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ARTICLE

Residential noise from nearby oil and gas well construction and drilling

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Abstract

Public concern about oil and gas (O&G) operations in residential areas is substantial. Noise from construction and drilling related to O&G operations may be greater than other phases of O&G operations; yet the impacts of audible and low-frequency noise during these operations are not extensively explored nor the effects on health well understood. This study documents the noise levels at a multi-well O&G well pad during construction and drilling in a residential area in Colorado. A-weighted (dBA) and C-weighted (dBC) noise measurements were collected at four locations during development over a 3-month period. The maximum 1-min equivalent continuous sound levels over a 1-month period were 60.2 dBA and 80.0 dBC. Overall, 41.1% of daytime and 23.6% of nighttime dBA 1-min equivalent continuous noise measurements were found to exceed 50 dBA, and 97.5% of daytime and 98.3% of nighttime measurements were found to exceed 60 dBC. Noise levels exceeding 50 dBA or 60 dBC may cause annoyance and be detrimental to health; thus, these noise levels have the potential to impact health and noise levels and associated health effects warrant further investigation.

Keywords Oil and gas operations · Drilling · Construction · Noise · Low-frequency noise · Sound · Health

Introduction

Oil and gas (O&G) development and operations has increasingly occurred near populated areas and has raised public health concerns [1–4]. Research near O&G sites to date has largely focused on chemical emissions from these sites or the potential risks and health effects in nearby populations [5–11]. While noise from O&G operations has been raised as a potential public health concern for communities near these sites [1, 4, 12, 13], the levels of audible and low-frequency noise during O&G operations in residential areas are not well documented in the peer-reviewed scientific literature.

Noise is generated during all stages of the O&G well development and operation life cycle (i.e., exploration, well development, production, and site decommissioning) and can come from numerous sources such as trucks, heavy equipment, generators, compressors, and gas flaring [1]. For example, in Garfield County, Colorado, audible noise levels at a distance of 1000 ft (304.8 m) were reported to be 69 A-weighted decibels (dBA) during drilling operations [12]. Low-frequency noise is also present during O&G operations [14, 15]. Low-frequency noise is measured using C-weighted decibels (dBC) and can measure audible noise in addition to the perception of pressure [16]. Boyle et al. (2017) found the nighttime C-weighted noise levels to be more than 15 dB greater than A-weighted noise levels for some homes near a compressor station, indicating increased potential exposure to low-frequency noise. Radtke et al. (2017) reported a mean noise level of 80 (SD = 2.1) dBC during hydraulic fracturing with operations running at full capacity without a sound wall. At present, we lack an understanding of the impacts of low-frequency noise levels from O&G operations in urban areas or the effect of incorporating best management practices, which can include noise mitigation by adding sound controls to equipment, constructing a sound wall, and using noise absorbing material [4]. Low-frequency noise and the impacts of mitigation approaches have been evaluated at O&G operations and this previous research has shown that the levels based on testing at isolated areas without outside sound interference and the presence of a sound wall would

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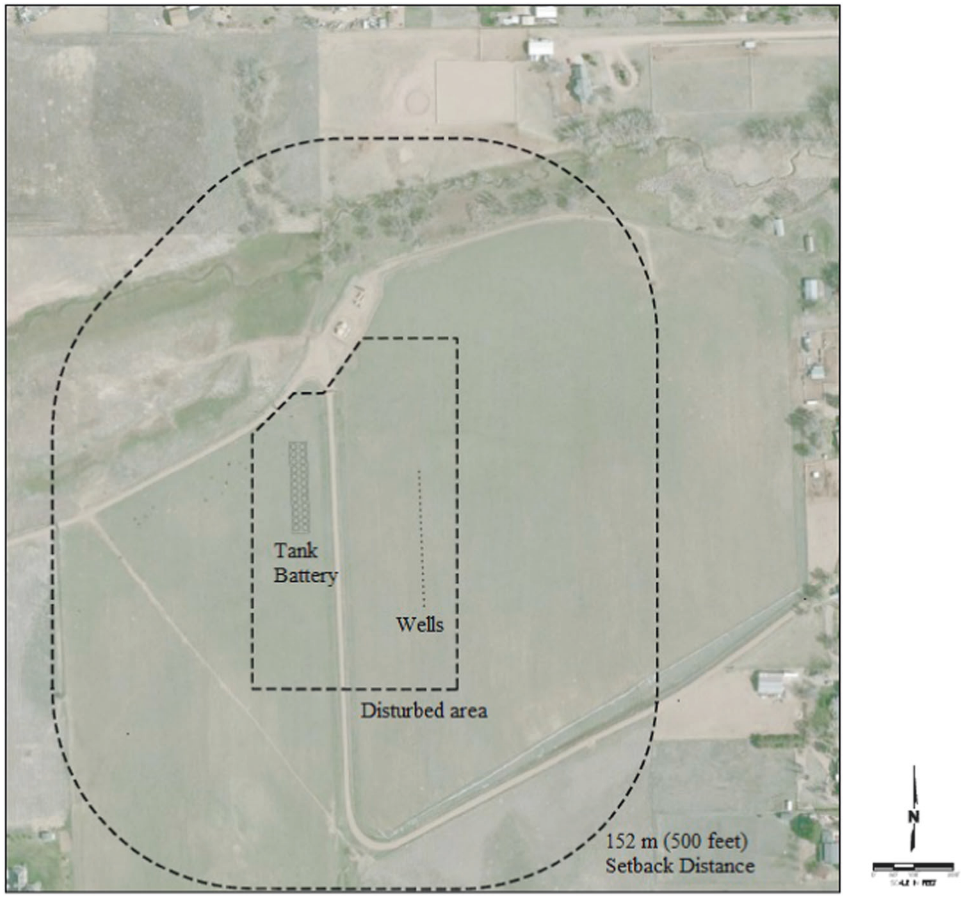

Fig. 1 : Map of location. The map highlights the proposed location of the wells, tank battery, area disturbed from well pad development, and the regulatory setback buffer

be of concern if these operations were near homes [14]. Still, the levels and public health implications of audible and low-frequency noise levels from the various stages occurring during O&G operations are not well understood. Public complaints and health concerns from increased noise are a common issue at many O&G operation sites. For example, between 35 and 55% of survey respondents in the Marcellus Shale region reported noise pollution as a stressor from O&G operations and development [17]. In the State of Colorado, noise was reported to be responsible for 10.4% of the complaints sent by the public to the Colorado Oil and Gas Conservation Commission from November 2001 to June 2013 (COGCC) [18]. More recently, 123 out of 330 (37.3%) complaints received by the COGCC in 2015 were related to noise [19], demonstrating that public concern from the noise related to O&G operations is likely increasing.

In Colorado, the COGCC regulates noise from O&G operations [20]. COGCC Rule 802 states that the maximum permissible noise level is not to exceed 55 dBA during daytime hours (7 am to 7 pm) and 50 dBA during nighttime hours (7 pm to 7 am) at 350 ft (106.7 m) from the noise source in residential, agricultural, and rural zones. COGCC Rule 802.b(1) increases the maximum permissible noise levels to 80 or 70 dBA during daytime and 75 or 65 dBA during nighttime, varying based on the distance of the nearest building unit, "for pipeline or gas facility installation or maintenance, or the use of a drilling rig, completion rig, workover rig, or stimulation." Furthermore, during the daytime, the permitted A-weighted noise levels may be increased by 10 dB for up to 15 min in a 1-h period. For low-frequency noise, levels greater than 65 dBC require the operator to send a low-frequency noise impact analysis to the COGCC that identifies any reasonable noise control measures.

While there is relatively little research on residential exposures and health concerns due to noise at O&G sites, several studies have documented health effects from noise exposure from other sources, such as traffic, wind turbines, airports, and railways. These studies indicate that noise starting at in the 50–55 dbA range can cause annoyance, nausea, and headaches, disturb sleep, impair cognitive performance, and is associated with an increased incidence of arterial hypertension, arterial stiffness, myocardial infarction, and stroke [16, 21–25]. For example, exposure to railway noise exceeding 50 dBA is related to an increased risk of cardiovascular diseases [26]; traffic noise in the range of 45–75 dBA was positively associated with hypertension per 5 dBA increase [27]; and the relative risk of coronary heart disease increased with every 10 dBA increase in weighted day–night traffic noise levels between 52 and 77 dBA [28]. Exposure to low-frequency noise may cause issues such as stress, fatigue, nausea, headache, and sleep disturbance [24, 25, 29]. For low-frequency noise levels, 60 dBC is recommended (65 dBC maximum) for continuous operations in residential areas to minimize health concerns and issues [16]. Furthermore, if the fluctuation in dBC levels are substantial (±5 dBC), the low-frequency noise criteria should be reduced by 5 dBC, to 55 dBC, to minimize health impacts from low-frequency noise [16].

This study measured and evaluated A-weighted and C-weighted noise levels during construction and well drilling at a 22 O&G well pad in a residential area of Greeley, Colorado USA. To the best of our knowledge, this is the first study evaluating residential audible and low-frequency noise levels during petroleum drilling activities; drilling is often considered to have greater noise levels than other O&G operations, such as production [4]. Our objective was to compare measured noise levels around a multi-well pad to regulatory levels and noise levels that are documented in the literature to have potential for detrimental effects such as annoyance, sleep disturbance, headaches, nausea, or increased cardiovascular risk.

Materials and methods

Site information

We conducted noise monitoring at four residences located between 320 m (1049.9 ft) and 550 m (1804.5 ft) from the center of a large multi-well O&G site (Fig. 1) between February and April 2017. The site is permitted for 22 wells, 22 oil tanks, 22 separators, 4 vapor recovery units, 2 water tanks, 3 modular large volume tanks, and 2 lease automatic custody transfer units [30]. The well pad site, with the expected location of the wells, tank battery, area of disturbance from well pad construction, and 152.4 m (500 ft) setback buffer, is shown in Fig. 1 [30]. [1]The dates when the drilling commenced for the location and wells at the site ranged between 29 November 2016 and 23 February 2017; therefore, our sampling period was during a period of well pad construction and drilling activity. The operations at this site used sound mitigation best management practices including the use of a sound wall that is 32 ft in height surrounding the site and use of electronic or modern low-noise equipment [30].

[1] The exact location of noise sampling is not shown to protect the identity of the property owners.

Sound level meter measurements

Noise monitoring was conducted at four residential locations: one each to the south, east, northeast, and northwest of the site. Landowner permission was obtained to access the sites. The locations were confirmed at each subsequent date using a Garmin (Schaffhausen, Switzerland) eTrex VentureCx handheld global positioning system (GPS). The SLM measurements were conducted to exclude other noise sources to evaluate the noise specifically from the O&G operations, rather than from other industrial or community sources, such as the trucking activity from this site. Therefore, when using the SLM, if nearby intermittent community or city noises (e.g., barking dogs, lawn mowers, vehicles/trucks) were encountered during sampling, the researchers waited for those intermittent noises to stop before proceeding with their measurements.

A-weighted and C-weighted noise levels were recorded using a Larson Davis Sound Expert LxT1-SE-FF Sound Level Meter (SLM; Depew, New York) with a PRMLXT1L preamplifier, 377B02 microphone, and a WS001 3.5-inch diameter windscreen. The SLM was calibrated by the manufacturer prior to data collection and re-calibrated before and after each sampling date using a Larson Davis CAL200 set at 114 dBA. The SLM was mounted on a portable tripod and raised to approximately 1.4 m (4.6 ft) off the ground during measurement. Three 5-s measurements of the sound pressure level were taken at each location and the arithmetic average of these three measurements was used. The SLM measurements were collected at the same time as the continuous noise measurement maintenance visits. Noise measurements with a corresponding hourly or gust wind speeds of less than 16.1 kilometers per hour (10 mph) were included in the final data set; all other data were omitted [14]. Wind speed data were obtained from a nearby weather station from wunderground.com and noise measurements were matched with the nearest documented wind speed measurement. A total of 42 dBA and 40 dBC measurements were included in the 5 s SLM results.

Continuous noise measurements

Continuous noise measurements were conducted at the same four locations surrounding the well pad during the same period and location as the SLM measurements. Data were collected for approximately 1 month at the South and East locations from 27 January 2017 to 24 February 2017 and for 2 months at the Northeast and Northwest sites from 24 February 2017 to 24 April 2017.

Noise measurements were collected with Larson Davis (Depew, NY) Spark 703+ and Spark 706RC dosimeters each with a detachable 10.6 mm microphone/preamp with integrated 1 m cable (MPR001) and a windscreen. Noise

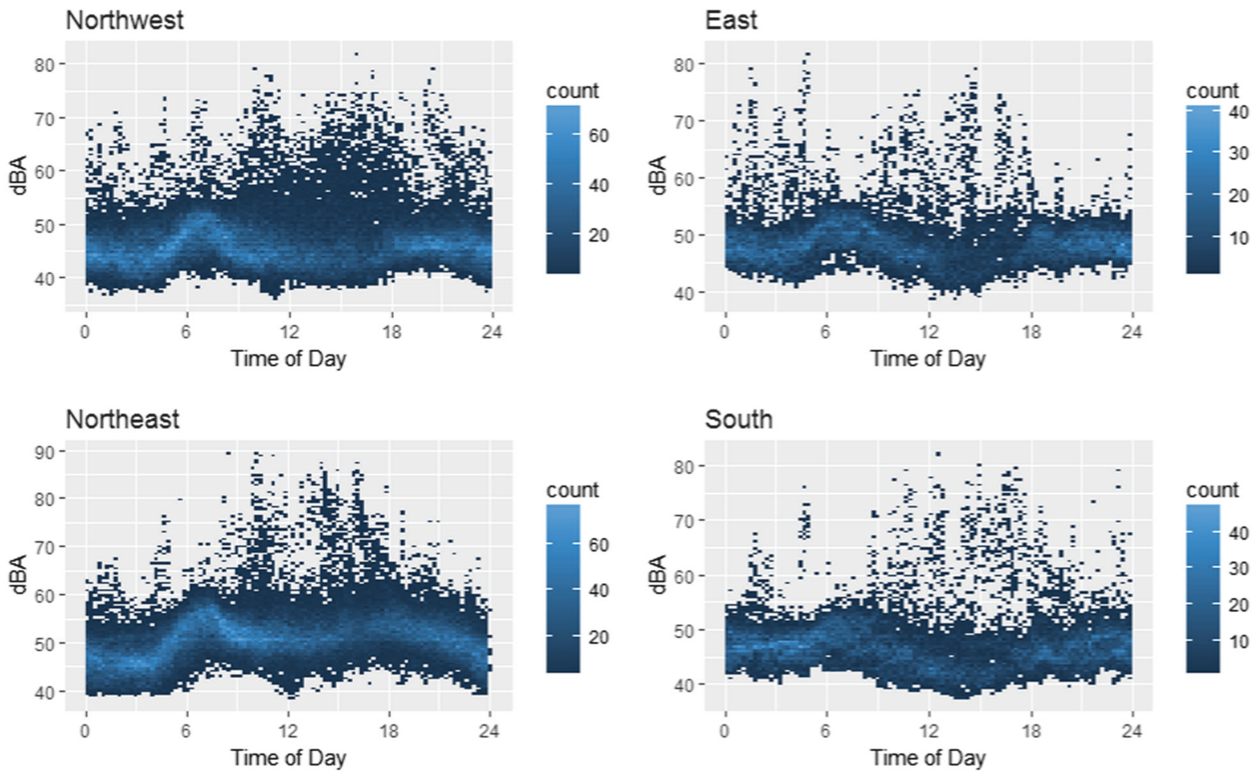

Fig. 2 Heat density of 1-min noise results for A-weighted noise data by time of day. A lighter shade is a greater count of values

measurements were recorded as the 1-min equivalent continuous noise level. The dosimeters were calibrated prior to deployment and were factory calibrated in November 2016. The dosimeter microphones were mounted 1.3 m from the ground and oriented towards the well pad site. Noise was not measured for short periods (30 min to an hour) during data downloads and equipment maintenance, which occurred every three to four days. A total of 244,584 dBA and 250,158 dBC 1-min noise measurements were recorded. Similar to the 5 s measurements, noise measurement with a corresponding average or gust speed greater than 16.1 kilometers per hour were omitted from our data analysis. As a result, 173,521 dBA (70.9% of the total) and 176,969 dBC (70.7% of the total) measurements were included in the analysis.

To consider the difference in day and night noise levels, measurements were divided at the benchmarks described in the COGCC regulations: daytime levels were considered from 7 am to 7 pm and nighttime levels were those between 7 pm and 7 am [20]. The noise levels at the various times in Figs. 2 and 3 were calculated using R v3.2.2 [31] and the ggplot2 package [32].

Comparison to health endpoints and COGCC rules

We used a 50 dBA threshold as a benchmark for all noise measurements regardless of time of day, which is the low end of noise levels that may cause adverse health effects, such as increased risk of cardiovascular diseases and hypertension [26, 27]. For low-frequency noise we used the 60 dBC benchmark for operations with continuous daytime and nighttime noise recommended to minimize known health impacts, such as nausea and headaches [16]. As we do not know the exact equipment operating at any given moment on the site, we also used the COGCC Rule 802 residential guidelines, which specify a maximum permissible level of 55 dBA during daytime and 50 dBA at night [20]. A noise level less than or equal to 55 dBA is also the US Environmental Protection Agency outdoor level recommended to prevent annoyance and activity disruption [33]. For low-frequency noise, we used the C-weighted noise level that would initiate a noise investigation, which is 65 dBC [20].

Statistics

We calculated the A-weighted and C-weighted average equivalent continuous sound level for the time period of interest ($L_{\mathrm{eq}\ T}$) using the following:

$$L_{\mathrm{eq},T} = 10\ \log_{10}\left(\frac{1}{N}\sum{}^{1}0^{0.1L_{\mathrm{eq}}}\right)$$

where N is the number of 1-min intervals and L_{eq} is the measured sound level over the 1-min time period [34, 35].

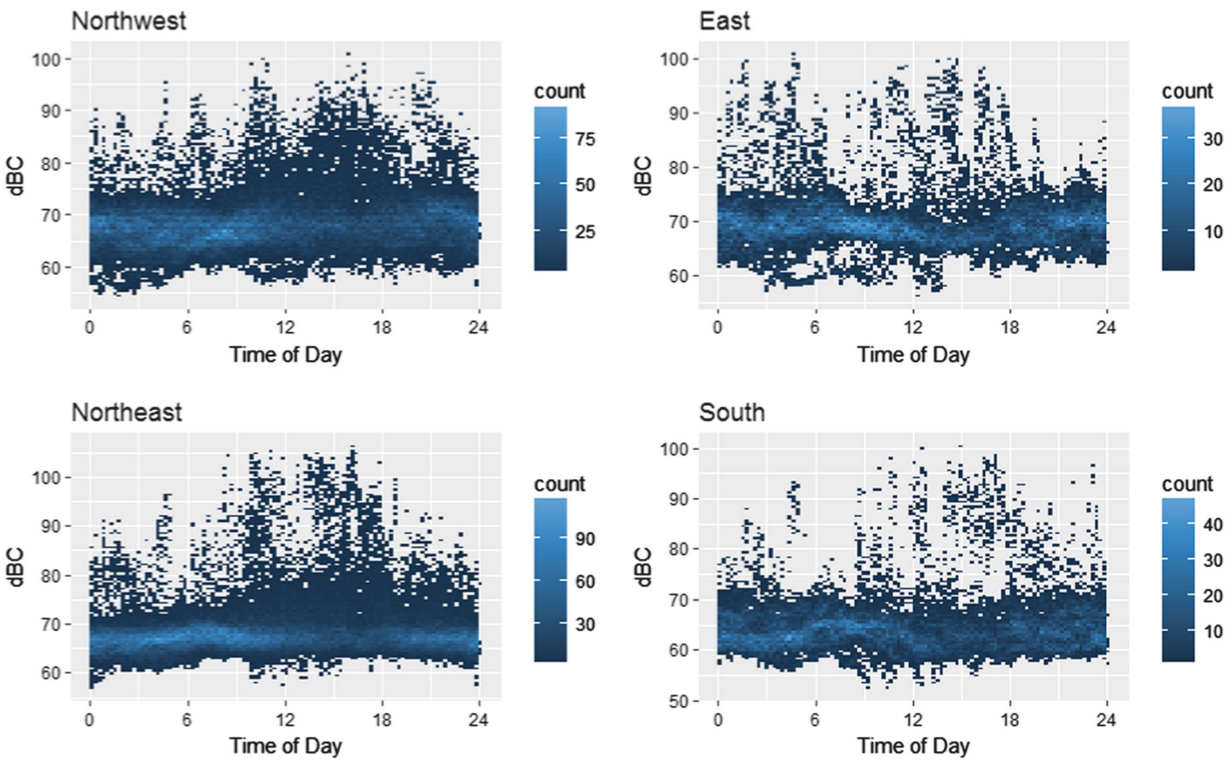

Fig. 3 Heat density of 1-min noise results for C-weighted data by time of day. A lighter shade is a greater count of values

Table 1 Short-term sound level meter 5-s data for A-weighted and C-weighted noise levels at the four locations

Location	East		South		Northeast		Northwest	
Weight	dBA	dBC	dBA	dBC	dBA	dBC	dBA	dBC
Count[a]	7	7	8	8	13	12	14	13
Minimum	43.2	59.8	34.8	58.5	41.7	62.3	42.2	63
Median	45.4	66.2	40.4	62.1	50	65.9	45.2	65.6
Maximum	50	68.1	50.1	67.6	59.8	82	50.8	76.7

[a]Count includes the number of 5 s noise measurements taken at each site over a 3-month period after omitting the data with high wind

We used the absolute difference between decibel levels when describing the difference between recorded or equivalent continuous noise measurements values.

Results

The summary of the results of the periodic three 5 s A-weighted and C-weighted SLM daytime noise level measurement at the four sampling locations are shown (Table 1). These measurements were taken during time periods without outside community noise or noise from traffic or trucking associated with the O&G operations. The median audible noise measurements ranged from 40.4 dBA at the South location to 50 dBA at the Northeast location. The median low-frequency noise levels ranged from 62.1 dBC at the South location to 66.2 dBC at the East location. The maximum A-weighted noise measurement was 59.8 dBA at the Northeast location and the maximum C-weighted noise measurement was 82 dBC at the Northeast location.

The summary of the results from the monthly continuous noise monitoring are shown for A-weighted (Table 2) and C-weighted (Table 3) noise levels. The monthly equivalent continuous levels ranged from 51.5 dBA at the northwest location to 60.2 dBA at the northeast location. The median levels were similar to arithmetic means and variance across locations were similar. The minimum 1-min equivalent continuous level recorded was 35.9 dBA and the maximum 1-min equivalent continuous noise measurement was 89.2 dBA. The low-frequency monthly equivalent continuous noise measurements ranged from 73.1 dBC at the northwest location to 80.0 dBC at the northeast location. The minimum observed 1-min equivalent continuous noise level was 52.4 dBC and the maximum was 106.4 dBC.

The percentage of 1-min noise measurements over levels of concern are also shown by location for dBA (Table 2) and dBC (Table 3). The maximum percentage of

Table 2 Summary statistics for the 1-min A-weighted noise levels collected at varying distances around an oil and gas production site measured over 3 months

	East	South	Northeast Visit 1	Northwest Visit 1	Northeast Visit 2	Northwest Visit 2
Dates	1 Jan 2017 to 24 Feb 2017	1 Jan 2017 to 24 Feb 2017	24 Feb 2017 to 24 Mar 2017	24 Feb 2017 to 24 Mar 2017	24 Mar 2017 to 24 Apr 2017	24 Mar 2017 to 24 Apr 2017
Count of included 1-min measurements[a]	22,742	26,239	30,343	30,234	32,017	31,946
Count of measurements excluded due to wind	11,913	14,030	9,803	9,912	12,737	12,668
Minimum (dBA)	38.4	37.2	38.3	35.9	38.8	37.0
Arithmetic average (dBA)	48.7	47.0	50.5	46.3	51.1	46.8
Equivalent continuous sound level (L_{eq}) (dBA)	54.6	54.2	60.2	51.5	57.8	53.5
Median (dBA)	48.2	46.6	50.4	45.8	50.9	45.8
Standard deviation (dBA)	4.3	4.5	5.3	4.1	4.8	5.1
Maximum (dBA)	81.5	82.0	89.2	79.2	87.4	81.7
Percentage of measurements >50 (day)	30.2%	17.6%	71.2%	13.9%	77.5%	27.5%
Percentage of measurements >55 (day)	7.4%	5.9%	19.3%	5.0%	24.2%	11.1%
Percentage of measurements >50 (night)	24.4%	13.9%	36.2%	11.5%	42.8%	11.6%

[a]Only includes data when hourly average wind speed or wind gust speed is less than 10 mph

measurements found to exceed 50 dBA was 77.5% during the day and 42.8% during the night, both occurring at the Northeast location during the second visit. During the day, the maximum percentage of measurements that exceeded 55 dBA was 24.2%, also at the Northeast location. For low-frequency noise, 100% of the measurements were found to exceed 60 dBC for both day and night measurements at the Northeast location during visit 2. More than 98% of the measurements during the day and night at the east, northeast, and northwest locations were greater than 60 dBC.

Across all locations from the 3-month period, 41.1% of daytime and 23.6% of nighttime 1-min equivalent continuous noise measurements exceeded 50 dBA and 12.7% of daytime and 4.5% of nighttime measurements exceeded 55 dBA. For low-frequency noise, 97.5% of daytime and 98.3% of nighttime measurements exceeded 60 dBC and 80.0% of daytime and 78.8% of nighttime measurements exceeded 65 dBC.

A time series of daily dosimeter A-weighted and C-weight noise level readings are shown for each of the four locations in Fig. 2 and Fig. 3, respectively. For each location, A-weighted noise increased in the morning, between 7 am to 8 am, decreased around 11 am, and a second increase was observed again around 4 pm (16:00). The C-weighted noise level results follow a similar pattern as the A-weighted noise levels; however, the peaks are less pronounced.

Discussion

This study measured and evaluated continuous audible and low-frequency noise levels during O&G well pad construction and drilling in a residential area. The monthly equivalent continuous noise levels were as low as 51.5 dBA and 73.1 dBC and as high as 60.2 dBA and 80.0 dBC. This work advances the literature on the environmental noise from O&G operations by collecting continuous 1-min A-weighted and C-weighted noise level data over a 3-month time period. The data were collected during construction and drilling of a large, multi-well pad in a residential area, a phenomenon that is increasingly common in the US as O&G development transitions towards larger operations on fewer pads, especially in more populated areas.

The maximum and monthly equivalent continuous A-weighted noise measurement results are of note because they are in excess of the 50 dBA threshold that may cause adverse health effects, such as increased risk of cardiovascular diseases and hypertension [26, 27]. The low-frequency noise levels we observed are of concern as they often exceeded the level of 60 dBC recommended to minimize impacts such as nausea and headaches [16]. The equivalent continuous noise measurement levels recorded at the northeast location were 60.2 dBA and 80.0 dBC from 24 February 2017 to 27 March 2017, which significantly exceeds the 50 dBA and 60 dBC recommended levels. Also, 41.1% of daytime and 23.6% of nighttime dBA 1-min

Table 3 Summary statistics for the 1-min C-weighted noise levels collected at varying distances around an oil and gas production site measured over 3 months

	East	South	Northeast Visit 1	Northwest Visit 1	Northeast Visit 2	Northwest Visit 2
Dates	1 Jan 2017 to 24 Feb 2017	1 Jan 2017 to 24 Feb 2017	24 Feb 2017 to 24 Mar 2017	24 Feb 2017 to 24 Mar 2017	24 Mar 2017 to 24 Apr 2017	24 Mar 2017 to 24 Apr 2017
Count of included 1-min measurements[a]	26,187	26,241	30,333	30,219	32,026	31,963
Count of measurements excluded due to wind	14,032	14,026	9,813	9,927	12,728	12,663
Minimum (dbC)	56.2	52.4	57.1	56.9	59.6	54.5
Arithmetic average (dbC)	69.7	64.4	67.9	68.5	68.7	68.3
Equivalent continuous sound level (L_{eq}) (dbC)	77.3	73.8	80.0	73.1	78.2	74.6
Median (dbC)	69.1	63.6	67.0	68.2	67.6	67.4
Standard deviation (dbC)	4.9	4.9	4.9	3.9	4.8	5.3
Maximum (dbC)	100.9	100.3	105.5	99.0	106.4	100.8
Percentage of measurements >60 (day)	99.1%	86.7%	99.9%	98.4%	100.0%	99.2%
Percentage of measurements >65 (day)	91.8%	33.6%	87.2%	85.0%	95.6%	79.3%
Percentage of measurements >60 (night)	98.7%	91.4%	99.8%	100.0%	100.0%	99.6%
Percentage of measurements >65 (night)	90.1%	35.1%	83.0%	87.9%	80.1%	93.1%

[a]Only includes data when hourly average wind speed or wind gust speed is less than 10 mph

equivalent continuous noise measurements were found to exceed 50 dBA and 97.5% of daytime and 98.3% of nighttime measurements were found to exceed 60 dBC. As the review by Basner et al. (2014) notes, nighttime average outdoor noise levels between 40 and 55 dBA are associated with adverse health effects, which highlights the long-term impact of continuously operating O&G sites. The low-frequency noise from O&G operations are at levels that may cause the common symptoms reported by individuals who reside in close proximity to O&G operations, such as sleep disturbance and headaches [11].

The 5-s SLM data were collected to explore the short-term noise levels without background noise or noise from nearby trucking activity. These results were collected in person so that the noise levels were attributable to the well pad alone and the methods more closely align with the shorter-term data collection often used to evaluate industrial noise levels. The maximum SLM measurements were 59.8 dBA at the Northeast location and 82 dBC at the Northeast location, which also exceed associated health concerns. Overall, the SLM values reported are indicative of the noise directly attributable to the O&G operations during the construction and drilling of this well pad.

The results of the operator's baseline noise test at this site conducted on 11 November 2016 found a 42.8 dBA and 55.8 dBC average noise level over a midday 1-h period with calm wind (Session Report 12/20/2016, downloaded from COGIS). The operator baseline levels were recorded at the south end of the site, approximately 40 ft from the nearest home. Our monthly equivalent continuous noise measurement results indicate an increase of between 8.7 to 17.4 dBA and 17.3 to 24.2 dBC over the operator's 1-h baseline measurement, depending on the time and location. Thus, the noise levels increased substantially over the baseline measure during the well pad construction and drilling. While there may be some differences between the operator's baseline noise measured at the well pad site and the noise levels recorded at our monitoring sites near homes, the operator's baseline measurements are likely a good approximation of baseline noise at four monitoring locations in this residential area.

The site we studied incorporated numerous best management practices for noise reduction. Their sound mitigation best management practices included: (1) 9.75 m (32 ft.) sound walls around the perimeter of the location during drilling and completion; (2) compliance with the municipal noise regulations (which includes requirements such as venting exhaust away from occupied buildings and special mitigation strategies for sensitive areas such as near schools and hospitals; (3) use of electric or modern low-noise diesel to power equipment; (4) continuous monitoring of noise by the operator; (5) completion of a baseline noise study; and (6) the operator to remedy sound levels exceeding 65 dBC measured from the nearest building unit within 48 h [30].

We find that the use of these best management practices was not sufficient to reduce noise levels to those below the operator find that the use of these best management practices was not sufficient to reduce noise levels to those below the operator proposed levels or levels associated with potential health concerns in the scientific literature.

Previous research evaluating noise under maximum operating conditions in unpopulated areas found all drilling, hydraulic fracturing, and completion at O&G sites to have noise levels greater than 65 dBC at locations with and without sound walls [14]. Based on our results, the dBC levels around this O&G operations site were also consistently greater than 65 dBC. For example, 93.1% of the nighttime measurements were found to exceed 65 dBC at the Northwest location from 24 March 2017 to 24 April 2017. Yet, the direct comparison of studies relating to noise from O&G operations is challenging due to the varying site equipment and operations, sound mitigation practices in place, and the presence of other community noise sources.

This study has several features that are improvements over existing studies, including long-term noise measurements at multiple locations and the simultaneous measurement of both low- and high-frequency noise. The continuous noise measurements demonstrate the environmental noise levels in this residential area from all activities, including from other community noises and trucking activity commonly associated with O&G development, were well into the range thought to affect health. Trucking activity at this site was reported as a concern to the COGCC by residents [30]. The concerns reported by community members near this location confirm that the noise levels from O&G trucking activity may be considered a nuisance for those residing near these operations and have the potential to cause stress, annoyance, sleep disruption, and cardiovascular impacts. Furthermore, the comparison of the 3 months of noise levels to the operator's baseline data collected from this site highlight the relevance and usefulness of the continuous noise data. Through the use of 1-min noise data collected continuously over a month at each location, which is over a much longer duration and offers more information than is generally reported at one of these sites, this work offers a more thorough understanding of the noise levels experienced by local residents living near a site with 24-h O&G operations.

The limitations of this work include representativeness of our measures and the averaging approach used to capture levels over time. These results, based on the continuous sampling at a single large multi-well pad over 3 months, may not be indicative of the noise from O&G operations at other locations with different topography, wind patterns, or noise mitigation strategies. Other noise sources from the community, such as local traffic or other household noises including other electronic or mechanical equipment, are present and will differ from site to site. Therefore, the noise levels we observed may not translate to the construction and drilling of all well pads and our results may or may not be representative of other multiwall pads with similar equipment. A second limitation is that due to the methods used to estimate long-term averages, the fluctuations from short-term loud noise levels that are less than 1 min in length may not be captured [16]. Future studies should consider pairing continuously collected noise data with operations data to separate noise from O&G operations from other residential or community noise sources.

Additional studies are needed to determine if the noise levels we measured are representative of other communities with large, multi-well O&G construction and drilling sites. These studies could also assess the impact of these levels on resident health, and whether mitigations that have been implemented, such as sound walls and electric powered equipment that reduce engine noise, can be further modified or managed to be more effective in reducing community noise exposure for nearby residents. Future efforts will document noise and air pollution levels at this site during hydraulic fracturing ("fracking") and the production stage. The noise levels surrounding these operations could also potentially be recorded using crowdsourcing methods and smartphone technology [36–39]. Overall, future research should focus on documenting noise level and resident health concerns due to high level, shorter duration audible and low-frequency noise as well as impacts on susceptible populations that may be disproportionally impacted by noise from O&G operations [4].

The measured noise levels in this and another study highlight the inadequacy of the current 152.4 m regulatory setback distance between O&G operations and residential buildings in Colorado [14, 20]. These data indicate that exposures to both audible and low-frequency noise exceed the level that can cause annoyance, sleep disturbance, cardiovascular impacts, and other health effects. We measured the noise levels at distances between 320 m (1049.8 ft) and 550 m (1804.5 ft) from the center of the well pad, which exceeds the regulatory setback distance. To the extent that this site is representative of O&G operations in Colorado, these results suggest that a setback distance of more than 500 ft (152.4 m), or other noise mitigation, will likely be needed to reduce community noise to levels below both health-based and COGCC standards.

Specific to Colorado regulatory efforts, we recommend that equivalent continuous noise levels for 24/7 operations should be required to be kept below 60 dBC to minimize annoyance and other impacts related to low-frequency noise [16]. Given the typical variation in dBC levels, it may also be appropriate to decrease the low-frequency noise criteria to 55 dBC to minimize health impacts from low-frequency noise. The current COGCC recommendation that 65 dBC will trigger an investigation by a noise consultant is in our judgment unlikely to reduce noise levels without changes in both site operations, mitigation approaches, and enforcement. Indoor low-frequency noise levels should also be considered as low-frequency noise is often less attenuated by homes and buildings potentially creating higher indoor levels through standing wave patterns in rooms [25]. The investigation of noise often requires a complaint and may not capture the highest noise levels. Publicly available continuous real-time noise monitoring results may offer much greater reporting, transparency, and accountability for both operators and nearby residents. Furthermore, the COGCC noise levels for residential areas (50 dBA) and other specific activities, such as the use of drilling rigs (75 or 70 dBA), should be reconsidered to align with the 40 dBA nighttime levels that are recommended to prevent health effects from nighttime noise [24].

Conclusion

Average noise levels at an O&G well pad during construction and drilling exceeded levels associated with annoyance, sleep disturbance, and cardiovascular health effects in studies involving noise sources such as traffic, airport, wind turbine, and railway related noise pollution. Furthermore, while low-frequency noise has received less attention than traditional A-weighted noise level research, these results highlight the need to further understand both the levels and health impacts of low-frequency noise in residential areas during drilling operations. The measurements collected during this study were also found at a distance greater than 152.4 m, thus highlighting that homes in closer proximity to operations will likely experience noise exposure at levels of concern even with the implementation of sound mitigation best management practices. Overall, further research is needed to address noise levels and test appropriate noise mitigation interventions to reduce exposure near O&G operations in residential areas.

Disclaimer

Any opinions, findings, conclusions, or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation

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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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