RESEARCH ARTICLE

Contribution of outdoor noise-induced health risk in schools located in urbanized arid country

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Abstract

Ambient noise pollution is deemed as one of the major growing public health issues, especially in developing countries. Therefore, it is crucial to assess the impact of noise pollution on public health. The aim of this study is to investigate the health risk of noise exposure levels in three schools: Kaab Bin Zeyd of Basic Education (school A), Hail Al-Awamour Girls school (school B), and Al-Fikr School (school C) in Muscat, Oman. The study employed a survey of 300 students, dose-response models, and regression models to quantify health risk and to determine the relationship between noise levels and perceived noise annoyance sources. The study found average noise levels (L_{Aeq}) of school A (70.03±8.21 dBA), school B (69.54±7.75 dBA), and school C (55.95± 5.67 dBA) to be higher than WHO's outdoor schools environment standard of 55 dBA and European (EN16798-1) classroom's critical limits of 30–34 dBA. Most of the students from schools A (30.9%), B (33.3%), and C (63%) have reported noise produced from traffic as extremely annoyed compared to aircraft of 15.4%, 11.5%, and 27.2%, respectively. Regression analysis shows that perceived traffic noise was strongly correlated with L_{Aeq} in school A (R^2 =0.481), B (R^2 =0.121), and C (R^2 = 0.132) when compared with other subjective noise types. The health risk assessment results show that the percentage of highly annoyed (%HA) was higher in school A (15.2%) and school B (14.95%) than in school C (8.18%). The estimated highly sleep disturbed (%HSD) based on mean noise levels were almost the same in schools A (15.62%) and B (15.19%) but far higher compared to school C (6.01%). However, there was an association between the mean noise exposure levels and the risk of developing ischemic heart diseases (IHD) in school A (RR= 1.172, 95% CI: 1.020–1.334), school B (RR=1.167, 95% CI: 1.020–1.325), and school C (RR=1.051, 95% CI: 1.006–1.095). Moreover, attributable risk percentage (AR%) for school A (AR% =14.675, 95% CI: 2.028–25.037), school B (AR% =14.310, 95% CI: 1.960–24.528), and school C (AR% = 4.852, 95% CI:0.596–8.742) have shown that a substantial portion of the population could be prevented from developing IHD. It is expected that findings of the study can be applied in other arid regions with sprawl urbanized built environments.

Keywords Health risk · Noise · Schools · Survey · Annoyance, Oman

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Introduction

Classrooms are frequently exposed to noise levels emanating from traffic (cars and aircraft), industrial activities, and commercial areas (Collins et al. 2019). The effects of these outdoor noise sources in schools are also being exacerbated by the noise produced from the operation of electronic devices (e.g., air conditions), door opening/closures, chatting, and the footsteps of people (Massonnié et al. 2020). The World Health Organization (WHO) has advised that noise levels in schools should be maintained at 35 dBA and 55 dBA to avoid speech/communication disturbance and external annoyance in both indoor (classrooms) and outdoor (playgrounds) environments of the schools (WHO 1999). While these guidelines could improve the cognitive and literacy performance levels of students, unfortunately, it has been reported that several schools in urban environments are subjected to noise levels reaching an average of 70 dB (Shield and Dockrell 2003), and these noise levels are equivalent to the noise produced from mower factories (Chen et al. 2021; Koppel et al. 2012).

A survey has shown that school children spend an average of 6.7 h/day and 178 days/year in schools (NCES 2008), indicating that children spend more than 50% of their time in classrooms. Another recent statistic shows that the number of compulsory instructional time used in public schools is about 799 h per year and an average of 7533 h throughout their primary and lower high school education (OECD 2018). These statistics show that school children are highly vulnerable to long-term excessive noise exposures, indicating a high risk of developing health problems during their lifetime. Noise annoyance and speech intelligibility problems are the most widely reported health issue from noise exposure among school children (Bitar et al. 2018; Eysel-Gosepath et al. 2012; Eysel-Gosepath et al. 2010). It is therefore important that minimal and mild hearing loss problems are diagnosed in children due to their elevated self-generating noise levels (Porter et al. 2020). The results from 3 schools have also shown that managing classroom noise is very important for children with autism spectrum disorders (ASD) (Kanakri et al. 2017) which might be due to restricted speech-in-noise recognition problems (Schelinski and von Kriegstein 2020).

Regarding teachers, review studies have concluded that excessive noise exposure in schools has increased the incidence of voice disorders, especially dysphonias among teachers due to an increase in their voice levels to the audible of the students (Martins et al. 2014; Mattiske et al. 1998). Survey studies from schools in both developing countries (e.g., Egypt) and developed nations (i.e., Germany) have confirmed that teachers have reported increased vocal efforts with a high prevalence rate found among male teachers (Nusseck

et al. 2020; Phadke et al. 2019). Penha et al. (2021) have recommended blended learning (online) approach, which could occur outside classrooms as one of the interventions for improving vocal health and reducing noise annoyance among teachers. The engineering mitigation approach involving classroom acoustic refurbishment can also reduce noise due to a decrease in reverberation time of 0.4 s compared to 0.68 s for classrooms without reverberation (Kristiansen et al. 2016). The application of both active (i.e., installation of acoustic ceilings) and passive (i.e., replacement of metallic furniture with wooden ones) intervention measures reduced annoyance index from 0.78 to 0.59 (Taborda et al. 2021).

While previous noise exposure assessment studies in schools have mostly focused on non-arid tropical environments (Bitar et al. 2018; Collins et al. 2019; Nedojedlá et al. 2018; Phadke et al. 2019; Quehl et al. 2021; Summan et al. 2020), the importance of noise exposure in arid areas with sprawl urbanization (e.g., Oman) has received little attention. In Oman, school buildings lack natural ventilation systems (closure of doors and windows) with excessive use of air conditioning systems, which is an important source of the noise. In addition, the lack of urban vegetation systems which could act as noise barriers and increased high usage of vehicles could be another potential source of noise exposures levels in schools in Oman's context including similar arid regions/countries across the globe. The overall aim of the study is to investigate the noise exposure levels among school children across schools in Muscat, Oman. More specifically, the objectives of the study are (1) to identify potential sources of noise levels in different microenvironments of the schools by employing objective and subjective assessments; (2) to estimate the health risk of noise exposures; and (3) to develop regression models to evaluate the effects of noise levels on perceived annoyance.

Research methodology

Study area

This current study was conducted in three public schools; (A) Kaab Bin Zeyd of Basic Education (school A), (B) Hail Al-Awamour Girls school (school B), and (C) Al-Fikr School (school C), all located in Muscat City which constitutes about ~30% of Oman's total population of 4.4 million people (NCSI 2021) (Fig. 1). Muscat is the most urbanized and densely populated city in Oman characterized by several landform features (i.e., residential areas, industrial estates, parks, shopping malls, local markets, universities). This wide spectrum of land use features and commercial activities is expected to generate excessive noise levels near the neighborhood of the three schools (i.e., schools A, B, and C). Thus, the schools were selected based on hypothesis that they may be affected

Fig. 1 A diagram showing the locations of the three elementary schools: Kaab Bin Zeyd of Basic Education (school A), Hail Al-Awamour Girls (school B), and Al-Fikr School (school C), in Muscat, Oman

by noise since they are located in the urbanized/business centers, which are the major sources of noise. Since Oman is both arid and semi-arid country, the mean annual ambient temperature conditions range from 16.7 to 40°C. The outdoor relative humidity levels are 15–90%, while the maximum precipitation levels reach only 16.7 mm which occurs only in winter season (November–February) (Amoatey et al. 2022).

Table 1 shows detailed land use characteristics and human-based activities surrounding the three schools. According to a previous study, the average community noise levels in the areas where these schools are located is 55.7–65.2 dBA; these noise levels are mainly due to aircraft, road traffic, and commercial activities (Al-Harthy et al. 2021).

Al-Mawaleh

This suburb is one of the most favored residential areas in Muscat due to its topographic mixture of low hills, and hollows descending gently to the closer proximity to the coastal zones. These unique topographical features allow the various buildings to be conspicuous from considerably far distant locations. The lands in Al-Mawaleh in the 1980s have been occupied by a high-income section of the Omani population for the construction of elegant, high-quality housing of innovative design. Among some of the prominent buildings are shopping malls and hotels which are located in closer proximity to school A.

Table 1 Summary description of the commercial and land-use features near the three schools

School	Location	Land use features
A	Al-Mawaleh	Airport, residential, commercial areas, newly built residential areas, shopping malls
B	AL-Hail	Commercial, residential areas, neighborhood airports, near highways, shopping malls
C	Al-Khoud	Commercial, sports, educational facilities, shopping malls, residential areas

AL-Hail and Al-Khoud

Due to the rapid increase in population in Muscat, and as a part of the effort of the Oman Ministry of Housing policies to curb the housing problem in the capital area, plans were drawn up for the development of commercial activities and residential housing in both AL-Hail and Al-Khoud. One of the main landmarks closer to these suburbs is international and domestic airports, a university, health facilities (i.e., hospitals, clinics), sports complexes (i.e., stadiums), and traditional markets. Thus, these diverse land use features and the vibrant economic activities in these areas serve as potential sources of outdoor noise levels to the nearby schools (schools B and C).

Acoustical measurements

Sound pressure level measurements were conducted every 5-min time interval, and A-weighted equivalent sound pressure levels (L_{Aeq}) were obtained from the three schools during the time when the school children were present. We measured the noise levels from morning (6:00 AM) to afternoon (1:00 PM) since both inside the school and the traffic noise are highly influenced by the dynamics of the different schedules throughout the day. These periods cover early morning, mid-morning, mid-day, and afternoon. In Oman, road traffic is a major source of community noise and normally peaks during these periods. The measures did not include evening times because most primary schools 2:45 PM. Measurements were taken continuously at the center of each school's compound and also at four (4) different locations of which three (P1, P2, and P4) of them were taken within the school and one outside (P3) the school compound (i.e., as the reference point) as shown by Fig. 2. The instrument used in this current study was a CR 703B meter fitted with an MK:224 capsule microphone (Cirrus Research plc, UK) and an IEC651- and IEC805-certified Type 1 precision sound level meter (Cirrus Research PLC 2002). To ascertain quality assurance, a noise meter was placed in an open space (to prevent direct obstruction of the students) at a height of 1.2 m during the measurements. Since the CR 703B meter was brand new, the manufacturer's default calibration value of 93.7dB was used throughout the measurement.

Survey study

Participants

The study recruited a total of 300 elementary school children (10–18 years old) to participate in the survey. All the students are living in Muscat (Oman) and were selected randomly across the classrooms (grades 9–12). Children who are below grade 9 were excluded from the survey due to the difficulties of providing appropriate responses as a result of their low cognitive performance levels. The schools near the
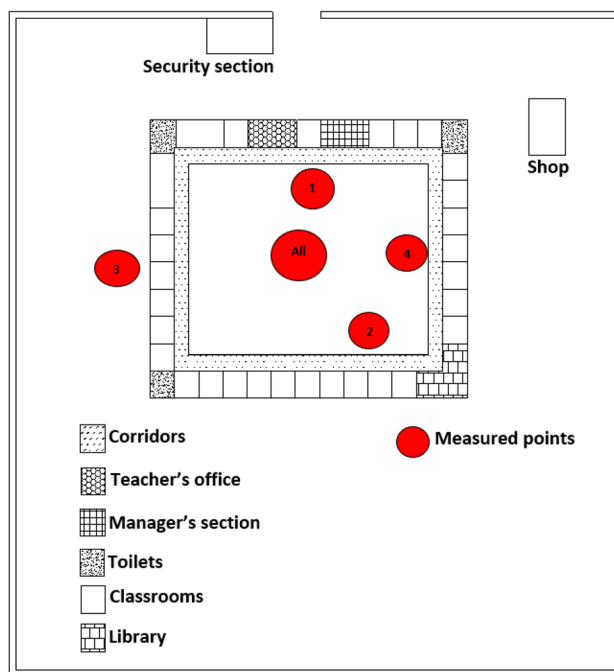
Fig. 2 Typical locations of noise measurements of the three schools

Table 2 Population characteristics of the school, students, and teachers

School	School's population	Number of students in a class	Number of teachers
A	1250	39–45	75
B	1326	35–42	75
C	687	15–25	47

study area are exposed to background ambient noise of > 65 dBA mainly due to aircraft and traffic noise (Al-harthy and Tamura 1999). The population characteristics of each of the three schools are shown in Table 2.

The study ensured a representative sample size of the respondents by calculating their sample size based on the total population size of each school (Table 2) according to Eq. 1.

$$n = \frac{Z\alpha^2 \times N\,(pq)}{e^2(N-1) + Z\alpha^2(pq)} \tag{1}$$

where n is the estimated sample size, N is the population of each school, Z is the percentile of normal distribution (1.96), α^2 is the confidence interval (0.95), e is the margin error (0.05), and pq is the standard deviation (0.5). Based on this equation and student population size shown in Table 2, the sample size of the school A (n =295), school B (n =299), and school C (n=247) were estimated.

Questionnaires

The study collected data from students across all three schools by using structured questionnaires. The questions were aimed at evaluating subjective noise exposures and annoyance in the school environments. This consists of allowing the students to answer questions about potential noise annoyance (AN) caused by traffic (TFAN), aircraft (ACAN), construction sites (CSAN), movement of tables/chairs (TCAN), chatting (CTAN), construction activities, air conditioning (AC) systems), and fans (AFAN). The degree of noise annoyance from these sources was determined using a 5-point Likert scale ("not at all," "heard/not annoyed," "neutral," "annoyed," and "extremely annoyed").

Data analysis

Descriptive statistics The study employed comprehensive descriptive statistical measures (percentage, mean, standard deviation, percentiles) to understand the effect of subjective and objective noise exposures among the students.

Regression analysis The relationship between explanatory (x) and response (y) variables which may be continuous or categorical are normally developed through logistic regression modeling, which predicts the probability of occurrence of an event (Okokon et al. 2015). In this study, the subjective noise annoyance responses (TFAN, ACAN, CSAN, TCAN, CTAN, and AFAN) through the survey were used as dependent categorical variables to determine the relationship with the measured noise levels (L_{Aeq}) as independent continuous variables. The calculated regression coefficient (R^2) at a 95% confidence interval (CI) where the significance level was taken as $p < 0.05$ through the linear regression modeling approach was used to ascertain the explained variance of each noise annoyance source. All analyses, including descriptive, data coding, and linear regression analysis, were performed using statistical package for social sciences

(SPSS) software version 23 (Chicago, IL, USA) and Microsoft Excel version 2016 (WA, USA).

Estimation of health risk

The potential health risks due to the noise pollution level exposures were calculated using exposure-response models (ERs) (Table 3) derived from meta-analysis review studies from several large cohort-based epidemiological studies (WHO 2011). For observed noise levels from each school (school A, B, and C), the percentage of highly annoyed (%HA), highly sleep disturbed (%HSD), and relative risks (RR) of ischemic heart diseases (IHD) at different levels of noise exposures (mean, minimum, maximum) were estimated. For RR_{IHD} and ERs, the lower and upper bounds of 1.08 95% CI (1.01–1.15) were obtained from Faulkner and Murphy (2022).

The attributable risk percentage (AR%) of IHD from these noise exposures was also determined using the following equation.

$$\%AR = \frac{RR - 1}{RR} \; x \; 100\% \tag{2}$$

This study did not estimate population attributable fraction (PAF) and the actual number/cases of students/population attributable to noise-induced IHD because of the lack of incidence rate data in Oman. Therefore, AR% is important to quantify the proportion of the exposed population/students that could be avoided from IHD if the noise levels were prevented. It should be noted that since all the observed noise levels were in the form of L_{Aeq}, they were converted to their equivalent L_{den} and L_{night} values by using the conversion scales developed by Brink et al. (2018) to help estimate the %HA, %HSD, and RR_{IHD}. These health outcomes were estimated because studies have shown that the younger ones are at risk of developing these health effects especially IHD (Fedchenko et al. 2017; Mandalenakis et al. 2016; Tiesler et al. 2013; Lee et al. 2021).

Table 3 Health risk-derived exposure-response (ERs) models

Health endpoint	Exposure-response models	Reference
%HA	$\%HA = 9.868 \; x \; 10^{-4} \; x(L_{den} - 42^{-3}) - 1.436 \; x \; 10^{-2} x \; (L_{den} - 42^{-2}) + 0.5118 \; x \; (L_{den} - 42)$	WHO (2011)
%HSD	$\%HSD = 20.8 - 1.05 \; x \; L_{night} + 0.01486 \; (L_{night})^2$	WHO (2011)
IHD	$RR_{IHD} = 1.08^{\left(L_{den-53}\right)/10}$	Selamat et al. (2021)

%HA, $L_{den} \geq 45 - \leq 75$ dB; %HSD, $L_{night} = 45–65$ dBA; OR-CVD, $L_{day} = 50–80$ dBA, and $RR_{IHD} = L_{den} \geq 53$ dB

Result and analysis

Evaluation of acoustics levels

The study has presented the descriptive statistics of the observed noise levels (L_{Aeq}) in Table 4 and its temporal variation levels during the daytime (6:00 AM–14:00 PM) in Fig. 3. These results were evaluated against the Omani noise standards (MREW 1994), WHO (1999) threshold limits, and European norms called EN 16798-1 (2019) developed specifically for indoor environmental quality (IEQ) factors as presented in Table 5. The results show that the average noise levels (L_{Aeq}) ± standard deviation (SD) for school A (70.03±8.21 dBA), school B (69.54±7.75 dBA), and school C (55.95± 5.67 dBA) have exceeded the classroom's recommended based on WHO (1999) and EN 16798-1 (2019) standards of 35 dBA and 30–34 dBA, respectively (Table 4). The average noise levels including the 50th (P_{50th}) to the 95th (P_{95th}) percentile noise values for schools A and B have all exceeded the WHO (1999)'s outdoor school playground standard of 55 dBA, including the Omani noise standards for residential environments (Table 5). The measured noise data of the schools did not obey normal distribution because they have negative

Table 4 Descriptive statistics of observed noise levels (L_{Aeq}) at the forecourts of the three school buildings/classrooms measured in dBA, Muscat, Oman

Schools	Mean ±SD	Min.	Max.	P_{50th}	P_{25th}	P_{75th}	P_{95th}	Skewness	Kurtosis
School A	70.03±8.21	48	88	70	66	75	81.4	−0.49	0.99
School B	69.54±7.75	48	80	71	68	75	78.2	−1.32	1.69
School C	55.95± 5.67	43	64	57	52	60	63.2	−0.56	−0.71

P percentile, *SD* standard deviation, *Min* minimum, *Max* maximum

Fig. 3 Temporal variations in measured noise levels (L_{Aeq}) within the school compounds: (**a**) Kaab Bin Zeyd of Basic Education (school A), (**b**) Hail Al-Awamour Girls school (school B), and (**c**) Al-Fikr School (school C)
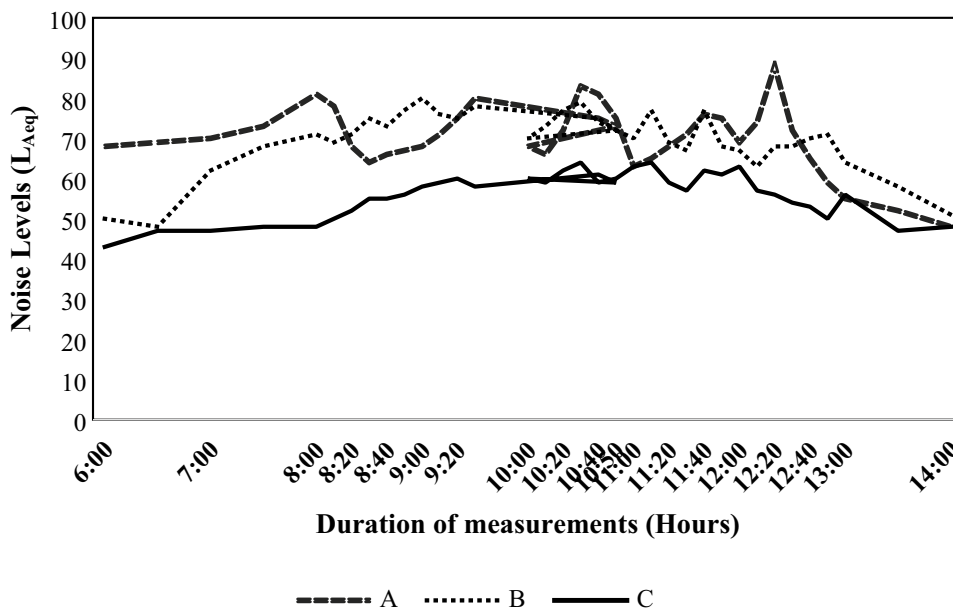
Table 5 Various local and international noise standards (dBA) for schools and residential environments

Location	Daytime (7:00 AM–6:00 PM)	Evening (6:00 PM–11:00 PM)	Night (11:00 PM–7:00 AM)	Source/regulation	Reference
Rural residential	60	55	50	Ministerial Decision 79/94,1994, Oman	MREW (1994)
Suburban residential	65	60	55		
School classrooms	35			Guidelines for Community Noise	WHO (1999)
School outdoor playground	55				
Classrooms	30–34			European Standard EN16798-1	EN 16798-1 (2019)

non-zero left skewness, and this may be caused by the small sample size of the noise data points.

Detailed analysis from Fig. 3 shows that from the hours between 6:00 AM and 14:00 PM, there have been similar patterns of sound pressure levels across all the schools except school C which observed slightly lower noise levels. The sharp increase and decrease in noise levels during 6:00 AM–8:00 AM and 12:00 PM–14:00 PM were caused by peak road traffic activities which have been recognized as an important source of urban noise levels in Oman according to a recent study conducted by Amoatey et al. (2020). Interestingly, the noise levels (Fig. 3) did not change significantly from 6:00 AM to 14:00 PM, because the locations (AL-Hail and Al-Khoud Al-Mawaleh) where these three schools are located all lie directly under a flight path and therefore are easily exposed to aircraft noise throughout the day (Al-Harthy et al. 2021).

As shown in Fig. 3, the noise levels measured inside (P1, P2, and P4) the school's compounds were compared with another location (P3) outside the school. This is to help determine the effect of the school's internal activities (shouting of the students, noise caused by teaching, walking/running, ringing of a bell, etc.) on noise levels across the three schools. Figure 4 shows spatiotemporal variations in noise levels across these four specific locations of the three schools (schools A, B, and C). The results show the lack of specific trends or significant changes in interior (P1, P2, and P4) noise levels and the outside noise (P3) during the entire measurement duration (6:00 AM–13:00 PM). An example of such an inconsistent trend in noise levels of the four locations was found during 8:00 AM, 10:00 AM, and 13:00. This shows that the observed noise levels were propagated from different sources (within the school, road traffic, aircraft, and commercial activities).

Subjective noise annoyance

A total of 300 students participated in the noise annoyance survey, and this comprised 41% males, 32% males, and 27% females from schools A, B, and C, respectively, as indicated in Table 6. The response rate of this survey study was 41% (school A), 32% (school B), and 33% (school C)

Fig. 4 Observed noise levels (L_{Aeq}) at various points (P1, P2, P3, and P4) during typical school hours (6:00 AM to 1:00 PM) for (**a**) Kaab Bin Zeyd of Basic Education (school A), (**b**) Hail Al-Awamour Girls school (school B), and (**c**) Al-Fikr school (school C)
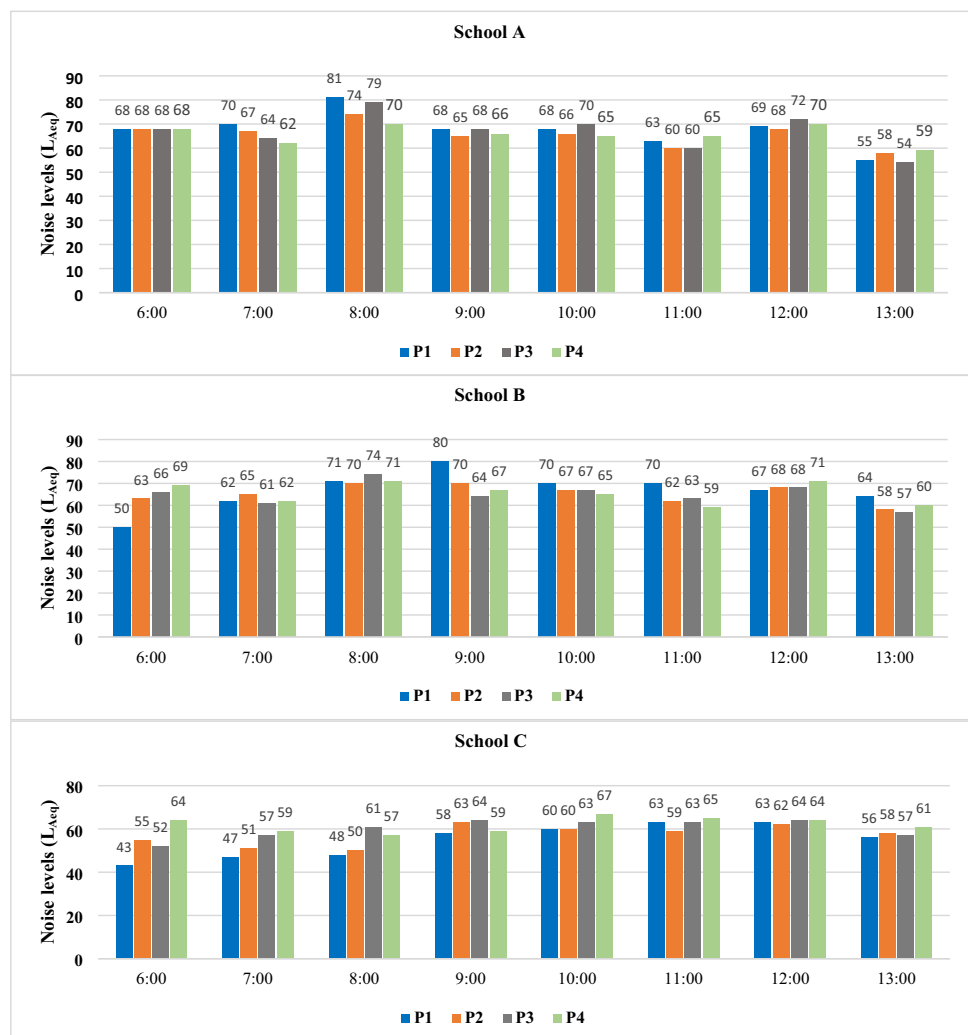
when compared to the calculated sample size. Table 6 shows the results of perceived noise annoyance levels of the students in each school based on different noise exposure sources. Here, students were asked to respond to levels of annoyance caused by noise from traffic (TFAN), aircraft (ACAN), construction sites (CSAN), noise caused by movement of tables/chairs (TCAN), and AC and fans (AFAN) (Table 6).

Most of the responders from schools A (30.9%), B (33.3%), and C (63%) consider noise produced from traffic as extremely annoyed compared to aircraft of 15.4%, 11.5%, and 27.2%, respectively. In the case of noise pollution caused by construction activities, the majority of the students from schools A (24.4%), B (31.3%), and C (37%) have described the level of annoyance as not at all, a similar larger proportion of them have also described the annoyance this same source as either heard but not annoyed or neutral (Table 6). There seem to be divergent views with regards to the annoyance caused by chatting among

the students as extremely annoyed versus not at all was reported to be 30.1% vs 25.2% for school A, 32.3% vs 31.3% for school B, and 49.4% vs 30.9% for school C. These contrasting results show that the degree of noise annoyance is dependent of individual's state of mind and sensitivity. Thus, what seems highly annoyed could be deemed low annoyance by another person (Benz et al. 2021). With regards to noise annoyance due to AC and fan operations, the majority of the students have described it as not at all, with very few people reporting it as extremely annoyed, especially in only schools A (11.4%) and B (7.3%) with no response from school C (Table 6). This reported low annoyance occurred because, in most Omani schools, split AC is the most common AC system used in almost all the classrooms and may produce minimal noise (Zurigat et al. 2003). In overall, this subjective analysis has shown that traffic, aircraft, and chatting are the most important source of noise annoyance to the schools.

Table 6 Distribution of perceived noise annoyance by the students based on different noise sources expressed as frequencies (*n*) and percentages (%) across the three schools, Muscat, Oman

Annoyance caused by	Response	School A (N=123 males)		School B (N=96 males)		School C (N=81)	
		N	%	N	%	N	%
Traffic (TFAN)	Not at all	22	17.9	8	8.3	-	-
	Heard but not annoyed	17	13.8	17	17.7	-	-
	Neutral	13	10.6	13	13.5	4	4.9
	Annoyed	33	26.8	26	27.1	26	32.1
	Extremely annoyed	38	30.9	32	33.3	51	63
Aircraft (ACAN)	Not at all	22	17.9	11	11.5	19	23.5
	Heard but not annoyed	23	18.7	23	24	23	28.4
	Neutral	31	25.2	31	32.3	17	21
	Annoyed	28	22.8	20	20.8	-	-
	Extremely annoyed	19	15.4	11	11.5	22	27.2
Construction sites (CSAN)	Not at all	30	24.4	30	31.3	30	37
	Heard but not annoyed	26	21.1	26	27.1	45	55.6
	Neutral	26	21.1	22	22.9	6	7.4
	Annoyed	27	22	11	11.5	-	-
	Extremely annoyed	14	11.4	7	7.3	-	-
Movement of tables/chairs (TCAN)	Not at all	25	20.3	25	26.3	44	54.3
	Heard but not annoyed	13	10.6	11	11.6	11	13.6
	Neutral	16	13	16	16.8	16	19.8
	Annoyed	35	28.5	18	18.9	10	12.3
	Extremely annoyed	34	27.6	25	26.3	-	-
Chatting (CTAN)	Not at all	31	25.2	30	31.3	25	30.9
	Heard but not annoyed	16	13	16	16.7	16	19.8
	Neutral	19	15.4	19	19.8	-	-
	Annoyed	20	16.3	-	-	-	-
	Extremely annoyed	37	30.1	31	32.3	40	49.4
AC and fans (AFAN)	Not at all	30	24.4	30	31.3	30	37
	Heard but not annoyed	26	21.1	26	27.1	45	55.6
	Neutral	26	21.1	22	22.9	6	7.4
	Annoyed	27	22	11	11.5	-	-
	Extremely annoyed	14	11.4	7	7.3	-	-

Modeling of annoyance

This aspect of the study has applied linear regression modeling to explore the relationship between annoyance sources (TFAN, ACAN, CSAN, TCAN, AFAN) as dependent factors and the observed noise levels (L_{Aeq}) as an independent variable. The results of the individual annoyance source indicating regression equations, Pearson's correlations (*r*), and R^2 values are shown in Table 7. As presented in Table 7, the observed noise levels (L_{Aeq}) correlated well with TFAN from schools A and C and ACAN from B and explained most of their chances because of their higher R^2 values. L_{Aeq} accounted for 48.1%, and 13.2% changes in perceived traffic annoyance (TFAN) for schools A (R^2 =0.481) and C (R^2 =0.132), respectively, and 17.8% changes in perceived aircraft annoyance (ACAN) in school B (R^2 =0.178). These changes in the proportion of the dependent variables (TFAN and ACAN) in all the three schools were significant ($p < 0.05$) at 95% CI. With regards to other annoyance sources, L_{Aeq} explained only 7.4% for both CSAN and AFAN in school A, 5.4% in CTAN in school B, and less than 1% (R^2 =0.008) of CSAN in school C. These low R^2 values of other annoyance sources compared to TFAN and ACAN clearly show that L_{Aeq} explained most of the changes

of the latter (i.e., TFAN and ACAN). Thus, the R^2 is an indication of the proportion of the variations in the dependent variable explained by the linear model (Faiyetole and Sivowaku 2021; Loftus 2022).

Health risk

As shown in Table 8, this study calculated the percentage of highly annoyed (%HA), highly sleep disturbed (%HSD), and relative risks (RR$_{IHD}$) of ischemic heart diseases (IHD) at different noise (L_{Aeq}) exposure levels (mean, minimum, maximum) across the three schools. Also, the attributable risk percentage (AR%) of IHD was estimated (Table 9).

The results indicated that the mean noise exposure accounted for 15.2%, 14.95%, and 8.18% of %HA in schools A, B, and C, respectively. The estimated %HSD based on mean noise levels were almost the same in schools A (15.62%) and B (15.19%) but far higher when compared to school C (6.01%). The mean noise exposure levels according to the relative risk (RR) dose-response calculations were found to be associated with the risk of developing IHD in school A (RR= 1.172, 95% CI: 1.020–1.334), school B (RR=1.167, 95% CI: 1.020–1.325), and school C (RR=1.051, 95% CI: 1.006–1.095) (Table 8).

Table 7 Regression analysis indicating the relationship between observed noise levels as an independent variable and different sources of annoyance perceptions as a dependent variable for school A

School A Independent variables	Dependent variables	Regression model	Correlation (*r*)	*p*-value	Standard error	R^2
Noise (L_{Aeq})	TFAN	TFAN = 0.029*L_{Aeq} + 2.816	0.694	0.00	0.253	0.481
	ACAN	ACAN = −0.021*L_{Aeq} + 2.857	0.342	0.038	0.474	0.117
	CSAN	CSAN = 0.015*L_{Aeq} + 0.628	0.272	0.103	0.452	0.074
	TCAN	TCAN = −0.024* L_{Aeq} + 3.032	0.366	0.026	0.508	0.134
	CTAN	CTAN = 0.056*L_{Aeq} -0.0224	0.306	0.066	1.454	0.094
	AFAN	AFAN = 0.015*L_{Aeq} + 0.628	0.272	0.103	0.452	0.074
School B Independent variables	Dependent variables	Regression model	Correlation (*r*)	*p*-value	Standard error	R^2
Noise (L_{Aeq})	TFAN	TFAN = 0.016*L_{Aeq} + 3.781	0.348	0.035	0.329	0.121
	ACAN	ACAN = 0.089*L_{Aeq} − 3.613	0.422	0.009	1.508	0.178
	CSAN	CSAN = 0.018*L_{Aeq} + 0.419	0.309	0.063	0.447	0.095
	TCAN	TCAN = −0.028* L_{Aeq} + 3.313	0.406	0.013	0.4989	0.165
	CTAN	CTAN = 0.045*L_{Aeq} + 0.554	0.233	0.165	1.486	0.054
	AFAN	AFAN = 0.018*L_{Aeq} + 0.419	0.309	0.063	0.447	0.095
School C Independent variables	Dependent variables	Regression model	Correlation (*r*)	*p*-value	Standard Error	R^2
Noise (L_{Aeq})	TFAN	TFAN = 0.022*L_{Aeq} + 3.622	0.364	0.027	0.327	0.132
	ACAN	ACAN = 0.070*L_{Aeq} − 1.328	0.242	0.148	1.614	0.059
	CSAN	CSAN = 0.007*L_{Aeq} + 1.297	0.089	0.601	0.468	0.008
	TCAN	TCAN = −0.013* L_{Aeq} + 2.09	0.139	0.411	0.540	0.019
	CTAN	CTAN = 0.045*L_{Aeq} + 0.554	0.145	0.392	1.512	0.021
	AFAN	AFAN = 0.070*L_{Aeq} − 1.328	0.242	0.148	1.614	0.059

Significant at $p < 0.05$

Table 8 Percentage of highly annoyed (%HA), highly sleep disturbed (%HSD), and relative risks (RR_{IHD}) of ischemic heart diseases (IHD) at 95% CI for different levels of noise exposures statistical metrics (mean, minimum, maximum) for the three schools

Health Endpoint	School A			School B			School C		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum
%HA	15.203	4.223	24.1603	14.95	4.223	20.172	8.185	1.731	12.198
%HSD	15.626	3.195	36.446	15.192	3.195	25.99	6.018	2.382	10.79
RR_{IHD}	1.172(1.020–1.334)	0.989 (0.99–0.98)	1.345 (1.039–1.715)	1.167 (1.020–1.325)	0.989 (0.998–0.981)	1.265 (1.031–1.533)	1.051 (1.006–1.095)	0.951 (0.993–0.914)	1.118 (1.014–1.226)

Table 9 Attributable risk percentage (AR%) of IHD from the noise exposures based on mean, minimum, and maximum noise exposure levels for the three schools at 95% confidence intervals (CI)

Schools	AR% of IHD, 95% CI		
	Mean	Minimum	Maximum
A	14.675 (2.028–25.037)	−1.112(−1.010 to −2.040)	25.650 (3.753–41.690)
B	14.310 (1.960–24.528)	−1.112 (−0.200 to −1.936)	20.948 (3.006–34.768)
C	4.852 (0.596–8.742)	−5.152 (−0.704 to −9.409)	10.554 (1.381–18.433)

As presented in Table 9, the attributable risk percentage (AR%) of noise levels at the three schools was estimated to determine the percentage of IHD that could be avoided if the current noise levels were mitigated. It was found that eliminating the mean noise exposure could prevent 14.67%, 14.31%, and 4.85% of the population from IHD in school A (AR% =14.675, 95% CI: 2.028–25.037), school B (AR% =14.310, 95% CI: 1.960–24.528), and school C (AR% = 4.852, 95% CI: 0.596–8.742), respectively. Overall, the results of these health risk estimates were highly dependent on the dose-response model used, and thus, it will be complicated to compare the results among the three schools.

Discussions

The measurements that were conducted on noise levels within the three main schools: Kaab Bin Zeyd of Basic Education (school A), Hail Al-Awamour Girls school (school B), and Al-Fikr School (school C) in Muscat, Oman, were in the average of 70.03 dBA, 69.54 dBA, 55.95 dBA, respectively. These noise levels were higher than the recommended acoustic comfort standards which have been established for typical classrooms (EN 16798-1 2019) and school's outdoor playground (WHO 1999), clearly indicating the noise pollution levels which the schools and residential populations living closer proximity to these urban areas are exposed. These reported high noise levels occurred because most of the schools (especially schools A and B) are located very close to urban commercial areas with several road networks serving as potential sources of traffic noise. In addition, the localization of these schools to the major international airport (Muscat International Airport) in the country has been identified as a major source of aircraft noise to the schools including the nearby residential areas according to Al-Harthy

et al. (2021). Interestingly, school C (Fig. 1) was located a far distance away from the airport (thus, is not directly under the flight path), and the major commercial centers of Muscat had lower noise levels compared to other schools. This confirms that these schools were affected mainly by outdoor community noise sources. Based on the results of the study, ambient noise traffic and aircraft mitigations strategies should be developed considering its potential public health risk to the exposed population. Apart from annoyance and sleepless conditions, among some of the short-term health effects of noise are depression and anxiety (Hao et al. 2022). A meta-analysis study based on data from 106 schools located closer to airport areas with noise levels ranging from 52 to 61.2 dBA has shown that school children have suffered from poor reading and increased hyperactivity (Clark et al. 2021). A study in Qatar showed that vehicular traffic density was associated with noise generation levels in multiple school environments. The findings showed that the observed noise exposure levels within the schools which exceeded the WHO limits as well as Qatar's local standards of 55 dBA were positively correlated with traffic volumes (Shaaban and Abouzaid 2021). This clearly highlights that noise is a major environmental factor that can cause annoyance and disrupt learning in schools and also cause a burden of diseases to the larger section of the population if effective mitigation measures are not implemented.

The results of the survey in this study have shown that traffic, aircraft, and human-induced noise sources such as chatting among the students are the most important causes of noise annoyance in schools. This was supported by regression models where the observed noise levels (L_{Aeq}) explained most of the changes in perceived traffic and aircraft annoyance levels among the students compared to other annoyance sources (e.g., annoyance caused by AC/fans, construction activities).

A similar study in Egypt has complained that students' own activities (playing, walking, talking) and teaching

activities (61%), road traffic (41%), and nearby classrooms (53%) are the major sources of noise in schools. It was concluded that the high noise levels force teachers to raise their voices to make lessons audible to the students (Phadke et al. 2019). These findings from the literature were consistent with subjective analysis results found under this where the quiet majority of the students attributed road traffic, aircraft, and internal noise (chatting/shouting/walking of students) as factors causing noise annoyance in their schools.

The estimated percentage of highly annoyed (%HA), highly sleep disturbed (%HSD), and relative risks (RR$_{IHD}$) of ischemic heart diseases (IHD) among the schools especially in schools A and C indicates that these health risks could be avoided if current noise levels could be mitigated to the acceptable limits. Though the study focused these health risk estimates on students, it should be noted that people who have lived within the commercial and residential neighborhoods with very high long-term noise exposure levels may experience more serious chronic health effects. To address any potential adverse health impacts, it is important that passive short-term and long-term noise mitigations strategies are developed to reduce exposures. Such immediate intervention approaches are by minimizing school children's exposure to traffic/aircraft noise by reducing the duration of time these students spend in outdoor environments, such as school playgrounds. Also, school closing before peak traffic rush hours and improving online learning could also contribute to reducing noise exposure. Another intervention approaches through the application of white noise has been found to have improved the sleep quality among boarding students, where Pittsburgh Sleep Quality Index (PSQI) decreased from 8.5 to 6.5 (Umbas et al. 2021).

In an urbanized arid city of Oman where natural vegetation is very limited, creating barriers between school compounds and outdoor noise sources (e.g., roads) through the planting of trees could be one of the cost-benefit measures for improving acoustic situations within schools. Growing green vegetation on the building façade of schools could also be an effective means of reducing noise pollution (Van Renterghem and Botteldooren 2009). These measures can also reduce the infiltration of air pollutants (i.e., particulate matter, ozone) into school buildings and also improve indoor thermal comfort conditions, indicating that noise mitigation has several environmental and ecosystem human health benefits.

Conclusions

This study determined the variations in noise exposure levels across three schools: Kaab Bin Zeyd of Basic Education (school A), Hail Al-Awamour Girls school (school B), and Al-Fikr School (school C) in Muscat (Oman) by utilizing objective and subjective assessment approach. A survey study involving 300 students was conducted to evaluate the potential sources of noise annoyance within the schools. Regression modeling is used to determine how the observed noise levels accounted for changes in variations in each perceived noise annoyance source. The health risk estimates, including highly annoyed (%HA), highly sleep disturbed (%HSD), and relative risks (RR$_{IHD}$) of ischemic heart diseases (IHD), were also determined using dose-response exposure models. The following major conclusions were drawn from this study:

- The average noise levels (L_{Aeq}) of school A (70.03±8.21 dBA), school B (69.54±7.75 dBA), and school C (55.95±5.67 dBA) have exceeded the classroom's standard of 35 dBA by WHO (1999) and 30–34 dBA by EN 16798-1 (2019).

- Schools A and B which were in closer proximity to major airports, under flight paths, and commercial areas of Muscat, experienced high noise levels exceeding WHO's ambient threshold limits of 55 by 21.4% and 20.9%, respectively, compared to school C (1.69%) which was further away from these sources. This highlights the contribution of outdoor community noise sources to sensitive environments such as schools and hospitals.

- There were no differences in noise levels at points located inside the school compound and points situated outside the school, indicating that school/student activities (walking, teaching, playing, etc.) might have equally contributed to noise pollution.

- Students from schools A (30.9%), B (33.3%), and C (63%) reported noise produced from traffic as extremely annoyed compared to aircraft of 15.4%, 11.5%, and 27.2%, respectively. For noise annoyance due to AC and fans operations, the majority of the students have described it as not at all, with very few people reporting it as extremely annoyed, especially in only schools A (11.4%) and B (7.3%) with no report from school C.

- Regression modeling showed that L_{Aeq} explained most of the changes in variations of perceived traffic annoyance by 48.1%, 12.1%, and 13.2% for schools A (R^2 =0.481), B (R^2 =0.121), and C (R^2 =0.132), respectively, followed by perceived aircraft annoyance.

- The health risk assessment results show that %HA was high in school A (15.2%), school B (14.95%), and then school C (8.18%). The estimated %HSD based on mean noise levels were almost the same in school A (15.62%) and B (15.19%) but far higher when compared to school C (6.01%). However, there was an association between the mean noise exposure levels and the risk of developing IHD in school A (RR= 1.172, 95% CI: 1.020–1.334), school B (RR=1.167, 95% CI: 1.020–1.325), and school C (RR=1.051, 95% CI: 1.006–1.095).

- Eliminating the mean noise pollution levels could prevent the populations in school A (AR% =14.675, 95%

CI: 2.028–25.037), school B (AR% =14.310, 95% CI: 1.960–24.528), and school C (AR% = 4.852, 95% CI: 0.596–8.742) from developing IHD.

- Future studies should use source-apportionment models to help account for the contribution of the major noise sources (traffic, aircraft, industries) in schools, including other sensitive environments such as hospitals.
- This study relied on dose-response models developed from European population. It is important for improve the accuracy of the current health risk estimates by using locally (Omani) dose-response models for future noise-related disease outcomes and annoyance.

Data Availability Not applicable.

Declarations

Ethical approval Not applicable.

Consent to participate The respondents who participated the field survey first received an option of "agree" or "decline" to participate in the filling of the questionnaires. Thus, consent has been sought for those who accepted to participate in this study.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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