Amplifying Disparities: The Inequitable Burden of Transportation Noise in Rural and Minority Communities

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ABSTRACT
Exposure to noise pollution has been linked to a variety of negative health effects including heart disease and hypertension. Exposure to noise is not distributed equally; minority communities are often adjacent to highways and airports and have been found to have disproportionately high levels of transportation noise exposure. What is not yet understood, however, is if transportation noise exposure is increasing or decreasing over time and for whom. In this research we examine the change in transportation noise between 2016 and 2018 in the U.S. with an emphasis on the types of communities impacted. We utilize modeled transportation noise data from the U.S. Department of Transportation and conduct bi-variate regressions with demographic data at the census tract level. Our results show that transportation noise pollution is increasing nationwide, with minority and rural communities disproportionately affected by this increase. We close with a discussion of the policy recommendations for combating the growing inequality in transportation noise exposure.

KEYWORDS
Noise Pollution; Transportation; Environmental Justice; Rural Communities; Minority Communities; Public Health; Geographic Information Systems; Spatial Data; Geography; Data Science

INTRODUCTION
Exposure to elevated levels of anthropogenic noise (*i.e.*, noise pollution) has been identified by the World Health Organization as the second most important environmental risk factor for public health after air quality.[1] Noise pollution has been linked to cardiovascular disease, sleep disturbance, cognitive impairment in children, permanent hearing loss and tinnitus, hypertension, endocrine disruption, and a variety of other chronic conditions.[2, 3] Noise can lead to a detrimental psychological impact and reduce the quality of life for those exposed, as noise annoyance is a direct mediator between exposure to noise and psychological stress.[4, 5]

Noise from cars, trucks, trains, and airplanes makes up a considerable proportion of the anthropogenic noise exposure. In the United States, transportation-based noise pollution is an environmental justice concern.[6, 7] Similar to other environmental injustices, noisy land uses—such as highways, industrial corridors, and airports—have been systematically placed in minority and low-income neighborhoods through processes such as redlining, post-war urban renewal highway construction, and the NIMBY-ism (Not In My Back Yard) of wealthy, White communities.[8–10] Recent research has found that formerly redlined neighborhoods (D-grade) experience three times the level of noise exposure compared to A-graded neighborhoods.[8] Redlined communities were often located in dense urban environments, near transportation corridors, and found to be the subject of discriminatory loaning practices even prior to the formal implementation of these policies.[11] Geographically, the burden of transportation noise has been pushed onto low-income and minority communities, and the close proximity to unwanted land uses like major highways and airports exposes these communities to higher levels of transportation noise.[12, 13] For example, overall noise exposure has been found to be 4-7 decibels higher in minority communities compared to White.[8, 14]

While there is strong evidence of race and socioeconomic disparity in noise exposure,[12, 14] what remains to be understood is where noise exposure is changing over time and for whom. As the population grows, transportation noise is expected to increase, resulting in an increased likelihood for dangerously loud or long exposures to noise.[15, 16] Additionally, a transition towards electric vehicles is projected to lower transportation noise levels in areas where the speed limit is below 30-50 km/hr (19-30 mi/hr), but for rural areas with higher speed limits, the potential noise decrease for electric vehicles will be negligible because rolling noise makes up most of the noise generated at faster speeds.[17] Lack of investment in alternative transportation methods, such as high-speed rail travel, may also contribute to this projected increase.[18] If the spatial distribution of noise increases mirrors the current inequality of noise exposure, minority and rural populations are most likely to be exposed to increased noise.

To fill this gap in understanding of noise exposure change over time, we examine how increases in noise pollution are distributed across American communities, with a particular focus on rural and minority communities because the environmental injustices experienced by these communities are compounded by a lack of access to high-quality health care.[2] For instance, Black and Hispanic individuals are more likely than Whites to report forgoing medical care because of cost[19] and minorities living in rural areas are less likely to have access to routine healthcare compared to both rural Whites and urban minority populations.[20, 21] Using census-tract level data from the American Community Survey, we empirically test transportation noise change over time by asking:

1. Are transportation noise levels increasing in the United States between 2016 and 2018?
2. Do rural, urban, or suburban areas experience the largest change in noise levels?
3. Which communities are disproportionately affected by increasing noise levels?

METHODS AND PROCEDURES

Data Sources

American Community Survey (ACS) five-year data for 2020 (2016-2020) at the census tract level at the census tract level provided the socioeconomic and demographic data. These were downloaded from the Integrated Public Use Microdata Series National Historic Geographic Information System (IPUMS NHGIS).[22] Census tract level data are appropriate for this study due to the nationwide scale of analysis and the uncertainty in smaller populations level estimates (such as census block groups).[23]

From the ACS, we selected several race, ethnicity, income, and inequality variables that are commonly used in environmental justice literature to understand differential impacts and inequalities between demographic groups.[14, 24, 25] Specifically, the variables used for this analysis were the number of households, the number of households that speak limited English, the number of people with a bachelor's degree or greater, total population, Hispanic population, White population, Black population, Native American (American Indian and Alaska Native) population, Asian population, Native Hawaiian and Other Pacific Islander population, population that identifies with another race, and population that identifies as two or more races, median household income, and the Gini coefficient. The Gini coefficient measures income inequality in a range from 0 (perfect equality) to 1 (perfect inequality).[26]

Road and aviation noise for the contiguous U.S. were downloaded from the U.S. Department of Transportation (DOT), Bureau of Transportation Statistics for the years 2016 and 2018.[27] At the time of research, modeled noise maps were available for 2016, 2018, and 2020; the years 2016 and 2018 were chosen for analysis to avoid the decline in traffic and transportation noise levels that occurred as a result of COVID-19 travel restrictions. The dataset is modeled noise levels measured in A-weighted decibels (dBA) averaged into a single "annual day".[28] dBA weights sound frequencies to the same sensitivity as the average human ear.[29] We selected this noise dataset because it is one of the few national level quantifications of transportation noise over multiple points in time. There are, however, limitations to the model. First, the model does not take into account areas where buildings and surrounding materials may naturally dampen sound.[23] Second, the model assumes all areas have acoustically soft ground which may result in an over-prediction or under-prediction of noise levels.[28] We utilized a change-over-time approach in order to compensate for many of these limitations because the same assumptions underly both years and we are examining only the differences between the two models (where noise was modeled to increase or decrease).

Data Preparation

Census Tracts. We classified each census tract in the contiguous U.S. on a rural to urban spectrum based on its population density, with different classifications shown in Oklahoma City, Oklahoma (**Figure 1**). The urban-rural classification method comes from the Housing Assistance Council's (HAC) tract designation.[30] This classification method was used in order to provide a more detailed definition of rural and urban America, as the U.S. Census classification of rural and urban simply defines rural as anywhere that is "not urban".[31, 32] Simplified rural-urban classifications do not capture the nuanced spatial transitions between cities, suburbs, and rural areas- a pattern recognized in new urbanist planning theories which conceptualize these transitions along a "urban-rural continuum" that delineates zones from the most rural to the most urban.[33] The Housing Assistance Committee classification scheme has been used in research determining the distribution of rural demographics, such as by the First Nations Development Institute.[34] Based on their definition, census tracts were divided into one of five different categories: tracts with less than sixteen housing units per square mile are designated as rural, tracts with 16 to 64 housing units per square mile are designated as exurban/small towns, tracts with 64 to 640 tracts housing units per square mile are designated as outer suburban, tracts with 641 to 1,600 housing units per square mile are designated as inner suburban, and tracts with more than 1,600 housing units per square mile are designated as urban.[34] In our analysis, the exurban and small town are a combined category because the degree of commuting was not considered. A potential imitation of this classification is the reliance on population density to determine classification. While non-populated tracts were removed from the dataset, some highly built-up areas may be classified as rural or exurban if they have low population density (*i.e.*, industrial corridors).

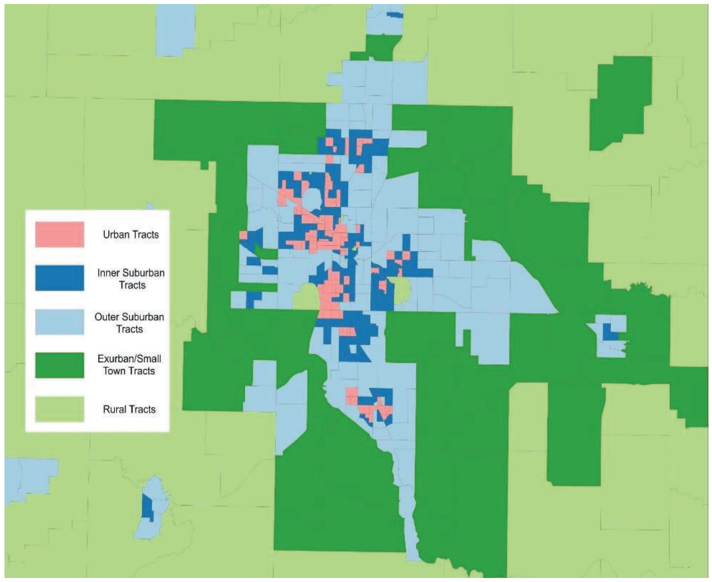

Figure 1. Oklahoma City, Oklahoma's urban to rural designation for census tracts based on the Housing Assistance Committee's Rural-Urban Classification Scheme.

Noise Data. The noise raster for each state was downloaded and mosaiced together to create two nationwide rasters for 2016 and 2018 respectively. In the raw noise raster, areas below 45dBA are "NoData".[28] Because we were interested in change over time, the "NoData" values in the 2018 and 2016 noise rasters were replaced with the value 44dBA, one dBA lower than the smallest recorded noise measurement in the DOT rasters. This allows for a more accurate evaluation of noise level changes when differencing the 2016 and 2018, while remaining conservative in estimation. Next the 2016 raster was subtracted from the 2018 raster to create a single raster showing the noise difference over time. Last, zonal statistics were used to calculate the average change in noise levels for each census tract.

Statistical Analysis. Census tracts with no population were removed[14] and then the Spearman rank-order correlation test was used to analyze the average level of noise change in each census tract compared to ACS variables. We tested the distribution of the data, and the Spearman test was chosen because the data had a non-normal distribution.[35] R version 4.2.1 and packages sf, dplyr, Hmisc, and raster[36–39] were used for analysis along with ArcGIS Pro version 3.1.3 and the ArcPy package.[40, 41]

RESULTS

Changes in transportation noise.

Across all census tracts we found an overall increase in transportation noise between 2016 and 2018. Approximately 9% of census tracts experienced an increase in noise greater than 0.5dBA, which corresponds to ~29.8 million Americans (**Table 1**). We used 0.5 dBA as a threshold because the average increase across tracts was 0.5 dBA. In rural and exurban tracts, noise levels changed from a 5.23 dBA decrease and a 18.3 dBA increase, while urban tracts ranged from a 10.6 dBA decrease to a 17.52 dBA increase.

	Increased (> 0.5 dBA)	**Similar** (-0.5- 0.5 dBA)	**Decreased** (< -0.5 dBA)
All Tracts (n = 83,301)	9.26%	85.21%	5.53%
Urban Tracts (n = 25,901)	16.25%	74.32%	9.42%
Inner Suburban Tracts (n = 19,155)	11.47%	81.70%	6.83%
Outer Suburban Tracts (n = 20,986)	5.17%	91.42%	3.41%
Exurban/Small Town Tracts (n = 9,021)	0.86%	98.48%	0.65%
Rural Tracts (n = 8,238)	1.70%	97.27%	1.03%

Table 1. Percent of census tract where average noise levels increased, decreased, or stayed the same between 2016 and 2018 for all tracts and by level of urbanization.

The proportion of tracts with increased noise was higher for urban (16%) and suburban (11%) census tracts. Approximately 16.6 million urban Americans experienced an increase in average noise levels. Rural and exurban/small town tracts saw the smallest increases (less than 1% and 1.7% respectively), this represents approximately 349,000 rural and exurban Americans.

Characteristics of communities most affected by transportation noise increases.
Table 2 presents the correlations between noise increases and the demographic and neighborhood characteristics for all census tracts in the contiguous United States.

	Coefficient	p-value
Gini Index (income inequality)	0.016	***
Percent college educated	0.083	***
Percent of households with limited English	0.14	***
Percent Hispanic population	0.14	***
Percent White population	-0.11	***
Percent Black population	0.067	***
Percent Native American population	-0.018	***
Percent Asian Population	0.13	***
Percent Hawaiian/Pacific Islander	0.020	***
Median household income	0.039	***

***Notes.* ***$p <$ 0.001, **$p < 0.01$, *$p < 0.05$, ^$p < 0.1$**
Table 2. Spearman correlation coefficients and p-values for the relationship between socioeconomic variables and the change in traffic noise for all tracts between 2016 and 2018.

	A. Urban Tracts		B. Rural and Exurban/Small Town Tracts	
	Coefficient	p-value	Coefficient	p-value
Gini Index (income inequality)	0.0017		0.029	***
Percent college educated	-0.0021		0.024	**
Percent of households with limited English	0.041	***	0.05	***
Percent Hispanic population	0.041	***	0.11	***
Percent White population	0.0080		-0.049	***
Percent Black population	-0.016	*	-0.053	***
Percent Native American population	-0.019	**	0.079	***
Percent Asian Population	0.0062		0.025	**
Percent Hawaiian/Pacific Islander	0.0034		0.057	***
Median household income	0.0030		-0.042	***

***Notes.* ***$p <$ 0.001, **$p < 0.01$, *$p < 0.05$, ^$p < 0.1$**
Table 3. Spearman correlation coefficients and p-values for the relationship between socioeconomic variables and the change in traffic noise for urban tracts (A) and rural and exurban (B) between 2016 and 2018.

We find a small, but statistically significant relationships for all variables considered. A greater proportion of White and Native American populations was associated with a smaller increase in transportation noise over the two-year period. In tracts where the percent Hispanic, Black, Asian, and Hawaiian/Pacific Islander populations were larger, the average change in noise was higher. Greater income inequality (Gini index) and a higher proportion of households with limited English were positively correlated with higher average noise change. Tracts with higher median household income and a higher proportion of the population with at least a bachelor's degree were also positively correlated with noise increases. Among these factors, the relationship between an increased proportion of the Hispanic population and greater average noise levels was the strongest.

Noise, and those impacted, in urban and rural environments may have different explanatory variables, so Spearman tests were conducted separately for the urban tracts (n = 25,901) and the rural and exurban/small town tracts (n = 17,259) separately (**Table 3**). We found both shared and distinct trends in noise change across urban and rural/exurban America, with rural and exurban tracts having greater statistical significance than urban tracts.
Across both urban and rural tracts, a greater proportion of households that speak limited English and higher percentages of Hispanic population were correlated with increasing noise levels. The percent Black population was correlated with a decrease in noise levels across both urban and rural tracts. In rural and exurban tracts (but not urban tracts), a greater percent White population, greater median household income, and lower income inequality was correlated with decreasing noise levels. A greater proportion of college educated individuals was associated with increased noise levels. The percent Native American population and the Hawaiian/Pacific Islander population are both correlated with increasing noise levels in rural tracts, while the Native American population is correlated with decreasing noise levels in urban tracts.

The proportion of households that speak limited English, the percent Hispanic population, and percent Black population are the only demographic variables associated with statistically significance increases in average noise across all our analyzes (national, urban, and rural; **Tables 2 and 3**). To dig into the impact of noise increases on racial and ethnic minorities, we summed the number of Hispanic, Black, Asian, Native American, and Native Hawaiian and other Pacific Islander residents in census tracts experiencing noise increases (**Figure 2**).

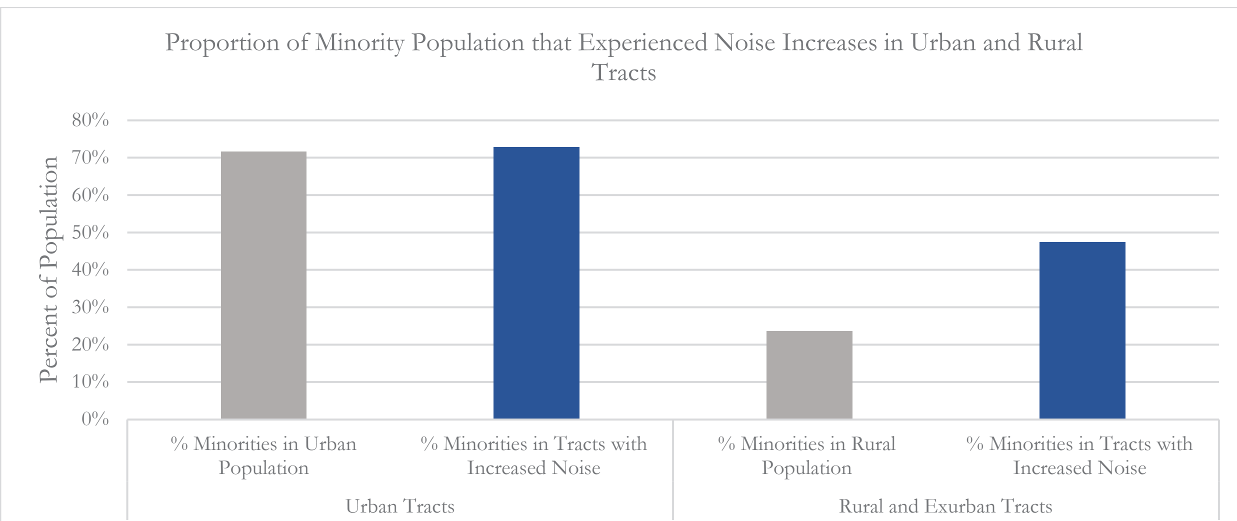

Figure 2. Bar chart displaying the proportion of minority population that experienced noise increases in urban compared to rural/exurban tracts.

In urban areas, racial and ethnic minorities make up 71.64% of the population, and account for 72.77% of the total urban population affected by increased noise levels. In rural and exurban areas, the difference between the proportions is larger: racial and ethnic minorities make up only 23.55% of the population, but account for 47.45% of the total rural and exurban population affected by increased noise levels.

DISCUSSION

Areas Impacted by Increasing Noise Levels.
Nationwide, we found that noise levels between 2016 and 2018 increased by about 0.5 dBA on average. More census tracts experienced an increase in noise levels than a decrease in noise levels across all levels of urbanization, but the majority of tracts that experienced a noise increase were in urban areas (**Table 1**). This finding is consistent with Seto and Huang's[42] result that more populated areas tended to experience higher noise levels. This increase in transportation noise is likely attributable to the growing population and increased use of air and highway transportation, particularly in urbanized areas.[16]

Socioeconomic Status and Noise Levels.
The increases in noise, however, were not distributed equally. We found that socioeconomic status significantly impacts exposure to increasing levels of transportation noise at the national scale. Nationwide, higher levels of economic inequality and a higher

proportion of households that speak limited English were associated with an increase in noise levels. This is consistent with Collins et al.'s[13] results that lower socioeconomic status children were more likely to be exposed to high levels of noise while at school. Other indicators of socioeconomic status—median household income and percent college educated—had the inverse relationship, however. In the national level analysis, higher median household income and proportion of the population with at least a bachelor's degree were correlated with increasing noise levels (the same was also true for percent college educated in rural/exurban tracts). This trend may be a result of louder neighborhoods being viewed as livelier and more desirable places to live. More opportunities for education and employment may attract more residents, resulting in higher population densities with higher noise levels. A similar trend was found by Havard et al.,[43] in which higher road traffic noise exposure increased with home value and education level in many areas of Paris, France. For rural and exurban tracts, however, a higher median income is associated with lower noise average noise changes.

Minority Demographics and Noise Levels.
Consistent with Collins et al.'s[12] and Casey et al.'s[14] findings focused on the populations most burdened by noise, we find that census tracts with a higher proportion of racial and ethnic minority populations are often associated with greater noise increases. Nationwide, census tracts with a higher proportion of Hispanic, Black, Asian and Hawaiian/Pacific Islander populations are associated with higher levels of noise change (**Table 2**). In contrast, census tracts with a larger proportion of White residents are correlated with a decrease in noise for the nationwide and rural area analysis (**Table 2, 3**).

While we found that greater minority populations were often correlated with noise levels increases, there are a few exceptions. At the nationwide level, we found that a greater proportion of the Black/African American population was associated with increased noise levels (**Table 2**), which is consistent with previous research that has found that neighborhoods with a higher percent Black population tend to have higher noise levels compared to surrounding neighborhoods.[14] The trend reversed, however, when looking at the urban and rural/exurban tracts separately—a higher proportion of Black population was associated with decreased noise (**Table 3**). The difference between these two results may be attributable to systemic disinvestment in Black communities that has resulted in a lack of job opportunities, deindustrialization, and other factors that result in population loss.[44] For example, many of Chicago's South Side neighborhoods have experienced net population decline between 1990 and 2016.[44] While many Black and minority neighborhoods have louder noise levels compared to wealthier and whiter neighborhoods;[12] systemic disinvestment has resulted in general population decline which could account for the decrease in transportation noise levels over time. The trends for Native American populations also vary depending on the region type. A greater proportion of Native American residents was associated with higher average noise change in rural/exurban tracts (**Table 3**), but noise decreases at the nationwide level (**Table 2**) and in urban tracts (**Table 3**). These findings are generally consistent with Casey et al.'s[14] study that found the Native American demographic to be correlated with lower noise levels, but inconsistent with Collins et al.'s[12] findings that Native American populations were correlated with increased aviation noise. The differences may be due in part to the uneven distribution of census tracts with high proportion of Native American residents caused by the reservation system.[34]

Rural Minorities and Noise Levels.
Despite the above exceptions, our findings suggest that rural minorities were substantially more likely than urban minorities to be exposed to increasing transportation noise levels. Racial and ethnic minorities make up 23.55% of the population in rural and small-town census tracts, yet they account for 47.45% of the rural and small-town population impacted by increasing noise levels (**Figure 2**). This finding contrasts with Casey et al.'s[14] result that the correlation between noise and higher minority populations is generally consistent between urban and rural/suburban areas. This may be because they examined overall noise while this research examines how noise levels changed between 2016 and 2018.

Rural and small-town minority populations face unique challenges compounded by a variety of factors, which will likely worsen as transportation noise levels continue to increase. First, agricultural noise is not included in the modeled noise data used for this analysis but is a major source of noise exposure for some rural minority populations. A sample of 150 migrant agricultural workers found that over half had some degree of hearing loss.[45] Second, rural and minority populations have decreased access to health care and other community health challenges. Rural Americans suffer from higher rates of death than their non-rural counterparts, in part due to compounding social factors including lack of access to nutritious food, social isolation, and rural poverty.[46] Being non-White further amplifies this issue. For example, Black rural residents are two to three times more likely than White rural residents to die from heart disease, one of the chronic health issues linked to long term exposure to noise pollution.[3, 47] Current noise research rarely focuses on rural areas, and as a result we see the impact of noise on rural minority populations as an important area of future examination.[47, 48]

Policy Recommendations
Noise control policies, regulations, and enforcement vary across the world, but are generally lacking within the U.S. at both the federal and state level. In the U.S. Noise Pollution and Abatement Act of 1970, the federal government delegated power for noise

regulation to the Environmental Protection Agency's Office of Noise Abatement and Control.[49] This department was defunded in 1982, leaving states to draft and enforce their own laws regarding environmental noise pollution.[50] Policies regarding noise control vary by state. Some states, such as Minnesota, have implemented noise control laws with explicit limits on noise in residential areas, while others, like Alabama, have very little state-level legislation and delegate the task to municipalities.[51, 52] Through the analysis conducted for this research, we have identified the census tracts across the U.S. that are most affected by increasing levels of transportation noise and, therefore, have greater need for policy interventions. These census tracts are ones that may merit further analysis and attention because noise can vary dramatically within a small spatial scale. Furthering this goal, we have made the census tract-level results publicly available in a web map to allow residents and policy makers to look-up their neighborhood (**Figure 3**). The web map is accessible at this link.

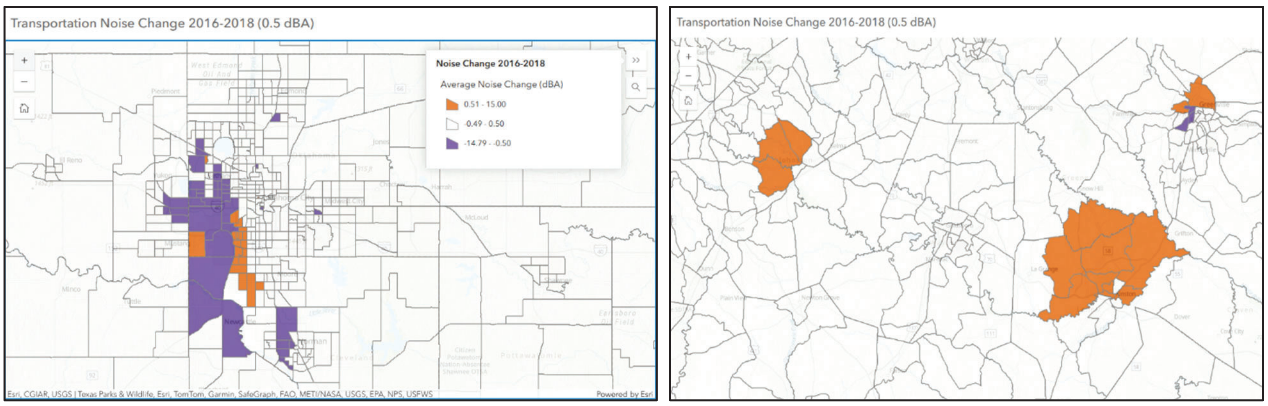

Figure 3. Screenshots of web map displaying Oklahoma City, Oklahoma (left) and Lenoir County, North Carolina (right). The web map shares the census tract-level results of transportation noise change publicly.

Using the web map, we identified that the rural and exurban census tracts with the greatest transportation noise increase during our study period were located near airports. Lenoir County in North Carolina was the rural tract with the highest noise increase of 7.77 dBA followed by Comanche County in Oklahoma with an increase of 6.93 dBA **(Figure 3).** The airports located near these areas of high noise increases (Kinston Regional Jetport and Lawton-Fort Sill Regional Airport) appeared to operate using traditional flight paths in which the same areas are continually subjected to high levels of noise. Measures such as modifying take-off and landing paths or optimizing aircraft type can reduce noise exposure by as much as 26.61 depending on the season and exact procedures implemented.[53]

For ground-based transportation, a potential multi-faceted intervention is the addition of green infrastructure directly adjacent to roadways and rail lines.[54, 55] The leaves and branches of vegetation scatter noise while the bark of trees (as well as soil) absorb noise.[56, 57] The implementation of green infrastructure near transportation hubs as well as in the communities most affected by the stressors of transportation noise will assist in mitigating the disproportional effects of transportation noise and provide a suite of co-benefits such as urban heat island reduction and carbon sequestration.[55, 58, 59] In addition to prioritizing communities with high noise levels and low levels of greenery, areas where speed limits are above 30-50 km/hr (19-30 mi/hr) should also be a focus because noise levels will stay elevated in these areas even as society undergoes a potential transition to quieter electric vehicles.[17] The newly proposed field of transportation forestry is well poised to contribute to these types of interventions. Transportation forestry combines the expertise of a variety of fields to site, select, plant, and maintain green infrastructure along transportation networks in a manner that improves safety and advances environmental justice.[60]

Additionally, city and town design that accommodates alternative (and largely noiseless) forms of transportation—such as walking or biking—can reduce transportation noise in higher density areas. Cities like Amsterdam have seen positive outcomes, including noise reduction, from investment in pedestrian-friendly infrastructure.[61] This is also the case in San Francisco, where city design has a strong influence on residents' choices to make trips by bicycle.[62] Market responsive planning and zoning can facilitate urban landscapes that promote land use diversity and "healthy cities".[62]

Overall, this and other research on the unequal distribution of noise pollution[8, 12–14] points to the need to establish a national framework for measuring transportation noise, setting scientifically informed targets, and ensuring enforcement to reach the targets. While municipal or state level policy action can move the needle, a national level approach could lead to greater equity than the current patchwork of state and municipal noise regulations. For example, the European Union's Environmental Noise Directive created four actions arenas: 1) noise mapping and assessments of noise health impacts, 2) sharing information with the public on noise and it's impacts, 3) preventing and reducing noise, and 4) preserving areas with low noise levels.[56] Each member state is then responsible for the conducting activities and reporting within these arenas.[63] A similar framework in the U.S. could encourage policy makers, urban planners, transportation engineers, and other urban professionals to prioritize noise and design compliant systems that do not unequally burden communities.

CONCLUSIONS

We find that transportation noise levels between 2016 and 2018 are increasing, with minority and rural communities disproportionately affected by the increased noise. Without purposeful intervention, our analysis suggests that the burden of noise pollution will continue to grow for these communities, compounding other environmental justice concerns such as lack of healthcare access. Many potential interventions to improve noise exposure already exist—such as modifying flight patterns and implementing green infrastructure along transportation networks—what is needed is a policy framework that will guide efforts to limit noise exposure, especially for vulnerable communities.

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PRESS SUMMARY
Noise is an increasing public health concern and is related to serious medical issues like hearing loss and sleep disorders. Our research finds that on average, noise pollution because of transportation has increased between the years 2016 and 2018. The change in noise levels overtime has not previously been studied on a nationwide scale in the United States. Minority and rural populations are disproportionately affected by the transportation noise increase.