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Mapping of transportation noise-induced health risks as an alternative tool for risk communication with local residents

Farah Elida Selamat [a], Junta Tagusari [b,*], Toshihito Matsui [b]

[a] Graduate School of Engineering, Hokkaido University, Hokkaido, Japan
[b] Faculty of Engineering, Hokkaido University, Hokkaido, Japan

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ABSTRACT

Environmental noise can adversely affect human health and well-being. It is typically quantified by evaluation through strategic noise mapping, indicating the sound level; however, most of the local residents of an area do not understand the significance of sound level because they are unfamiliar with the relationship between sound level and health risks. Therefore, dissemination of information regarding the local health risks due to noise exposure is extremely important for effective risk communication. This study aims to transform noise maps into risk maps indicating the health risks to improve the risk communication with local residents. To this end, we developed a noise map, applied the exposure–response functions established by the World Health Organisation Regional Office for Europe to convert the sound levels into health risks and, finally, obtained the geospatial distribution of the health risks: health risk maps. Subsequently, we investigated the health risks due to road traffic noise in Sapporo City, Japan. High annoyance, high sleep disturbance, and ischaemic heart disease (IHD) were the observable health outcomes. In contrast to ordinary noise maps indicating the sound level, the health risk maps exhibited the percentages of highly annoyed and highly sleep-disturbed people and revealed the prevalence and mortality rates for IHD. In addition, the total number of residents affected by noise exposure was obtained using these health risk maps. To our knowledge, this is the first study showing health risks due to the road traffic noise of an entire city in Japan. The health risk maps can help the public realise the significant impact noise exposure has on general health. Furthermore, they can be utilised to demonstrate the potential reduction of the risks in future noise mitigation strategies.

1. Introduction

Recently, environmental noise has been recognised as a serious public health issue that needs to be addressed publicly. The World Health Organisation Regional Office for Europe (WHO-EU) has issued Environmental Noise Guidelines [1], which include various noise-induced health effects, ranging from sleep disturbance to cardiovascular diseases.

Globally, a large number of people are exposed to traffic noise even while they are in their homes; this can affect their health and well-being. In western European countries, traffic noise is the second worst environmental pollutant [2] and causes a considerable loss of at least one million healthy years of life every year [3]. A health impact estimation of 32 European countries showed that long-term exposure to environmental noise causes approximately 12,000 premature deaths and contributes to another 48,000 new cases of ischaemic heart disease (IHD) annually [4].

To reduce environmental noise pollution, the European Union issued the Environmental Noise Directive in 2002 (Directive 2002/49/EC). The Directive requires Member States to develop strategic noise maps for the assessment and management of environmental noise to protect the health of citizens [5]. At present, noise maps are used for the pre-evaluation of acoustic plans to mitigate the adverse noise impacts on the local residents of an area [6–11].

The sound level around residential houses can be compared with the standard noise level using a noise map. However, sound level estimation is not useful in risk communication with the public because a noise map typically displays acoustic intensity instead of the potential health effects. Therefore, explaining the health risks to residents using noise maps is challenging for effective risk communication because residents are typically unfamiliar with the relationships between sound levels and health risks. Moreover, local residents find noise maps incomprehensible as

* Corresponding author.
E-mail address: j.tagusari@eng.hokudai.ac.jp (J. Tagusari).

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they are unable to recognise the quantitative health impacts from an ordinary noise map. Therefore, information regarding the health risks needs to be appropriately structured to be understandable to the public [12,13]. Thus, an alternative tool that displays the health risks transparently, i.e. maps, would be invaluable for enhancing risk communication [14,15].

This study was conducted to develop an alternative tool for enhancing risk communication by visualising the health risks due to environmental noise in health risk maps translated from ordinary noise maps. The risk maps are expected to exhibit numerical information of specific adverse health risks that may affect an entire community, thereby serving a variety of risk communication purposes. To this end, we developed a road traffic noise map and health risk maps of Sapporo City (area: 1121 km^2), Japan. To convert the sound level into risks, the exposure–response functions established by the WHO-EU [1] and national and global health statistics and surveys in Japan were employed. Here, we propose the development of risk maps instead of noise maps for convenient understanding of the adverse noise impacts on a community's health. To the best of our knowledge, this is the first study showing the road traffic noise map of an entire city in Japan.

2. Materials and methods

2.1. Façade noise map

Our study area was Sapporo City, which is located in Hokkaido-the northernmost island of Japan. It has an area of 1121 km^2 and the total population is currently 1.97 million. First, we estimated the sound level and developed a noise map. The expressways and trunk roads for which the traffic volume information was available, were considered (see Fig. 1).

First, we estimated the noise emission using the Common Noise Assessment Methods in the EU (CNOSSOS-EU). The geometrical information (i.e. height and width) of the roads was obtained from the 2015 Digital Road Map Database issued by the Japan Digital Road Map Association. The database was linked with the road traffic volumes measured in the 2010 Road Traffic Census, issued by the Road Bureau, Ministry of Land, Infrastructure, Transport and Tourism of Japan. The total length of the roads included in the calculation was 712.5 km, and the average traffic volumes of the roads are in the range of 0.5–19.8 million vehicles per year. Based on the typical vehicle speed limits in Japan, we assumed the average speeds of 60 km/h and 100 km/h for the vehicles on trunk roads and expressways, respectively.

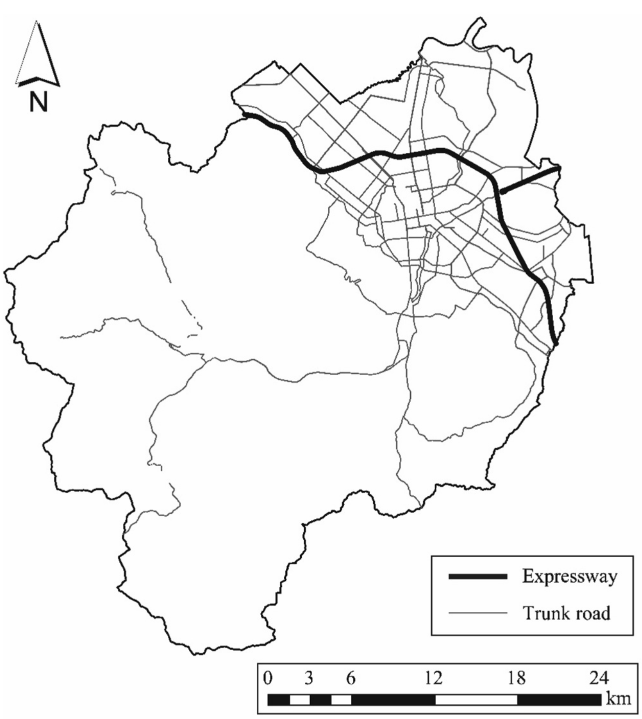

Fig. 1. Road network in Sapporo City, the study area.

CNOSSOS-EU was also used to estimate the noise propagation. A 10.0 m grid topographic base map, issued by the Geospatial Information Authority of Japan, Ministry of Land, Infrastructure, Transport and Tourism, was used for the ground elevation data in the calculation. The building geodata, including the heights, were obtained from Zmap–AREAII version 2015–3 (Zenrin, Tokyo).

The annual average metrics of the day–evening–night equivalent sound level (L_{den}) and night-time equivalent sound level (L_{night}) of the most noisy façade of each building in the whole city area were calculated to estimate the health risks according to the exposure–response relationships in the guidelines issued by the WHO-EU [1].

All calculations were performed with ArcGIS 10.4.2 (ESRI Japan, Tokyo) and SoundPLAN 8.1 (Ono Sokki, Tokyo).

2.2. Health risk map

We developed health risk maps by converting the sound level to health risks. The procedure employed is depicted in Fig. 2. We selected high annoyance (HA), high sleep disturbance (HSD), and IHD as noise-induced health effects in our study because their exposure–response relationships with the sound level were available in the guidelines [1]. The health risks were estimated by employing the exposure–response relationships between the sound level at the building façade and health risks established by the WHO-EU [1]. Furthermore, the health risk maps exhibit the geospatial distribution of the health risks: the prevalence and mortality rates for IHD and the percentages of high annoyance (%HA) and high sleep disturbance (%HSD) in the residents.

The exposure–response relationships between the façade sound level and health risks (the percentages of high annoyance (%HA) and high sleep disturbance (%HSD) and the relative risk (RR) of the incidence of IHD) are as follows:

$$\%HA = 78.9270 - 3.1162 \times L_{den} + 0.0342 \times {L_{den}}^2 \text{ in the range of } 40\text{ dB} \le L_{den} \le 80\text{ dB} \quad (1)$$

$$\%HSD = 19.4312 - 0.9336 \times L_{night} + 0.0126 \times {L_{night}}^2 \text{ in the range of } 40\text{ dB} \le L_{night} \le 65\text{dB} \quad (2)$$

$$RR = 1.08^{(L_{den}-53)/10} \text{ in the range of } L_{den} \ge 53\text{dB} \quad (3)$$

The risks of the HA and HSD were directly shown with the %HA and %HSD, whereas those of the IHD (prevalence and mortality rates) were estimated using the population attributable risk [16] and the national and global health statistics of the total number of patients and deaths in Japan. The statistics for the number of patients and deaths were obtained from the 2014 triennial Patient Survey issued by the Ministry of Health, Labour and Welfare, Japan and the WHO Global Health Estimates 2015: Deaths by Cause, Age, Sex, by Country and by Region, 2000–2015, respectively. The average prevalence and mortality rates for the IHD in the country were estimated to be 610 and 120 per 100,000 people, respectively.

We also estimated the number of affected residents in Sapporo City using the health risk maps. The population of each building was estimated by assuming the population of a building in a block

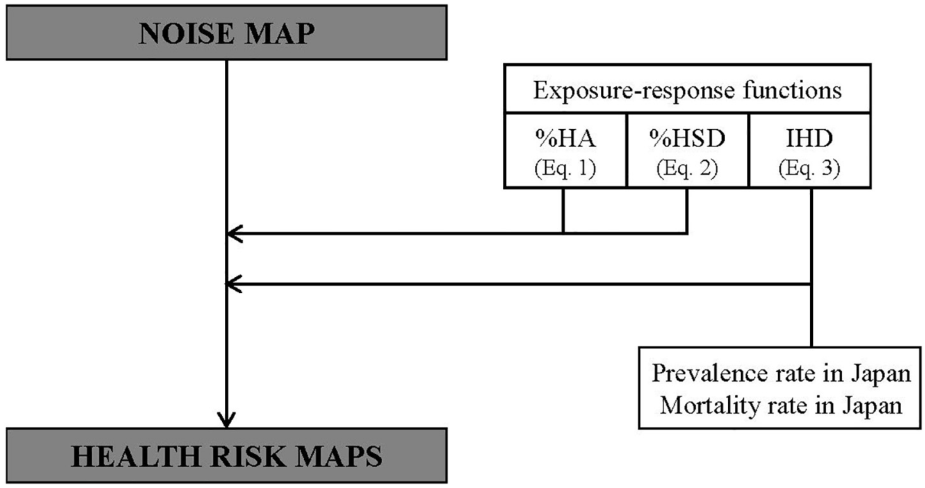

Fig. 2. Schematic diagram of the procedure used to generate health risk maps from noise maps by applying the exposure–response functions on health impacts due to noise. To estimate the risk of IHD, the prevalence rate and mortality rate were employed.

area to be proportional to the floor area in the block area population. We obtained the floor area of each building from the geodata (Zmap–AREAII version 2015–3, Zenrin, Tokyo) and the population of block areas from the 2015 National Population Census issued by the Statistics Bureau of Japan, Ministry of Internal Affairs and Communications.

Fig. 3. An example of the façade noise map of the road traffic noise in Sapporo City in L_{den}.

3. Results and discussion

3.1. Façade noise maps

Figs. 3 and 4 show sample façade noise maps in Sapporo City for L_{den} and L_{night}, respectively. The façade noise maps show a highly noise-exposed area, for which the total average traffic flow was approximately 11.5 million vehicles per year, adjacent to the interconnected expressways and trunk roads. It should be noted that the shapes of the buildings were replaced with the geographic information provided by the Geospatial Information Authority of Japan for copyright protection.

The map developed here is the first large-scale road traffic noise map in Japan; this directly contrasts with previous studies which roughly estimated the sound level in small areas [17–19]. Despite the availability of traffic and geometrical information to estimate them, information regarding the sound level and health risks due to noise exposure was not disseminated previously in Japan.

While the policy makers can estimate the impacts of noise exposure on health using the façade noise maps, the local residents will experience difficulty understanding the health risks from an ordinary noise map that exhibits the acoustic intensity instead of the health effects. Comprehensive estimation of the health risks is extremely important in communicating the health risks to the public.

3.2. Health risk maps

Fig. 5 displays health risk maps for HA and HSD of the same area shown in Figs. 3 and 4. Fig. 6 exhibits the prevalence and mortality rates per 100,000 people in the risk maps for the IHD of the exact same area as in Figs. 3 and 4. In these health risk maps, the buildings are shown in different colour shades indicating different risk levels to the residents of the buildings. The colour shades from light to dark correspond to the low- to high-risk levels.

Therefore, the geospatial distribution of the health risks are visualised using the health risk maps, while the mean acoustic intensities are shown in Figs. 3 and 4. For instance, %HA of approximately 15.0% instead of 60 dB L_{den} and %HSD of approximately 6.0% instead of 55 dB L_{night} were estimated. Furthermore, in terms of the risk of IHD, a prevalence rate of 60 per 100,000 people instead of 65.1 dB L_{den} and 10 deaths per 100,000 people instead of 63.5 dB L_{den} were approximated.

An enlarged view of the mortality risk map at another highly noise-exposed area is shown in Fig. 7 to distinguish between the mortality risk levels of residents of different buildings.

Evidently, residents of building C with a mortality rate of >5 per 100,000 people are less susceptible to death from noise-induced IHD as compared to those living in buildings A and B. This is because the residents in buildings A and B have mortality rates of >20 and 10 per 100,000 people, respectively. Therefore, individ-

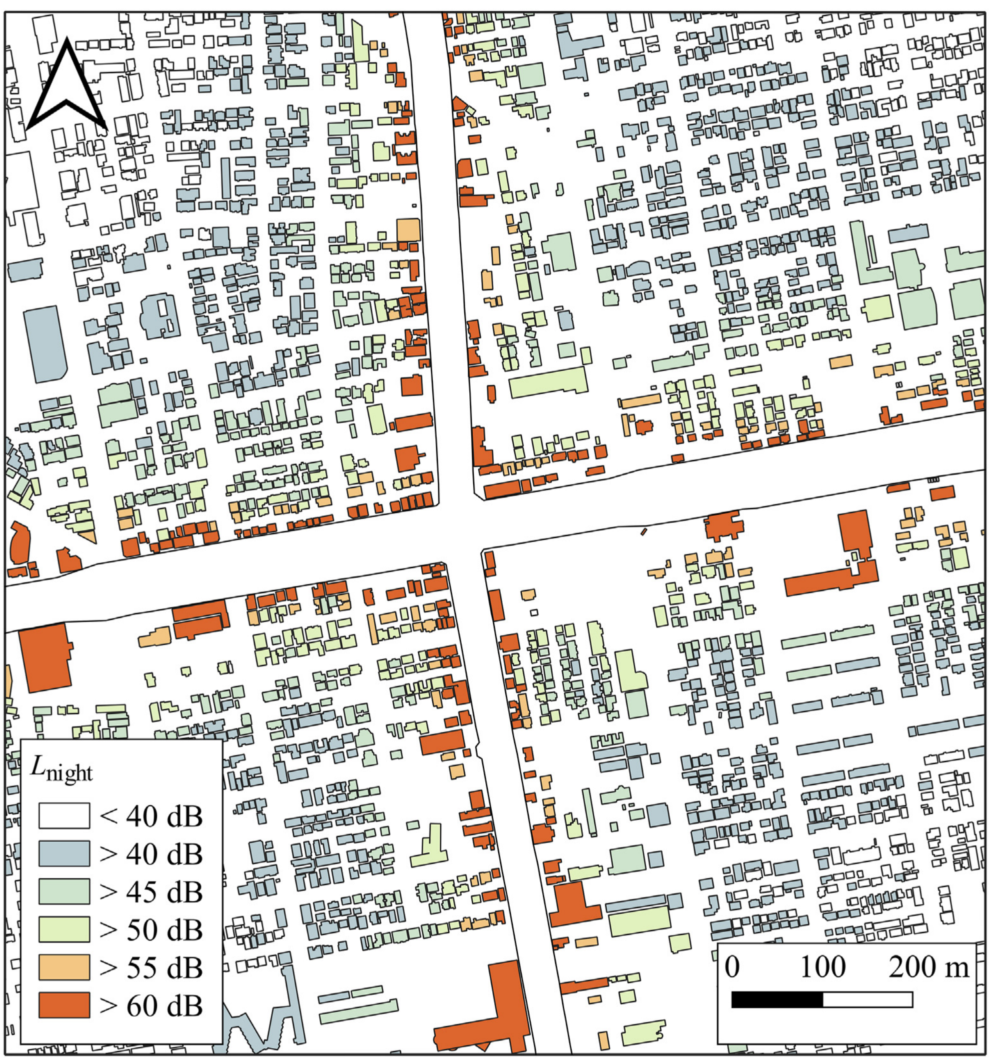

Fig. 4. An example of the façade noise map of the road traffic noise in Sapporo City in L_{night}.

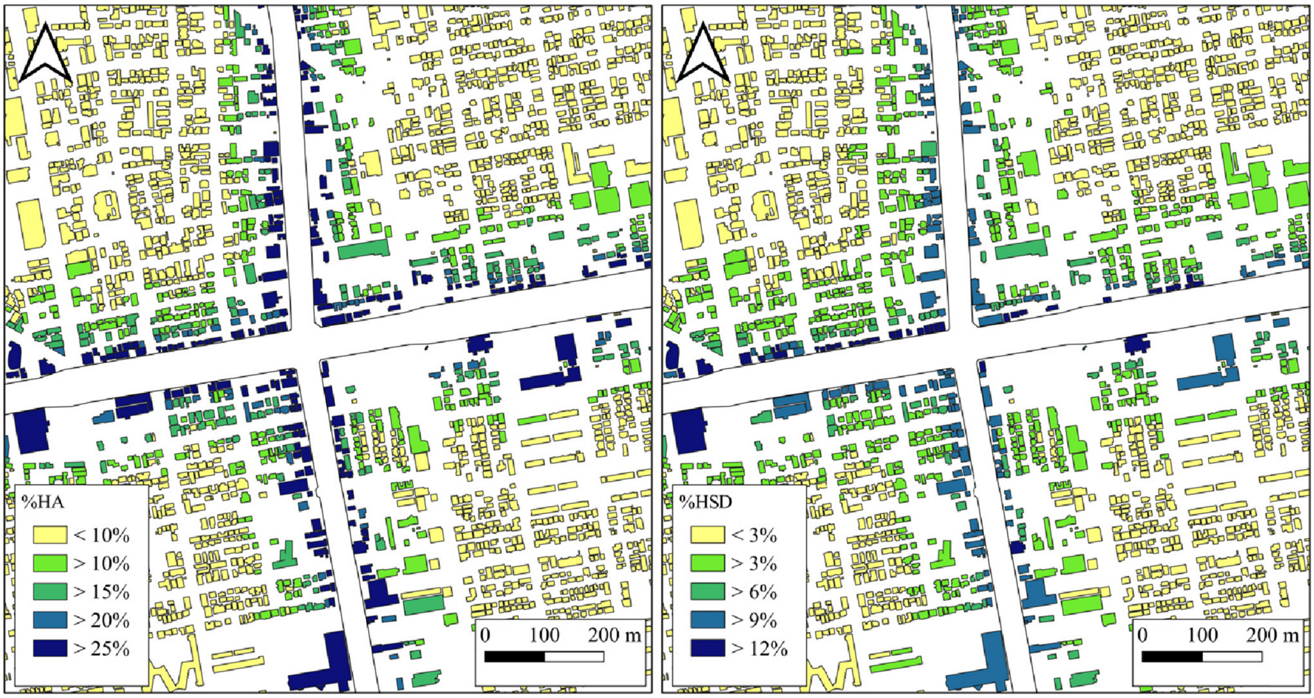

Fig. 5. An example of the health risk maps for the percentage of people highly annoyed (%HA) (left panel) and highly sleep-disturbed (%HSD) (right panel) at a highly noise-exposed area in Sapporo City.

ual health risks can be recognised owing to the spatially precise risk estimation.

Table 1 lists the number of mortalities and mortality rates due to various causes of death in Sapporo City as reported in the 2015 Demographics Statistics issued by the Ministry of Health, Labour and Welfare. These statistics can be compared with the health risk maps (see Figs. 6 and 7) to obtain an estimate of the severity of the noise-induced health risks. For instance, in the highly exposed areas, where the mortality rate of IHD is >20 per 100,000 people, the health risk due to noise exposure is equivalent to that due to kidney failure and is significantly higher than that due to leukaemia, traffic accidents, influenza, and tuberculosis in terms of the mortality rate. This comparison can educate local residents regarding the gravity of the noise-induced health risks in their houses.

The greatest advantage of the health risk maps is that they can avoid potential misinterpretation of the risks from the noise maps by directly showing the health risks. The goal of risk communication is to assist stakeholders in taking risk-based decisions based on a balanced judgement, which results from factual evidence regarding the risks [20–22]. Communicating the risks based on ordinary noise maps may lead to misperception of the risks and subsequent inaccurate judgements in those situations by the public.

Another aspect that affects risk communication is the trustworthiness and credibility of the communicated information [15,23,24]. Significant public trust can be gained using health risk mapping owing to the transparent and convenient visualisation of the health risk distribution. The health risk maps graphically quantify the risks of each building and can help the public to comprehend the gravity of the health risks due to noise exposure.

The visualisation of health risks through health risk mapping clearly reveals the risks posed to the community. For environmental risk factors, the acceptable 'lifetime risk' is 1 per 100,000 people [25]. Therefore, local residents can realise the risks they are facing by comparing the health risk map for mortality rate due to noise-induced IHD and the acceptable lifetime risk. The health risk maps can be effective in public health risk communication as they can contribute to knowledge-sharing between local communities and can help in raising public awareness.

Although we employed the exposure–response relationships established by the WHO-EU, uncertainties remain in the risk estimations. Naturally, vulnerable groups of people (i.e. the elderly, new-born babies, and those with illnesses) are more at risk from noise exposure than healthy adults. In addition, the health risk maps depend heavily on several factors, such as the availability and quality of the information on population, exposure, and health, which may contribute to a misclassification of the severity of risks and can, subsequently, affect the reliability of the health risk maps. Therefore, information regarding the reliability should be provided in the risk communication.

Moreover, as the methodology substantially depends on data availability, not all the noise sources can be considered for estimating the health risks. Therefore, the noise sources should be specified while communicating the risks to the local residents. Graphical representation of risk communication (maps in particular) is acknowledged for its usefulness in several fields, such as public health, environmental pollution, and meteorological risk assessment [14,15]. Disease mapping and mapping for risk communication regarding various natural hazards, such as wildfires [26], floods [27,28], and volcanic eruptions [29,30], are common practices, and they are evolving with time. Regarding environmental exposures and health risks, there are a few studies that provide health risk information to the public (specifically, asthma and cancer risk in relation to air pollutants [31,32]). Numerous studies have been conducted on the overall communication effectiveness of risk maps for the general public [31,33–36].

Thus far, only a handful of studies have mapped the health risks due to road traffic noise [37,38]. However, those maps are not intended for use in risk communication, where numerically and spatially precise estimations of the health risks are required. Although this study introduced health risk maps as an alternative tool to enhance risk communication, the effectiveness of this approach should be further investigated. The skills to interpret risk maps would vary for both health and environmental health literacy

Fig. 6. An example of the health risk maps for the prevalence rate (left panel) and mortality rate (right panel) of the IHD due to noise exposure at a highly noise-exposed area in Sapporo City.

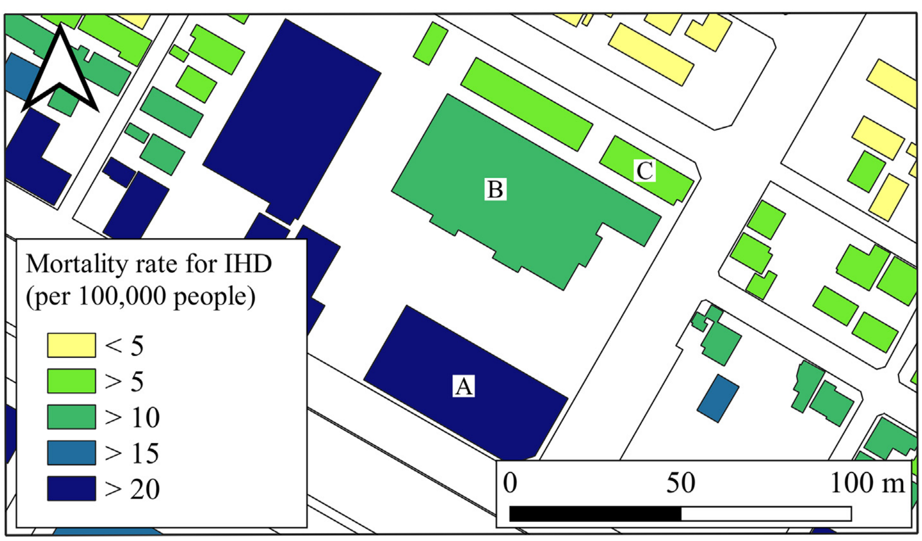

Fig. 7. Enlarged view of mortality risk map displaying the mortality rate of the IHD for different buildings at a highly noise-exposed area in Sapporo City.

in accordance with personal characteristics, including age, language proficiency, education level, and socio-economic status [14]. It is necessary to examine and establish a framework for risk communication of noise exposure using risk maps.

3.3. Estimated population exposed to noise, number of patients, and deaths

In this study, we carried out numerical calculations on the health risks in Sapporo City. It should be noted that this is the first study to reveal health risks due to road traffic noise in an entire Japanese city. Tables 2 and 3 list the estimated exposed population and health risks attributed to road traffic noise in Sapporo City for L_{den} and L_{night}, respectively, in 5 dB ranges.

The data show that approximately 27% of the total population are exposed daily to road traffic noise levels higher than the threshold of the health effects, i.e. L_{den} > 55 dB, whereas approximately 49% of the total population of Sapporo City are exposed to L_{night} > 40 dB.

High annoyance and sleep disturbance are the leading health effects due to road traffic noise, of which affected populations were estimated to be approximately 110 thousand and 48 thousand, respectively, in Sapporo City. Although the relationship between annoyance and noise-induced diseases such as cardiovascular diseases remains unclear, road traffic noise would threaten the

Table 1
Number of deaths and mortality rates due to various causes in Sapporo City for a comparison with the noise-induced health risks.

Cause of death	Number of deaths	Mortality rate*
Cancers	5769	296.8
Ischaemic heart diseases **	1675	86.1
Stroke	1361	70.0
Kidney failure	418	21.5
Suicide	322	16.6
Leukaemia	118	6.1
Traffic accident	49	2.5
Influenza	17	0.9
Tuberculosis	14	0.7
Total	17,523	901.6

* Per 100,000 person-year.

well-being of a significant proportion of people in the city. The number of patients with sleep disorders due to noise would be very large and important for public health because high sleep disturbance is also regarded as a mild sleep disorder [3].

The numbers of patients and deaths due to IHD were approximately 300 and 60, which eventually results in total prevalence and mortality rates of 15.1 and 2.9 per 100,000 people. The estimated mortality rates of IHD due to road traffic noise were 1.4 per 100,000 in Japan [39], and 1.9 per 100,000 in European countries [4]. Given that the estimation of the present study is mainly for the urban areas, the result would be consistent with the existing studies. The overall mortality risk of IHD due to road traffic noise in Sapporo City is higher than that of traffic accidents, influenza, and tuberculosis (see Table 1). It should also be noted that it is higher than the typical acceptable lifetime risk of environmental risk factors of 1 per 100,000 people [25]. Our results provide evidence that the total risk of road traffic noise in Sapporo City cannot be left unaddressed and needs to be reduced with high priority.

Moreover, as also shown in the risk maps, the affected people are concentrated in the areas highly exposed to road traffic noise. That is, 2/3 of deaths due to noise-induced IHD are concentrated in 12% of the people, who are exposed to L_{den} of higher than 65 dB. The estimated mortality risk in the areas is higher than 10 per 100,000, which is higher than the major causes of deaths (see Table 1). Risk communication with local communities is desirable to prevent and/or mitigate the health risks, in particular for the people highly exposed to environmental noise.

4. Conclusion

Noise-induced health issues are a threat to the community; thus, the public should be aware of the adverse impacts of noise on their health for a better understanding of the risk level to which they are exposed. In this study, we proposed health risk mapping, which is a potential alternative communication approach to a noise map. Health risk mapping uses scientific evidence to quantify the noise impacts on health and to identify and assess health risks for effective public health risk communication. Because health risks are graphically displayed in health risk maps, it is easier for the public to comprehend the significance of health risk maps than noise maps.

Our proposal to develop health risk maps is not limited to the road traffic noise and health risks mentioned in this study. These maps are also applicable to other types of transportation noise, such as railway and aircraft noise, and health risks. However, the limitations of reliable data and their analysis and the uncertainty in estimation of the health risks need to be addressed before expanding this method. Hereafter, risk communication using such an easily comprehensible tool can be employed by local communities to raise awareness in general people on the adverse health effects of noise exposure and to design policies for reducing the noise exposure. Nevertheless, the efficiency of health risk maps as an alternative risk communication tool and public opinion and acceptance pertaining to this method should be further examined. This can be done by, for example, measuring the public risk percep-

Table 2
Estimated population exposure to health risks in Sapporo City due to road traffic noise for L_{den}.

	L_{den} (dB)						Total
	<55	55–60	60–65	65–70	70–75	>75	
Exposed population	1,432,928	169,184	111,452	111,267	126,123	1,402	1,952,356
Population percentage (%)	73.4	8.7	5.7	5.7	6.5	0.1	100
Highly annoyed							
Percentage affected (%)	0.0	12.82	17.76	24.41	32.77	42.84	–
Number of affected	0	21,688	19,792	27,157	41,326	601	110,564
Ischemic heart disease							
Relative risk	1.00	1.04	1.08	1.12	1.16	1.21	–
Number of patients	0	37	52	80	125	2	296
Number of deaths	0	7	10	16	24	0	57
Prevalence rate*	0.0	21.6	46.5	72.3	99.2	127.1	15.1***
Mortality rate**	0.0	4.2	9.0	14.0	19.3	24.7	2.9***

* Per 100,000 person.
** Per 100,000 person-year.
*** Total average.

Table 3
Estimated population exposure to health risks in Sapporo City due to road traffic noise for L_{night}.

	L_{night} (dB)						Total
	<40	40–45	45–50	50–55	55–60	>60	
Exposed population	1,004,463	344,011	201,719	129,353	86,128	186,682	1,952,356
Population percentage (%)	51.4	17.6	10.3	6.6	4.4	9.6	100
Highly sleep-disturbed							
Percentage affected (%)	0.0	2.51	3.51	5.15	7.41	10.30	–
Number of affected	0	8641	7088	6656	6380	19,228	47,995

tion following pre- and post-risk communication with the ordinary noise maps and health risk maps, respectively.

This is also the first study showing the health risks due to road traffic noise in a Japanese city using recent evidence provided by the WHO-EU. The prevalence and mortality rates of IHD in Sapporo City were estimated to be 15.1 and 2.9 per 100,000 people, respectively. Considering the remarkably large number of people exposed to high noise levels, the burden of disease is substantial despite the relatively small prevalence and mortality rates. Therefore, we infer that noise-induced IHD morbidity and mortality are significantly worrying, and adoption of appropriate prevention measures is of utmost importance. Health risk estimations all over Japan are desirable to evaluate the risks of environmental noise and to enforce mitigation policies.

CRediT authorship contribution statement

Farah Elida Selamat: Formal analysis, Investigation, Writing - original draft. **Junta Tagusari:** Data curation, Validation, Writing - review & editing. **Toshihito Matsui:** Conceptualization, Methodology, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] World Health Organization. Environmental noise guidelines for the European region. Copenhagen: WHO Regional Office for Europe; 2018.
[2] Hänninen O, Knol AB, Jantunen M, Lim T-A, Conrad A, Rappolder M, Carrer P, Fanetti A-C, Kim R, Buekers J, Torfs R, Iavarone I, Classen T, Hornberg C, Mekel OCL. Environmental Burden of Disease in Europe: Assessing Nine Risk Factors in Six Countries. Environ Health Perspect 2014;122(5):439–46. https://doi.org/10.1289/ehp.1206154.
[3] World Health Organization. Burden of disease from environmental noise: Quantification of healthy life years lost in Europe. Copenhagen: WHO Regional Office for Europe; 2011.
[4] European Environment Agency. Environmental noise in Europe — 2020. Luxembourg: Publications Office of the European Union; 2020.
[5] European Commission. Directive 2002/49/EC of the European Parliament and the Council of 25 June 2002 relating to the assessment and management of environmental noise. In: Official Journal of the European Communities. Brussels: The European Parliament and the Council of the European Union; 2002.
[6] Paschalidou AK, Kassomenos P, Chonianaki F. Strategic Noise Maps and Action Plans for the reduction of population exposure in a Mediterranean port city. Sci Total Environ 2019;654:144–53. https://doi.org/10.1016/j.scitotenv.2018.11.048.
[7] Murphy E, King EA. Scenario analysis and noise action planning: Modelling the impact of mitigation measures on population exposure. Appl Acoust 2011;72(8):487–94. https://doi.org/10.1016/j.apacoust.2010.10.006.
[8] Vogiatzis K, Remy N. From environmental noise abatement to soundscape creation through strategic noise mapping in medium urban agglomeration in South Europe. Sci Total Environ 2014;482:420–512.
[9] Rey Gozalo G, Barrigón Morillas JM, Trujillo Carmona J, Montes González D, Atanasio Moraga P, Gómez Escobar V, Vílchez-Gómez R, Méndez Sierra JA, Prieto-Gajardo C. Study on the relation between urban planning and noise level. Appl Acoust 2016;111:143–7. https://doi.org/10.1016/j.apacoust.2016.04.018.
[10] Di H, Liu X, Zhang J, Tong Z, Ji M, Li F, Feng T, Ma Q. Estimation of the quality of an urban acoustic environment based on traffic noise evaluation models. Appl Acoust 2018;141:115–24. https://doi.org/10.1016/j.apacoust.2018.07.010.
[11] Wang H, Chen H, Cai M. Evaluation of an urban traffic noise-exposed population based on points of interest and noise maps: the case of Guangzhou. Environ Pollut 2018;239:741–810.
[12] World Health Organization [Internet]. General information on risk communication; c2020 [cited 2020 Aug 20]. Available from: https://www.who.int/risk-communication/background/en/.
[13] World Health Organization. Health and environment: Communicating the risks. Copenhagen: WHO Regional Office for Europe; 2013.
[14] Stieb DM, Huang A, Hocking R, Crouse DL, Osornio-Vargas AR, Villeneuve PJ. Using maps to communicate environmental exposures and health risks: review and best-practice recommendations. Environ Res 2019;176:108518.
[15] Dransch D, Rotzoll H, Poser K. The contribution of maps to the challenges of risk communication to the public. Int J Digit Earth 2010;3(3):292–320.
[16] World Health Organization. Methodological guidance for estimating the burden of disease from environmental noise. Copenhagen: WHO Regional Office for Europe; 2012.
[17] Bhaskar A, Chung E, Kuwahara M. Development and implementation of the areawide Dynamic ROad traffic NoisE (DRONE) simulator. Transport Res D-Tr E 2007;12(5):371–8.
[18] Fujimoto K, Anai K. Geographic information system for evaluation of road traffic noise along the road. In: Forum Acusticum 2002, Sevilla, Spain; 2002.
[19] Oshino Y, Tsukui K, Hanabusa H, Bhaskar A, Chung E, Kuwahara M. Investigation into the noise map based on traffic flow prediction in the citywide road network. In: Euronoise 2006, 2006.
[20] OECD. Guidance document on risk communication for chemical risk management. Paris: Organization for Economic Co-Operation and Development (OECD), Environment Directorate; 2002. Report no. ENV/JM/MONO(2002)18.
[21] Paek HJ, Hove T. Risk perceptions and risk characteristics. Oxford Research Encyclopedia of Communication. New York: Oxford University Press USA; 2020.
[22] Sjöberg L. The allegedly simple structure of experts' risk perception: an urban legend in risk research. Sci Technol Hum Values 2002;27(4):443–517.
[23] Gamhewage G. An introduction to risk communication; c2020 [cited 2020 Aug 20]. Available from: http://www.who.int/risk-communication/background/en/.
[24] World Health Organization. Communicating risk in public health emergencies: a WHO guideline for emergency risk communication (ERC) policy and practice. Geneva: World Health Organization; 2017.
[25] Ministry of Environment, Japan.Setting environmental standards for substances without thresholds: a report by the expert committee on health risks (in Japanese). J Jpn Soc Atmos Environ 1997;32(4-2):3–5
[26] Mozumder P, Helton R, Berrens RP. Provision of a wildfire risk map: informing residents in the wildland urban interface. Risk Anal 2009;29(11):1588–613.
[27] Hagemeier-Klose M, Wagner K. Evaluation of flood hazard maps in print and web mapping services as information tools in flood risk communication. Nat Hazards Earth Syst Sci 2009;9(2):563–612.
[28] Macchione F, Costabile P, Costanzo C, De Santis R. Moving to 3-D flood hazard maps for enhancing risk communication. Environ Modell Softw 2019;111:510–3.
[29] Haynes K, Barclay J, Pidgeon N. Volcanic hazard communication using maps: an evaluation of their effectiveness. Bull Volcanol 2007;70(2):123–216.
[30] Nave R, Isaia R, Vilardo G, Barclay J. Re-assessing volcanic hazard maps for improving volcanic risk communication: application to Stromboli Island. Italy. J Maps 2010;6(1):260–310.
[31] Hammond D, Conlon K, Barzyk T, Chahine T, Zartarian V, Schultz B. Assessment and application of national environmental databases and mapping tools at the local level to two community case studies. Risk Anal 2011;31(3):475–513.
[32] Severtson DJ, Myers JD. The influence of uncertain map features on risk beliefs and perceived ambiguity for maps of modeled cancer risk from air pollution. Risk Anal 2013;33(5):818–20.
[33] Caley LM, Shiode N, Shelton JA. (2008). Community/campus partnership: tailoring geographic information systems for perinatal health planning. Prog Community Health Partnersh 2008;2(1):23-6.
[34] deLemos JL, Brugge D, Cajero M, Downs M, Durant JL, George CM, et al. Development of risk maps to minimize uranium exposures in the Navajo Churchrock mining district. Environ Health Glob Access Sci Source 2009;8(1):29.
[35] Milillo TM, Sinha G, Gardella Jr JA. Use of geostatistics for remediation planning to transcend urban political boundaries. Environ Pollut 2012;2012(170):52–110.
[36] Lieske DJ, Wade T, Roness LA. Climate change awareness and strategies for communicating the risk of coastal flooding: a Canadian Maritime case example. Estuar Coast Shelf Sci 2014;140:83–111.
[37] Park T, Kim M, Jang C, Choung T, Sim KA, Seo D, et al. The public health impact of road-traffic noise in a highly-populated city, Republic of Korea: annoyance and sleep disturbance. Sustainability 2018;10(8):2947.
[38] Hanigan IC, Chaston TB, Hinze B, Dennekamp M, Jalaludin B, Kinfu Y, et al. A statistical downscaling approach for generating high spatial resolution health risk maps: a case study of road noise and ischemic heart disease mortality in Melbourne, Australia. Int J Health Geogr 2019;18(1):20.
[39] Tagusari J, Matsui T. Estimation of health risk due to road traffic noise in Japan based on the environmental noise guidelines for the European region (in Japanese). Jpn J Hyg 2021;76:19014.