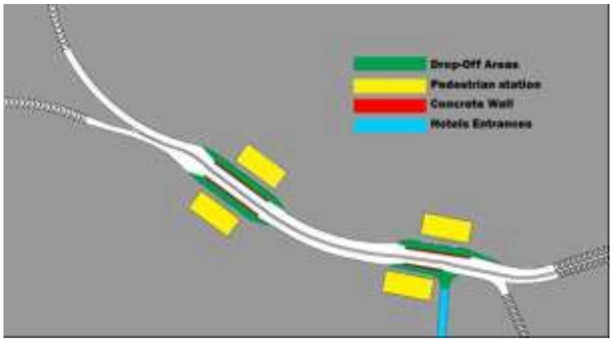

Figure ٥ : Study area plan. **Figure ٦ : The photo shows the Study area.**

Figure 7 sketches the cross-section of the tunnel space, explaining its various subareas and mechanical components. The tunnel has a wavy concrete roof and several ventilation openings connecting it to the Grand Mosque plaza. The tunnel's walls are covered with a vertical ventilation (for fresh air supply) grill with 10 cm openings.

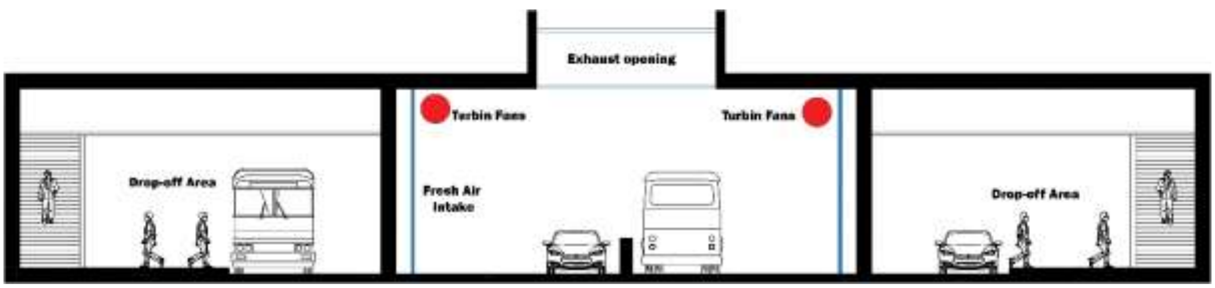

Figure ٧ : Cross section showing tunnel sup-areas and mechanical components.

The space contains many factors that confirm the existence of a noise problem that needs to be investigated, as it was found from the field visit to the site that there is a noise problem summarized in the following points:

- Suspended ventilation turbofans are on both sides of the walls at four meters' height. Each has a diameter of 1,5 meters and a length of four meters and is suspended at a height of four meters. Figure 8 shows their distribution on the plan. These fans produce continuous noise.

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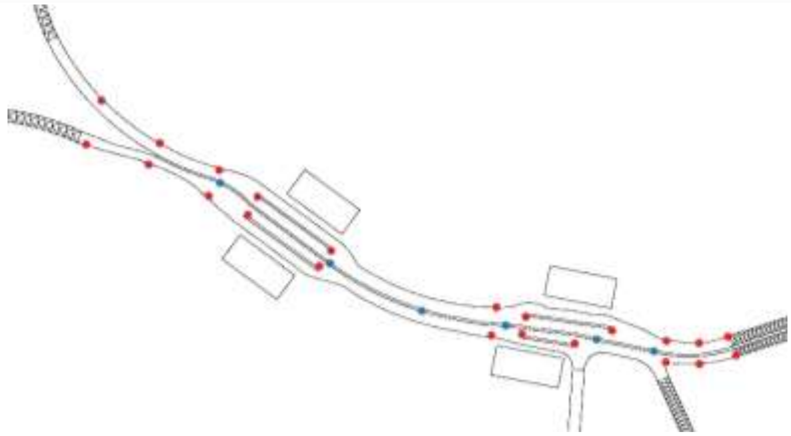

Figure ٨ : Tunnel body and distribution of turbine fans and ventilation openings.

- Car engines and horns of various types are waiting in the tunnel, resulting in frequency noise, as shown in the photos in Figure 9.
- Emergency cars and bus horns passing through produce sudden noise.
- The voices of tens of pedestrians waiting for their transportation and vendors.
- The curved shape of the tunnel body and finishing materials causes sound reflections in different areas, increasing the noise problem.

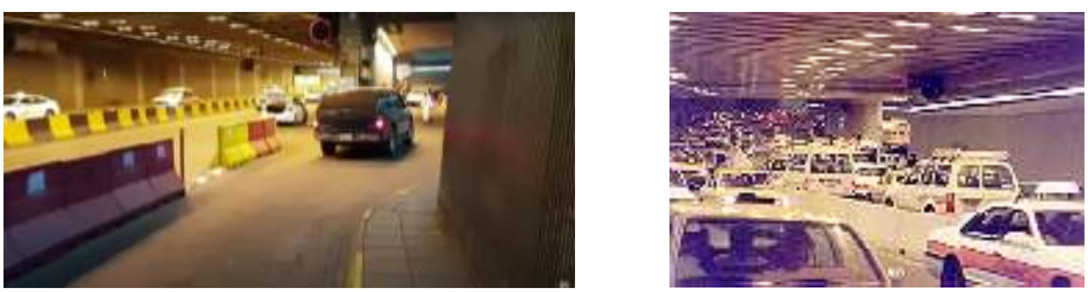

Figure ٩ : Tunnel shape causes sound reflections.

4.2. Pedestrian Activities within the Tunnel:

Field surveys of the tunnel relied on observation to determine the type, intensity, and distribution of activities within the different areas of the tunnel. The survey was conducted weekly and daily throughout the busiest months of Shaaban and Ramadan. These visits revealed that the activities that were taking place inside the tunnel were as follows:

1. Pedestrians' movement on the walkways parallel to the traffic lanes of the tunnel.

2. The density of cars varies throughout the day and week. An increase in the traffic densities between six and nine o'clock was noticed. Thursdays and Fridays were the busiest days of the week.
3. Vehiculs' speed varies along the tunnel between its different areas.
4. Several street vendors squatter in the drop-off areas leading to the hall leading to the escalators. Fridays between 10 am and 2 pm were the busiest.
5. Due to the traffic congestion and the drop-off area, many drivers drop passengers and collect them outside the dedicated drop-off areas, which exposes them to pass through the noisy traffic area.
6. Police and traffic personnel maintaining order and managing traffic in the tunnel spent eight hours inside the noisy traffic areas.

Based on observing the activities and their intensities, tunnel areas could be divided into three main categories. These categories shown in Figure 10 are as follows:

Category A: The tunnel traffic entrances' sub-area where passing vehicles at varying speeds according to the traffic congestion degree.

Category B: Drop-off areas and attached pedestrian halls. With its two lanes and sidewalk. It has an aluminum false ceiling and granite tiles for walls and floors.

Category C: Traffic areas for cars opposite the drop-off stations. These sub-areas are separated from the drop-off station by a full-height concrete wall.

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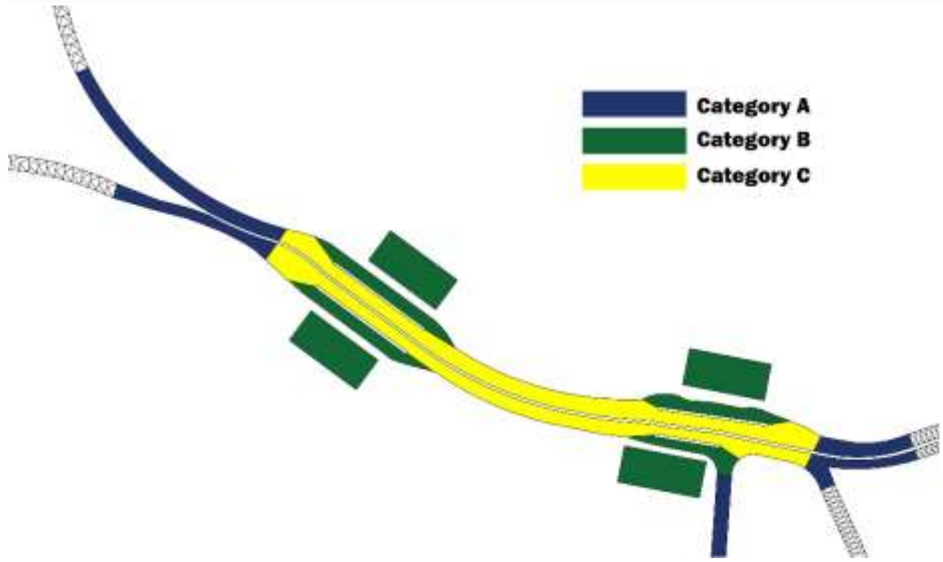

Figure ١٠ :Subzones of the case study areas

The survey reveals that several pedestrian movements were noticed as movement toward entrances and exits of the drop-off areas and movement within areas of category B as many pedestrians have to move in to take taxis or cross to the opposite side, where the openings in the traffic barriers allow pedestrian crossing. It was also noticed that many pedestrians along the sidewalks were heading to one end of the tunnel Figure 11 illustrates a contour map for the density of the commuters activities within the tunnal zones.

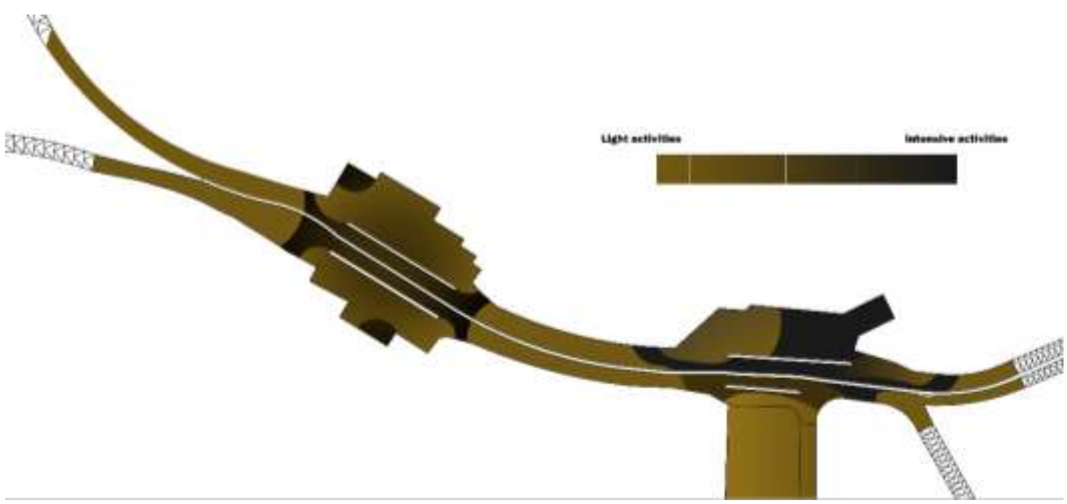

Figure ١١ : Activities intensities distribution over the study area.

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4.3. Measuring the noise within the tunnel spaces:

4.3.1. Equipments:

Sound meter:	Modular Precision Sound Level Meter
Mic:	1/2 inch Free field
Microphone calibration device:	Product of Bruel & Kjaer, Model No. Ex18
Data collection procedures:	Several procedures have been carried out for calibrating and adjusting the device to the following positions: Sound meter Adjustments: – Time Weighted. – Poser range: 50-120 decibel. – Time intervals: 20 seconds. Registration was set to auto at the end of registration time and turned into standby mode.
Used software:	– Unit model No. BZ 7115 – Model No. BZ 7111 to frequencies measurements throughout 1/3 Octave – Unit model 1625 to frequencies separator.

1.1.1. Noise measurement plan:

Measurement points distribution: Fifty-five Measurement points were distributed over the entire tunnel area. Figure 12 shows the mearing point distribution.

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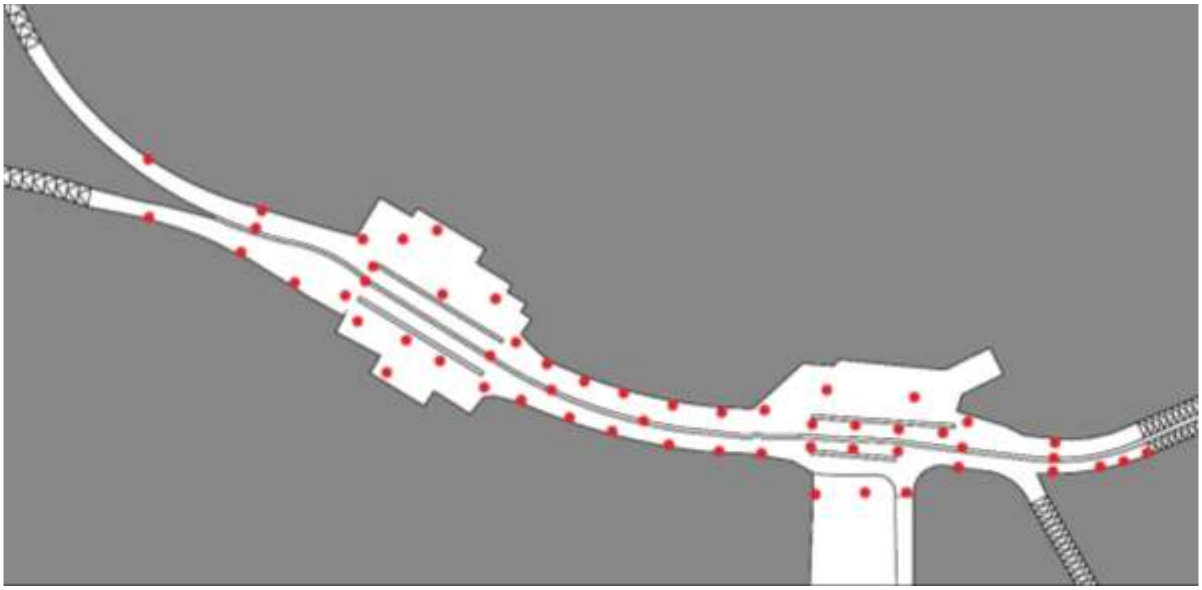

Figure ١٢ : Distribution of measuring points

Collected data type and range over three different days extended to

Dates and times of the Date and period for the first survey	The survey was done on Thursday, the ninth of Ramadan, immediately after the end of the night prayers, between 9:00 pm and 10:50 pm.
Measured values:	LEQ - SEL - MINL - MAXL - MAXP - PEAK.
Dates and period of the second survey	The survey was done on Thursday, the ninth of Ramadan, immediately after the end of the night prayers, between 9:00 pm and 10:50 pm.
Measured values:	LEQ – SEL - L99 - L90 - L50 - L10 - L1 – INST - Min. RMS - MAXL - MAXP - PEAK.
Dates and period of the third survey	The survey was done on Thursday, the ninth of Ramadan, immediately after the end of the night prayers, between 1:30 pm and 3:30 pm.
Measured values:	Peak – MAXP – INST – SPL – MAXL – MINL – LEQ – OL – LN - L_N - L.

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Measured frequencies: 25 Hirtz, 31.5 Hirtz, 40 Hirtz, 50 Hirtz Hirtz, 63 Hirtz, 80 Hirtz, 100, 135 Hirtz, 160 Hirtz, 200 Hirtz, 250 Hirtz, 315 Hirtz, 1.25 KHirz, 1.6 KHirz, 2 KHirz, 2.5 KHirz, 3.15 KHirz, 4 KHirz, 6.3 KHirz, 8 KHirz, 10 KHirz, 12.5 KHirz.

5. RESULTS AND DISCUSSION:

During the first and second field surveys, the equivalent sound level was recorded over the entire tunnel surface, and Figure 12 illustrates a contour map representation of the average equivalent sound pressure level measured over the entire tunnel surface. The contour map in Figure 13 shows a significant difference in the noise level between the drop-off areas and the rest of the tunnel sub-areas, where the values inside the drop-off stations ranged between 82 and 86 dB, while in the rest of the areas ranged between 92 and 100 dB. The map also shows that the highest rate was recorded near the areas immediately surrounding the pedestrian stations (C areas).

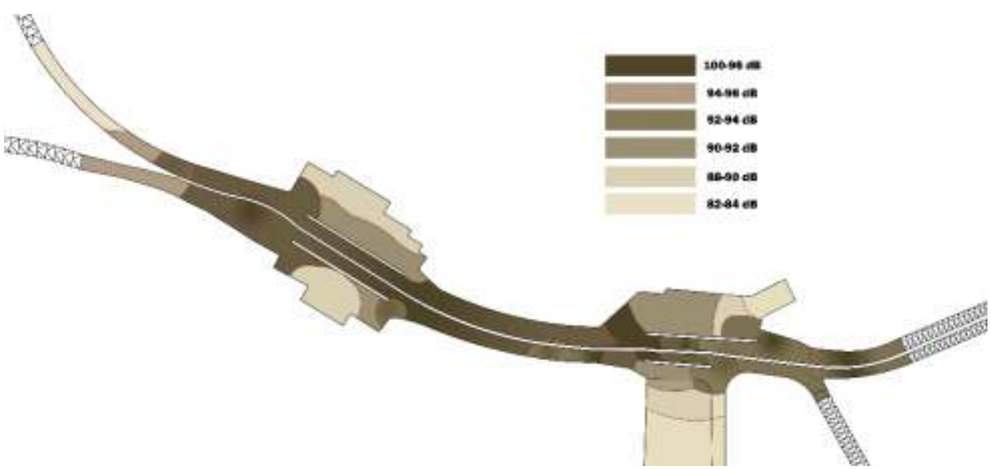

Figure ١٣ : Equivalent sound level distribution over the tunnel area

Figure 14 shows that the exposure level at 68% of the measurement points exceeded 100 dB, while it exceeded 100 dB at 94% of the measurement points.

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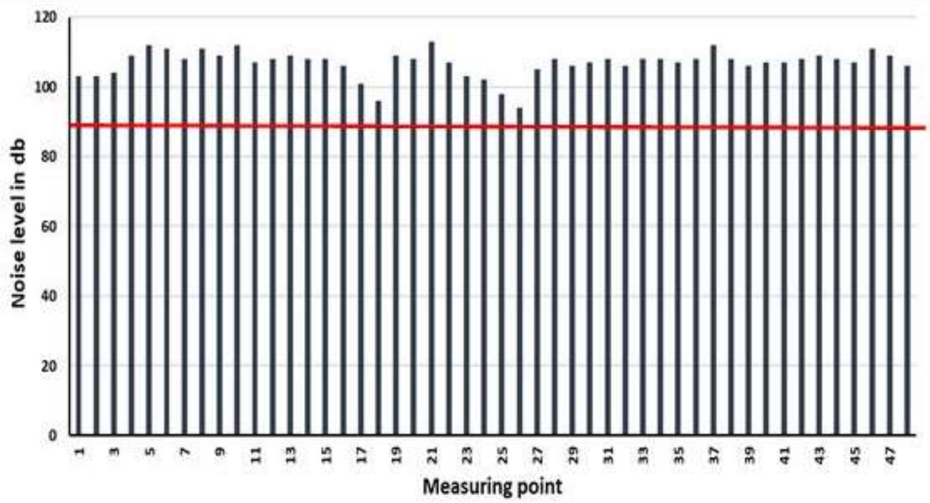

Figure ١٤ : Exposing noise levels at testing points within the study area.

Figure 15 shows a full-frequency graph of the audible sound of noise inside the tunnel, where it is clear from the drawing that there are two types of noise:

- Intermittent traffic noise concentrated at low frequencies between 20 Hz and 400 Hz with a medium intensity level of 80 dB.
- Resonant noise with a frequency of 630 Hz, a sound card of 90 dB, a frequency of 1.25 kHz, a sound card of 88 dB, a frequency of 4 kHz, and a lower energy of 85 dB.

Figure 14 shows the highest recorded sound level within one second of measurement, where it is clear that almost all values exceeded the 100 dB limit and reached 115 dB at two of these points.

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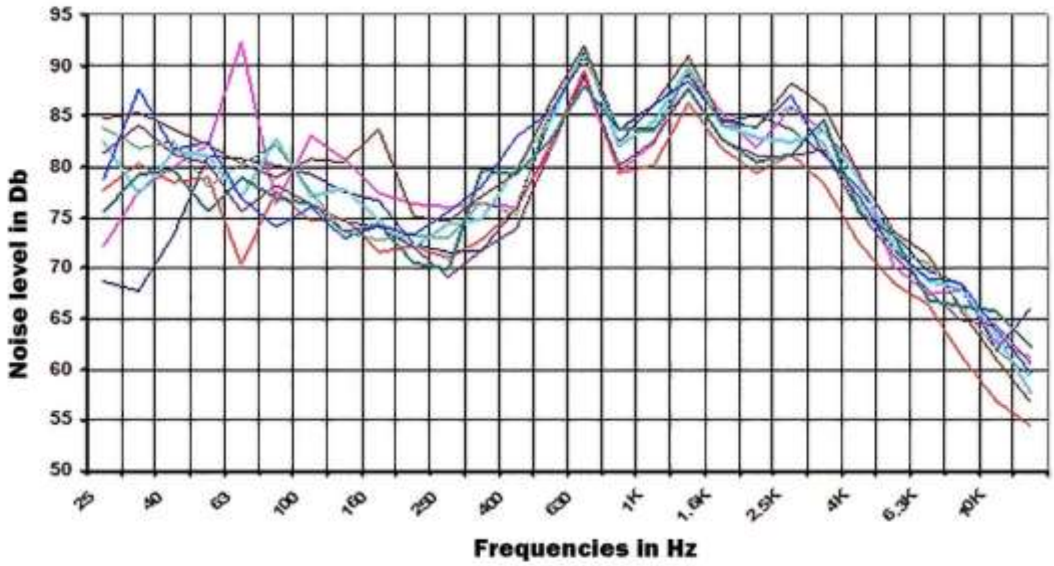

Figure ١٥ : Equivalent Noise Level L_{eq} for all audible frequencies at test points.

The graph in Figure 16 shows the highest sound pressure level recorded during one second at each point, and the Figure shows that almost all the values exceeded 100 dB and reached 110 at two points.

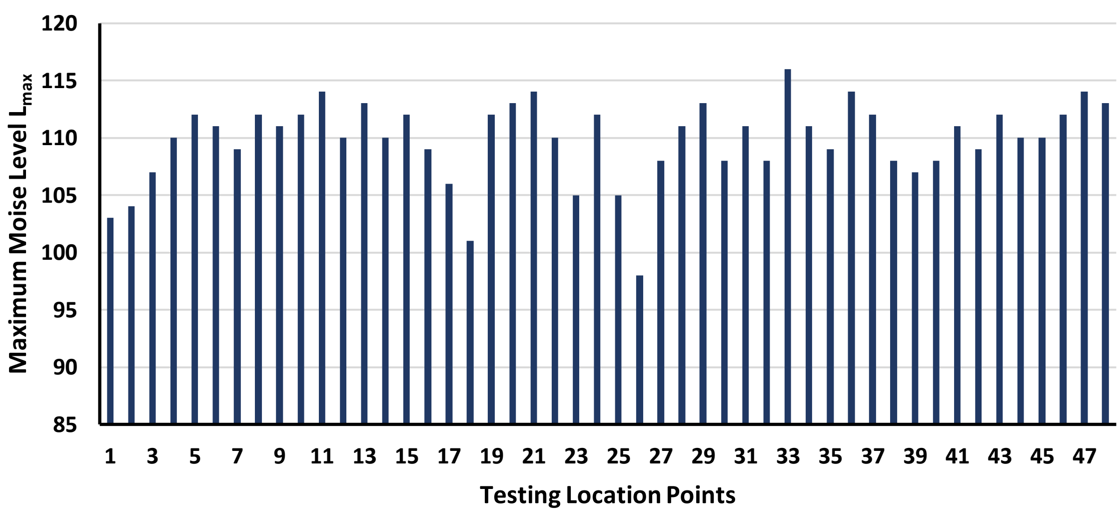

Figure ١٦ : Equivalent Noise level L_{eq} in one second at testing points

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Figure 17 The highest noise level equivalent to the audible frequency was recorded at the measurement point. The graph shows that the average of these values is 105 decibels and reached 110 at three points.

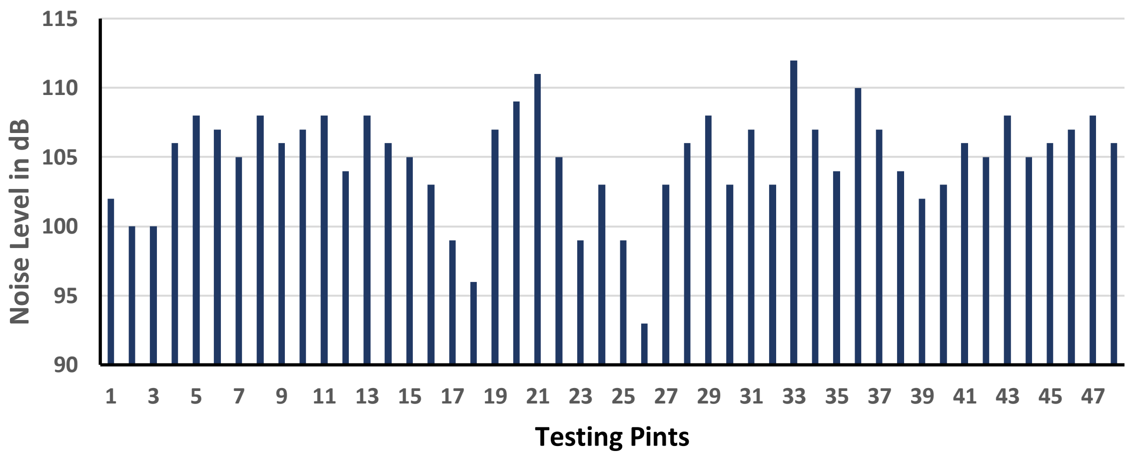

Figure ١٧ : The highest recorded Equivalent Noise Level L_{max} in one second for the whole octave of audible sound at testing points

6. Conclusion:

From the results presented above, it is clear that the tunnel has a noise problem, and this problem is twofold:

6.1.The first issue:

The first issue is the presence of noise of different types.

Noise sources were identified, and their noise types and levels were defined. The primary sources of sound energy that create noise inside the tunnel are:

- The giant ventilation turbo
- The intermittent traffic noise produced by passing cars' and buses' motors and horns.

Three types of noise have been identified at rates that may cause psychological and physical damage to tunnel users and users. These types are:

- Continuous noise: Tunnel ventilation fans generate noise levels ranging from 92 to 100 dB

- Melodic noise is produced by 630 Hz ventilation fans, 90 dB sound level, 1.25 kHz, 88 dB sound card, 4 kHz, and 85 dB lower power.
- Frequent noise: Car horns and motors cause this noise at an intensity level of 100 dB Lmax, concentrated at low frequencies between 20 Hz and 400 Hz.

6.2.The second section:

The second issue is the exposure of some categories of users to high levels of noise for relatively extensive periods, and these categories, respectively, are:

- Mentainace workers, traffic, and security men are exposed to more than 110 dB decibels Lmax for eight hours daily and 120 hours during the season.
- Passengers wait for hotels' shuttle service, ranging from 20 to 45 minutes. The study showed that vulnerable users, including women or older people, cannot compete with others during congestion hours. Therefore, their waiting periods extend for more than 1.5 hours, which increases their exposure periods. The measured exposer noise level ranges between 88 and 102 dB.
- As a result of congestion, commuters are forced to exit from the protected waiting areas to C-category areas, which have the highest noise levels.
- The traffic congestion increases by allowing for U-turn openings, reducing vehicles flowing through the tunnel, which makes the riders more aggressive, and the horn use is at its highest.
- Openings in the central traffic barrier allow pedestrians to cross from one side to the other, exposing them to risks and increasing the obstruction of cars.

7. Recommendations:

Several international organizations have suggested changing infrastructure to reduce noise at its source and align its route to the impacted population [7, 18].

Noise mitigation interventions suggested by WHO are defined in the guidelines as follows [5]:

- Reducing the noise at the source through changing the emitted noise levels of sources and/or restricting operation hours of the source.

- Obstruct the noise path by changing the path between the noise source and the population or/and insulating the designated space.
- Renewing or Replacing the source with one with controlled emotions.
- Changing the finishings or dimensions of the exposed physical space.
- Reduce exposure periods by changing individuals' behavior and educating the community.

7.1. General recommendations:

- Attention should be paid to monitoring environmental noise levels in buildings where users are subject to spaces where their activities mix up with machinery.
- When dealing with environmental noise, attention must be paid to the activities, time, and periods and linking them to exposure levels.
- Environmental noise data require a good archiving system that allows for time tracking and analysis tools. Database Systems like GIS may provide a good tool for such analysis.

7.2. Recommendations for the Case Study:

For the case study sample, the following is recommended to address the identified noise issues:

- Align the working hours and periods of maintenance, traffic, and security inside the tunnel as per the WHO and OSHA standards and recommendations to protect them from psychological and health problems.
- Adopt a traffic plan that reduces the traffic congestion within the area.
- Reroute the shuttle hotel transport service outside the tunnel to protect commuters from exposure to these high noise levels.
- Add sound insulators to the turbine ventilating fans.

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