Road Traffic Noise
Annoyance, Sleep Disturbance, and Public Health Implications

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Background: The WHO has recognized environmental noise as harmful pollution that causes adverse psychosocial and physiologic effects (i.e., annoyance and sleep disturbance) on human health. In Europe, noise-related health studies have been actively conducted, but the U.S. has lagged behind in this research field.

Purpose: This research predicted ambient levels of road traffic noise for a highly urbanized area: Fulton County GA. Assessment was made of noise impacts on the population, focusing on annoyance and sleep disturbance.

Methods: All the data sets were collected during 2009–2011, and data analysis was performed in 2010–2011. The study used a sound-propagation model for noise-level prediction and derived noise-impact indicators for annoyance and sleep disturbance from exposure-response models. Then, annoyed and sleep-disturbed populations were predicted with the use of each noise-impact indicator.

Results: It was predicted that 109,967 people would be at risk of being highly annoyed, with 19,621 people at risk for high sleep disturbance for Fulton County GA. Noise-impact indicators such as the percentage of those who were highly annoyed and who had high levels of sleep disturbance were expected to be valuable metrics to compare noise equity among urban communities.

Conclusions: Many residents of the greater Atlanta area may be exposed to noise levels that put them at risk of being highly annoyed or having high levels of sleep disturbance. These results, if generalized to other urban areas with high levels of road traffic, indicate that it may be important for the public's health to update existing noise-related policies or develop new ones to control and abate noise concerns in urban communities.
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Introduction

Noise is unwanted or undesirable sound, and it can be either occupational or environmental, depending on its source. Occupational noise occurs at workplaces, and environmental noises are produced from all other non-workplaces including roads, railways, airports, and even neighborhoods.[1] In the modern world, transportation is the major source of environmental noise regardless of economic development status.[2–4]

The WHO has recently considered community noise to be a harmful environmental pollutant,[1] and noise has been reported to have adverse psychosocial and physiologic effects on public health. The most substantial psychosocial outcomes of environmental noise are annoyance and sleep disturbance.[1,5,6] The WHO has suggested that outdoor environmental noise should not exceed 55 dB(A) and 40 dB(A) for daytime and nighttime, respectively, to prevent potential psychosocial effects.[1,7]

Considering these adverse effects of environmental noise, the European Union recently issued Environmental Noise Directive 2002/49/EC, which mandates assessment and management of environmental noise exposure by creating strategic noise maps of major transportation features such as roads, railways, and airports.[8] In the

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European countries, many research projects associated with environmental noises have been performed or are ongoing, such as hypertension and exposure to noise near airports (HYENA); noise pollution health effects (NOPHER); and road traffic and aircraft noise exposure and children's cognition and health (RANCH).

The U.S. vigorously conducted noise-related research during the 1970s, following the Noise Control Act of 1972. The Office of Noise Abatement and Control (ONAC) at the Environmental Protection Agency (EPA) coordinated all noise abatement and control programs in the nation. The ONAC's research activities were codified in the Quiet Communities Act of 1978, which established noise sources that are subject to regulation and noise emission standards. Because federal funding for ONAC was discontinued in 1981, noise abatement programs have been shifted to state and local governments.

Since then, road traffic noise in the U.S. has become an issue of increasing concern.[9,10] The Organization for Economic Cooperation and Development estimated that 37% of the total U.S. population in 1980 was at risk for being annoyed by road traffic noise.[9] According to the Department of Transportation (DOT), the total miles of vehicular travel in the U.S. had increased annually with a 3.1% growth rate from 1980 to 1996,[9] which suggests a potential increase in population risk for annoyance. The U.S. Census Bureau conducted an American Housing Survey (AHS) for 38 metropolitan areas, including metropolitan Atlanta, in the late 1990s and early 2000s. The survey included noise-related questions. In approximately 29% of target household units, respondents indicated that they felt the impact of street or traffic noise.[10]

Nevertheless, there have been few recent studies assessing the impact of road traffic noise on health in the U.S. To address this research need, the current project was initiated to investigate the association between road traffic noise and potential health effects through the creation of noise maps and the assessment of population exposure in a GIS. The CDC is currently focusing on the metro-Atlanta area, Georgia, and it created road traffic noise surface maps of Fulton County, a highly urbanized area in the metropolitan region.[11] Given that annoyance and sleep disturbance are outcomes of road traffic noise,[12] this research presents the estimated number and prevalence of population potentially affected by the noise at county and city levels, and it also provides their geographic distributions across the county.

Methods

The Atlanta metropolitan area experienced a considerable increase in daily vehicular travel miles from 1982 to 1996 (119%), compared with its population growth (53%) during the same time period.[9] The increased vehicular travel likely would cause increased negative noise impacts on communities.[9] Fulton County, a highly urbanized area incorporated in the metropolitan region, was selected for this research. It has a total land area of approximately 1369 km^2 with 14 municipal cities, and it is the largest county in the metropolitan area in terms of population, housing units, and degree of urbanization. According to the Georgia Department of Transportation (DOT),[13] Fulton County has a well-developed road network with a total length of 2678.37 km. In particular, Interstate Highway 285 runs around the heart of the county, and the area inside I-285 has a complex road network at high density. All the data sets were collected in 2009–2011, and data analyses were conducted in 2010–2011.

Data Collection

The model-based prediction of road traffic noise exposure levels requires essential data on topography; building footprints and heights; road network including highways, arterials, and local roads; vehicle volume and speed; and the composition of vehicle types. Relevant data sets were collected from the Fulton County, Georgia DOT, and the Atlanta Regional Commission (ARC), which is a Metropolitan Planning Organization (Table 1).

LandScan USA™ 2008 data were delivered through the National Geospatial-Intelligence Agency as a part of the Homeland

Table 1. Summary of input data used in this research

Data type	Parameter	Data producer	Production year	Data access constraints
Building	Footprint	Fulton County	2008	Proprietary
	Heights	Fulton County	2008	Proprietary
Topography	Elevation	U.S. Geological Survey	2008	Public
Road	Network	Georgia Department of Transportation	2008	Proprietary
Vehicle	Volume	Georgia Department of Transportation	2008	Proprietary
	Type	Atlanta Regional Commission	2008	Proprietary
	Speed	Georgia Department of Transportation	2008	Proprietary
Population	Daytime and nighttime population	Oak Ridge National Laboratory	2008	Proprietary

Security Infrastructure Program Gold Dataset 2010. The LandScan data included daytime and nighttime populations. The daytime population represents a snapshot of a typical working day when children are in school, while the nighttime population is representative of people who are at home overnight (ML Urban, GIST Group, Oak Ridge National Laboratory, personal communication, 2010). The LandScan population data have a grid size of 90 m, which is much finer in size than that of the block-level population data provided by the U.S. Census Bureau.

Road Traffic Noise Prediction

The current study used the Traffic Noise Model of the U.S. Federal Highway Administration, implemented in SoundPLAN™ (version 7.0), to produce two road traffic noise maps for daytime (7:00AM–10:00PM), represented by L_D, and nighttime (10:00PM–7:00AM), denoted by L_N, periods across Fulton County. L_D and L_N were computed with a constant sound pressure level (L_{eq}) with a grid size of 90 m to be consistent with the grid size of the LandScan population data. L_{eq} indicates a constant noise level over a given period.

The current study used the following equation to calculate L_D and L_N:

$$L_{eq,1h} = EL_i + A_{traffic(i)} + A_d + A_s ,$$

where EL_i indicates the empirical noise level of the ith vehicle type, $A_{traffic(i)}$ the adjustment for traffic flow such as speed and volume of vehicle, A_d the adjustment for distance between road and receiver, and A_s the adjustment of all shielding and ground effects between road and receiver. Then, day–night noise levels (i.e., L_{DN}) were derived by SoundPLAN to use for the assessment of highly annoyed population in the next section as follows:

$$L_{DN} = 10\log[(15/24) \times 10^{L_D/10} + (9/24) \times 10^{(L_N+10)/10}],$$

where L_D and L_N stand for constant noise levels in L_{eq} of daytime and nighttime periods, respectively.

Annoyance and Sleep Disturbance

The current study employed two measures to estimate the populations at risk of annoyance and sleep disturbance, based on exposure to noise levels. They were the percentage of highly annoyed people (%HA, in equations) and the percentage of people with high levels of sleep disturbance (%HSD, in equations). These two noise-impact metrics indicate the probabilities that certain percentages of the population, exposed to certain levels of road traffic noise, would be highly annoyed or have high levels of sleep disturbance, respectively, at a given spot.[14–16] They also were used to predict the burden of disease from environmental noise (e.g., disability-adjusted life-years) for European countries.[12]

Miedema and Oudshoorn[14] and Miedema et al.[15] utilized the observations included in existing noise surveys of people showing each of the two effects, with specific road traffic noise levels, in order to derive the coefficients of third- and second-order polynomial approximations for the percentage of each, respectively, as follows:

$$[\,\%\,HA = 9.994 \times 10^{-4}(L_{DN} - 42)^3 - 1.523 \times 10^{-2}(L_{DN} - 42) + 0.538(L_{DN} - 42)]^{14}$$

$$[\,\%\,HSD = 20.8 - 1.05L_N + 0.01486L_N^2]^{15}$$

where L_{DN} denotes the average noise level during the 24-hour period and L_N indicates nighttime noise in L_{eq}(A). The percent annoyed (%HA) and percent with high sleep disturbance (%HSD) in Fulton County were computed with the polynomial equations using Esri ArcGIS because all the input parameters were in a grid data format. Then, the two percentages were individually multiplied by LandScan population at each grid to estimate the number of people in each group, because all three data sets were produced in grid format with the same size.

This research used Getis-Ord Gi* in Esri ArcGIS (version 10) to identify significant hot and cold spots across the study area, based on the two populations (highly annoyed and high levels of sleep disturbance). Hot spots represent spatial clusters with large numbers of people in each group; cold spots indicate geographic clusters with small numbers of people in each group.

Results

The estimated daytime and nighttime road traffic noise levels for Fulton County are shown in Figures 1a and 1b, respectively. Five-decibel increments were used to represent road traffic noise levels suggested by the U.S. Environmental Protection Agency.[17] The current study found that the highest levels of road traffic noise occurred along highways and major state roads during both daytime and nighttime periods. During the daytime, downtown Atlanta, denoted by a black outline in Figure 1a, has a complex network of non-arterial roads that contributes to the production of high levels of noise. The overall nighttime noise of the county was less severe than during the daytime (Figure 1b).

This research estimated the number of people who were highly annoyed and the number with high levels of sleep disturbance. According to the prediction results, 109,967 people (9.5% of the total daytime population of 1,152,550) in Fulton County were estimated to be at risk of being highly annoyed during the daytime. The present study also predicted that 19,621 people (2.3% of the total 857,184 nighttime population) in Fulton County were at risk of having high levels of sleep disturbance.

The current study examined road traffic noise impacts on annoyance and sleep disturbance at a city level. Table 2 describes the total populations, people in the two groups, and prevalence of people in each of the two groups, for each city, for both daytime and nighttime. The total populations of each city came from LandScan USA daytime and nighttime population data sets. The city of Mountain Park was excluded from the current study because only a very small portion of the city is incorporated in Fulton County.

The city of Atlanta had the largest predicted number (n=67,016), which contributed to approximately 61% of the county-level estimate of highly annoyed people (Table 2). The cities of Sandy Springs and Alpharetta followed Atlanta with predicted numbers of highly

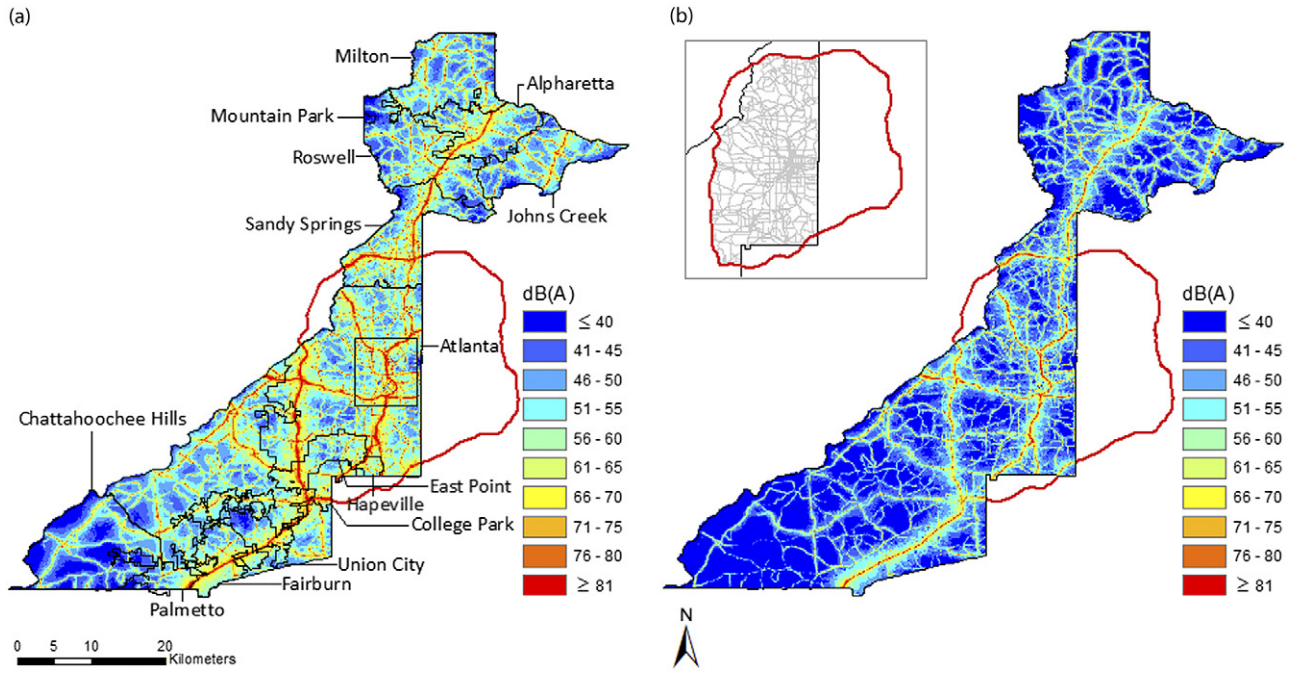

Figure 1. Road traffic noise levels for Fulton County GA

Note: (a) Daytime (7:00AM–10:00PM) and (b) nighttime (10:00PM–7:00AM). The red line represents I-285, and the road network inside the I-285 boundary and the county appear in the small map located at the upper left (b). The black rectangle (a) indicates the approximate boundary of the Atlanta downtown area.
dB(A), A-weighted decibels

annoyed people of 12,329 and 7824, respectively. The total number for Fulton County was discovered to be largely affected by the three cities (approximately 79% of those who were highly annoyed in the Fulton County population). Considering nighttime noise impact, it was found that the city of Atlanta had the largest number of people (n=11,313) followed by the cities of Sandy Springs and Roswell, with 2662 and 1390, respectively. The population with high levels of sleep disturbance in these three cities was approximately 15,365 (78%), compared with the total number of people with high levels of sleep disturbance in Fulton County (n=19,621).

In terms of the number of people experiencing the two effects, the city of Atlanta seems to be the most severely affected by road traffic noise among urban communities of the county. However, it may provide a biased view about the severity of noise impacts based on population because each city has a different total population. The prevalences of populations with high levels of annoyance or of sleep disturbance (Table 2) represent the percentages of people experiencing each of the two effects against the total daytime and nighttime populations of individual cities, respectively.

On the basis of prevalence, the city of College Park was discovered to be the community most negatively affected, 11.3% and 3.7% of the daytime and nighttime populations, respectively, compared with other urban neighborhoods. The cities of Sandy Springs and Hapeville followed it with 11.3% and 11.0% of the population highly annoyed during the daytime; the cities of Atlanta and Alpharetta showed 10.2% and 9.7% affected, respectively. At nighttime, the cities of Sandy Springs, Atlanta, and Union City and Hapeville followed College Park, and they had a higher prevalence than Fulton County of people with sleep disturbance.

Figure 2 depicts the geographic distributions of the populations affected by road traffic noise, and it also shows their hot and cold spots based on Getis-Ord Gi* analysis. Many of the people affected appeared inside I-285: ~75,171 highly annoyed and ~12,583 with high levels of sleep disturbance (Figures 2a and 2b). Those people contributed to 68% and 64%, respectively, for the total populations of Fulton County experiencing high levels of annoyance and sleep disturbance. The present study revealed that the proportion of vehicle volume (n≈136,435,400) within that area was 60% of the total volume of the county (n≈226,059,100) at daytime. The nighttime vehicle volume of the area (n≈26,968,900) contributed to 62% of that of Fulton County (n≈43,536,000).

The Getis-Ord Gi* analysis results (Figures 2c and 2d) show that a large number of hot spots for annoyance and sleep disturbance were located within the I-285 boundary, although the cold spots for annoyance were larger in area than those for sleep disturbance. The area inside the I-285 boundary includes the cities of College Park, Atlanta, Hapeville, and East Point, which had higher

Table 2. City-level effects of road traffic noise on population annoyance and sleep disturbance in Fulton County GA

	Daytime high annoyance			Nighttime sleep disturbance		
City	Total population	Population affected	Prevalence (%)	Total population	Population affected	Prevalence (%)
Alpharetta	807	78	9.7	486	7	1.5
Atlanta	6,553	670	10.2	4,057	113	2.8
Chattahoochee Hills	7	0.04	0.6	21	0.04	0.2
College Park	259	29	11.3	200	7	3.7
East Point	345	29	8.4	402	9	2.2
Fairburn	70	5	6.9	68	1	1.0
Hapeville	82	9	11.0	61	2	2.5
Johns Creek	569	34	5.9	602	5	0.9
Milton	209	12	5.7	173	0	0.3
Palmetto	24	1	5.2	34	0	0.4
Roswell	747	55	7.4	846	14	1.6
Sandy Springs	1,093	123	11.3	908	27	2.9
Union City	106	9	8.5	147	4	2.8
Fulton County	11,526	1,100	9.5	8,572	196	2.3

Note: Population given as *n*, in 100s.

prevalences of populations experiencing each of the two effects. A portion of Sandy Springs City is also contained in that area.

Discussion

This research demonstrated that the overall road traffic noise of a highly urbanized area (i.e., Fulton County [greater Atlanta] GA) can be substantial, which might be indicative of poor environmental quality in this urban community. However, it may be a mistake to assume that environmental noise exists only in the heart of cities. In 2007, one study of noise levels in rural Chittenden County Vermont, found daytime levels exceeding 55 dB(A) in 20% of residential buildings and nighttime levels exceeding 45 dB(A) in 30% of building units.[18]

Another study[16] in the same year predicted highly annoyed populations in San Francisco CA using a model-based road traffic noise map and Year 2000 block-level census population data. The percentage of highly annoyed people was estimated at 17% (132,044 people). Nonetheless, in this study, no sleep-disturbance indicators were included. For Fulton County, the current research estimated the percentage and overall populations of those who had high levels of annoyance or sleep disturbance at 9.5% (n=109,967) and 2.3% (n=19,621), respectively. Thus, two research teams found populations that were considerably affected in two urban communities: San Francisco[16] and Fulton County. Together, these two studies give surprising insights into how severe road traffic noise affects urban communities.

These results give rise to the following question: how severe are the potential impacts of ground vehicular traffic noise in other large U.S. urban communities? The summary of the American Housing Survey (AHS) from the U.S. Census Bureau (Figure 3) provides a partial answer to this question. It summarizes data from the AHS questions of vehicular traffic noise on the street for 38 metropolitan areas, focusing on the percentage of noise presence, the percentage of those who deemed it bothersome, and the percentage of those who want to move because of being bothered by noise. Taking into account the summary, the current research results, and the fact that the Atlanta metropolitan area had the lowest percentage of households (14%) reporting the presence of road traffic noise among all surveyed households, it may be assumed that even more people would be annoyed in other densely populated U.S. metropolitan areas.

The two psychosocial effects of road traffic noise (i.e., annoyance and sleep disturbance) have been associated with negative health outcomes and may lead to the development of certain chronic diseases. Results from multiple studies have demonstrated these and other risks. Long-term exposure to noise could increase the risks of myocardial

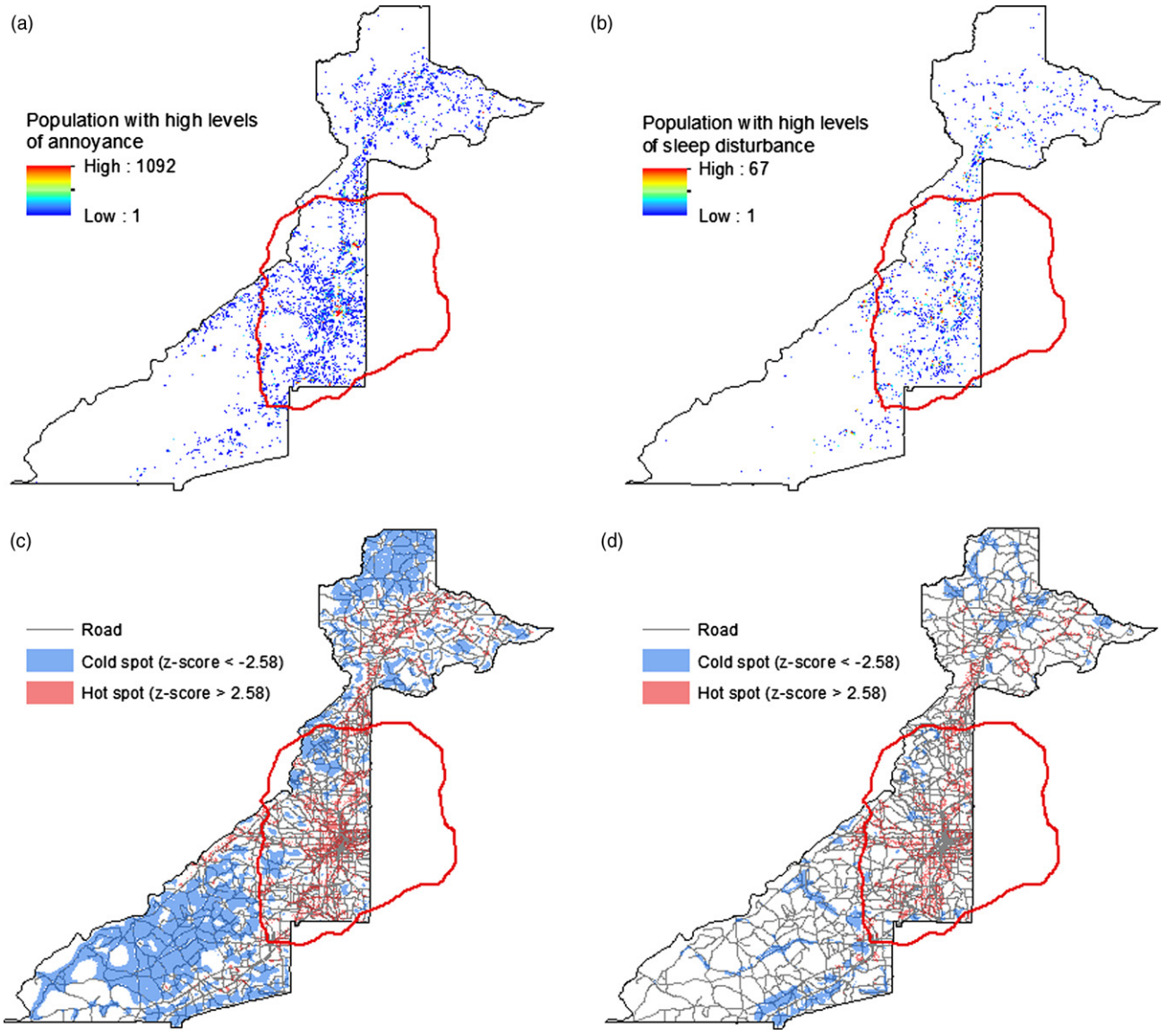

Figure 2. Geographic distributions of noise traffic effects on the population of Fulton County GA

Note: (a) High annoyance levels, with hot and cold spots (c); (b) high levels of sleep disturbance, with hot and cold spots (d). In (a) and (b), a white background indicates areas without populations with high levels of annoyance or sleep disturbance; each hot and cold spot was significant at $p<0.01$ (99% CI). The values in (a) and (b) indicate the range of the number of people with high levels of annoyance (1–1092) or sleep disturbance (1–67) in a given area, as shown by the color coding.

infarction,[19–21] high blood pressure,[22] hypertension,[23,24] and ischemic heart disease.[25,26] Nighttime noise was discovered to reduce sleep quality[27] and increase morning tiredness[28] and insomnia.[29] Most studies associated annoyance and sleep disturbance with an acoustic factor (i.e., noise levels), but the sensitivities of individual people, as a non-acoustic factor, may need to be considered in assessing noise impacts.[30] In addition, it is necessary to disentangle the links between air pollution, noise, and adverse health outcomes because the major determinant of the noise is from transportation, particularly automobiles.

The current study has limitations to consider. One is that the computations of percentages of those with high levels of annoyance and of sleep disturbance were largely based on road traffic noise surveys of European countries. Additionally, the vehicle types of Fulton County came from the Atlanta Regional Commission, and it included passenger cars, medium trucks, and heavy trucks. Therefore, the other road traffic types such as buses and motorcycles could not be used in noise-level predictions. LandScan population data were a major source of population distribution in this study, but detailed building-based population data

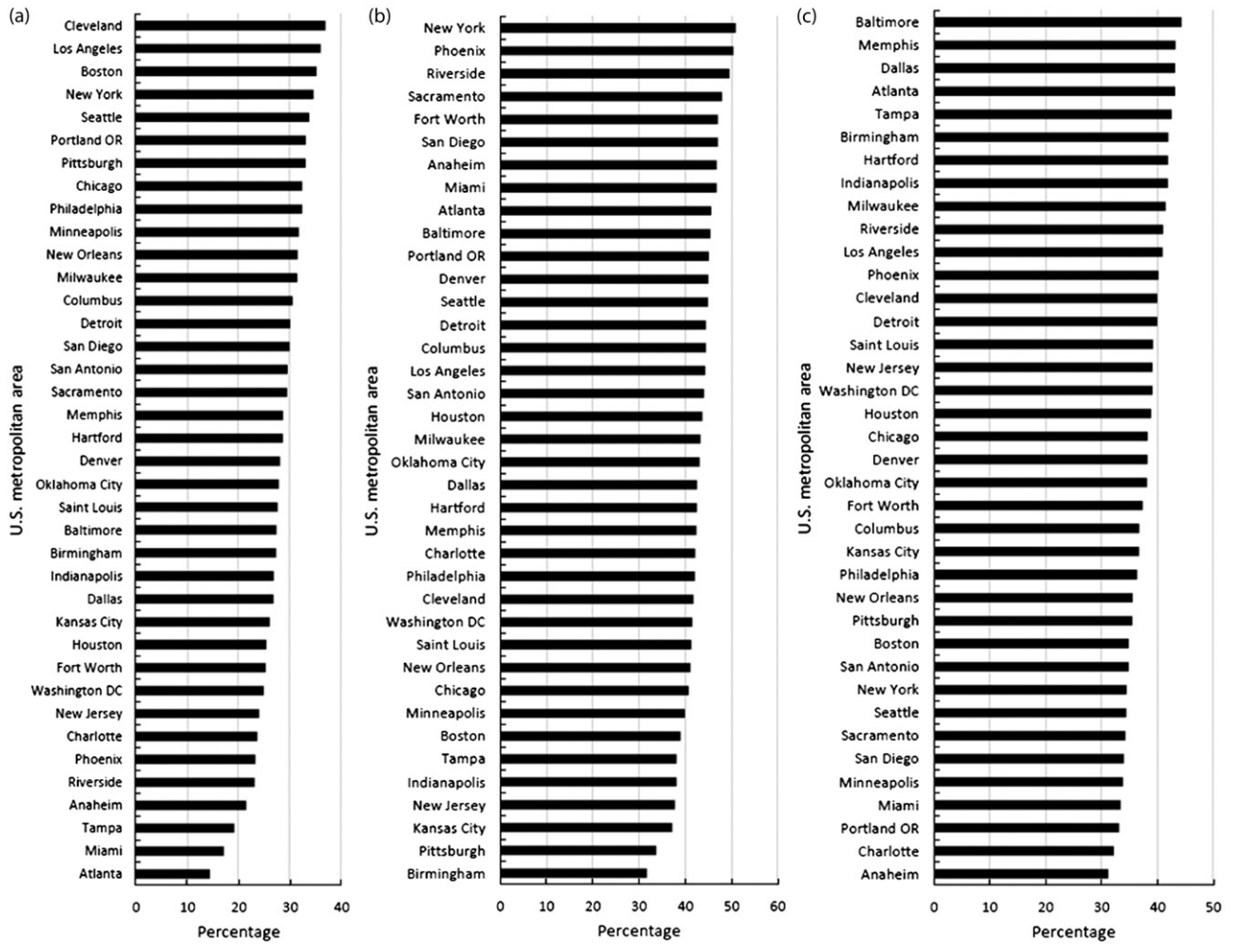

Figure 3. Summary of American Housing Survey (AHS) for 38 metropolitan areas in the U.S.
Note: Conducted by U.S. Census Bureau: (a) the percentage feeling the presence of noise among total surveyed housing units; (b) the percentage of those bothered by noise among units with noise present; and (c) the percentage of those, among (b), who want to move out of their current housing units

would be preferable in estimating populations exposed to and affected by road traffic noise in order to obtain more-accurate prediction results.

This research did not consider the effect of railway and aircraft noises on annoyance and sleep disturbance. In Fulton County, a railway network appears within the boundary of I-285, and Hartsfield-Jackson International Airport is located near the cities of College Park and Hapeville. Therefore, the combination of road, railway, and aircraft transportation may affect more people in terms of annoyance and sleep disturbance.

Conclusion

This study demonstrated that urban communities in the U.S. might be at risk of high exposures to road traffic noise. However, more studies will be required to gain insights into the severity of road traffic noise in U.S. urban communities that is related to populations with high levels of annoyance and sleep disturbance. Besides road traffic, the subway system of New York City was found to produce noise levels high enough to cause noise-induced hearing loss for riders.[31] Therefore, it may not be easy to avoid traffic-related noise, particularly in urbanized cities of the modern world.

Compared with European countries, the U.S. has lagged behind in environmental noise research. These findings suggest a need for more extensive traffic-related noise research and discussion of how such research can inform potential urban planning policies that could prevent or reduce noise problems in urban communities. Researchers may need to collaborate with local governments or institutions when conducting similar studies because most data sets related to traffic-related noise mapping are not open to the public, which may have potentially fine-scale population data (e.g., LandScan). Adequate restful sleep[32] (about 7–9 hours for adults) and mental well-being[33] are as essential to good health as adequate nutrition and physical activity. Assessing and

alleviating environmental noise is an essential element for improving or creating healthy communities where adults and children can work, play, and live.

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