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Increases in noise complaints during the COVID-19 lockdown in Spring 2020: A case study in Greater London, UK

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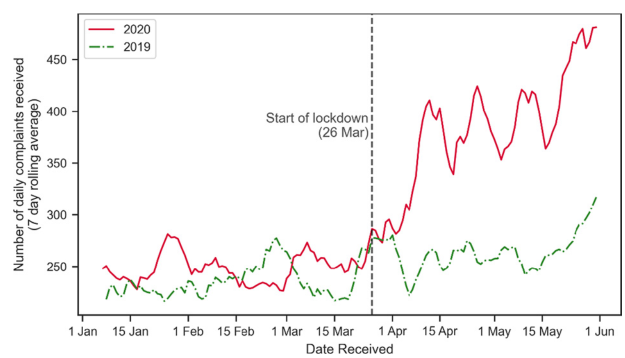
HIGHLIGHTS

- Noise complaints increased significantly (47.54%) across London during the lockdown.
- Complaints about construction and neighbourhood noise reported significant increases.
- Housing and demographic factors played a more significant role than traffic noise.
- Higher change rate in areas with higher unemployment rate and lower house price
- Areas with more residents with no qualifications have higher change rate.

GRAPHICAL ABSTRACT



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ABSTRACT

Many cities around the world have claimed that the enforcement of lockdown measures to contain the spread of COVID-19 and the corresponding limitations of human activities led to reduced environmental noise levels. However, noise complaints reported by many local authorities were on the rise soon after the local lockdowns came into force. This research took Greater London in the UK as a case study. The overall aim was examining how noise complaints changed during the first stages of the lockdown implementation, during Spring 2020, both locally and at city scale, and how urban factors may have been influencing them. Noise complaint and urban factor datasets from the Government's publicly available data warehouse were used. The results show that during the COVID-19 lockdown the number of noise complaints increased by 48%, compared with the same period during Spring 2019. In terms of noise sources, complaints about construction (36%) and neighbourhood (50%) noise showed significant increases. Urban factors, including housing and demographic factors, played a more significant role than the actual noise exposure to road and rail traffic noise, as derived from the London noise maps. In detail, the change rate of noise complaints was higher in areas with higher unemployment rates, more residents with no qualifications, and lower house price. It is expected that this study could help government with allocating resources more effectively and achieve a better urban environment.

1. Introduction

The coronavirus disease 2019 (COVID-19) was first identified in December 2019 and quickly started to affect many regions of the world in the following months. In January 2020, the World Health

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Organization declared the outbreak a “Public Health Emergency of International Concern”, and subsequently escalated it to a “pandemic” in March 2020 (Brown and Horton, 2020). In order to prevent and slow down the spread of the virus, many countries adopted a series of policies and actions, which in the most restrictive scenarios were commonly identified as “national lockdowns”.

In general, lockdown measures involved “staying at home” recommendations, social distancing, stopping non-essential commercial activities, banning public gatherings, limiting traffic mobility and alike. Specifically, the UK Government passed the Health Protection (Coronavirus, Restrictions) (England) Regulations 2020, which were put into force at 1:00 pm on 26th March 2020 (Public Health England, 2020). Under these restrictions, the public were only allowed to leave their homes once per day for essential activities and exercise. All offices and shops selling non-essential goods were told to close, gatherings of more than two people in public were banned, and individuals were advised to only interact with members of their own household. These restrictions were set to be reviewed by the Secretary of State at least once every 21 days and would continue indefinitely until they were no longer necessary to prevent the spread of infection in England. In practice the lockdown continued through the spring of 2020 and was first partially eased on 1st of June, with school children in England returning to school, but the broader lockdown continued throughout the summer.

Such measures at global scale were unprecedented and suddenly changed human behaviours and communities' life around the world, with considerable impacts on society. For instance, from psychological perspectives, acute panic, anxiety, obsessive behaviours, paranoia, and depression can be produced (Ausín et al., 2021; Dubey et al., 2020; Dzhambov et al., 2021). The socio-economical condition can also be impacted, where financial uncertainty, decrease in income, fear of job loss, and food insecurity are some major challenges (Ali et al., 2020; Rasheed et al., 2021). Yet, in spite of the adverse societal and economic implications, the lockdown implementations to contain the COVID-19 outbreak led to some improvements in the urban environment, particularly in terms of air quality and noise pollution. For instance, in the United States, NO_2 levels declined by 25.5% during the COVID-19 pandemic compared to historical data, and $PM_{2.5}$ levels declined in urban counties and those instituting early business closures (Berman and Ebisu, 2020). In China, because of the lockdown, NO_2 emissions dropped by 30%; CO_2 emissions decreased by 25% (Dutheil et al., 2020). Furthermore, early reports in China show that the improved air quality avoided a total of 12,125 NO_2 and $PM_{2.5}$ -related deaths during the lockdown period (Chen et al., 2020).

Noise pollution followed similar decreasing trends, with environmental noise levels dropping particularly in urban contexts, due to the lack of human activities in public spaces and overall reduction of traffic volumes. In Paris (France), since the lockdown measures were implemented, the noise levels from road traffic reduced by 7.6 dB(A) (L_{den}) on average, and aircraft noise reduced by 21.5 dB(A) (L_{den}) (Bruitparif, 2020). In Barcelona (Spain), the noise pollution levels dropped by 9 dB(A) (L_{day}) after one week of lockdown, and an additional 2 dB reduction after two weeks was observed (Ajuntament de Barcelona, 2020). In Athens (Greece), noise levels (L_{den}) reductions of up to 6 dB(A) and 8 dB(A) were measured on road networks and in proximity of the Athens International Airport, accordingly, as a consequence of the lockdown restrictions (Vogiatzis et al., 2020). In London (UK), an average reduction of 5.4 dB (L_{Aeq}) was observed across 11 sampled locations by comparing a dataset of noise measurements from Spring 2019 and one from Spring 2020, during the UK lockdown (Aletta et al., 2020).

The cases mentioned above are just examples: the reduction in environmental noise levels observed in these cities is likely to be common also to other urbanized areas of the world, for which monitoring data is not yet available. Consequently, one could reasonably expect that since there was a reduction in noise pollution levels, the general attitude of the public towards the urban acoustic environments would have improved during the lockdown confinements. However, focusing merely on the “physical” acoustic environment rather than how it is experienced and perceived by people is a major issue that needs further discussion, for the manifold implications that noise annoyance can have on people's lives. Indeed, focusing on the UK context, soon after the national lockdown was implemented on March 26th 2020, reports started to appear in news outlets claiming that noise complaints were on the rise in many UK councils (BBC, 2020). The underlying reasons seemed to be that since people were spending more time at home to comply with lockdown restrictions, they would become more sensitive to neighbourhood-related noise sources. Some city councils had to release specific guidance on possible coping strategies and/or special “noise advice” (Royal Borough of Greenwich, 2020). An excerpt from the Gateshead Council website on the “Neighbour noise advice during the Coronavirus (COVID-19) pandemic” page stated:

> “A considerable number of people will need to work from home and children will be doing school work at home […] that means we will probably be seeing and hearing more of our neighbours than we are used to. In some situations, this may lead to frustrations or annoyance with noise we do not want to hear. With this in mind, we urge everyone to be considerate of their neighbours by thinking about how noise from your home could be causing problems and upset to others. For the same reason, we urge everyone to be more tolerant and patient with noise and activity that they won't be used to hearing” (Gateshead Council, 2020).

The rationale for this study is ascertaining whether such informal claims were indeed supported by noise complaints data, using Greater London as a case study.

2. Aim and scope

Greater London has approximately an 8.9 M population and a population density of 64.16/ha. There are 32 boroughs divided into Inner London and Outer London (Butler et al., 2008). There are three reasons that London is well-suited as a case study: the noise complaint, noise level and urban factors datasets are all available in London; the lockdown measures were consistent across all London boroughs; and it includes areas with various urban factors (such as housing, transport, demographics, and noise sources). In England, reporting noise complaints is carried out under environmental legislation and managed by the local authorities. This noise complaint dataset can provide a basis for the government decision-making. In this context, if residents have a problem with noise, they can report through service hotlines, websites, or in-person to the local council, which can then seek to address this problem.

Noise complaints typically dominate the amount of environment-related complaints that local authorities have to deal with (Kang, 2006). The topic has received increased research attention across several disciplines, such as psychology, sociology, and urban studies (Kang and Aletta, 2018; Tong and Kang, 2020). For instance, Nieuwenhuis et al. (2013) examined negative relationships between neighbours and proposed that property ownership is not correlated to neighbour conflicts, involving noise annoyance complaints. Legewie and Schaeffer (2016) examining 311 noise complaints datasets in New York City, found that ethno-racial diversity is positively associated with the number of complaint calls. Hong et al. (2019) created heat maps using a kernel density estimation to examine clustering patterns of the major construction and noise complaints. This study found that construction activities were associated with higher volumes of noise complaints. The results suggest that a one-unit increase in construction activity was associated with an approximately 6% higher incidence rate of noise complaints. Tong and Kang (2020, 2021a) investigated the effects of urban development patterns and socio-economic factors on noise complaints across different local authorities in England. The results suggested that the rate of noise complaints is generally significantly related to urban morphology, road network, demographic, and housing factors. The rate of noise complaints is always higher in large, centralised or compact cities. Specifically, the noise complaint rates are positively related to population density, primary road density, and unemployment rates, but negatively related to mean age and average number of cars owned. For housing factors, noise complaint has a negative relationship with home ownership, while it has a positive relationship with the percentage of rented homes.

Noise complaints depend on individual attitudes, perceptions, and objective noise levels (Hong et al., 2019; Public Health England, 2018). It seems apparent that the amount of noise complaints would be related to noise level, particularly road traffic and rail sources. However, the perception of noise and the act of filing a complaint might also be affected by a number of urban planning parameters involving demographic, transport, housing factors. For instance, the road network is the main source of noise, primarily affecting the sound pressure level, which can be characterised through urban planning factors such as road density and the mode for commuting (Calixto et al., 2003; Tong and Kang, 2020). Secondly, the influence of demographic factors such as population density, age, occupation, education level, and health states on sound evaluation have been broadly studied (Aletta et al., 2018; Licitra et al., 2016; Miedema and Vos, 1999; Rey Gozalo et al., 2018; Yu and Kang, 2008). Finally, housing factors such as price, housing size, house type, and ownership have been proved to have a relation to the sound environment and evaluation (Fields, 1993; Tong and Kang, 2021a). However, the changing patterns of noise complaints during the lockdown and the effect of such urban factors have not been investigated in detail yet.

The aim of this study is to examine how noise complaints changed during the first stages of the lockdown implementation during Spring 2020, both locally and at city scale, and how urban factors, including housing, demographics, transport, and traffic noise level bands, may have been influencing them. More specifically, the research questions are:

(1) How did the noise complaints received by local authorities in London change because of the lockdown measures?
(2) Did this change in noise complaints during the lockdown vary depending on the noise complaint type (i.e., categories of noise sources)?
(3) To what degree are these changes mediated by other factors related to urban and socio-economic characteristics of the local environment, including housing, demographic, transport, and traffic noise level band?

For this purpose, a case study in Greater London was considered. Noise complaint datasets were requested from London's Borough Councils for the years 2019 and 2020 in order to compare the noise complaints received during the lockdown in Spring 2020 and the noise complaints received during the same period from the previous year.

3. Methods

3.1. London noise complaint dataset

The noise complaint dataset was applied for from the local Borough authorities under the Freedom of Information Act 2000 (FOI), which provides public access to information held by public authorities (UK Government, 2000). As of the 16th of July 2020, noise complaint datasets from 24 boroughs were received by the researchers: 22 datasets without missing data or a crucial missing field (e.g. date) were used for this analysis. The data includes received date, complaint type, and location information for the single complaint record. The geographic location information of noise complaints is based on the coordinate points, postcode, or ward, depending on the reporting policies of the various boroughs. Among them, ward level was selected to get the same level of geographic labelling across all of the provided data (i.e., if postcode and coordinate points information were available, these were assigned to the corresponding ward) (Fig. S1 in the Supplementary File). Wards are the administrative level below boroughs, which are the local government areas within Greater London (Fig. 1).

The datasets received from some local authorities include other environmental complaints in addition to noise complaints. These include complaints related to odours, anti-social behaviours, dust, etc. These complaints were identified based on the type label and were excluded from this analysis in order to focus solely on noise complaints.

The classification for the "type of noise complaint" was not consistent among the London boroughs: some would use multiple-answer options with pre-defined categories, others a free-text field for users to fill; thus, a further categorization step was necessary to handle the complaints type variable in a meaningful way. From the original database, a set of 484 unique labels used to characterize the type of noise complaint was extracted. These were then manually screened and sorted into 4 categories: Industry (36 labels), Construction (29 labels), Neighbourhood (373 labels), and Undefined (46 labels) (Table S1 in the Supplementary Files). The rationale for clustering the labels in this way was being aligned as much as possible with the World Health Organization categorization for community noise, defined as "noise emitted from all sources except noise at the industrial workplace […] including: road, rail and air traffic, industries (i.e., 'Industry' label in this study), construction and public work (i.e., 'Construction' label in this study), and the neighbourhood (i.e., 'Neighbourhood' label in this study). […] Typical neighbourhood noise comes from premises and installations related to the catering trade (restaurant, cafeterias, discotheques, etc.); from live or recorded music; sport events including motor sports; playgrounds; car parks; and domestic animals such as barking dogs" (World Health Organization, 1999). So the first category would essentially cover transportation and industries; the second category have a connotation of "public" works, as opposed to construction noise from a neighbour's flat for instance (as that would fall into the following category); the third category is possibly the broadest in scope, yet, from the perspective of the person complaining, the main difference between category 1–2 and category 3 is whether the complaint is directed towards an "infrastructural element" (for which local authority is accountable most likely) or towards a clearly identifiable person/group/premises generating the noise (thus the conflict is between to private subjects). The fourth category ("Undefined") does not indicate missing data, but rather lack of clear category, as sometimes the labels in the database did not allow classification (e.g. "other noise"; "noise"; or alike). Unique labels for the noise complaints with the category to which they were assigned were presented in Table S2 in the Supplementary Files.

3.2. The Spring 2020 Lockdown period

For the purpose of analysing the data, it was decided to compare the same period of the year in 2019 and 2020; that is: 27th March 2019-31st May 2019 (Spring 2019), and 27th March 2020-31st May 2020 (Spring 2020), the latter capturing the start and development of the UK lockdown period. This resulted in 43,186 complaints being analysed. Only for the analysis of the temporal variations in noise complaints, the periods considered range from 1st January to 31st May, both in 2019 and 2020, because of the need to detect potentially sudden changes (i.e., transitioning from a non-lockdown to a lockdown scenario).

3.3. Urban factors

To explore affecting urban factors causing the difference in noise complaints changing among London boroughs, housing, demographics, transport, and traffic noise level bands were discussed. Generally, (high) noise levels are expected to lead to increased noise complaints in any

Fig. 1. Borough and ward boundary in London.

given area, therefore the possible influences of the exposure to road and rail traffic noise sources on the noise complaints change rate were explored. To test this, L_{den} (day-evening-night sound level) values were extracted at a ward level from the noise pollution datasets obtained from the Department of Environment, Food and Rural Affairs (2018) for Greater London. The two indicators, namely road L_{den} and rail L_{den}, were selected as they are the main parameters represented in noise maps (Figs. S2&S3 in the Supplementary File). Using ArcGIS 10.3, L_{den} data at ward level was extracted and each ward was assigned a rank (0–5) automatically based on the percentage of its area covered by a certain noise level band (split by 5 dB). Among 383 wards covered by noise complaint data, 373 wards were covered by the road L_{den} data and 295 were covered by the rail L_{den} data. They received ranks from 0 to 2 for road and from 0 to 1 for rail noise, with rank 0 representing a ward ranked to a noise level band below 55 dB(A), and rank 2 representing a ward ranked in the noise level band of 60–64.9 dB(A) (Figs. S4&S5 in the Supplementary File). For instance, the ward of Barnsbury in the borough of Islington features a total area of 83 ha, with 7.1 ha (8.5%) of which is covered by data modelled for road L_{den} above 55 dB(A). The amount of area covered by each noise level band in Barnsbury is as follows: 3% in the 55–59.9 dB(A), 1.6% in the 60–64.9 dB(A), 1% in the 65–69.9 dB(A), 1.9% in the 70–74.9 dB(A), 1% in the area covered by the noise level band above 75 dB(A) and 91.5% of the area left uncovered by any noise level band, meaning the L_{den} exposure was modelled below 55 dB(A) for the most of the ward's footprint. Therefore, Barnsbury was assigned the rank of 0 for road noise.

In addition, according to previous studies, the decrease in noise levels during the enforcement of lockdown measures varies in different types of areas (Aletta et al., 2020). However, the noise complaint or perception might be also affected by other factors like a number of urban planning parameters involving housing, demographic, and transport factors as mentioned in the introduction. Apart from considering factors mentioned above, the data availability is also considered when selecting the urban planning parameters. London Ward Profile is the main data source used, downloaded from the London Datastore (Greater London Authority, 2015). In this dataset, all the indicators have been aggregated to the ward level. For instance, the mean age is the average age for all residents in the ward; 'cars per household' means the average number of cars per household in the ward. Meanwhile, in this dataset, the tax band codes from A to H, were categorised into three groups (A or B; C, D or E; F, G or H) by Department for Communities and Local Government and indicate the tax rate from lowest to highest (UK Government, 2020). Finally, 18 indicators were selected and grouped into four categories - housing, demographics, transport, and noise level bands (detailed parameters are in Table 1).

It is worth noting that some urban factors show significant inter-correlations. Significant correlations exist both within and between categories, such as between qualification and household income. This multicollinearity should be paid attention to when building and selecting a regression model. However, as this study focuses on the correlation between each individual urban factor and noise complaints, rather than the inter-relationship between the factors this is not considered a primary concern. The coefficient values given are the Spearman correlation strength between noise complaint change rate and each individual urban factor.

3.4. Statistical analysis

In order to characterise how the noise complaints changed across the boroughs and wards investigated, the rate by which noise complaints changed from Spring 2019 to Spring 2020 was calculated. The equation for this change rate is shown as follows:

$$R = \left(N_{Spring\ 2020} - N_{Spring\ 2019}\right)/N_{Spring\ 2019} * 100 \quad (1)$$

where R is the change rate of noise complaints in percentage; $N_{Spring\ 2019}$ is total number of noise complaints during spring 2019; $N_{Spring\ 2020}$ is total number of noise complaints during spring 2020. The results return to positive and negative values. Negative values mean the number of noise complaints decreased, while the positive values mean increase (Kenton and Mansa, 2020). The change rate of noise complaints in three wards were extremely high and identified as outliers, namely Gospel Oak and Highgate in the borough of Camden and Heathfield Ward in the London borough of Richmond upon Thames. These were considered outliers due to their very low number of noise complaints in Spring 2019 (which may itself be an anomaly for year-over-year numbers in that borough), meaning a relatively small increase in absolute numbers of complaints results in a very high percentage change. They were not considered in further analyses.

The variables in this study are not normally distributed, according to the Shapiro-Wilk test (Ghasemi and Zahediasl, 2012; Yap and Sim, 2011). Therefore, Spearman's rho, as a nonparametric test which does not assume normal distributions (Hauke and Kossowski, 2011), was applied to measure the correlations between the urban factors and noise complaints. This process was conducted using SPSS software (version 25) (Landau and Everitt, 2003). The correlation analysis was conducted at ward level, as all indicators are available at ward level (Kendall's Tau was also examined. The results were similar to Spearman correlation and those are presented in Table S3 in the Supplementary File). Meanwhile, the Mann-Whitney U test, as a non-parametric test, was used to compare differences in the number of noise complaints between Spring 2020 and Spring 2019 for each borough and source breakdown individually.

In order to further investigate how the factors interact with each other as well as with the noise complaint outcome, a Random Forest (RF) regression model was built, which can better handle multicollinearity and non-linear relationships than multivariate linear regression. As a widely used ensemble learning method, the core idea of this model is to construct a series of decision trees to obtain scores of variable (urban factors) importance in determining the dependent variable (noise complaints). The higher the score, the more important the indicator is, and vice versa. Only the variables with significant Spearman correlation coefficients were included for analysis. The whole process was implemented using the sci-kit learn 0.19.1 in Python 3.7.0 (Pedregosa et al., 2011).

4. Results

During the Spring 2020 lockdown period (27th March – 31st May), local authorities experienced a significant increase of noise complaints compared to the same time period in the previous year ($p < 0.001$ via Mann-Whitney U test). In total during the lockdown, there were 25,740 noise complaints reported, with approximately 4.29 complaints per 1000 people. During the same period in 2019, there were 17,446 and 2.97, respectively.

To investigate the effects of the containment measures on the amount of noise complaints received, the time series of total daily noise complaints for the first half-year of 2019 and 2020 is shown in Fig. 2. To better demonstrate the general trends, a seven-day rolling average window is applied, accounting for observed weekly patterns in received noise complaints. In general, 2019 exhibits a relatively stationary pattern with small fluctuations above and below 250 daily noise complaints, showing no clear increasing or decreasing pattern during this period. Likewise, the pre-lockdown period of 2020 also exhibits a stationary trend with fluctuations around 250 daily noise complaints. However, shortly after the imposition of a national lockdown on 26th of March, there is a marked increase of the 2020 trend. Within two weeks the number of daily noise complaints has nearly doubled compared to the same time period in 2019 and continues to grow throughout the lockdown period.

In the month before the start of the lockdown, local authorities received an average of 282 new complaints per day and 8454 individual noise complaints in total. In the first month after the start of the lockdown, these numbers had increased significantly with 402 new cases every day and 12,071 reports in total, representing an increase of 42.55% for the whole of London. For the second month since enforcing lockdown, this rate of increase began to slow, with local authorities receiving 442 reports per day, an increase of 10% compared to the first month.

4.1. Variations in noise complaints at borough level

To explore more characteristics of the variation in noise complaints due to the implementation of lockdown measures among boroughs, the spatial distribution of the change rate of noise complaints during the lockdown compared with Spring 2019 was mapped, as shown in Fig. 3 and Fig. 4. This figure shows the change rate of noise complaints between Spring 2020 and Spring 2019, by borough. In 21 of the 22 boroughs for which data of noise complaint numbers were available, the rate of complaints increased during the lockdown. The increases were significant in 15 of the 21 boroughs (the details were shown in

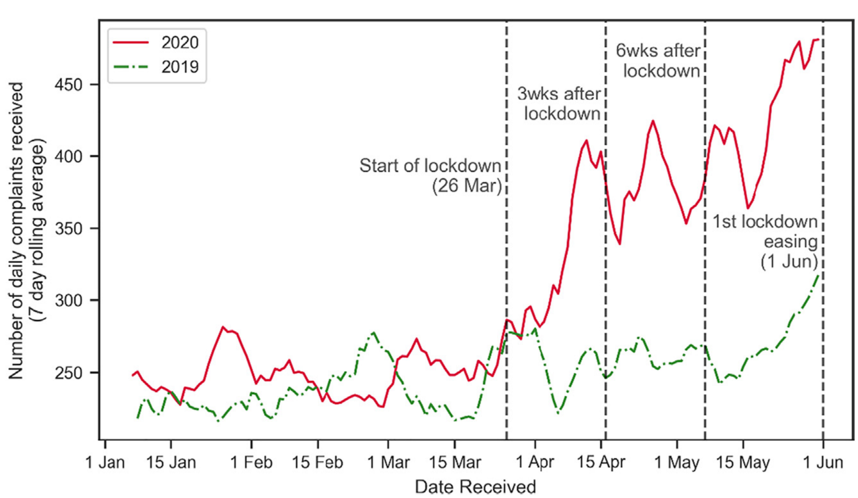

Fig. 2. Time series of the number of noise complaints in the first half year in 2019 and 2020. A 7-day rolling average window is applied to account for weekly patterns in noise complaint reporting.

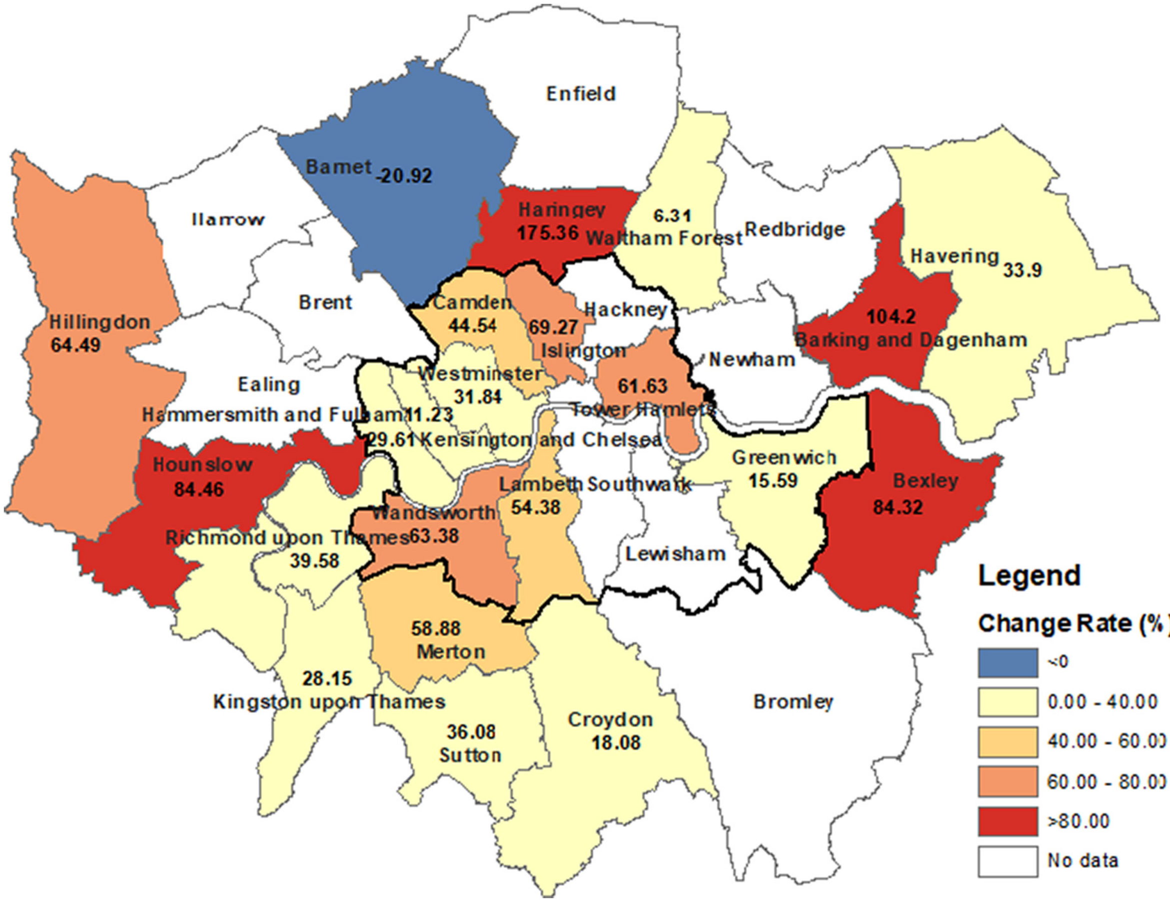

Fig. 3. Change rate of noise complaints by boroughs. * Difference is significant at the 0.05 level as per the Mann-Whitney *U* test. ** Difference is significant at the 0.01 level as per the Mann-Whitney *U* test.

Table S4 in the Supplementary File). Contrary to the rest of the boroughs, Barnet experienced a decrease (−20.92%) in noise complaints during the lockdown period.

On the other hand, Haringey, which is adjacent to Barnet, has the highest increase in noise complaints (+175.36%), followed by Barking and Dagenham (+104.2%), Hounslow (+84.46%), and Bexley (+84.32%), all located in Outer London. Apart from Barnet, the lowest change rate was observed in Waltham Forest (+6.31%), followed by Kensington and Chelsea (+11.23%), Greenwich (+15.59%), and Croydon (+18.08%). The change rate was substantially lower across

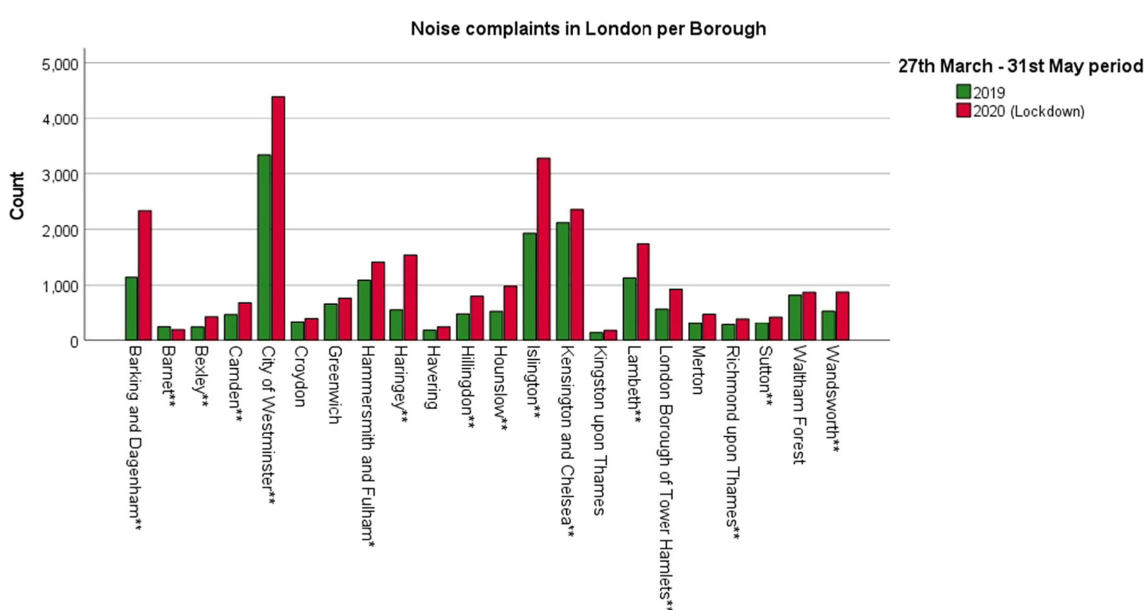

Fig. 4. Differences in the number of noise complaints between Spring 2019 and Spring 2020 by borough.

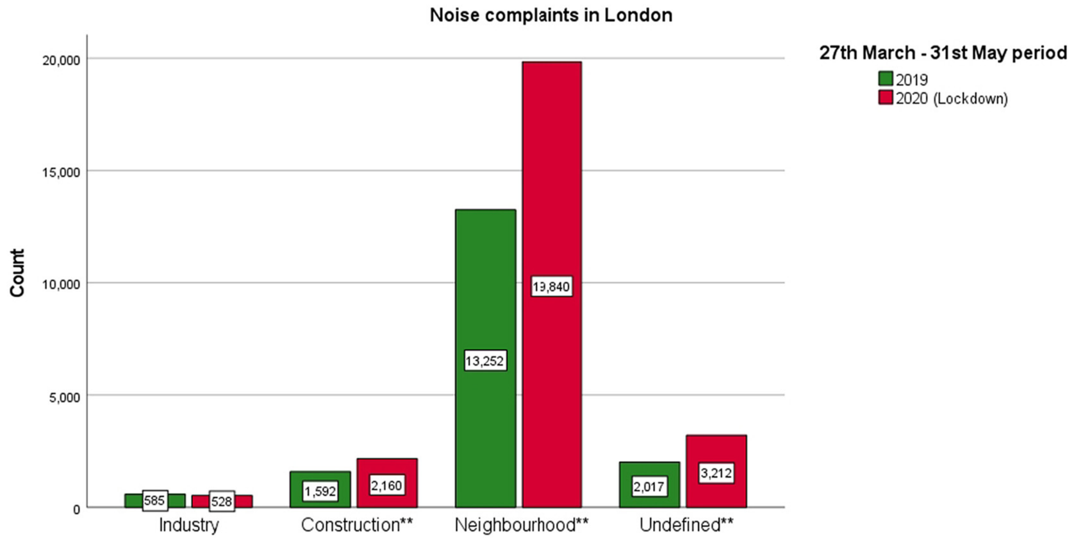

Fig. 5. Differences in the number of noise complaints between Spring 2019 and Spring 2020 by Noise source category. ** Difference is significant at the 0.01 level as per the Mann-Whitney U test.

Inner London (+38.67%) compared to Outer London (+66.37%). Indeed, the difference in change rate is also more dramatic for the first month of the lockdown. Overall, it can be observed that the number of noise complaints increased significantly after the lockdown measures were implemented and the change rate of noise complaints was distributed unevenly across London.

4.2. Variation by types of noise complaints

In order to further investigate the driving factors in the general increase in noise complaints during the lockdown period, the data are analysed according to the type of noise complaints. Fig. 5 shows the number of complaints received during the lockdown period and the same period in 2019, across all boroughs, for the four types of noise sources (Industry, Construction, Neighbourhood, and Undefined). These categories were aggregated from the various tags provided by the borough data, as described in Section 3.1.

The most common noise complaint category in both 2020 and 2019 is Neighbourhood, followed by Undefined, then Construction and Industry. Interestingly, in this last category, which includes transportation noise, complaints remained at approximately the same level with only a slight decrease (ca. -9%), despite road traffic and other noise-generating industrial activities being dramatically reduced during the lockdown. Indeed, the decrease in Industry noise complaints did not show significance ($p = 0.126$). All other categories reported significant increases: Construction (+36%), Neighbourhood +50%, Undefined +59% (p values < 0.001 via Mann-Whitney U test).

4.3. The effect of urban factors on noise complaint increase

From the previous results (Fig. 2), it can be concluded that the change rate of noise complaints varies across Greater London. Hence, urban planning factors such as housing, demographics, transport, and traffic noise level bands may be contributing factors to this variation. The Spearman correlation coefficients between these urban planning factors and the change rate across wards are shown in Table 1. Regarding housing factors, several significant relationships are revealed with noise complaints. Median house price and median household income, which reflect the economic status of the family, were negatively related to the change rate of noise complaints, with coefficient values of −0.108 and −0.140, respectively. This result means that the number of noise complaints in rich areas had increased less since the lockdown was enforced. As for property ownership, the change rate of noise complaints was positively related to the percentage of households that social rented. No significant difference was found for bands A or B. Therefore, the results of dwellings in council tax bands further support, as previously mentioned, that noise complaints from residents living in expensive housing had increased less during the lockdown period. In a word, the noise complaints increased less in areas with a higher proportion of expensive houses.

In terms of demographic factors, no significant relationship was found with population density, mean age, or subjective well-being average score. The change rate of noise complaints was positively related to unemployment rate, and the percentage of residents with no qualifications. In contrast, it is negatively related to life expectancy. For transport factors, no significant relationship was found with road density, cars per household, and average public transport accessibility score. Noise complaints were positively correlated with the percentage of residents who travel by bicycle to work.

Table 1
Spearman correlation coefficients between the change rate of noise complaints and urban planning factors.

Factors	Indicators	Correlation coefficients
Housing	Median House Price (£)	−0.108*
	Median Household income estimate	−0.140**
	% Households Owned	−0.078
	% Households Social Rented	0.160**
	% Households Private Rented	−0.073
	% dwellings in council tax bands A or B	0.087
	% dwellings in council tax bands C, D or E	0.134**
	% dwellings in council tax bands F, G or H	−0.131*
Demographic	Population density	0.059
	Mean age	−0.066
	Unemployment rate	0.114*
	% with no qualifications	0.129*
	Life Expectancy	−0.123*
	Subjective well-being average score	−0.016
Transport	Road density	−0.080
	Cars per household	−0.064
	Average Public Transport Accessibility score	−0.043
	% travel by bicycle to work	0.119*
Noise level band	Road Lden rank	−0.114*
	Rail Lden rank	0.006
	% in the highest noise level band (road Lden ≥ 75 dBA)	−0.082
	% in the highest noise level band (rail Lden ≥ 75 dBA)	−0.068

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

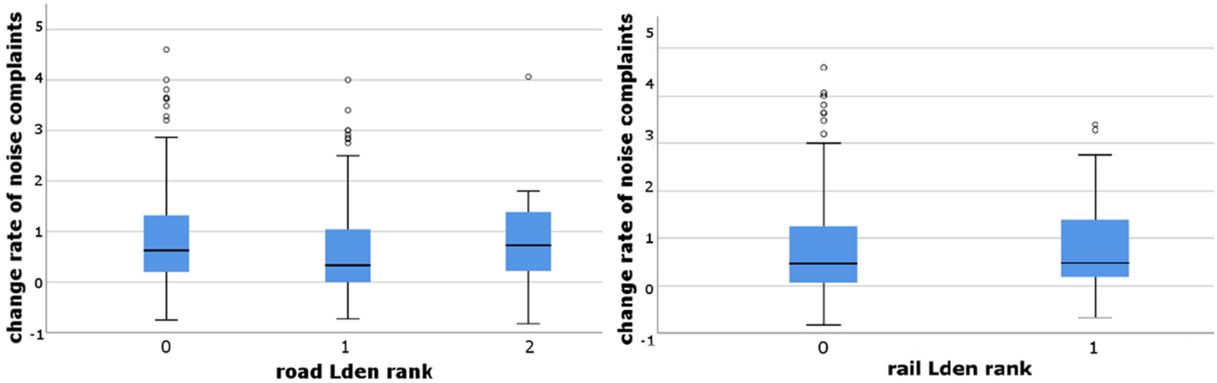

Fig. 6. Boxplots showing the change rate of noise complaints (in percentage) per noise level band ranks for road L_{den} (left) and rail L_{den} (right). For the purpose of this study, noise level band ranks were defined at ward level as follows: 0 ≤ 54.9 dB(A), 1 = 55–59.9 dB(A), 2 = 60–64.9 dB(A).

In particular, it seems fair to assume that actual noise exposure should be an important factor causing noise complaints and negative noise perception; however, significant correlation was observed only between the noise complaint growth rate and road L_{den} noise level band. No statistically significant correlation was observed between the other data derived from noise level bands and complaints (Table 1). Furthermore, Fig. 6 shows that the median value of the complaint change rate does not increase with the noise rank, i.e. the median value of the noise complaint change rate for wards ranked in the noise level band L_{den} 55–59.9 dB(A) (rank 1) is the lowest. The noise complaints have increased significantly during the lockdown unrelated to whether an area is quiet or noisy, to some extent. These findings also reinforce the results discussed above, which shows no relationship between noise from road and noise complaints.

Apart from the correlation analysis, multivariate regression analysis between noise complaints and urban factors was also conducted. Comparing with multivariate linear regression, the RF has better performance with a mean absolute error value of 0.8. Correspondingly the variable importance to determine the contribution of urban factors to noise complaints was identified using RF models. The results are presented in Table S5 as a Supplementary File. the results suggest that the percentage of households social rented and the percentage of residents who travel by bicycle to work contribute more in determining noise complaint change rate, followed by unemployment rate and the percentage of residents with no qualifications. Such findings can help the government organisations to prioritise resources for dealing with noise complaint issues from the urban factors, and to informing more effective noise management strategies.

5. Discussion

This study investigated the variation of noise complaints in London during the COVID-19 lockdown period and tried to explore affecting factors causing the difference in noise complaints changing across London boroughs. Having so many people staying home because of the lockdown-related restrictions created unprecedented scenarios and forced people to adjust to their new surrounding (indoor) acoustic environment, raising questions on how they relate to it and to its sound sources (e.g., neighbours, construction noise, etc.). Recent literature on the topic is identifying some emerging trends. Lee and Jeong (2021) conducted an online survey about noise annoyance in London in May 2020, with 183 participants, before the lockdown eased. They reported that neighbour noise was more annoying than outdoor noises during the lockdown, suggesting that this type of noise source is more problematic than other typical sources of community noise, when considered in the context of an enforced “stay home” policy. This brought other researchers to question what the positive role of indoor soundscape could be to promote well-being in times of social distancing (Andargie et al., 2021; Dzhambov et al., 2021).

5.1. Changes in noise complaints by numbers, types and affecting factors

5.1.1. The number of noise complaints increase during lockdown

Overall, it can be observed that the number of noise complaints increased significantly after the lockdown measures were implemented, indicating that residents have been more annoyed with noise during the lockdown, hence the negative impact on psychology well-being could be more serious. This impact is not one-directional – the Covid-19 pandemic has caused a crucial effect psychologically, such as anxiety, depression, and annoyance as mentioned in the introduction. In turn, these negative psychological states could make residents more annoyed with noise and trigger them to report a noise complaint. On the other hand, during lockdown, more family members could stay in the house, hence more noise could be produced, particularly with children kept at home due to school closures. These results are in line with a previous study, where Miedema and Vos (1999) suggested that residents living in a large family are more annoyed by noise than residents living alone. However, during the lockdown period, noise-inducing human activities reduced dramatically, as did the traffic volumes. Therefore, the urban environmental noise levels decreased in several cities worldwide, as reported by studies on environmental noise levels during the COVID-19 lockdowns which show decreases in the 5–15 dB range (Arenas, 2020; Aletta et al., 2020; Asensio et al., 2020; Bartalucci et al., 2020). Thus, combining these results with the previous research, it can be pointed out that, noise complaints are not only driven by noise events, there should be other factors impacting the noise complaints/perception.

The 2020 lockdown has sparked further discussion on future patterns of people working from home for a higher percentage of time. The results of this study indicate that large proportions of the population permanently working from home could result in a considerable and lasting increase in noise disturbance, even as urban noise levels decrease. In new dwelling developments, sound insulation is more important and need to be increased, such as soundproof window and materials. However, it is unclear to what extent this effect would remain under a non-lockdown scenario when people have more options for managing and changing their environment.

5.1.2. Results from type of noise complaints

The increase in absolute numbers of complaints across London by type shows patterns that are expected when considering the experiences of people spending more time at home. The results seem to confirm that neighbourhood noise is the main trigger for complaints and the one that witnessed a dramatic increase during lockdown. This could be a direct consequence of people spending more time at home, thus being exposed to noises they would not normally experience if they were at the workplace. It is also likely that Neighbourhood noise sources are perceived as being closer and/or more easily identifiable (e.g., a neighbour, a domestic animal, catering premises, etc.), so that a complaint would be meaningful, as from the perspective of the person complaining it would be easier for a local authority to enforce complaint (compared, for instance, with road traffic noise from a highway). Indeed, neighbourhood is the most common noise complaints category in both 2020 and 2019. This result is in line with Tong and Kang (2021b): they found the proportion of residential/neighbourhood noise complaints was approximately 50% in New York City.

Construction noise complaints, which here include public works or perceived-to-be public works (i.e., excluding DIY and small construction/refurbishment noises coming from neighbouring flats), show a significant increase. The construction industry did not fully stop during the lockdown measures as UK Government policy was to assimilate it to “critical activities” and prioritize its re-start (Mayor of London, 2020). So, in a relatively quieter background noise (less traffic, fewer people on the streets, etc.) it is likely that construction noises became more salient also because of their spectral and temporal features (e.g., very different sound sources, unsteady, often impulsive noises, etc.).

In the Industry category (which included transportation noise sources) the slight, and possibly negligible decrease, in noise complaints contrasts with considerable decreases in traffic noise levels seen in other studies. The lack of an observable impact of the lockdown measures and the low absolute numbers of transportation-related noise complaints compared to other categories, indicates that traffic noise is not a major driver of community noise complaints, when considering aggregated data at ward level or higher. This is further confirmed by the lack of any relationship between the relative level of traffic noise within a ward (as derived from the DEFRA noise map) and the change rate of noise complaints. However, this does not necessarily indicate a complete decoupling between traffic noise levels and complaints. It may be that transportation-related complaints are driven by cases and locations of extremely disturbing traffic noise (e.g., only at major intersections and exposure to major motorways). Aletta et al. (2020) showed that traffic-dominated locations in London (Camden Town and Euston Road intersection) experienced only a limited decrease in noise levels (4.5 dB, L_{Aeq}) during the lockdown period, which may not be enough to drive a noticeable decrease in noise complaints.

5.1.3. The effect of urban planning factors on noise complaint increase

By examining potential affecting factors on the change of noise complaints, (high) noise levels are expected to lead to increased noise complaints in any given area. However, the noise level (as characterised by noise bands derived from noise maps) did not show significant correlations with change rate of noise complaints. Especially, according to Aletta et al. (2020) during the lockdown, it is highly likely that the road L_{den} values across Greater London were lower than presented in the noise maps. The observed lack of correlation between the increase in noise complaints and the noise ranks assigned to wards could be explained by hypothesising that noise complaints are driven more by single noise events than the overall levels represented by $L_{den.}$

Furthermore, housing factors show a significant relationship with noise complaints. The result that noise complaints increased less in the area with expensive houses could be explained that the expensive houses could have more bedrooms and yards. Hence, the residents are able to choose a quiet room to stay and the green space in the yard could reduce noise annoyance (Bodin et al., 2015). As for property ownership, in this study, the change rate of noise complaints was positively related to the percentage of households that social rented. This result contradicts Nieuwenhuis et al. (2013), who proposed that ownership is not correlated to neighbour complaints. However, it is supported by other previous studies. For instance, Gillen and Levesque (1994) suggested complaint probabilities appear to be higher in the areas with high tenancy rate. Michaud et al. (2016) also indicated that ownership can contribute to differences in high noise annoyance. Indeed, housing policy and target are a key difference between Inner and Outer London (Butler et al., 2008). For instance, density of dwellings in outer London is lower than in inner London (the detailed density of dwellings was shown in Table S6 in the Supplementary File). These results could support the finding that the change rate of noise complaints was distributed unevenly in London; in detail, the four boroughs with the highest change rates were located in Outer London area. This difference could be correlated with the base value before the lockdown. Boroughs in inner London have relatively high number of noise complaints in Spring 2019, which means an increase in absolute numbers of complaints results in a relatively low percentage change. In addition, the high complaint levels of Inner London in 2019 could be explained by the density and diversity. Legewie and Schaeffer (2016) found that residents living between racial enclaves tend to complain more about noise than those who live within clearly defined racial boundaries. Nieuwenhuis et al. (2013) also indicated religious diversity lead to a higher likelihood for negative relationships between neighbours. In addition, during normal periods, high density areas have more noise complaints or higher noise annoyance level (Liu et al., 2019; Zheng et al., 2014). Compared with previous study findings, we found that the effect of several urban planning factors on change rate of noise complaints during lockdown is different from its effect on noise complaint/annoyance at normal times. For instance, normally, population density and road density have strong positive correlations with the rate of noise complaints (Tong and Kang, 2020). While population density didn't prove to be a significant factor, another explanation behind this phenomenon might simply be the number of residents who were spending more of their time in their homes during the lockdown, as Outer London has higher population than the Inner. In terms of the positive correlations between noise complaints and the percentage of residents who travel by bicycle to work, it could be explained that cyclists are especially strongly exposed to noise in urban environments, particularly because of their proximity to road traffic (Jérémy and Apparicio, 2019). To some extent, this finding is consistent with Tong and Kang (2020), where they found that cities/regions with higher percentages of residents taking energy-efficient transport modes to work tend to have more noise complaints. From a demographic perspective, the positive relationships between residents with no qualification and the change rate of noise complaint rate is supported by Gillen and Levesque (1994), who found that areas with high education level are less likely to exhibit complaint activity. Indeed, the results from the housing and demographic factors are consistent; higher unemployment rate and low qualification are always related to low quality of house and income. All these factors are likely to increase the change rate of noise complaints. This finding is also in line with previous studies; in normal time, cities/regions with higher unemployment rates are also likely to receive more noise complaints (Tong and Kang, 2021a).

Overall, it can be concluded that in such extraordinary circumstances, such as a nation-wide lockdown, contextual urban factors proved to be more significant for the increase in noise complaints than the actual noise exposure to road and rail traffic noise. Even though the noise level decreased during lockdown, the number of noise complaints increased significantly. It is expected that the findings can inform policymakers from the perspective of acoustic impacts and urban factors, allocating resources more effectively and leading to noise management strategies during the lockdown. For instance, a number of actions have been carried out to prevent noise pollution from road noise, such as noise barriers and noise level limitations for trucks. However, from the finding of housing factors impacting on noise complaints, the noise abatement for housing which focus on more than road noise and simultaneously prevent transfer from out-to-in could be paid more attention, such as the use of sustainable sound absorbing material. During the lockdown, the house is the main place where residents live, work and sleep, and it appears that increased working from home will continue to be a trend in the future. Therefore, the home environment will likely play an increasingly important role in human wellbeing. From previous studies, green spaces have been proven to have relationships with noise perception, applying an absorption or scattering effect on noise propagation and influencing individual perception of noise (Hao et al., 2015; Margaritis and Kang, 2017). From an urban planning perspective, the accessibility and visibility of green space from houses could be emphasised, such as utilising fragmented parks/yards.

5.2. Limitations of the study

The first aspect to consider is certainly related to the noise complaints dataset. The goal was to provide an overview for the Greater London area, by aggregating data from its boroughs since they are the local authorities responsible for handling such complaints. However, there could be some inconsistencies and/or deviations due to how single boroughs gather and process noise complaints records. For instance, sudden peaks or lows in numbers of complaints may be due to how easy (or difficult) it is to approach the local authority (e.g., via an app, a dedicated telephone line, etc.). The pandemic itself is likely to have affected the borough environmental departments' operations and ability to react to complaints (e.g., reduced staffing, increased remote working, etc.). Taking the Borough of Barnet as an example, where a 21% decrease in noise complaints rate was observed between 2019 and 2020, the information provided on its website states that during the lockdown "*The council will continue to run a Noise Line Service, but with a reduced response capacity. You can still call to report ongoing noise by calling* [telephone number]" (Barnet Council, 2021). Information is not explicitly available on this matter for all boroughs, but it is fair to assume similar circumstances apply. On the other hand, in boroughs where particularly high increase rates were observed, it could be that complaints could be filed via different channels (thus streamlining the process for the user), like in the case of Haringey, which accepted complaints both online and via telephone (Haringey Council, 2021; Havering Council, 2021). While this is certainly a possible limitation, we consider that, in the aggregate, such issues are averaged out and the trends are observed are still representative of the 2019–2020 variations.

Related to this, is the fact that this analysis is based on a comparison to only one year of past data. It is therefore potentially impacted by anomalous or random fluctuations in the noise complaints received during the investigated period in 2019. This, as well as year-to-year changes in boroughs' complaint collection methods, could be addressed in future studies by comparing to an average of multiple years of previous noise complaint data. This issue is also common to other studies being conducted on similar topics, but different context. For instance, Yildirim and Arefi (2021) compared the noise complaints in Dallas (USA) after the COVID-19 outbreak, from March to December 2020 and the same period in 2019. The authors in this case surprisingly observed reduced noise complaints during the COVID-19 period by about 14% compared to the pre-COVID-19 period. It seems reasonable to assume that there could be a lag to the effect that lockdown policies have on noise complaints, and this lag time can be difficult to distinguish from normal levels of week-to-week variations. In the Dallas case, it appears there was not enough time for the lockdown effect to show up, at least when compared to 2019 levels alone, before regulations were changing again. Thus, it is generally difficult to observe these patterns with such recent data, yet it is worth to extract preliminary information to inform possible future policies.

The analysis is of course affected by the categorization of noise complaints performed in Section 2.1. While we tried to adhere to the framework provided by the World Health Organization about community noise to define the categories in this study, we still have the Undefined category showing the highest increase proportionally, and, in absolute numbers, being larger than two other categories (i.e., Industry and Construction). During the categorization it was not possible to allocate these items with certainty to any other category; many occurrences refer to complaints where the type was inputted manually as a free-text by the complainant and the label was too generic (e.g., "noise" or "other noise"). Following a statistical approach, we could allocate the Undefined complaints either proportionally or evenly to the remaining three categories. In both cases, this would not change the patterns we have observed, so we consider it to be a minor methodological limitation.

For the other data types, this study only considered basic housing, demographic, and transportation factors. Therefore, if datasets are available. More indicators could be explored. In addition, the sampling strategy at the ward level resulted in the low effect of the highest noise level bands on the analyses as most of the wards were ranked in the low bands. The ward area covered in the noise level band above 75 dBA is typically below 1% and the ward coverage of the noise map data (above 55 dBA) for road L_{den} is typically below 50% and 30% for rail noise. Hence, no ward received a rank above 2. This approach was used as it was not possible to acquire the representative number of noise complaints at a level more detailed than a ward.

6. Concluding remarks

Taking Greater London as a case study, this study investigated the change of noise complaints in terms of their spatial and temporal distributions in London during the lockdown period and tried to explore affecting factors causing the difference in noise complaints changing across London boroughs. The main results are:

(1) During the COVID-19 lockdown the number of noise complaints increased significantly after the lockdown was implemented, with an overall increase of 47.54%. This change rate of noise complaints was distributed unevenly across the Greater London area.
(2) In terms of noise sources, complaints about construction and neighbourhood reported significant increases, with the value of 36% and 50%, respectively.
(3) Finally, the change rate of noise complaints is higher in areas with higher unemployment rates, more residents with no qualifications, and low house price. Meanwhile, no significant difference in the change rate was observed across traffic and rail noise level bands as derived from the DEFRA noise map. It can be inferred that in such extraordinary circumstances, such as a nation-wide lockdown, contextual urban factors proved to be more significant for the increase in noise complaints than the actual noise exposure to road and rail traffic noise.

While this study has focused on the first lockdown in Spring 2020, at the time of writing the pandemic (unfortunately) continues, and lockdown measures are still being frequently enforced. This work provided a cross-sectional dataset, but it would be interesting to examine the effect of longer-term lockdown policy on noise complaints. Meanwhile, to get a comprehensive picture of environmental noise complaints, other types of complaints such as odours, air pollution, and dust, as well as inter-relationships among them need to be further investigated. In addition, the specific lockdown measures vary from country to country, so it would be worth comparing noise complaint variations across regions, if the data is available.

Despite the contingent lockdown measures, the dramatic events of 2020 did change the way people look at "working from home", probably for good, and it is likely this will become an increasingly common practice in the future. Noise complaints (and particularly from neighbourhood sources) will then be an even more crucial factor in the context of public health and people's well-being. It is expected that this study could inform government about the pattern of noise complaints and help with allocating resources more effectively and achieve a better urban environment.

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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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Appendix A. Supplementary data

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