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RESEARCH ARTICLE

Exposure assessment to road traffic noise levels and health effects in an arid urban area

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Abstract

Road traffic noise exposures have been recognized as serious environmental health concerns, especially in most developing countries with arid climate conditions, rapid increase in vehicle population, and limited traffic management systems. The excessive noise exposure level is associated with increase in the incidence of cardiovascular diseases and anxiety, including annoyance. This study aimed at determining traffic noise levels in residential areas, including the assessment of its annoyance and health effects based on the people's perception and reportage. To do so, field measurement and traffic noise modeling were carried out in six road points to estimate the current noise levels along various roads close to human inhabitants in Muscat Governorate, Sultanate of Oman. The detailed measured noise levels in urban residential areas across the selected roads showed that noise levels have exceeded the local and international threshold limits at all locations during the entire day. The high sound levels (48.0–56.3 dBA) were observed using the US Federal Highway Administration's Traffic Noise Model (TNM, version 2.5) results, which were in agreement with the observed (56.3–60.4 dBA) data. To assess health implication to residents through interviews ($n = 208$), annoyance at home was found to be little (32%), moderate (28%), and high (9%) in comparison with workplace settings of 42%, 43%, and 15%, respectively. Nineteen percent of the interviewees had difficulties in sleeping, while 19.8% experienced stress due to road traffic noise exposures. Moreover, a strong association ($p < 0.05$) was established between the use and objection of noise barriers. The study revealed high noise levels and the prevalence of annoyance and health effects among the exposed population. Therefore, immediate action is required to tackle the current noise levels.

Keywords Traffic noise pollution · Field measurement · Noise model · Health effects · Annoyance · Road traffic

Introduction

Road traffic noise exposure is gradually becoming an emerging environmental health problem considering an increase in massive importation and usage of preowned vehicles by most developing countries (Ajayi and Dosunmu 2002; Brink et al. 2019; Eze et al. 2018; Rajé et al. 2018). In the case of arid countries, the higher outdoor climatic conditions (temperature > 35 °C and humidity > 90%) during long summer seasons (April–September) and limited public transportation systems have led to rapid increased in vehicular population, thereby serving as potential causes of traffic noise levels in these countries (Amoatey and Sulaiman 2017; Lelieveld et al. 2016; Al-Harthy and Tamura 1999). What makes the situation serious is that most developing countries, including many arid urban areas, have poor urban planning and transport systems, where the majority of residents are living in close proximity to major roads, thereby increasing the frequency and the intensity of road

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traffic noise exposures (Jones et al. 2015; Lee 2018; Traoré 2019). According to the World Health Organization (WHO), A-weighted equivalent sound pressure levels (L_{Aeq}) of 50–55 decibels average (dBA) over 16 h in ambient residential areas could result in moderate and serious annoyance, whereas noise levels exceeding 70–100 dBA could lead to permanent hearing loss and increased in cardiovascular mortalities and morbidities (WHO 2011). Even in most European countries with improved road traffic management systems, it has been estimated that more than 100 million people among 33 European Union (EU) member countries have been exposed to the average day-evening-night (L_{den}) noise levels of ≥ 55 dBA (European Environment Agency 2018).

Several studies have revealed an association between road traffic noise exposure and increased in cardiovascular diseases (Recio et al. 2018), systolic blood pressure levels (Enoksson Wallas et al. 2019), and body mass index among young children (Wallas et al. 2019). Also, an increase in daily 1 dBA of road traffic noise exposure level has been found to be associated with mortality rates for aged (≥ 65 years) population from diabetes and chronic obstructive pulmonary diseases (COPD) (Recio et al. 2016). In addition to the above unnoticeable health effects, traffic noise has also been found as one of the major causes of sleep disturbance (de Kluizenaar et al. 2009), annoyance (Fredianelli et al. 2019a; Licitra et al. 2016; Miedema and Oudshoorn 2001), and cardiovascular effects (Babisch et al. 2005). Moreover, learning impairment (Ascari et al. 2015; Lercher et al. 2003) and ischemic heart diseases (van Kempen and Babisch 2012) have been found among children and adults due to higher traffic noise levels, respectively. In California, an average of 72 dBA of traffic noise exposure was found to be associated with reduced lung function among children when adjusted with NOx levels (Franklin and Fruin 2017). Another road traffic noise exposure assessments among six major cities in Cairo, Egypt, has shown high noise levels with minimum and maximum noise levels of 64.2 and 87 dBA, respectively. In these cities, about 53% of the respondents complained of high annoyance levels among their residential areas (Ali and Tamura 2003). Di et al. (2012) found that traffic noise annoyance levels were more experienced in people living closer (1–50 m, noise = 82 dBA) to roadways compared with those living far (251–300 m, noise = 14.8 dBA) distant areas.

Sustainable traffic noise mitigation measures through application of recyclable materials have been well explored in several studies (Fredianelli et al. 2019b; Gori et al. 2016). For example, the utilization of recycling textile materials (Danihelová et al. 2019), reuse of rubbers from recycled tires (Pfretzschner and Rodriguez 1999), and optimization of road pavement designs (Licitra et al. 2019) have been recognized as some of the promising sustainable works in reducing noise levels. The pragmatic approach of reducing excessive exposure to traffic noise levels and formulate efficient traffic policies will require analysis of a more reliable noise exposure datasets (Bravo-Moncayo et al. 2019). Employing traditional field measurements can be very laborious and expensive when assessing noise levels from multiple roadways in cities (Oyedepo et al. 2019). Hence, several studies have employed noise prediction models to estimate traffic noise levels to aid in designing efficient noise abatement programs (Lee et al. 2014; Okokon et al. 2018; Seong et al. 2011). To date, most developing countries are facing difficulties in obtaining accurate noise prediction levels due to lack of reliable road traffic data, which are key input parameters in noise modeling (Zhong et al. 2012). Therefore, it is essential for cities to develop efficient traffic management systems to generate comprehensive traffic database, including traffic counts, road length/width, speed limits for different road networks, and vehicles (cars, heavy- and light-duty vehicles) (Can and Aumond 2018; Zhong et al. 2012).

Despite the relatively frequent studies on air pollution levels due to the high number of on-road vehicles (Abdul-Wahab and Fadlallah 2014; Amoatey et al. 2020; Charabi et al. 2018), only limited studies have assessed noise pollution in arid climate countries such as Gulf Cooperation Council Countries (GCC), where private vehicles are the major part of individuals' life (Al-Harthy 2006; Al-Harthy 2007). For example, AlQdah (2013) measured noise levels on a single mobile car under different engine speed limits. Al-harthy and Tamura (1999) conducted one of the earliest studies in Muscat on the assessment of noise levels at schools. Literature review revealed that more comprehensive studies covering larger domains are needed for better estimation of road traffic noise exposure and their associated annoyance/health effects in GCC countries.

Owning to the limited studies on noise pollution among countries with arid climates across the globe (Hamad et al. 2017; Steinberg and Miranda 2005), this is the first presented study that measured and modeled traffic noise data together with field survey data are employed to assess health implication of residents in arid urban areas. The objective was to assess the association between road traffic noise exposure and self-reported annoyance in residential areas .The goal has been achieved by applying the US Federal Highway Administration's Traffic Noise Model (TNM, version 2.5) to predict noise levels across six road points characterized by different vehicle types. The predicted levels were compared with the observed values which were measured through mobile noise sensors. In addition, self-reported noise survey study through questionnaires (see the supplementary document) was employed to assess the impact of noise levels on the health of residents. This study is important to the relevant transportation service, public health, and urban planning agencies to assist in future policy measures and to reduce road traffic noise exposures among the residents.

Materials and methods

The study consists of three major components, including (i) field measurement through the implementation of mobile noise monitoring instrument near various roads, (ii) modeling of traffic noise levels by applying TNM from various road points, and (iii) a survey study on the perceptions and annoyance of people living in close proximity to the roads as a result of road traffic noise exposure levels.

Study area

The study took place in Muscat, where the governorate is strategically located in the north of Sultanate of Oman along a coastal zone. Due to the urbanized centralized nature of Muscat, it is the most populated governorate in Sultanate of Oman with an estimated 1,459,249 inhabitants, which account for about one-third of the national population. The population of Muscat has a notably contrasting structure compared with other governorates with a majority (63.7%) of residents being expatriates (National Centre for Statistics and Information 2018). Also, the climate in Muscat is generally harsh compared with other governorates, especially during long summer seasons (March–September). According to Directorate General of Meteorology (2017), Muscat has the highest temperature (18–46 °C), humidity levels (15–92%) and lowest (16.5 mm) annual rainfall among the other governorates. It is estimated with an average of about one vehicle per every household (Amoatey and Sulaiman 2017). The most common vehicle types in Muscat are private vehicles and buses, including several heavy-duty vehicles depending on the road type (i.e., express highways, access roads, and streets). However, unlike many countries, the use of motorcycles is very limited in Muscat (Muscat Municipality 2019). The high population, high ambient temperature, and limited public transportation networks have led to an increased number of road vehicles in Muscat. In addition, the governorate is known as a transportation hub of Oman due to its geographical and geopolitical location. All above factors have a high tendency to increase road traffic noise levels in the governorate, especially due to limited urban vegetation in residential areas, which could reduce noise pollution from nearby roads (Amoatey et al. 2018).

Road traffic noise exposure assessment

Mobile noise field measurement

The field measurement was carried out across various road points by MK:427 noise sensors, which were installed on two Airpointer (Recordum, Austria) platforms at the height of about 3 meters to the reflecting surfaces according to US FHWA protocols (US Federal Highway Administration 2018). The noise sensor was developed by Cirrus Research PPL (https://www.cirrusresearch.co.uk/products/environmental-noise-monitors/mk427-noise-sensor/), which was purposely designed for environmental noise monitoring levels ranging from 30 to 100 dB in accordance with the generic emission standard for residential, commercial, and light industrial environment (EMC) directives 89/336/EEC. In addition, the noise sensors follow the International Electrotechnical Commission (IEC) standard as a Class 1 outdoor noise level instrument (Cirrus Research 2019). In this study, traffic noise level monitoring campaign via field measurement was carried out from January 2018 to April 2019 across six individual roads for more than 60 days. The duration is deemed sufficient to provide adequate assurances to understand the current traffic noise levels from these roads (Fig. 1). Table 1 shows a detailed description of field measurement profiles and road waypoint location features. The six roads were selected for this study because they serve as collector roads to various residential and commercial areas of Muscat. They are also linked to a total of more than 20 different residential streets, thereby making them hot spots for traffic noise emissions caused by their relatively high traffic volumes (Muscat Municipality 2011). Besides, a recent study revealed high traffic volumes in these roads in Muscat and thus warranted further research to assess their noise exposure levels (Al-Shidi et al. 2020).

In this study, traffic noise levels were measured in both residential areas and workplaces located near roadways where the majority of people are living/working in two–three-story buildings (the most common type of building). To ensure the safety of the noise measurement equipment and to avoid non-traffic-related noises, the instruments were placed near roadways relative to the center of each single road lane as most of these roads were located in residential areas.

Road traffic noise modeling

In selecting a suitable noise model for this study, several factors were considered including the complexity of the model and availability of field data. There are several types of traffic noise models (German model RLS-90, Swiss model STL-86, English model CoRTN) available in the literature (Bravo-Moncayo et al. 2019; Tezel et al. 2019). Among them, the commonest ones are French Method (NMPB) and Common Noise Assessment Methods in Europe (CNOSSOS-EU) (Garg and Maji 2014; Pallas et al. 2016). The study did not consider CNOSSOS-EU and NMPB models due to lack of specific vehicle classification data required by the models (Bravo-Moncayo et al. 2019). For example, CNOSSOS-EU requires input data for mopeds, tricycles of ≤ 50 cc and motorcycles, and tricycles of ≥ 50 cc, which were not available based on the collected datasets. Hence, TNM, which has been developed by the Federal Highway Administration (FHWA)

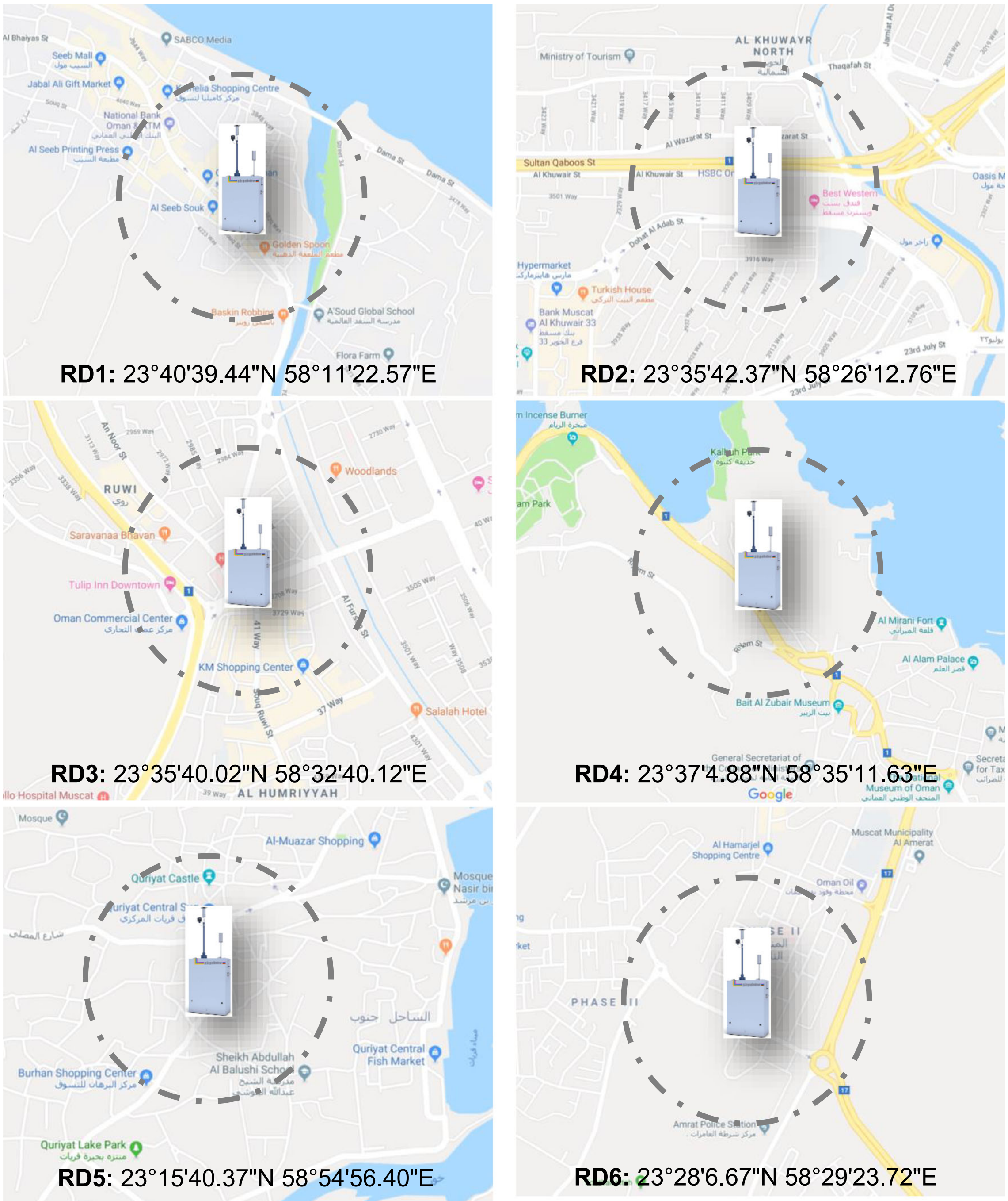


Fig. 1 A map showing the measured and modeled noise levels across the various major roads (RD1–RD6) for each neighborhood indicated by cycles in Muscat Governorate

of the US Department of Transportation (US Federal Highway Administration 2017), was utilized due to its flexibility to the available data. TNM is the most up-to-date model, which has been developed for the prediction of road traffic noise. In this study, TNM was used to estimate community noise equivalent levels (CNEL) in day-evening-night (L_{den}) as a result of road traffic activity. The CNEL is estimated according to Eq. 1. The TNM utilizes average daily traffic (ADT) volumes for the various proportions (%) of different vehicle categories, including Auto (AT), Medium Trucks (MT), Heavy Trucks (HT), Buses (BS), and Motorcycles (MC) of each roadway (Franklin and Fruin 2017; Seong et al. 2011).

$$L_{\text{den}} = L_{\text{AE}} + 10 \times \log_{10}\left[N_{\text{day}} + 3N_{\text{evening}} + 10N_{\text{night}}\right] – 49.4 \text{ (dB)} \quad (1)$$

Table 1 Mobile field traffic noise measurement profiles

Road points	Actual days of measurement	Date	Site description	Distance from road (m)	Elevation (m)
RD1	123	01/18–05/18	Urban	10	18.28
RD2	67	01/18–05/18	Suburban	7.0	132.58
RD3	40	03/18–05/18	Commercial	11.0	6.4
RD4	64	02/18–06/18	Suburban	5.0	10.36
RD5	63	03/18–06/18	Urban	7.0	39.01
RD6	61	03/19–05/19	Rural	9.0	10.36

L_{AE} denotes sound pressure exposure levels (dB). N_{day}, $N_{evening}$, and N_{night} represent the number of on-road vehicles by-passing between 07:00–19:00, 19:00–22:00, and 22:00–7:00 in local time, respectively. Thus, adjustment penalty of 10 dB is applied for vehicles by-passing during 22:00–7:00, while 49.4 dB is a daily constant of sound energy levels from by-passing vehicles.

The model also requires average speed, pavement type, atmospheric conditions, elevation, and landscape type to estimate the noise levels at a particular exposed residential area. The study employed traffic data were collected by the Muscat Municipality (2011), which were further analyzed to conform to the model vehicle categories' input data requirements (Fig. 2). Although the traffic data are out of date, it is the only comprehensive dataset currently available in Muscat. The more recent (2014) traffic data is based only on the total vehicle population, which is limited to cities outside Muscat (Charabi et al. 2018). Since, each vehicle type should be at least 1% in the model, the vehicle types which were found less than this value was rounded to meet this proportion. The average vehicle speed limit of 100 km/h was assumed in these major roads. TNM default values for number and height of buildings, sound barriers, and tree zones of the residential areas were used since Muscat has very limited green infrastructures and noise barriers between roadways and the residential areas. Figure 2 shows the detail protocols (step-by-step procedures) used in modeling the traffic noise levels using TNM model.

It can be clearly understood from Fig. 3 that AT were the highest vehicle composition representing about 89, 94, 94, 93, 76, and 92% for road points RD1 to RD6, respectively. However, average daily HT counts (11%) were reported high in RD5 compared with RD1 (2%) and other roads which were found to be as low as 1%, because RD5 is composed of urban, industrial, and commercial sites named Ruwi. In general, the lower HT counts across all the roads were due to the presence of express highways where most of HT pass to ease congestion and accelerate the transport of goods and services. Similarly, MT and BS populations were found very low across all the roads. BS in Muscat are normally used in the transportation of students and workers and thus are not regularly found in roads compared with other vehicle categories. Thus, the selected roads have the potential of reducing noise levels in Muscat.

Assessment of noise on annoyance and health of the residents

Resident population

This is a cross-sectional study involving individual adults who have lived at the radius of ~ 10 to 300 m from each of the roadways in Muscat. The residents were all classified as individuals who have been exposed to traffic noise since they were living in areas with several roadways. Unlike most cities across the globe where summer weather conditions are favorable, the situation in arid cities/countries is different where maximum summer temperature and humidity level could reach about 50 °C and > 90%, respectively. In order to reduce human exposure to these harsh weather conditions, several single-lane access roads to residential communities have been provided in Muscat which in turn serve as the main sources of traffic noise pollution.

According to the formula employed by Paiva et al. (2019), in this study, sample size (n = 208) was obtained through random sampling technique. This survey size was based on the WHO (2011) which estimated the prevalence rate (25%) of sleep disorders and annoyance caused by noise at 95% confidence intervals. The apartments/buildings of the residential areas were selected, and their respective distances were determined from roadways through Google Earth Pro software (version 7.3.2). The Sultan Qaboos University (SQU) research team, who were highly proficient in both Arabic and English languages, explained the objectives of the study and its significance to the community to the identified households. The respondents were assured that their personal information such as names and identity information would not be included in the study. Also, they were informed with the option of receiving a summary of the survey findings at the end of the study through appropriate communication networks (text and email). The credibility of the research team to the resident communities was ascertained as the team were issued official letters and identity cards by SQU.

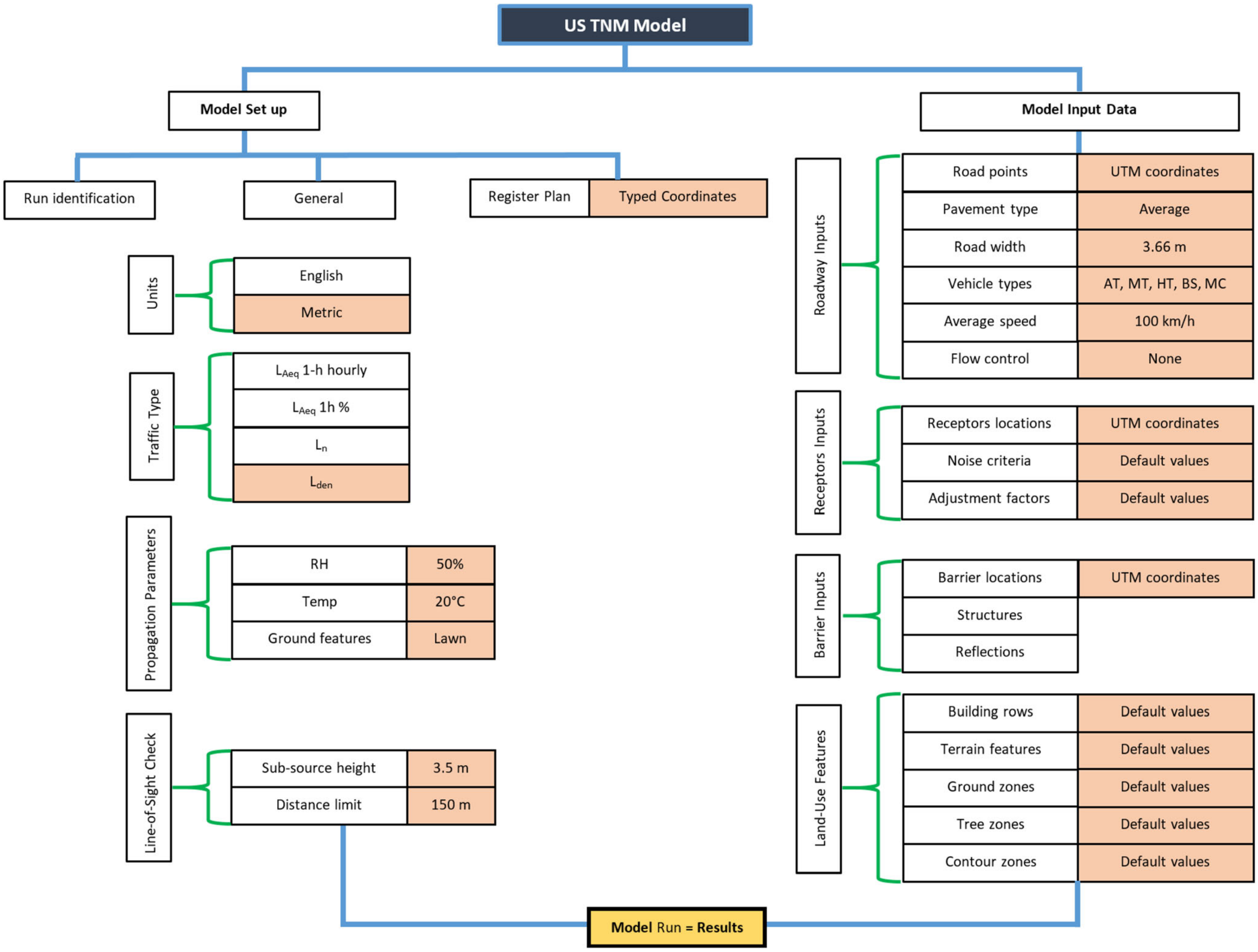
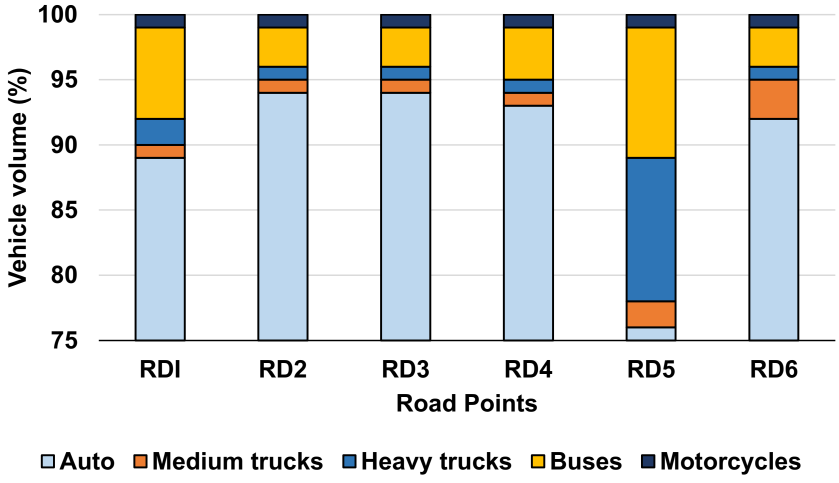


Fig. 2 A flow chart showing a step-by-step procedure for TNM traffic noise modeling. The boxes are not directly linked because each box represents a step that first requires proper inputs. When the minimum input requirements are met, the model can be run

Survey methodology

The self-administered and interview-based survey was conducted based on the structured questionnaire (see the supplementary document) in both English and Arabic versions. The data collection involved questions about the respondent's sociodemographic profiles, duration (years) lived in the area, and perception of noise at homes and/or workplaces (within

Fig. 3 Average daily traffic volumes and vehicle categories of each road point in 2011



the measured distances from the roadways). Noise levels caused by traffic at both homes and/or workplaces, including weekend Jumma prayer times, were assessed through dichotomous questions such as yes/no questions. Also, data on annoyance rates of noise (do not/little/moderate/high) and knowledge of potential health problems (yes/no/no idea) including insomnia, hearing loss, stress, anxiety, learning difficulties, and communications interruptions were collected according to the method used by Paiva et al. (2019) and Brown et al. (2015). In addition, sleeping difficulties (never/sometimes/always) due to traffic noise levels, suggested noise reduction measures (yes/no) through the installation of noise barriers, and living in city suburbs with very low noise levels were assessed.

Statistical analysis

Descriptive analysis was used to compare the proportions (%) of sociodemographic features, duration of noise exposure based on a number of years lived in the place, perception of noise at home and/or workplace, and knowledge of health effects between the exposed population. Chi-square statistical test was carried out to determine the association of road traffic noise exposure levels, annoyance (home and/or workplace), perceived health effects, sleep disorders, and noise reduction measures. The Chi-square test was applied to both categorical and binomial responses for all the annoyance questions. The analysis was performed with IBM SPSS (statistical package for social sciences, version 23) at 95% confidence interval, whereas p value < 0.05 was considered statistically significant.

Results

Noise exposure levels

Measured noise levels

The measured average noise levels are listed in Table 2. The recorded noise levels were found consistent and similar ranging from 60 to 60.4 dBA across all the roads except for RD6 which showed a slight reduction of 56.3 dBA (Fig. 4). This is because RD6 is located in a less populated rural area compared with other roads which are located mostly in urban, suburban, and commercial areas (Table 1). The high measured noise levels could be attributed mostly to noise sources including nearby roads, airplanes, moving machines, and industrial activities in these locations. The noise equivalent levels at all six locations were beyond the standard levels set by the government of Oman (MECA 1994) in all areas during day, evening, and night times (Table 3).

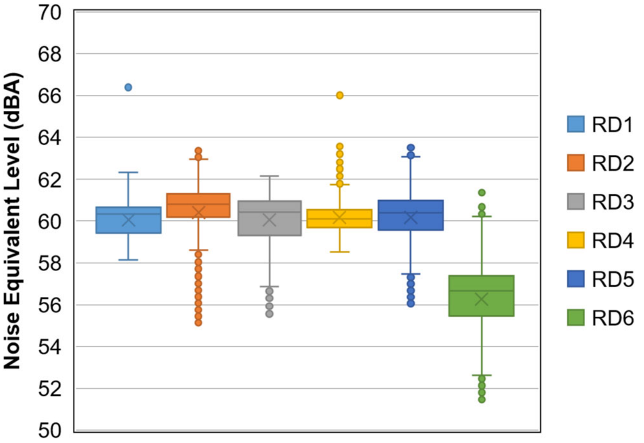


Fig. 4 Boxplots of the noise equivalent levels at each site

Figure 5 shows the detailed measured noise levels based on day, evening, and night times across the selected roads in Muscat. The noise levels in Fig. 5 have all exceeded the limits of the Oman Ministry of Environment and Climate Affairs (MECA) guidelines (Table 3). Even in RD6, which was experienced the lowest noise exposure levels (Fig. 4), the evening noise pressure level (54.8 dBA) far exceeded the MECA limit (35 dBA) for rural residential. The study found relatively similar noise levels during day and evening times, which were slightly higher than the night time levels. For example, in RD2, similar day-evening noise pressure levels of approximately 61 dBA were observed, while in the night time, a slight reduction (59.9 dBA) was observed. A similar situation also

Table 2 Difference between measured and predicted community noise equivalent levels (L_{den}) in Muscat Governorate, 2018

Points	Community noise equivalent level (L_{den})		Difference (dBA)
	Predicted L_{den} (dBA)	Measured, L_{den} (dBA)	
RD1	48.0	60.0	12.0
RD2	50.2	60.4	10.2
RD3	53.2	60.0	6.8
RD4	56.3	60.1	3.8
RD5	53.2	60.2	7.0
RD6	51.2	56.3	5.1

Table 3 Traffic noise levels standards of the government of Oman (MECA 1994)

Site type	Community noise equivalent level, L_{den} (dBA)		
	Day	Evening	Night
Rural residential	45	40	35
Suburban residential	50	45	40
Urban residential	55	50	45

NB: MECA's definition of noise standards set for day (7:00 AM–6:00 PM), evening (6:00 PM–11:00 PM), and night (11:00 PM–7:00 AM) time limits

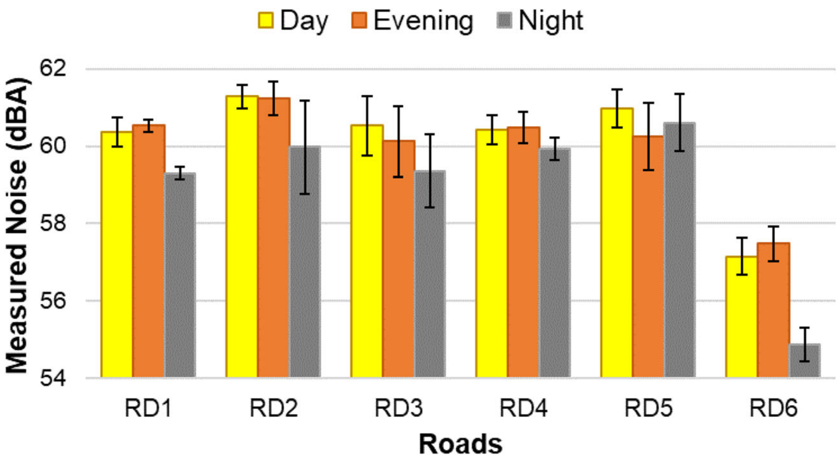


Fig. 5 Measured noise equivalent levels for the day, evening, and night at each site. Error bars represent standard deviations from the average values

occurred in RD3, RD4, and RD6, respectively, for higher and slightly lower noise exposure levels for day-evening and night times. The above-measured noise levels may be a reliable dataset for mitigating noise pollution in Muscat as it determines the real-time noise levels compared with modeling results (see the subsequent section).

Modeled noise levels

The maximum predicted traffic noise level (L_{den}) was found to be 56.3 dBA with a slight reduction in other points (Table 2). As expected, noise levels were generally high in the modeled roads as a result of a higher number of daily AT (10,275) compared with BS (654), HT (241), MT (135), and MC (34) vehicles. There were very low predicted (48 dBA) noise levels in RD1 compared with RD5 which showed higher noise levels of 53.3 dBA. High BS and HT vehicles which occasionally move along these residential areas may be the main factors to observe high noise exposure levels (Fig. 4).

The predicted traffic noise levels exceeded the critical limits set by MECA for day (45 and 50 dBA), evening (40 and 45 dBA) and night times (35 and 40 dBA) in rural and suburban residential areas, respectively (Table 3). Although most of the predicted levels in outdoor areas were found within the WHO's interim noise exposure target level of 55 dBA (WHO 2011), the predicted noise levels during night times far exceeded for all residential areas in Muscat. Very high measured traffic noise levels exceeded both the MECA and WHO limits of about 5–20 dBA (Table 3). The highest and the lowest differences between the measured and the predicted levels were found to be 12 and 3.8 dBA, respectively. These large differences could be due to several factors including old traffic data (2011) used in the modeling study in comparison with the recently measured noise values obtained in 2018. It is expected that the traffic population has been increased in Muscat over 7 years (2011–2018) and this could be the main reason for the lower predicted noise levels. Additionally, the recommended default atmospheric parameters, including temperature (25 °C) and humidity (50%) levels used in TNM model, were low compared with the local atmospheric conditions (around 46 °C and 92%) that may also contribute to low modeled noise values.

Noise annoyance and health impact assessment

A total of 208 interviews consisting of Omanis (30.6%) and expatriates (69.4%) were conducted in both Arabic and English languages. The selected households were located in close proximity to the road traffic zones in Muscat within a range of 10 to 300 m. The majority of the respondents (43%) were within the age group of 26–34 years old followed by 35–44 years old (22.2%), while the lowest (2%) was the elderly group (> 65 years old) (Table 4). Among these age groups, most interviewees were married (64.7%), while 33.8% were found to be singles. In overall, more males (87.6%) participated in the survey compared with females (12.4%). From an educational perspective, most of the residents had high educational qualifications (27.7% secondary school certificate and 25.7% college diploma) (Table 4). The majority (44.9%) of the study population stated that they have dwell in the exposed area up to 5 years, while a good number of them (32.7%) had lived in similar areas for > 10 years (p = 0.00). Regarding the occupational status, 88.6% of the interviewees (p = 0.00) worked outside their homes, and 52.4% (p = 0.00) spent more than 10 h in their workplace. The health history revealed that only 14.9% of the interviewees (p = 0.00) were reported with chronic diseases consisting of hypertension, high cholesterol levels, diabetes, asthma, and depression (Table 4).

In general, a higher proportion (55.8%) of the residents viewed road traffic as the main source of noise pollution in Muscat (p = 0.096). According to the respondents, this much noise level was found to be moderate (40.6%) and high (11.6%) at the various residential homes (p = 0.00). However, 42.8% of the people attributed traffic as a source of noise in the workplace environment. Also, the auditory

Table 4 Sociodemographic profiles, duration lived in the locality, information on having worked at residence, hours spent at the workplace, and history of chronic diseases reported by various residents in Muscat, Sultanate of Oman

Characteristics	*N*	%	Total	*p* Value
Sex				0.00
Male	156	87.6	178	
Female	22	12.4		
Marital status				0.00
Single	69	33.8	204	
Married	132	64.7		
Widow	3	1.5		
Residency				0.00
Omani	63	30.6	206	
Expatriate	143	69.4		
Age				0.00
18–25	31	15.0	207	
26–34	89	43.0		
35–44	46	22.2		
45–54	27	13		
55–64	10	4.8		
> 65	4	2.0		
Education				0.00
Primary school	25	12.1	206	
Secondary school	57	27.7		
College	53	25.7		
University education	51	24.8		
Postgraduate education	20	9.7		
Duration lived in residence				0.00
0–5 years	92	44.9	205	
6–10 years	46	22.4		
> 10 years	67	32.7		
Work outside residence				0.00
Yes	179	88.6	202	
No	23	11.4		
Hours spent at the workplace				0.00
0–5 h	11	6.0	185	
6–10 h	77	41.6		
> 10 h	97	52.4		
Previous chronic disease				0.00
Yes	31	14.9	208	
No	177	85.1		

condition was reported to be very good (62.6%) and good (36.9%) among the interviewees. The residents complained of high traffic noise levels at night times (50%) compared with the afternoon (12%), while the majority (80.4%) reported very low traffic-related noise levels during Jumma prayer times (on Fridays) ($p = 0.00$ at 95% CI) (Table 5).

Table 6 shows the perception of traffic noise annoyance levels, the reported health effects, and the measures of mitigating the situation. In this study, the traffic-related noise annoyance at home was reported by the respondents to be low (32%), moderate (28%), and high (9%), while 31% was in disagreement ($p = 0.00$). In workplace environments, about 42%, 43%, and 15% of the respondents found annoyance to be low, moderate, and high, respectively ($p = 0.00$). Moderate proportion (37.6%) of the residents had experienced sleep disturbance as a result of traffic noise levels. With regard to health effects, most of the respondents (47.9%) had general knowledge about potential health impacts of noise exposure, while 27.1% stated that there was no health effect from noise pollution, and 25% of them did not have any idea about the negative health implications from noise exposure (Table 6).

Assessment of direct health effects of noise levels among the studied population showed that 19% of the interviewees experienced insomnia and a relatively similar number (19.8%) experienced stress due to high noise levels at their residences. Also, 14.7% of the interviewees stated that communication interruptions normally occur as a result of high noise levels. With regard to the current traffic noise levels, 58.5% of the population wanted the current noise levels in their respective home and workplace environments to be reduced ($p = 0.01$). However, the majority (63.4%) of the residents suggested considering noise barriers such as planting of trees along the various roadways to reduce noise levels with their home and workplace environments (Table 6).

Discussion

The noise measurement and modeling outputs for Muscat showed high noise levels with maximum sound pressure levels of 60.4 and 56.3 dB, respectively. These levels were found to have exceeded the permissible standards established by MECA and WHO, especially for night times. The study has revealed the nature of the current acoustic situations for residents who are living and working near these roadways in Muscat. The traffic noise exposure levels in this study were found to be consistent with other similar arid urban cities which had similar vehicular traffic densities as Muscat. A study conducted in arid urban streets of Tripoli city, Libya, showed high noise levels compared with the standards established by the local environmental authorities (Mohareb and Maassarani 2019). This is also similar in the situation of Jeddah city in Saudi Arabia where the measured noise levels in most residential areas exceeded the national standards (Zytoon 2016). The findings from this study suggest that sustainable urban planning and traffic management may be the plausible means of mitigating traffic noise levels in Muscat, especially where harsh outdoor environmental conditions have led to an increase in vehicle populations.

Table 5 Perceptions (%) of traffic exposure levels at residence, workplace, and during Jumma prayer times among the residents

Indicators	N	%	Total	*p* Value
Auditory condition				0.00
Very good	129	62.6	206	
Good	76	36.9		
Poor	1	0.5		
Perception of traffic noise				0.096
Yes	116	55.8	208	
No	92	44.2		
Perception of noise at residence				0.00
Quiet	99	47.8	207	
Moderate	84	40.6		
Noisy	24	11.6		
Durations of high traffic noise levels at residence				0.00
Always silent	62	32.0	196	
Morning (6:00 AM–11:00 AM)	12	6.0		
Afternoon (12:00 PM–6:00 PM)	24	12.0		
Night (8:00 PM–12:00 AM)	98	50.0		
Perception of noise at the workplace				0.048
Yes	80	42.8	187	
No	107	57.2		
Source of noise at the workplace				0.001
Traffic*	115	62.2	185	
Non-traffic	70	37.8		
Perception of traffic noise during Jumma prayer time				0.00
Quiet	164	80.4	204	
Moderate	35	17.2		
Noisy	5	2.4		

*Traffic includes all road vehicles types and motorcycles

In Muscat, high ambient temperatures, especially during the summer season, and limited public transport networks have yielded to very high traffic volumes across the city, thereby serving as the main source of noise levels (Al-Harthy and Tamura 1999). The high noise levels do not only affect the health of the people living in residential homes but also cause annoyance to schools, hospitals, and mosques which are closer to the roads. Any interventions that could be adopted by MECA and Muscat Municipality will not only reduce the current environmental exposures but also contribute to building sustainable cities and communities as envisage in United Nation’s Sustainable Development Goal eleven (United Nations 2019). Thus, this goal ensures the building of sustainable transport systems and reducing environmental impacts, especially to the vulnerable populations (i.e., elderly ones, women, and children) (United Nations 2019). Thus, the failure of achieving this goal may increase cardiovascular-related morbidities and mortalities (Tobías et al. 2015) among the aged groups and children as a result of traffic noise exposures (Dreger et al. 2015).

In this study, the individual modeled roads in most rural and urban residential areas had noise levels exceeding the MECA standards. Similarly, the field measurement campaign conducted across the various roads within the residential areas has even shown high noise levels compared with the modeled results. In addition, noise levels during the day, evening, and night times across all the residential areas were all found to have exceeded the acceptable limits set by MECA. Most importantly, roads found in commercial and urban areas recorded higher measured traffic noise levels compared with rural locations.

As mentioned in the WHO report (2011), road traffic noise exposure is not only annoyance but also a silent health effect such as increased in hypertension, ischemic heart diseases, tinnitus on aged populations, and cognitive impairment among children. Even annoyance, which is deemed as the common impacts of noise, depends on several factors including age, prior noise exposure levels, and sensitivity of individuals (Park et al. 2018). Our survey considered all residents living and working closely within the radius of ~ 10−300 m

Table 6 Distribution of Muscat residents (%) to traffic annoyance levels, health effects, and mitigation measures

Parameters	*N*	%	Total	*p* Value
Annoyance at home				0.00
Do not	63	31	202	
Little	64	32		
Moderate	57	28		
High	18	09		
Annoyance at workplace				0.00
Little	51	42	121	
Moderate	52	43		
High	18	15		
Perception of noise on health				0.00
Yes	92	47.9	192	
No	52	27.1		
No idea	48	25.0		
Effect on sleep				0.00
Yes	77	37.6	205	
No	128	62.4		
Perception on the effects of traffic noise*				0.00
Insomnia	89	19.0	469	
Hearing loss	52	11.0		
Communication interruption	69	14.7		
Distraction	59	12.5		
Stress	93	19.8		
Anxiety	48	10.0		
Learning difficulties	41	9.0		
Heartbeat	18	4.0		
Reduction of current noise level				0.015
Yes	120	58.5	205	
No	85	41.5		
Noise barrier				0.00
Yes	128	63.4	202	
No	74	36.6		

*Respondents gave one or more answers

from the roads as an exposed population. The study revealed that residents complained about traffic annoyance at both home and workplace environments. However, the majority found traffic-related annoyance levels at homes to be low compared with workplaces. This was partly attributed to the fact that majority of the respondents in Muscat lived in well-insulated buildings (with doors and windows always closed), thereby shielding the occupants from the excessive outdoor traffic noise levels.

The annoyance has a high potential to affect the physical, mental, and social well-being of the exposed group. Regarding the effects on sleep disturbance, the percentage of people who disagreed with this statement 'noise cannot affect sleep' was about 50% higher than those who were knowledgeable about the impact of traffic noise on sleep. In a similar study in Brazil, traffic noise levels caused highly annoyance (62.8%) with about poor sleep among the three quarters (74.5%) of residents during the night (Paiva et al. 2019). Another study compared similar traffic noise annoyance of developed country (Switzerland) and a developing country (South Africa). The results indicated that the individuals in the former country were more sensitive (35.1%) and felt highly annoyed (20.5%) compared with those in the later country where less sensitivity (26.9%) and annoyance (12.4%) were reported (Sieber et al. 2018). Reviewing conducted studies shows that traffic noise annoyance may be dependent on the level of development of a country where education, traffic regulation, sociodemographic factors, and people's perception may play an important role. However, it should be noted that the exposure-response to annoyance and sensitivity levels among people from different cultures and countries may depend on the scale of measurements.

On health, the respondents have reported more than one health effects such as insomnia, difficulties in hearing, stress, anxiety, and heartbeat problems caused by exposure to road traffic noise in their home and workplace environments. All the aforementioned effects did not show any significant difference among the exposed study population; however, they were the most occurring health effects. These complaints clearly show that the residents have experienced multiple negative impacts from high traffic noise levels, especially exacerbated by sports cars and limited motorcycles during the night.

In this study, 63.4% of the respondents who wanted to reduce the current noise levels (58.5%) suggested for the implementation of appropriate noise barriers. This traffic noise mitigation measures have already been recognized as an action plan employed by the European Environmental Agency to reduce traffic noise levels among member countries through acoustic planning approach (EEA 2014). In Gothenburg, engineering solution through the introduction of low noise tires and the pavement was found to have decreased noise levels of about 13–19% within the residential areas where the noise level exceeded 55 dB (Ögren et al. 2018). Also, vegetation-based barriers at a height of 10 m were found to decrease traffic noise by 11 dB (Ow and Ghosh 2017). These facts show that such mitigation measures could reduce noise exposure levels among the residents of other countries when effectively utilized by the relevant government authorities. The overall noise reduction measures could have a long-term benefit of improving cardiovascular health among the residents.

This is the first study that has compared modeling output with measured noise results, including exposure assessment via noise survey in Muscat compared with other cities with a similar climate. This comprehensive noise assessment study provides strong evidence about the current noise situation in Muscat city. However, the study faced several limitations. One of the major setbacks was the inability to generate noise contour levels among the various modeled points which is important in determining the spatial and temporal noise pollution levels from the source of propagation. Furthermore, the distance between the individual roads was very long (between 15 and 50 km) making it unsuitable to generate noise maps to cover a wider area. Such a map could help in assessing the effectiveness of mitigation measures with time as one can easily visualize which residential area has experienced noise reduction after the implementation of mitigation measures.

In addition, the survey study was biased towards gender (high number of males compared with females) and nationality (low contribution from Omani citizens compared with foreigners) of the surveyed residents. All these low representations were due to the social and cultural factors, thereby hindering the accessibility to these group of people. It is therefore highly recommended that future studies should generate noise maps to help determine the degree of noise exposure levels at each residential area as well as employing online survey to ensure equal representations of the respondents irrespective of cultural or nationality differences. Finally, utilizing the most recent traffic populations and vehicle compositions dataset will help to determine more realistic traffic noise modeling situations for future policy actions.

Conclusion

In this study, field monitoring and modeling of traffic noise were employed to estimate the level of traffic noise across residential communities in Muscat, Oman. The perception, annoyance, and health effects due to traffic noise exposures among the nearby residents were also assessed. The study found that the observed and modeled traffic noise levels have exceeded both the local and international threshold limits, whereas slightly higher noise levels were obtained during the field measurement compared with the model. The residents reported high traffic noise levels, especially during the night times, which caused annoyance at home and workplace environments. Also, the interviewees declared several health effects due to noise exposures, more specifically for insomnia, stress, anxiety, and hearing difficulties. In addition, most residents have suggested that noise barriers should be employed to reduce the current noise levels in the city. This is the first study in an arid urban area of Middle Eastern region where comprehensive traffic noise exposure levels and human health impact assessments have been carried out. However, further study is highly warranted to generate more reliable noise maps via up-to-date traffic data and to assess the feasibility of employing low-cost, but sustainable materials for mitigating traffic noise levels, such as textile waste materials such as (i) used clothing and fashion accessories (cotton, silk, polypropylene, and polyamide fabrics), (ii) tire fluff and steel wastes, and (iii) husks from maize farms.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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