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A spatiotemporal analysis of the impact of the COVID-19 outbreak on noise pollution in Tehran, Iran

Omid Reza Abbasi,[1] Yasser Ebrahimian Ghajari,[2] Ali Asghar Alesheikh[1]

[1]Department of GIS, Faculty of Geodesy and Geomatics Engineering, K. N. Toosi University of Technology, Tehran; [2]Department of Civil Engineering, Babol Noshirvani University of Technology, Mazandaran, Iran

Abstract

Noise pollution is one of the non-natural hazards in cities. Long-term exposure to this kind of pollution has severe destructive effects on human health, including mental illness, stress, anxiety, hormonal disorders, hypertension and therefore also cardiovascular disease. One of the primary sources of noise pollution in cities is transportation. The COVID-19 outbreak caused a significant change in the pattern of transportation in cities of Iran. In this article, we studied the spatial and temporal patterns of noise pollution levels in Tehran before and after the outbreak of this disease. An overall analysis from one year before until one year after the outbreak, which showed that noise pollution in residential areas of Tehran had increased by 7% over this period. In contrast, it had diminished by about 2% in the same period in the city centre and around Tehran's Grand Bazaar. Apart from these changes, we observed no specific pattern in other city areas. However, a monthly data analysis based on the *t*-test, the results show that the early months of the virus outbreak were associated with a significant pollution reduction. However, this reduction in noise pollution was not sustained; instead a gradual increase in pollution occurred over the following months. In the months towards the end of the period analysed, noise pollution increased to a level even higher than before the outbreak. This increase can be attributed to the gradual reopening of businesses or people ignoring the prevailing conditions.

Correspondence: Omid Reza Abbasi, Department of GIS, Faculty of Geodesy and Geomatics Engineering, K. N. Toosi University of Technology, Mirdamad Blvd., No 470 Tehran, Iran. Tel.: +98 936 992 9908
E-mail: oabbasi@mail.kntu.ac.ir

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Introduction

The corona virus disease of 2019 (COVID-19) is a pandemic that has severely affected the lives of human societies in various aspects, such as health, economic structures and social relations (Siche, 2020; Pokhrel and Chhetri, 2021). The global response to this phenomenon, including business closures and social distancing, has had significant consequences. An important one is the change in the level of air and noise pollution in cities (Mostafa *et al.,* 2021). Numerous research articles have reported the reduction of air pollution in cities due to the reduction of traffic. Since it is known that the main source of both air and noise pollution is due to the traffic situation, this brings up the question whether the outbreak has caused a reduced noise pollution. Understanding how rapid changes in human behaviour affect noise pollution can lead to healthier and more sustainable societies, informed governmental decisions and better management.

Noise is a type of pollution that is caused by unwanted, unexpected or unpleasant sounds due to human activities (Hogan and Latshaw, 1973). Examples include noise from urban transportation (Vijay *et al., 2*014), airplanes (Ogneva-Himmelberger and Cooperman, 2010), garbage collection machines (Oralhan *et al.,* 2017), construction sites (Ng, 2000) and factory production processes (Oyedepo and Saadu, 2009). Noise pollution is thus the product of technological development and progress and indeed one of the most critical environmental pollutants in urban areas (Marx, 1956). This type of pollution is one of the main problems in today's world and many people, at their place of work or at home, are at risk of exposure. Reducing noise pollution would raise the quality of life, diminish effects on health and solve one a major environmental problem. It is thus an obvious priority.

Population growth across the globe has led to enlargement of cities and the creation of jobs, housing and activities necessary to sustain life. It has also led to intra-city travel using motorized transportation, with the consequential increase of various kinds of pollution levels. According to the World Health Organization (WHO), noise is the third most dangerous type of pollution (WHO, 2005; Menkiti and Agunwamba, 2015). The effect of noise pollution on human health is a global concern and can lead to stress and anxiety and other mental illnesses (Belojević *et al.,* 1997). Studies show that a 5 decibel (dB) increase in ambient noise can lead to a 3.4% increase of blood pressure (Oh *et al.,* 2019). Researchers have also found that exposure to loud noises can lead to hormonal disorders, which can cause severe damage to the cardiovascular system (Münzel and Sørensen, 2017; Hahad *et al.,* 2022). In addition, researchers have found that transportation noise can increase the risk of gestational diabetes (He *et al.,* 2019).

Research has been conducted on the relationships between the spread of COVID-19 and environmental sustainability (Arora and Mishra, 2020; Mekonnen and Aragaw, 2021; Praveena and Aris, 2021). However, given the recent spread of the virus worldwide, little research has been done on the relationships between the COVID-19outbreak and noise pollution. For example, Basu *et al.* (2020) used data from 12 noise pollution monitoring stations to analyse noise pollution in Dublin, the capital of Ireland. The researchers concluded that noise was significantly reduced during the quarantine implemented to lower transmission of the virus. In addition, their findings showed that the noise reduction in the centre and airport was less than in other parts of the city. In another study, Asensio *et al.* (2020) measured and analysed noise pollution in the city of Madrid, Spain from March to June 2020. They found that the noise reduction was highly dependent on the time pattern of days, especially weekends. The results of their study also showed that the level of noise was sharply lower at the time of sunset after the COVID-19 outbreak compared to before.

Caraka *et al. (*2021) used various statistical methods, such as Fisher and Wilcoxon tests and the Bayesian Monte Carlo Markov chain, to determine the significance and extent of noise pollution in Taiwan before and after the outbreak. These researchers used data from the number of vehicles in statistical tests and concluded that noise pollution in Taiwan during the pandemic had decreased with 95%statistical significance. Mishra *et al.* (2021) studied the effect of quarantine on noise pollution in different parts of Kanpur, India. In their article, the city was divided into three areas: residential, industrial and silent areas. The data sources of this research included sensors measuring the sound intensity. The results showed that, except in industrial areas, noise pollution had decreased everywhere. However, the sound levels in all areas were still higher than recommended standards. Terry *et al.* (2021) measured sound levels in three urban protected areas in Boston, USA and found that the noise levels in urban centres decreased by an average of 1 to 3 dB during and instituted period of quarantine. Still, in areas near highways, the noise intensity at the time of pandemic had increased by 4 to 6 dB. The authors attributed this increase to increased speed of cars on the highways during the outbreak. Kalawapudi *et al.* (2021) investigated the effects of the COVID-19 pandemic on changes in noise pollution caused by festivals and rituals in India. They measured noise pollution levels during festivals in Mumbai City in 2020 and compared them to corresponding times in 2018 and 2019 reporting a significant reduction in noise pollution from festivals after the outbreak (from about 100 dB to 76 dB). Aletta *et al.* (2020) simulated the traffic volume on different types of roads in Rome, Italy by utilizing origin-destination matrices to assess the impact of official mobility restrictions on noise pollution. They reported a 64% reduction in traffic volume for private intra-city trips during lockdowns and concluded that the restrictions had reduced pollution. However, the amount of reduction varied depending on the type of road.

The COVID-19 outbreak is a global crisis with positive and negative environmental consequences leading to different measures and strategies in developing environmentally sustainable cities (Rume and Islam, 2020). Tehran is the largest and most populous city in Iran, which means that the amount of air pollution and noise pollution caused by human activities there is more evident than in other parts of the country. Iran experienced three peaks of new cases during the time intervals chosen for our study, the last of which caused the death of nearly 500 people per day (Dong *et al.,* 2020). With the spread of COVID-19 in Iran, many people restricted their activities outside their homes. In addition, at some points, officials imposed formal restrictions on traffic control and social distancing throughout the city. According to the measures taken by the government, the universities and schools were closed during the time interval used in the study (Ranjbar *et al.,* 2021). However, the businesses were open and free to do their businesses except for a two-week period of mandatory closures (Bendavid *et al.,* 2021). Tehran is one of the largest and most populous cities in Asia. With a high population density, the city requires a stable public transportation system and a dense transportation network with high access. Blockages of streets and heavy traffic in the network of roads and streets in Tehran, especially during rush hours, occur frequently. The present study was designed to measure the impact of restrictions on air pollution and noise pollution in Tehran due to the impact of the COVID-19 outbreak. Given that this pandemic is an emerging phenomenon in the world, its effects on different aspects of life are important. The results can help understand the way decisions affect society and the environment. To the best of our knowledge, no research has been conducted on the relationships between the COVID-19 outbreak and noise pollutionin Iran. The results of this study can assist how and to what extent official decisionscan affect the situation in the city.

Materials and Methods

The present two-year study took place in Tehran from 21 February 2019 to 21 February 2021. We applied statistical methods, such as *t*-test and regression analysis to deduce the patterns in the samples and discover changes in noise pollution.

Dependent t-test for paired samples

Using the two-sample (or paired) *t*-test, it can be determined whether there is a significant difference between the means of the two samples (Dodge, 2008). In the case of statistical samples consisting of multiple measurements on a population, a *t*-test of two dependent samples is used. This test is widely used in cases where a phenomenon has caused possible changes. In this case, a sample of the population before the event and another of the same population after the event were used. The value obtained from the equation below determines the difference between the two samples (the larger the value of *t*, the greater the difference), while the null hypothesis is usually given as no difference between the mean values (*i.e.* = 0).

$$t = \frac{\bar{X}_D - \mu_0}{\frac{S_D}{\sqrt{n}}} \quad (1)$$

where $\overline{X}_D$ and S_D are the mean and standard deviation of the differences between all measurement pairs, respectively; and μ_0 the assumed mean value in the null hypothesis. The lower the p-value, the less likely the result of the test result is random (Ahmadkhani and Alesheikh, 2017).

Regression analysis

Regression analysis can be used to discover the functional relationship between independent and dependent variables. In this analysis, the least-squares method is usually used to estimate the coefficients of the optimal function, the result of which can be used to predict the value of the dependent variable for the given values of the independent variable (Freedman, 2009). Discovering and evaluating temporal and spatial patterns is vital in many environmental issues, such as pollution. With time as the independent variable, this analysis is a suitable way to determine whether the trend of the dependent variable decreases or increases over time. In this case, a linear function is fitted to points based on the least-squares method. If the slope of the resulting linear function is positive, the dependent variable has an increasing trend over time (Mogull, 2004).

Sound measurement units

Three different aspects of sound can be measured: pressure, intensity and frequency. The sound pressure level (SPL) is expressed in dB (an algorithmic unit) and indicates the pressure relative to the prevailing atmospheric pressure when a sound wave propagates through space; the sound intensity is expressed in Watts per square meter (W/m^2) and refers to the flow of sound in an area; while the frequency is given in Hertz (Hz) that expresses the number of sound waves emitted per unit of time. In research related to noise pollution, sound pressure is mainly used to measure noise, which can be calculated according to (Morfey, 2000) as follows:

$$L_p = 20\log_{10}\left(\frac{p}{p_0}\right) \quad (2)$$

where L_p is the sound pressure in dB and p the effective sound pressure with ρ_0 the reference sound pressure, which in air is usually considered as

$$\rho_0 = 20\ \mu\text{Pa} \quad (3)$$

This level of sound pressure is equal to the lower limit of human hearing. Measurements related to noise pollution are commonly divided into day and night time units. The daily time unit is usually between 7 AM and 7 PM. In Iran, this period is between 7 AM and 10 PM.

Dataset

The volume of traffic has a significant impact on the noise pollution in anycity and particularly in Tehran. Sound pressure in residential areas during the day and night should not be more than 55 and 45 dB, respectively (Abdur-Rouf and Shaaban, 2022). However, in Tehran these figures (2017 data) were 68 and 66 dB, respectively. In this study, a dataset from the Sound Unit of Tehran Air Quality Control Centre was employed. This dataset is continually collected by 27 fixed noise monitoring stations scattered throughout the city in such a way that they covered the entire city as uniformly as possible. Figure 1 shows their locations.

The stations shown in Figure 1 measure sound pressure at hourly intervals and the average of the observations in this interval was recorded as the output. Also, the data were recorded using daily (from 7 AM to 10 PM) and nightly (from 10 PM to 7 AM) time intervals. Figure 2 shows the snapshot of sound pressure level, which is a graphic representation of the predicted situation with regard to noise from particular noise sources, with different colours representing the different noise levels. The map demonstrates the level of noise pollution with regard to highways and the volume of traffic and illustrates the impact of transportation on the noise pollution.

The dataset included daily and nightly sound pressure values. To evaluate the effect of the COVID-19 outbreak on noise pollution, the dataset was divided into two long-term temporal periods: from 21 February 2019 to the same date in 2020, *i.e.* one year before the spread of the virus, and from 21 February 2020 to the

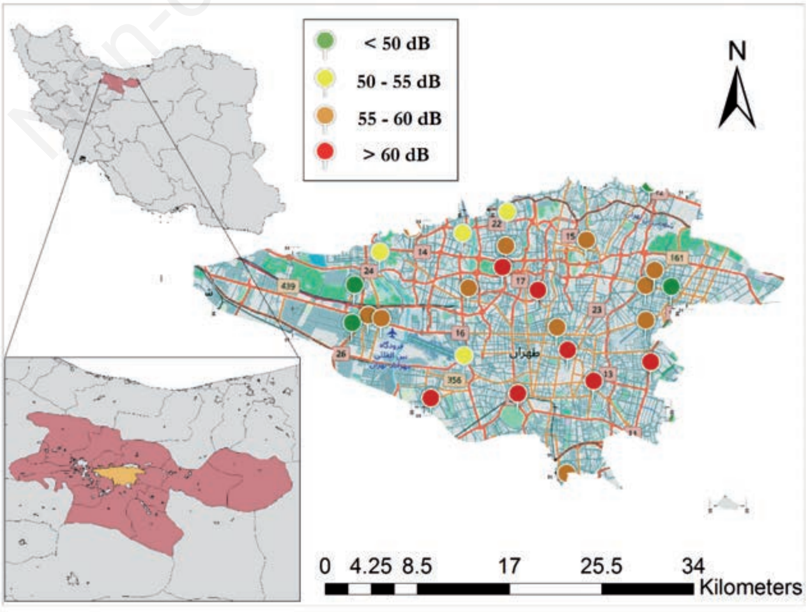

Figure 1. A snapshot of the noise monitoring stations across Tehran.

same date in 2021, *i.e.* one year after the outbreak. The average of the pollution corresponding to these two periods was calculated for each station. Then, using inverse distance weighted (IDW) interpolation the level of noise pollution was estimated over the periods.

The data were pre-processed, in which outliers were removed. We first performed an overall analysis for the one-year periods, which was followed by an investigation of the data on a monthly basis to determine the trend of change in more detail.

Results

Figure 3 shows the anomaly map of sound pressure resulting from subtracting sound pressure maps before and after the outbreak. In other words, the map illustrates the difference of the average sound pressure between 21 February 2019 – 2020 and 21 February 2020 – 2021. As seen in the figure, the changes in noise pollution did not correspond to a specific pattern, except in the

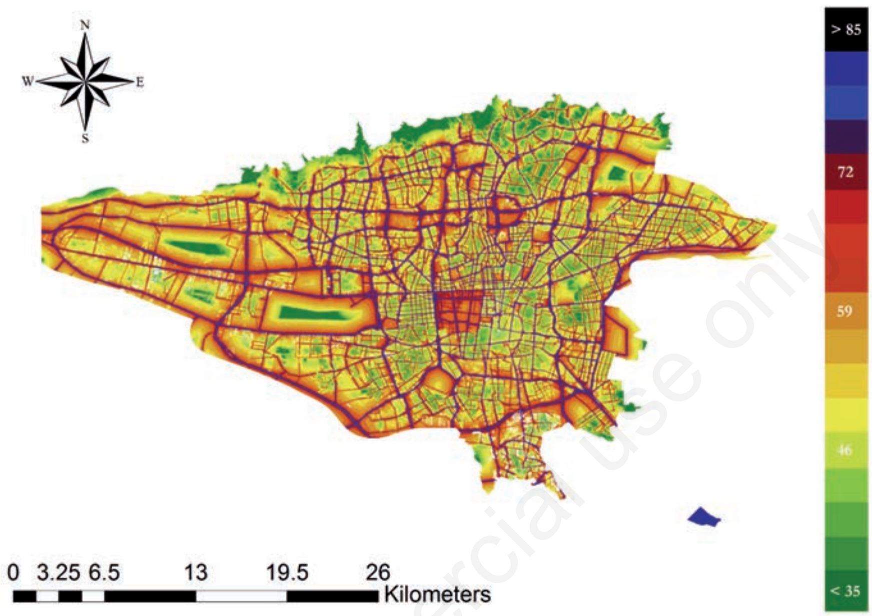

Figure 2. A snapshot of the sound pressure level around the streets and highways of the city. The levels of sound pressure, mainly distributed along streets and highways, are given in decibels expressed by the colours given in the legend at the left side of the figure.

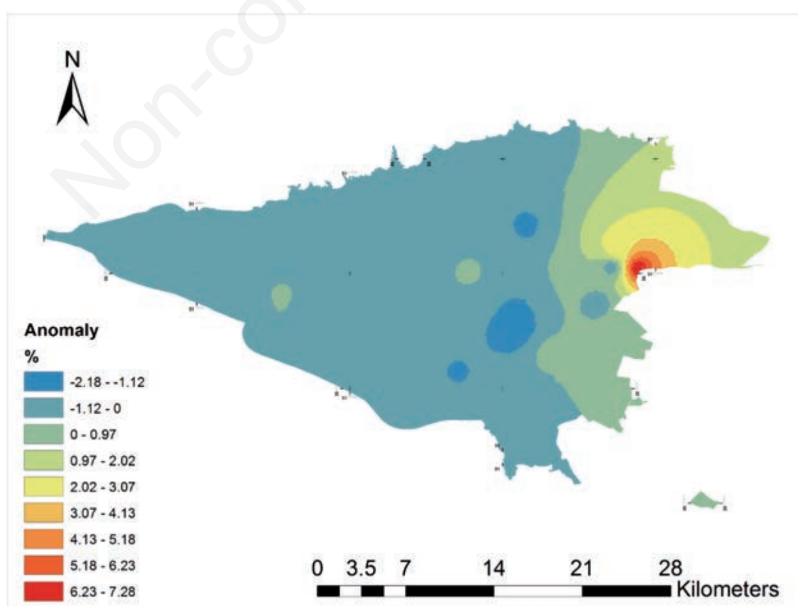

Figure 3. Map of the noise pollution anomaly during the COVID-19 outbreak. The figure shows the change of the average sound pressure during pressure between 2019 – 2020 and 2020 – 2021; mainly increasing in the eastern part and decreasing in the centre and eastern part of Tehran.

eastern part of Tehran. In other words, in some areas, the average noise pollution decreased after the outbreak, but increased in other locations.

An interesting point in the anomaly map is the increase of about 7% in noise pollution in the mainly residential areas of Tehran and the decrease of about 2% in the central areas close to its Grand Bazaar. These changes occurred in the first year after the beginning of the outbreak. In addition, there was an increased pollution at the entrances of the roads leading to the North, which faced an increase in traffic load during the holidays compared to the situation before the outbreak.

Table 1 shows the test results for all months before and after the outbreak of the pandemic including the mean differences and their statistical significance assessed by the *t*-test. In some months, the noise pollution decreased after the outbreak, but this is not true for all months. As seen in Table 1, a reduction of pollution occurred mainly in the first months after the outbreak. However, in some months of the second half of the year, the sound pressure was even higher than before the outbreak. The lack of a clear spatial pattern in Figure 3 is due to this issue. In order to study the trend of changes over time, and to determine the momentum, regression analysis was applied on the results shown in Table 1. Figure 4 gives the values obtained from the *t*-test with the corresponding *p*-values and the regression line obtained. As can be seen in Figure 4, there are two null hypothesis rejections; one occurring immediately after the beginning of the outbreak and the other when the

Table 1. Results of the *t*-test based on monthly noisedata.

Month	Period	Mean	Mean difference	Pearson correlation	*P*-value	Null hypothesis
March	PRE	66.37	-2.35%	0.27	0.53	Accept
	POST	64.81				
April	PRE	66.55	-1.09%	0.45	0.000039	Reject
	POST	65.82				
May	PRE	65.88	-0.48%	-0.16	0.02	Reject
	POST	65.56				
June	PRE	65.19	+0.88%	0.08	0.64	Accept
	POST	65.77				
July	PRE	65.54	-0.22%	0. 11	0.34	Accept
	POST	65.39				
August	PRE	65.52	+0.12%	-0.13	0.13	Accept
	POST	65.60				
September	PRE	65.04	+0.23%	-0.22	0.16	Accept
	POST	65.17				
October	PRE	64.57	+1.42%	-0.39	0.43	Accept
	POST	65.49				
November	PRE	64.47	+2.24%	-0.26	0.2	Accept
	POST	65.92				
December	PRE	65.54	+1.46%	0.39	0.00033	Reject
	POST	66.50				
January	PRE	65.84	+0.39%	-0.5	0.07	Accept
	POST	66.10				
February	PRE	64.78	+1.49	0.19	0.0067	Reject
	POST	65.75				

PRE=21 February 2019-21 February 2020; POST=21 February 2020-21 February 2021; Green cells demonstrate noise pollution improvement and the red cells an increase in the average noise pollution.

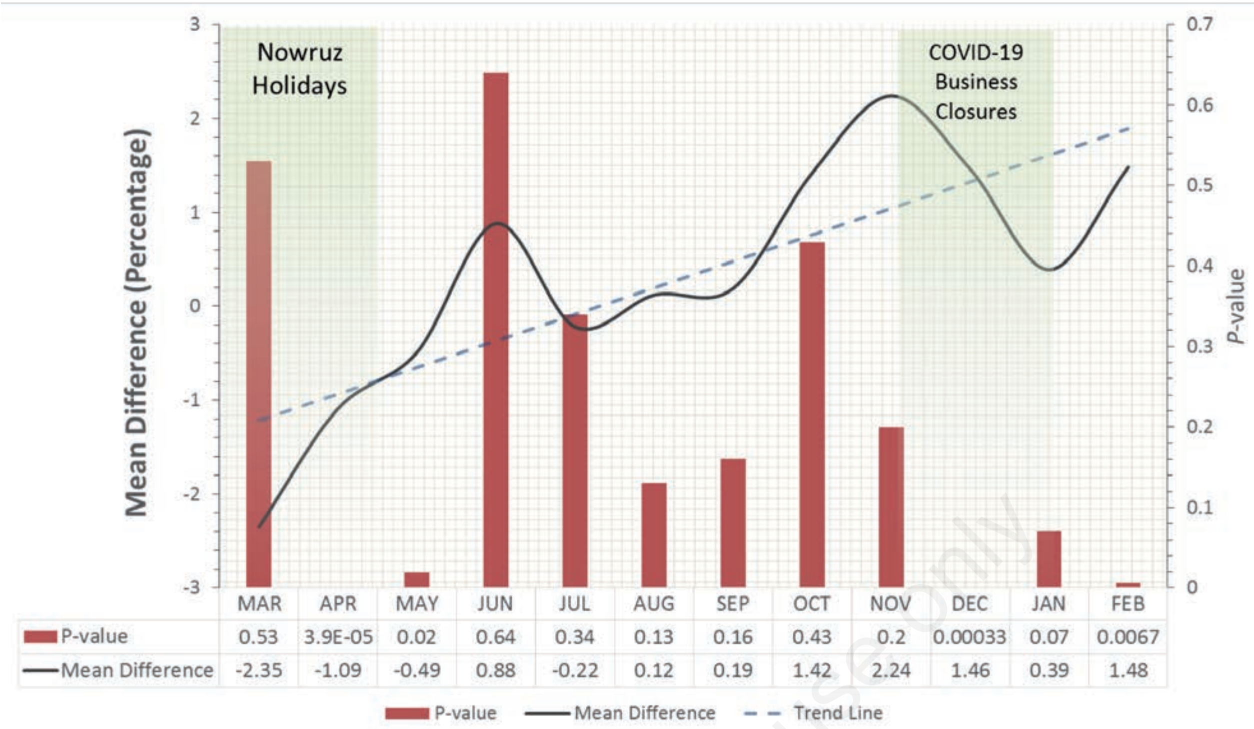

Figure 4. The monthlychange in noise pollution in Tehran during the study period. The bars and the curved line in the plot correspond to the *p*-values and the mean differences in Table 1. The dashed line is represents a regression of the curved line.

mandatory closures were implemented. The regression analysis showed that the sound pressure clearly increased during the year after the outbreak. The reduction of noise pollution decreased in March (the first month of the outbreak), but not at a statistically significant level ($p = 0.53$). However, in April and May, there were significant noise pollution reductions reaching $p= 0.000039$ and $p=0.02$, respectively.

Discussion

Noise pollution is a phenomenon of spatial nature, which ensures the suitability of spatial analysis tools in studying the phenomenon. Various research publications have focused on the spatial nature of noise pollution in cities (Monazzam *et al.,* 2015; Morillas *et al.*, 2018). While the choice of the interpolation method may affect the accuracy of the results, the aim of our study was to understand the general, large-scale distribution of pollution, not at the scale of streets or highways.

In this article, we analysed the impact of changes in transportation patterns due to the outbreak of the COVID-19 virus in Tehran, Iran. The overall analysis, accounting for the year before and the one following the outbreak showed that noise pollution in the residential areas of Tehran increased by 7%, while it fell by 2% in the city centre and around the city's Grand Bazaar. Apart from these changes, no specific pattern was observed. This phenomenon could be related to the closure of markets and shopping malls in the days following the outbreak of the COVID-19 (Borhani *et al.,* 2021). The monthly analysis showed that the early months of the virus outbreak were associated with a reduction in pollution. However, this reduction in noise pollution was not sustainable, and a gradual increase in pollution in the following months was observed. In the months leading to the time period used in the analysis, the level of noise pollution increased to a level even higher than before the outbreak, a situation probably rooted in the reopening of businesses and markets, resulting in intensified motorized traffic across the city. Citizens' ignorance of conditions may also have led to an increase in transportation-related activities in the city. While a steady increase is seen in the trend of data, the governmental measure to mandate the closure of businesses in December, due to the COVID-19 outbreak, has resulted in a reduction of noise pollution. As seen in Figure 4, the two null hypothesis rejections stress the role of the public reaction at the beginning of the pandemic and the business closures implemented in Tehran. In contrast to this result, the null hypothesis was not rejected in the other months of the study leading to the possibility that the pollution increases or decreases may have occurred by chance.

Conclusions

This analysis showed that the outbreak of COVID-19 in Tehran led to increased noise pollution in residential, while it was reduced in the city centre and business areas. The early months of the virus outbreak were associated with an initial reduction in noise pollution, but that this reduction was not sustainable but was followed by an even higher noise level than before the outbreak. This gradual increase could be due to reopening of businesses and/or people initially observing advice given but later ignoring regulations.

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