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Acoustic contamination assessment during the transition between the COVID-19 restrictions and reactivation: A exploratory analysis in Guayaquil

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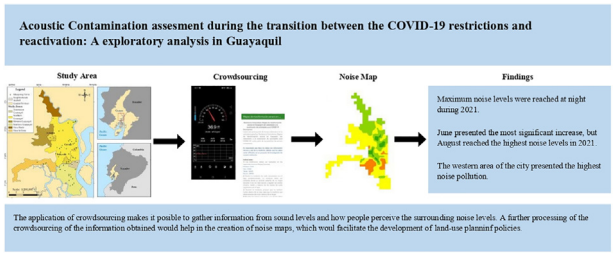
HIGHLIGHTS

- The crowdsourcing method facilitated the obtainment of noise measurements.
- The maximum noise levels occurred at night during 2021.
- The western area of Guayaquil experienced the highest noise level variation.
- Maps helped identify areas with increased noise levels and focus on solutions.

GRAPHICAL ABSTRACT



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ABSTRACT

Noise pollution is becoming a critical health risk for city life. In 2020, the COVID-19 pandemic forced many cities to implement several mobility restrictions. These restrictions changed human activity patterns and decreased the noise levels and noise pollution that often affect urban settings. As the number of infections decreased, so did the outdoor activities, influencing the population's perception of noise. This paper aims to evaluate the changes in noise levels associated with mobility restrictions between 2020 and 2021 in Guayaquil, Ecuador. This study used crowdsourcing with the help of smartphones and mobile applications to collect geo-referenced environmental noise data. The data was used to generate noise maps in different time frames. Finally, noise level maps were created using GIS-based tools to identify the urban areas that experienced the highest noise level variation during the study period. The results show that the most significant noise increase occurred at night. Furthermore, when analyzing noise level changes in different urban areas, the western area of Guayaquil was the one that experienced the most significant noise level variation. Findings inform the perception of noise pollution and could potentially serve as a reference for decision-makers during the proposal of public policies that ensure a better quality of life for its citizens.

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1. Introduction

At the beginning of March 2020, the World Health Organization declared the coronavirus a pandemic after evaluating the emergence and increase of COVID-19 cases worldwide (Cevallos-Valdiviezo et al., 2021). In order to control the spread of the disease, public health authorities in their respective countries implemented measures such as immediate quarantine, travel bans and restrictions, isolation of infected people, social distancing and cancellation of massive events (Ayouni et al., 2021; Wang and Ping, 2022). Due to the imposed regulations, governments worldwide have also faced economic and social challenges (Islam et al., 2020; Lambert et al., 2020). For example, in Ecuador, after the National Risk and Emergency Management Service proclaimed a state of emergency, measures such as the cancellation of school and work activities, mandatory confinement, zonal risk-based traffic lights and border closures were put in place (Ching-Ávalos et al., 2021).

The restrictions from the Sars-Cov-2 outbreak in most countries implied a significant interruption in society's dynamic (Terry et al., 2021). The cessation of human activities would cause a decrease in noise levels in cities (Bhat et al., 2021; Díaz et al., 2021). As a result, several studies have evaluated the effect of adopting control measures on the perception of noise pollution (Yang et al., 2022). At the beginning of the pandemic, Stuart Fowkes launched a project to develop a global sound map of collaboration that would reflect the change in the population's acoustics (Bakare, 2020). In Guadeloupe, French Antilles, the first COVID-19 lockdown made it possible to measure the effect of human-caused noise on underwater soundscapes (Bertucci et al., 2021). In Madrid, between 4 and 5 dB reductions were detected for noise levels during different time frames in the day, afternoon and night (Asensio et al., 2020). Similarly, an average reduction of 5.4 dB in equivalent sound levels was recorded in London (Aletta et al., 2020).

Noise is an unwanted sound that negatively affects human or animal life (Murphy and King, 2022). More specifically, environmental noise is any unwanted or harmful sound created by human activities, including noise emitted using transport, road, rail, air traffic and industrial activity (European Environment Agency, 2018). Environmental noise is considered a form of pollution, which can cause damage to the hearing system (Martínez Gavilanes, 2017) and cause health problems such as hypertension, coronary heart disease and strokes (Münzel et al., 2020; Themann and Masterson, 2019). In addition, it may cause psychological effects, such as changes in behavior or sleep, impaired performance, fatigue, and irritation (Alimohammadi et al., 2018; Alimohammadi and Ebrahimi, 2017).

The Environmental Protection Agency and the World Health Organization recommend keeping ambient noise below 70 dB to prevent noise-induced hearing loss. On the other hand, government agencies have set goals to mitigate the effects of noise pollution; for example, the European Union, in their attempt to attenuate road noise, has projected a 3 dB decrease in noise values for the year 2032 (Eurocities, 2020). At the same time, researchers seek to analyze the behavior of this phenomenon. For example, in China, studies examined the influence of anthropogenic sounds based on a criterion called the open space soundscape index (Li et al., 2022; Yang et al., 2022). Other approaches involve the development of applications, such as NoiseCapture, to propose the use of "Open Science" methodologies, where the participatory aspect makes citizens more aware of their sound environment (Garcia et al., 2021; Picaut et al., 2019; Zipf et al., 2020). A similar study includes calibrated smartphones, so students from different countries in Asia can take measurements of noise levels and use that information to generate noise maps (Dubey et al., 2020; Lee et al., 2020; Zuo et al., 2016).

To mitigate this problem, Ecuador established maximum permissible noise limits by time frames based on land use. The land use classifies as: hospital and educational, residential, mixed residential, commercial, mixed commercial, industrial, and habitat preservation (Ministerio del Ambiente, 2018). Likewise, studies on this phenomenon have been conducted in different cities. For example, in Quito, it was detected that values higher than 75 dB come from the main roads (Bravo-Moncayo et al., 2017). While in Cuenca, emissions of up to 77 dB are reached during the day and at night (Martínez Gavilanes, 2017).

In Guayaquil, the restrictions applied in 2020 caused collateral effects, such as decreased noise levels. A year later, mobility restrictions lessened, causing noise levels to return to normal. Based on this context, the present research aim to understand how the noise level varied in Guayaquil between 2020 and 2021, and assess the spatial distribution of noise in different urban areas and time frames. This paper evaluates the variation of noise levels in two scenarios, one with partial mobility restrictions in the context of the COVID-19 pandemic and another one without restrictions. In this sense, the production of noise maps, using data collected via crowdsourcing, complements local authorities' work by evaluating the zones and times with the most significant variation in noise levels.

This manuscript has five sections: the first section, or introduction, describes the global context generated by the COVID-19 pandemic and its implications on environmental noise, as well as the objectives of the study; the second section describes the study area, its main activities and land use established for the city, and this section also details the noise data collection and processing; the third section explains the results by time frames and neighborhoods; the fourth section discusses the results and the implications for citizens; and the fifth section concludes the paper and outlines future works.

2. Materials and methods

The methodology implemented in this study consisted of six phases (Fig. 1). Phase I covered the participants' registration through an online survey. Phase II included the participants' training through virtual sessions on Zoom, where they learned the procedure to measure noise levels. Phase III focused on data collection using crowdsourcing; mobile applications were used to measure noise dB and a virtual survey to record the information. Phase IV included data purification. Phase V focused on the statistical analysis of the data through statistical criteria. Finally, in Phase VI noise maps were created.

2.1. Study area

The study area focuses on the city of Guayaquil (2°02′S – 2°18′S and 79°50′W– 79°59′W), located on the coast of Ecuador, the capital of the Guayas province (Fig. 2). According to Ecuador's National Institute of Statistics and Census, the 2022 annual population projection for Guayaquil is 2,723,665. The city is one of Ecuador's most important industrial centres, consolidating various economic activities such as manufacturing, construction, and hospitality (Vesna, 2010). In addition, the city has a significant vehicular flow, often accompanied by excessive horn use, considered the largest source of noise (Mora-Araus et al., 2021). Around 500,000 vehicles per year move in the city (INEC, 2018). Another significant source of noise comes from informal businesses established in the city centre (Zambrano-Monserrate and Ruano, 2019). Among the informal activities carried out in the city are: transportation, commercialization of clothing, candy, vegetables and trinkets; luggage industry, weaving, and handicrafts (Quispe et al., 2020).

The study area was divided into six zones to facilitate a more detailed analysis in different urban areas (Fig. 2); the zones encompass neighborhoods or road sectors with urbanizations in their surroundings. Zone 1: located in the south of Guayaquil, corresponds to the Guasmo, Fertisa, Batallón del Suburbio, Pradera and Esteros neighborhoods; Zone 2: located in the centre of the city, encompasses the nueve de Octubre neighborhood, Cerro and Puerto Santa Ana, and places of interest such as the Bay and Malecón 2000; Zone 3: located in the north of the city, corresponds to Atarazana, Kennedy, Urdesa, Bellavista, Mapasingue, Ceibos, Florida, El Fortín, Garzota, Alborada, Sauces, Samanes and Pascuales, Orquídeas, Metrópolis and Mucho Lote; Zone 4: located to the west of

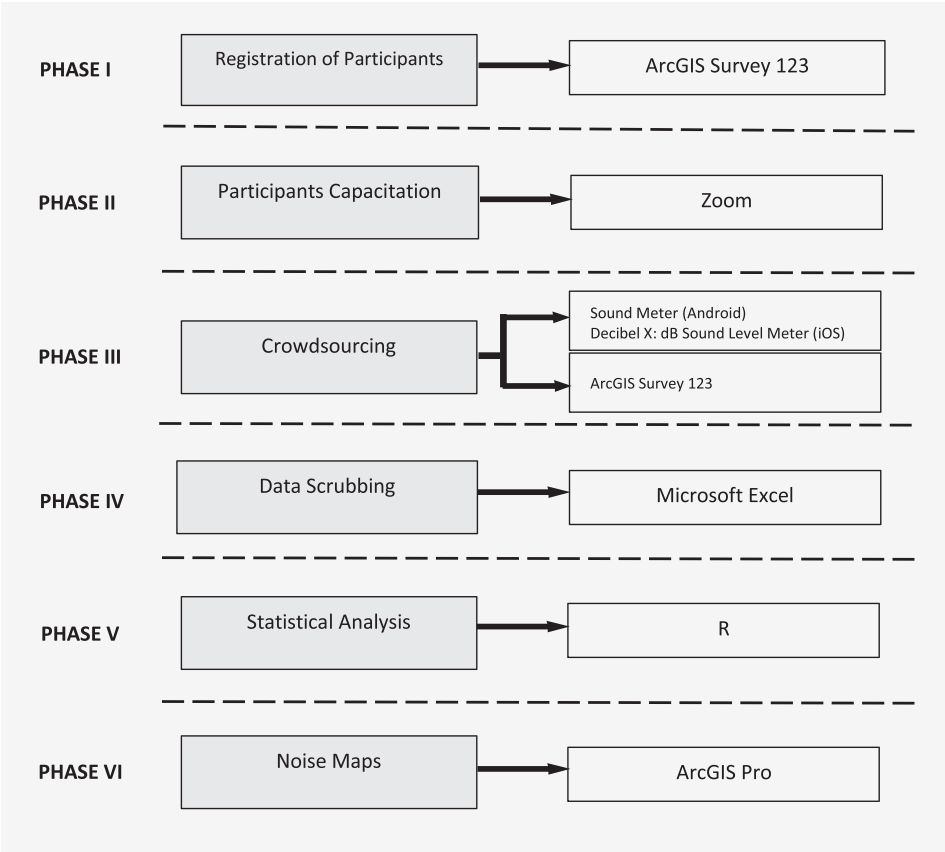

Fig. 1. Diagram of the methodological framework used in this study.

Guayaquil, includes Balerio Estacio, Flor de Bastión, Monte Sinaí and Socio Vivienda. Finally, there are two areas of recent urban growth, Zone 5: Via a la Costa, and Zone 6: Via a Daule.

In addition, an important factor to consider in noise studies is the permitted land use in cities (Margaritis et al., 2020). Land use is the set of activities allowed to be performed in different areas of the city, such as residential, industrial, commercial, protection, among others (GAD de Guayaquil, 2022). In Guayaquil, residential use occupies the largest territorial extension, which extends through the northern, southern and coastal sectors. On the other hand, industrial use concentrates mainly in the highway of the Daule sector (Fig. 3).

2.2. Data collection

This study began as part of an Escuela Superior Politécnica del Litoral (ESPOL) community service project. As a result, the measurement period corresponds to part of the academic cycles, from June to August, in the years 2020 and 2021. A total of 95 students contributed actively to the data collection, supervised by 12 volunteer teachers from ESPOL. Both groups resided in the city of Guayaquil during the development of the project.

In 2020, 70 students participated, while in 2021, only 25 students did. The difference in the number of participants is due to the restrictions implemented during the COVID-19 pandemic in 2020. These restrictions resulted in students having fewer places to choose from when participating in internships. As a result, a greater number of students joined in 2020.

The project implemented a crowdsourcing methodology, carrying out measurements collaboratively to study noise levels in the city. The sound pressure was recorded using the Sound Meter (Smart Tools Co., 2020) and Decibel X: dB Sound Level Meter applications (SkyPaw, 2019), for smartphones with Android and iOS operating systems, respectively. For an adequate noise characterization, measurements were made daily in 4 different time frames: 9:00 a.m., 1:00 p.m., 4:00 p.m., and 8:00 p.m.

Prior to measuring the sound pressure waves, the students needed to stabilize the noise measurement application. To achieve this, the App had to be left operating for approximately 5 min without registering the measurement (OSHA, 2015). Once the stabilization was achieved, the participants completed the measurements in 2 min from their respective homes, ensuring that the noise came from sources outside the home. In addition, mobile applications made it possible to record the maximum, minimum and average levels through the sound pressure measurement period.

Subsequently, the ArcGIS Survey123 application (Esri, 2022) was used to record the noise data and automatically obtain the geolocation of measurements. Additionally, the participants specified the date and time of each measurement, the noise levels, the predominant emitting source, and any important observations during the measurement.

2.3. Data scrubbing

Once the noise measurements and recording were completed, the resulting data was filtered to identify the months in which complete measurements were obtained. First, a statistical criterion was applied to work with representative data. Then, a geographic positioning criterion was used to obtain the data within the areas of interest.

The first filtering criterion analyzed the continuity of the monthly data, which made it possible to ensure that the participant had performed at least 70% of the measurements during the month of study. Accordingly, 11,528 and 4,533 records were obtained between June and August for 2020 and 2021, respectively. On the other hand, the second criterion evaluated the geolocation of the data using the ArcGIS Pro application (version 2.8), where the sound pressure records located

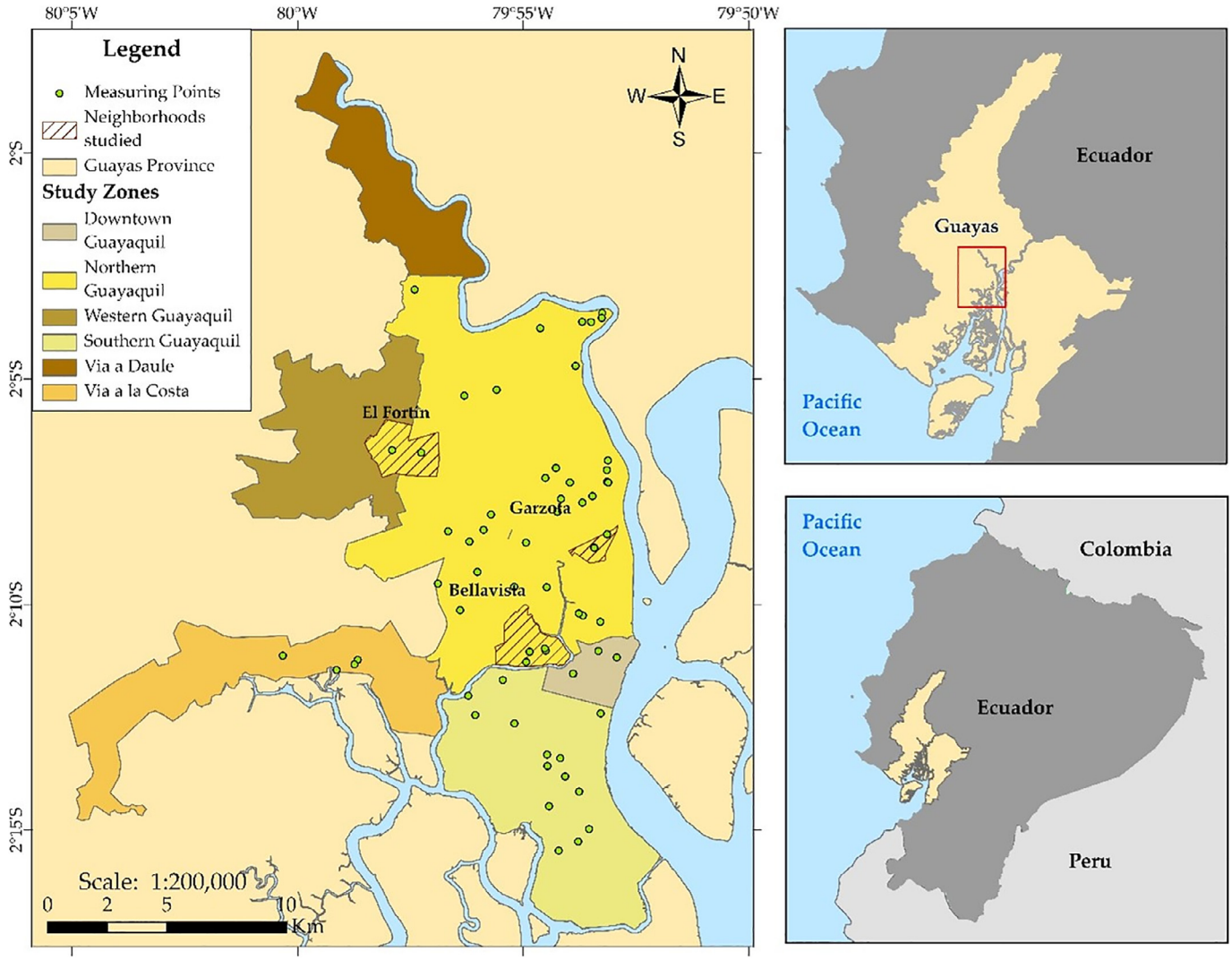

Fig. 2. Six zones for the characterization of noise in the study area and distribution of measuring points.

Table 1
Sample sizes for each time slot.

	Sample size in 2020	Sample size in 2021
Morning (9:00)	2,529	845
Day (13:00)	2,374	839
Afternoon (16:00)	2,282	817
Night (20:00)	2,278	850
Total	9,463	3,351

within the study areas were extracted (Fig. 1). As a result, 9,463 and 3,351 observations were obtained for 2020 and 2021, respectively.

The average values of a sample are the most representative (Picaut et al., 2019), which is why such values were considered for the analysis of noise levels. Table 1 shows the distribution of the data collected for each time frame.

2.4. Statistical analysis

Descriptive statistics such as mean estimators, variances and standard deviations were used to characterize the noise pressure levels during June, July and August for the years 2020 and 2021. Then, the change in the noise pressure levels was calculated through the differences and percentage variations between the noise levels from 2020 to 2021. This descriptive method was previously implemented in Bochum, Germany, to compare the average monthly noise levels over two years. They considered monthly sample sizes greater than 30, using Z hypothesis tests for two independent samples (Hornberg et al., 2021).

The study also used the R software, considering the results of the test hypothesis as significant for p values ≤ 0.05. Additionally, the data were stratified by geographical neigborhoods (six urban areas) to compare the monthly growth of noise levels from each sector based on the variation percentage. Table 1 presents the sample sizes in the different time frames by neighborhoods. Only the neigborhoods with monthly data in both years were selected to compare the average monthly noise levels by sector between 2020 and 2021. These neighborhoods are: Bellavista, La Garzota and El Fortín. Shapiro Wilks normality tests were applied because the sample size of these three neighborhoods was less than 50. The result determined that the neigborhoods data does not come from normal distributions. Finally, the study used a non-parametric hypothesis test called the Wilcoxon Range Sum test to determine significant differences between the selected range's medians. This test was previously used in other studies, such as Puyana-Romero et al. (2022).

2.5. Maps

The Kriging interpolation method was used to visually represent the data. The Kriging method is a univariate geostatistical method that uses

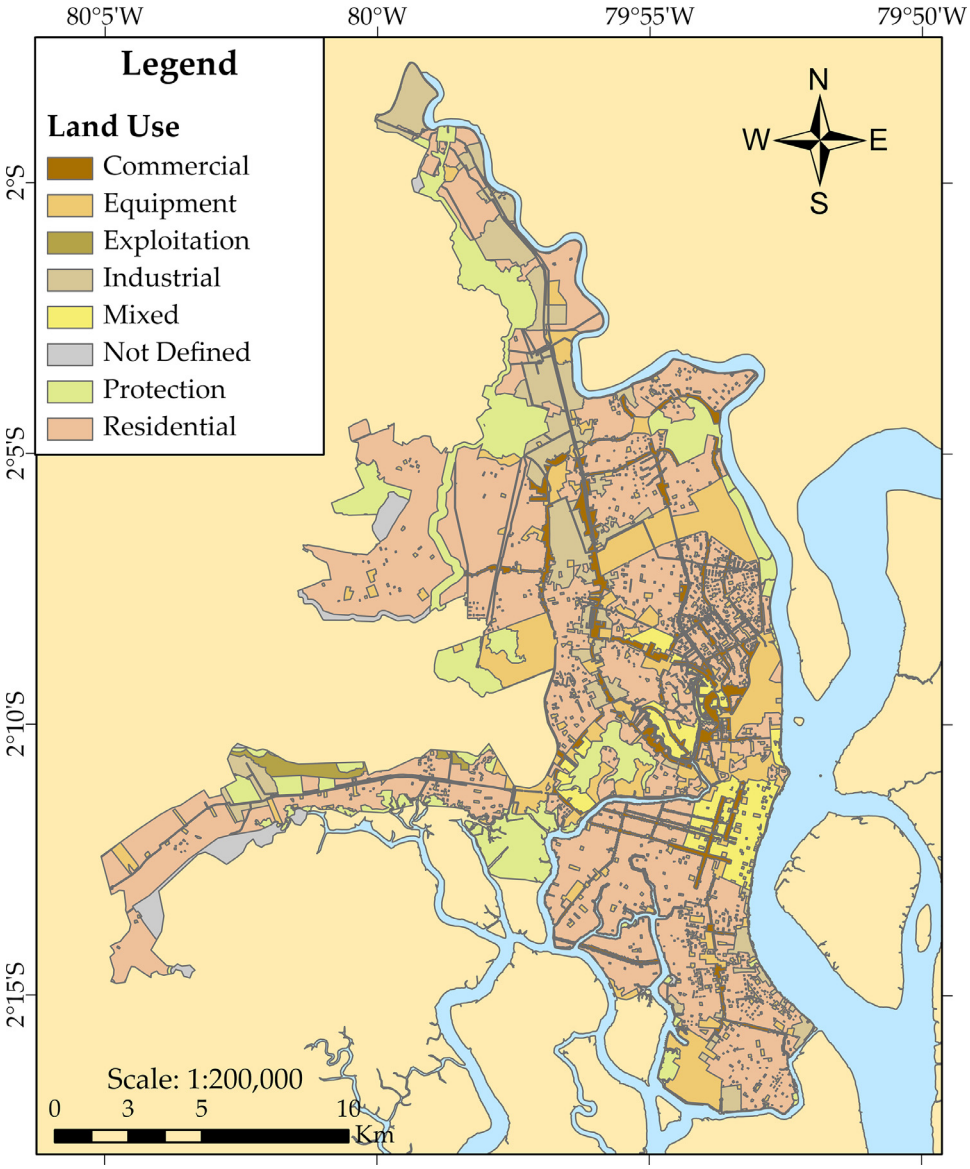

Fig. 3. Land use in Guayaquil for year 2022.

Table 2
Point estimation.

	June			July			August		
	2020 (dB)	2021 (dB)	Variation(%)	2020 (dB)	2021 (dB)	Variation(%)	2020 (dB)	2021 (dB)	Variation(%)
Morning	60.85	62.48	2.68	61.37	62.27	1.47	61.79	62.63	1.36
Day	62.04	64.11	3.33	62.41	64.47	3.33	63.56	63.26	0.00
Afternoon	60.93	63.95	4.96	62.29	63.98	2.71	63.81	62.87	-1.47
Night	60.56	63.86	5.17	60.95	63.67	4.46	61.67	62.76	1.77

the weighting principle of the sample values for the predictions and considers the sample points' spatial arrangement for the weight value (Munyati and Sinthumule, 2021). Kriging is widely employed in the field of prediction of environmental variables (Xu et al., 2022), for instance, to estimate the danger posed by noise exposure of on-site workers (Ellis et al., 2022). In addition, the interpolation method has been used to assess the impact of traffic-generated environmental pollution in countries like India and Pakistan, where they produced spatial noise prediction maps (Banerjee et al., 2009; Latif et al., 2022).

The noise maps were created by importing the refined data and establishing the World Geodetic System (WGS 1984) as the datum. Next, the layers were generated through a selection by attributes, based on the month and time frame when the measurements took place. Finally, the Kriging tool created the interpolation surface that covered the administrative area of the city.

3. Results

3.1. Analysis by time frames

Tables 2 and 3 show the point and interval estimators of the noise levels for the years 2020 and 2021 (from June to August).

According to Table 2, during the three months of the study, most of the time frames experienced an increase in noise levels. However,

Tabla 3
Interval estimation.

	June				July				August			
	2020		2021		2020		2021		2020		2021	
	Standard deviation	95% Confidence interval	Standard deviation	95% Confidence interval	Standard deviation	95% Confidence interval	Standard deviation	95% Confidence interval	Standard deviation	95% Confidence interval	Standard deviation	95% Confidence interval
Morning	9.96	(60.22, 61.48)	9.9	(61.32, 63.64)	9.24	(60.76, 61.98)	10.55	(61.13, 63.42)	9.9	(61.06, 65.52)	11.48	(61.19, 64.08)
Day	9.28	(61.43, 62.66)	9.54	(62.98 65.23)	9.01	(61.80, 63.01)	9.54	(63.04, 65.17)	9.36	(62.85, 64.27)	11.28	(61.88, 64.64)
Afternoon	8.86	(60.93, 62.16)	9.75	(62.78, 65.12)	8.97	(61.68, 62.90)	10.7	(62.78, 65.17)	9.31	(63.09, 64.53)	11.04	(61.49, 64.26)
Night	8.81	(59.96, 61.16)	10.23	(62.14, 65.08)	8.86	(60.34, 61.55)	10.06	(62.58, 64.77)	9.57	(60.93, 62.41)	10.6	(61.45, 64.06)

Table 4
Hypothesis testing (MN = morning noise, DN = day noise, AN=afternoon noise, NN=night noise).

		June		July		August	
Hypothesis Ho	**Hypothesis H1**	***p*-value**	**Conclusion**	***p*-value**	**Conclusion**	***p*-value**	**Conclusion**
MN 2021 = MN 2020	**MN 2021 > MN 2020**	**0.008**	**Decline H0**	**0.086**	**Decline H0**	**0.153**	**Do not decline H0**
DN 2021 = DN 2020	**DN 2021 > DN 2020**	**0.001**	**Decline H0**	**0.001**	**Decline H0**		
AN 2021 = AN 2020	**AN 2021 > AN 2020**	**0.000**	**Decline H0**	**0.007**	**Decline H0**		
NN 2021 = NN	**NN 2021 > NN 2020**	**0**	**Decline H0**	**0**	**Decline H0**	**0.078**	**Do not decline H0**

the night time frame experienced a more significant variation in noise levels. It is important to note that June registered the most significant variation in all the time frames. This effect may be associated with mobility limitations due to COVID-19 being implemented around the same time.

Table 3 shows the confidence intervals for the noise level mean points estimated for each time frame. The interval widths for the computed statistics are small, indicating the validity of their interpretation. In addition, the 2021 intervals present higher minimums and maximums than those observed in 2020, with a higher standard deviation.

Table 4 presents the test hypothesis results used to verify if the average noise values per time frame in 2021 were higher than those observed in 2020.

According to Table 4, the *p*-value for June and July in each time frame indicates that the 2021 noise levels, on average, are higher than those observed in 2020. However, the noise recorded during the morning and night in August 2021 was not higher than that obtained in 2020 during the same month. In addition, the day and afternoon time frames were not considered for this last month because they presented a decrease in the average noise level.

3.2. Monthly analysis by neighborhood

Table 5 shows the variation of the mean and median noise levels of the three neighborhoods, which obtained similar data for each time frame in both years.

Table 5 shows growth in the noise levels, means and medians for the three sectors. The results indicate that El Fortín is the neighborhood with the most significant increase in noise levels. In June, particularly during the morning, this sector experienced the highest variation with a 36.36% mean and 59.18% median. Another sector that experienced a significant change during June was Bellavista. However, this change occurred in the afternoon, with a 23.27% mean and a 26.09% median. In addition, in this area, the noise levels decreased during August for the day, afternoon and night time slots. Finally, La Garzota experienced the most significant variation during the night time slot in June, with a 17.06% mean and a 13.33% median. There was also a decrease in noise levels during the afternoon for July and August.

Table 6 shows the results of the normality test monthly for each time slot.

Table 5
Monthly noise level mean and median variation (%) by Guayaquil neighborhoods.

	Morning (09:00)					
	Mean			Median		
Neighborhoods	**June**	**July**	**August**	**June**	**July**	**August**
Bellavista	16.64	12.80	9.53	22.92	18.75	8.57
La Garzota	2.96	0.38	1.48	3.17	-1.56	0.78
El Fortín	36.36	27.09	28.47	59.18	28.23	33.87
	Day (13:00)					
	Mean			Median		
Neighborhoods	**June**	**July**	**August**	**June**	**July**	**August**
Bellavista	19.75	-0.76	-0.73	20.41	-3.70	3.85
La Garzota	4.04	4.83	1.87	2.38	3.17	2.34
El Fortín	32.81	22.61	28.08	34.45	25.40	29.69
	Afternoon (16:00)					
	Mean			Median		
Neighborhoods	**June**	**July**	**August**	**June**	**July**	**August**
Bellavista	23.27	4,29	-9.12	26.09	4.85	-10.17
La Garzota	1.92	-1.00	-3.47	0.00	0.00	-5.47
El Fortín	26.20	23.63	17.73	29.51	26.40	18.57
	Night (20:00)					
	Mean			Median		
Neighborhoods	**June**	**July**	**August**	**June**	**July**	**August**
Bellavista	6.40	3.14	-4.44	0.89	0.00	-4.39
La Garzota	17.06	7.87	2.31	13.33	4.84	3.17
El Fortín	26.54	25.09	19.25	28.69	18.18	22.96

According to Table 6, seven results do not show normality in the Bellavista neighborhood. In La Garzota, eight bands do not indicate a normal distribution, and in Fortín, nine bands do not reach normality. Since a normal distribution was not obtained in all the samples, a non-parametric hypothesis test took place for the monthly comparative study by neighborhood for 2020 and 2021.

Table 6
Shapiro Wilks normality test by Guayaquil neighborhoods (N = normality; NN = non-normality).

	Morning (09:00)											
	2020						2021					
Neighborhoods	June *p*-value	Result	July *p*-value	Result	August *p*-value	Result	June *p*-value	Result	July *p*-value	Result	August *p*-value	Result
Bellavista	0.000	NN	0.053	NN	0.330	N	0.636	N	0.245	N	0.218	N
La Garzota	0.071	N	0.000	NN	0.486	N	0.000	NN	0.103	N	0.001	NN
El Fortin	0.063	N	0.829	N	0.006	NN	0.487	N	0.000	NN	0.000	NN
	Day (13:00)											
	2020						2021					
Neighborhoods	June *p*-value	Result	July *p*-value	Result	August *p*-value	Result	June *p*-value	Result	July *p*-value	Result	August *p*-value	Result
Bellavista	0.175	N	0.081	N	0.031	N	0.290	N	0.001	NN	0.062	N
La Garzota	0.191	N	0.000	NN	0.032	N	0.119	N	0.026	N	0.174	N
El Fortin	0.089	N	0.820	N	0.959	NN	0.050	NN	0.085	N	0.213	N
	Afternoon (16:00)											
	2020						2021					
Neighborhoods	June *p*-value	Result	July *p*-value	Result	August *p*-value	Result	June *p*-value	Result	July *p*-value	Result	August *p*-value	Result
Bellavista	0.002	NN	0.001	NN	0.593	N	0.020	NN	0.003	NN	0.185	N
La Garzota	0.175	N	0.007	NN	0.001	NN	0.071	N	0.259	N	0.075	N
El Fortin	0.202	N	0.324	N	0.202	NN	0	NN	0.925	N	0.001	NN
	Night (20:00)											
	2020						2021					
Neighborhoods	June *p*-value	Result	July *p*-value	Result	August *p*-value	Result	June *p*-value	Result	July *p*-value	Result	August *p*-value	Result
Bellavista	0.204	N	0.054	N	0.268	N	0.069	N	0.069	N	0.015	N
La Garzota	0.002	NN	0.226	N	0.426	N	0.433	N	0.058	N	0.006	NN
El Fortin	0.082	N	0.753	N	0.051	N	0.103	N	0.436	N	0.005	NN

Table 7
Wilcoxon rank sum hypothesis test by Guayaquil neighborhoods.

Morning (09:00)				Day (13:00)			
Neighborhood	Month	*p*-value	Conclusion	Neighborhood	Month	*p*-value	Conclusion
Bellavista	June	0.000	Decline H0	Bellavista	June	0.000	Decline H0
	July	0.013	Decline H0		July	0.576	Do not decline H0
	August	0.001	Decline H0		August	0.429	Do not decline H0
La Garzota	June	0.009	Decline H0	La Garzota	June	0.011	Decline H0
	July	0.714	Do not decline H0		July	0.001	Decline H0
	August	0.018	Decline H0		August	0.188	Do not decline H0
El Fortin	June	0.000	Decline H0	El Fortín	June	0.000	Decline H0
	July	0.000	Decline H0		July	0.000	Decline H0
	August	0.000	Decline H0		August	0.000	Decline H0
Afternoon (16:00)				**Night (20:00)**			
Neighborhood	Month	*p*-value	Conclusion	Neighborhood	Month	*p*-value	Conclusion
Bellavista	June	0.000	Decline H0	Bellavista	June	0.054	Do not decline H0
	July	0.074	Do not decline H0		July	0.250	Do not decline H0
	August	0.994	Do not decline H0		August	0.859	Do not decline H0
La Garzota	June	0.117	Do not decline H0	La Garzota	June	0.000	Decline H0
	July	0.722	Do not decline H0		July	0.003	Decline H0
	August	1.000	Do not decline H0		August	0.998	Do not decline H0
El Fortín	June	0.000	Decline H0	El Fortín	June	0.000	Decline H0
	July	0.000	Decline H0		July	0.000	Decline H0
	August	0.000	Decline H0		August	0.000	Decline H0

Table 7 shows the conclusions of the Wilcoxon Rank Sum hypothesis test for all study time slots. The null hypothesis (H0) stated the equality of noise levels in the years of study, and the alternative hypothesis (H1), stated that there would be a higher noise level in 2021 compared to 2020.

According to Table 7, the null hypothesis is rejected during five-time slots in the Bellavista sector, showing a change in the magnitude of the noise. On the other hand, in La Garzota, six-time slots showed a difference in the noise level, and in the El Fortín neighborhood, all time slots showed increased sound pressure levels.

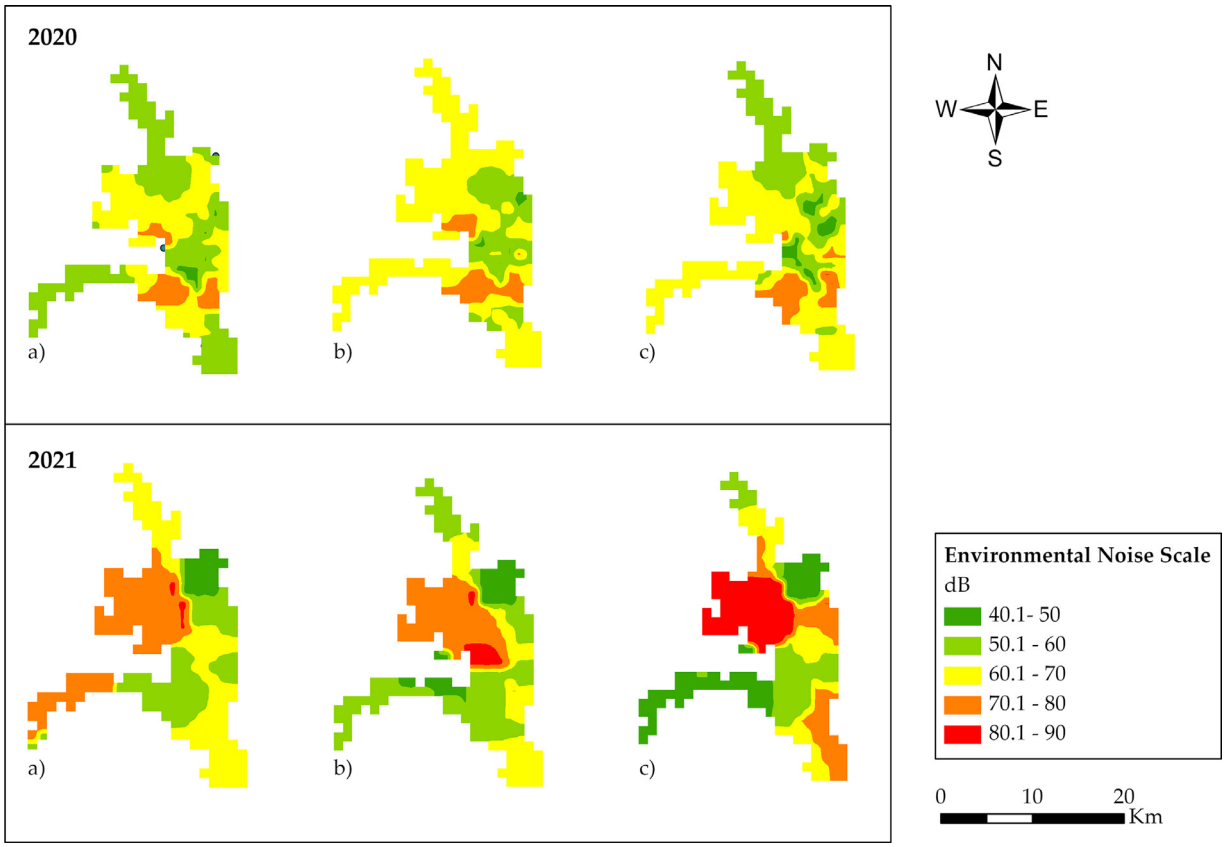

Fig. 4. Noise maps at moring (09:00) of years 2020 and 2021, for the months of a) June , b) July and c) August.

Of the neighborhoods analyzed, El Fortín, located in the west of the city, showed a more significant increase in its noise levels during the three months of the study, especially during the morning. On the other hand, the Bellavista neighborhood, located to the north of the city, presented an increase in noise levels in June and a decrease in its levels in August, both during the afternoon. Lastly, La Garzota, also located to the north, experienced an increase in noise magnitude in June during the night time, and a decrease in July and August, during the afternoon. In other words, during June, it was possible to perceive an increase in the magnitude of the noise, while in August, lower sound pressure levels were detected.

3.3. Noise maps

Statistical validation and geolocation made generating maps for each time slot and year possible. A cell size of 0.00935 m was specified. Figs 4, 5, 6, and 7 show the monthly and annual variation by band.

3.3.1. Morning

The year 2020 reached a maximum noise level of 80 dB. From June to August, such sound pressure remained constant at the via a la Costa entrance and in neighborhoods that border the Estero Salado and downtown Guayaquil. Minimum noise levels of 40 dB were reached in neighborhoods north of the city during June and August. In 2021, the maximum noise level increased to 90 dB; this value was perceived during July in areas north of Guayaquil and during August in the west of the city. On the other hand, the northernmost neighborhoods recorded minimum noise levels from June to August. Via a la Costa also registered such values only in August. Concerning the analysis of the annual variation, the western area of the city increased its noise levels by 10 dB in June and July and by 20 dB in August. Via a la costa increased the noise level by 20 dB in June and decreased by 10 and 20 dB in July and August, respectively. In the city's south, noise values increased by 10 dB in June and August.

3.3.2. Day

The year 2020 reached a maximum noise value of 80 dB during the three months of study at the via a la Costa entrance and in the city's central, western, and southern areas. The city's northern sector recorded a minimum noise level of 40 dB between June and July. In 2021, the highest sound pressure records occurred in the city's western sector, in June and August. At the same time, the lowest sound pressure levels originated on via a la Costa and in neighborhoods located north of Guayaquil in July and August. Analyzing the annual change can determine an increase in noise on via a la Costa of 10 dB in June but a decrease of 20 dB in July and August. In the city's western sector, the noise level increased by approximately 20 dB. The northern industry remained between 50.1 and 70 dB. The southern sector remained with magnitudes between 60.1 and 70 dB. Finally, in the city's center, noise levels were reduced by around 10 dB.

3.3.3. Afternoon

For 2020, a maximum noise value of 80 dB was reached during the three months of study at the via a la Costa entrance, in the city's center, the western and southern areas. The city's northern sector recorded a minimum noise level of 40 dB between June and July. In 2021, the highest sound pressure records occurred in the city's western sector, in June and August. At the same time, the lowest sound pressure levels originated on via a la Costa and in neighborhoods in the north of Guayaquil in July and August. Analyzing the annual change determined an increase in noise on via a la Costa of 10 dB in June but a decrease of 20 dB in July and August. In the city's western sector, the noise level

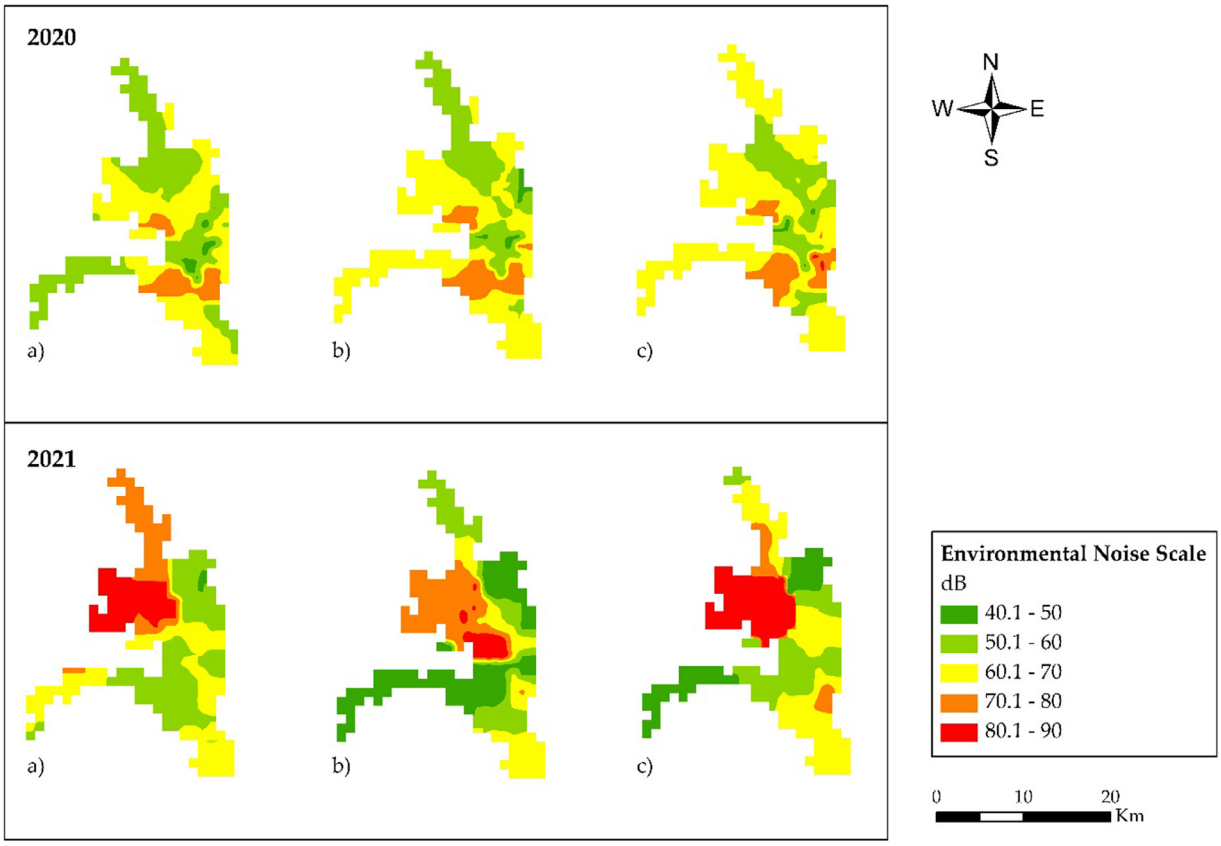

Fig. 5. Noise maps at day (13:00) of years 2020 and 2021, for the months of a) June , b) July and c) August.

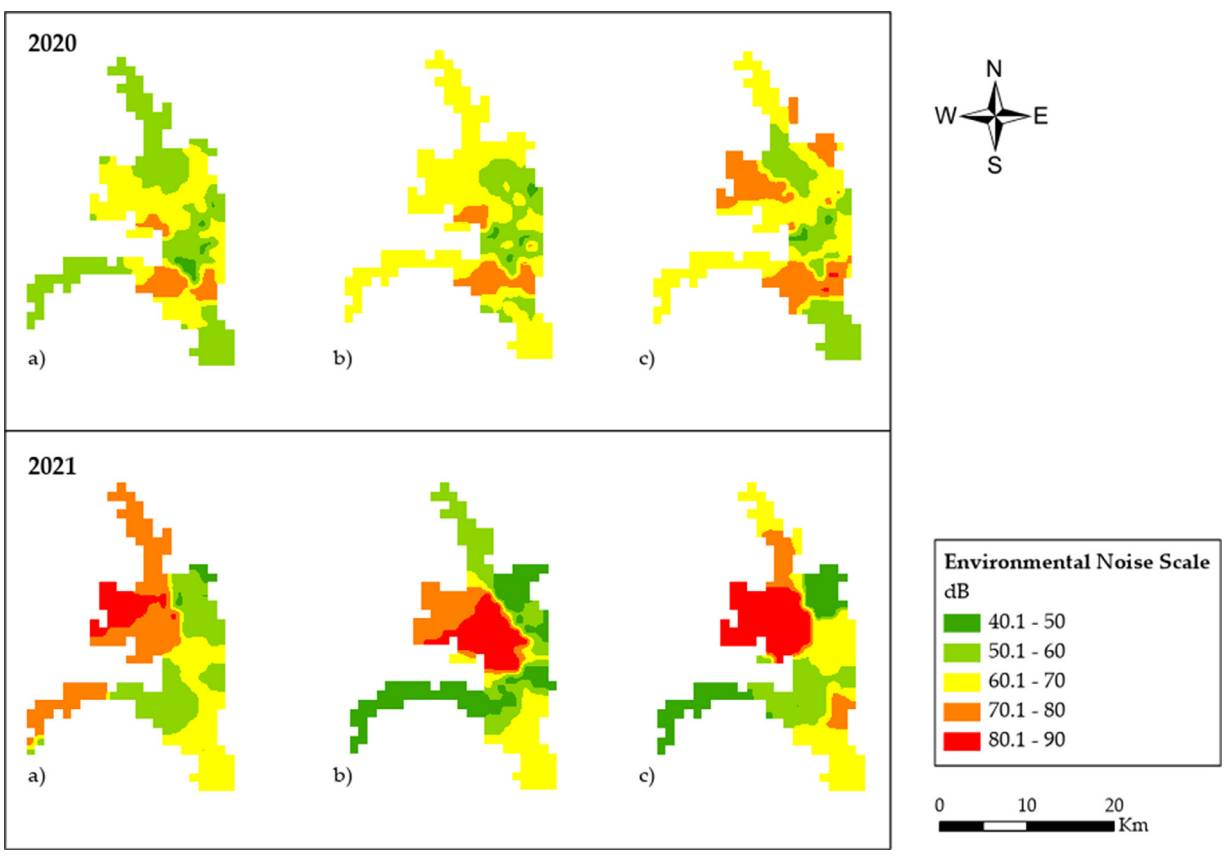

Fig. 6. Noise maps at afternoon (16:00) of years 2020 and 2021, for the months of a) June , b)July and c) August .

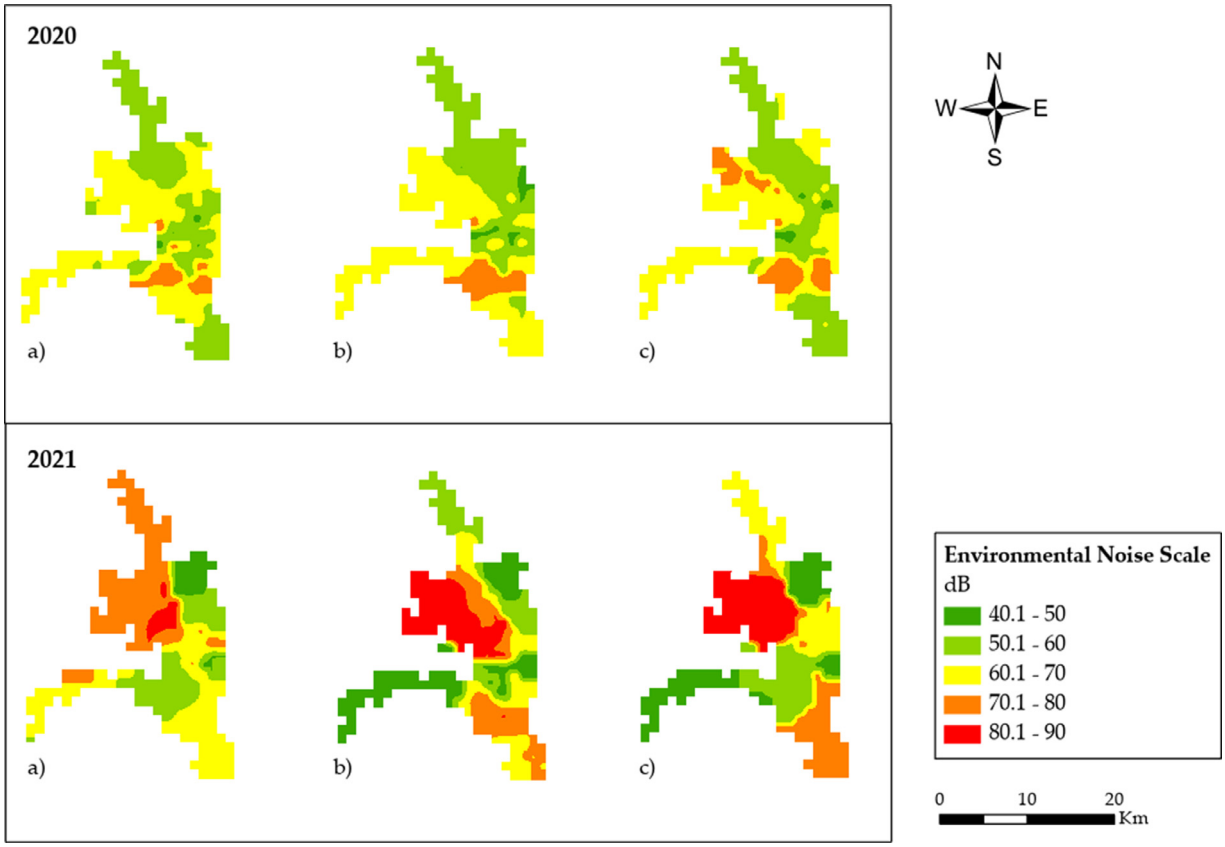

Fig. 7. Noise maps at night (20:00) of years 2020 and 2021, for the months of a) June , b) July and c) August .

increased by approximately 20 dB. The northern industry remained between 50.1 and 70 dB. The southern sector remained with magnitudes between 60.1 and 70 dB. Finally, in the city's center, noise levels were reduced by around 10 dB.

3.3.4. Night

The 2020 night time slot had similar behavior to the other three time slots, with values between 50.1 and 70 dB in the north and south of the city. In addition, there is a decrease in the areas with ambient noise levels between 70.1 and 80 dB. On the other hand, for the following year, there is an increase of 10 dB in the magnitudes of sound pressure, especially in the south of the city, not a minor fact since less noise perception is expected for this time. When analyzing the annual change, the western part of the city increased its noise levels from 60.1 dB, in 2020, to 90 dB, in 2021, during the three months of study. The via a la Costa sector decreased its noise levels in the second year, in July and August. The via a Daule sector registered an increase of 20 dB in June, remained constant in July, and increased 10 dB in August. The city's south increased its noise levels by 10 dB in June and July and by 20 dB in August.

In summary, during 2021, there was an increase in noise levels, mainly in the city's western and southern neighborhoods, in the four-time slots, where their values were between 70.1 and 90 dB. Similarly, via a Daule increased an average of 10 dB in noise magnitude. On the other hand, Via a la Costa and the northernmost neighborhoods experienced a decrease in their noise levels in the four-time slots. Sound pressure waves between 40.1 and 60 dB were recorded in such places. The city center also showed an average 10 dB reduction in noise level. The months with the highest noise indices were July and August 2021, especially in the afternoon and evening slots, as shown in the maps with larger areas with tones representing dB above the permissible ones.

4. Discussion

Guayaquil is the second most populated city in the country, surpassed only by the capital city, Quito (INEC, 2022). It has a vehicle fleet of approximately 450,000 units, while Quito has approximately 500,000(INEC, 2018), making them the cities with the highest urban noise in Ecuador (Carrasco et al., 2022). High levels of noise pollution (more than 80 dB) can seriously affect the health of several inhabitants. The population could experience chronic hearing loss and even suffer behavioral changes (Bidelman et al., 2020; Gasco et al., 2020). Other proven health complications include increased heart rate and blood pressure, worsening peripheral circulation, and increased glucose and cholesterol as noise levels exceed 55 dB (Favres-Marqui et al., 2005).

These health problems are excelled because previous research done in the city has already found certain areas with noise values over the threshold of 80 dB. For instance, in 2016, the north of Guayaquil experienced noise levels between 70 and 90 dB, both during the day and evening (Arteaga et al., 2016). One year later, the north and south of the city registered intensities of approximately 70 dB during all the time slots, concluding that the quality of life is unacceptable in these areas (Calero et al., 2017). Finally, in 2018, both areas registered average noise levels of 80 dB during the morning and afternoon (Andrade et al., 2018).

Nonetheless, Guayaquil presents a moderate degree of noise pollution compared to Quito or Cuenca. In Quito, noise levels are above 65 dB both during the day and night time slotes at the north and center of the city (Bravo-Moncayo et al., 2017), while in Cuenca, the third most populated city in the country, noise levels have exceeded 70 dB during the morning, midday, afternoon and night time for the last five years (Armijos et al., 2022). However, Ecuador's three most populated cities present a discontinuity in noise monitoring studies (Martínez Gavilanes, 2017).

COVID-19 reduced human activities, which resulted in the reduction of pollution levels, including noise pollution. At the beginning of March 19, 2020, Ecuador was quarantined due to the coronavirus pandemic. This resulted in restrictions on public gatherings and international travel, as well as schools and universities having to teach online instead of on campus. In early May same year, by decision of the National Emergency Operations Center (COE from its Spanish acronym), the country entered social distancing measures through traffic lights for each department of the country. With the distribution of the vaccines between January and May 2021, restriction measures started to diminish, and almost all people returned to their activities in the so-called new normality. The easing of the measures drove people from popular areas, particularly in the southern and western side of the city, to return to their old habits, such as the use of amplifiers until late in the night, and the traffic returned to almost pre-covid levels, increasing the number of heavy vehicles which transit near urban-marginal areas. For sectors such as Via la Costa and midtown, the reduction of restrictions allowed for certain entertainment centres (pubs and discotheques) to reopen their doors, and for restaurants to open until much later hours than in the last trimester of 2020. All these factors caused the increase of noise levels around to almost pre-covid levels.

The noise measurements achieved in 2020 and 2021 and the implementation of ArcGIS Survey123 allowed participants to specify the predominant noise source during the measurement, an improvement since transportation was usually considered the only emitting source in prior studies of this phenomenon (Picaut et al., 2019). Additionally, this study allowed us to characterize the noise sources and associate them with the permitted land use in each city zone. Finally, the crowdsourcing application allowed for a more significant involvement of Guayaquil´s inhabitants in environmental policy issues and raised public health awareness.

By comparing the results of 2020 with the permissible noise values according to local regulations (Ministerio del Ambiente, 2018), it can be confirmed that in the central-south residential area of the city, the permitted 55-65 dB is exceeded. Similarly, the industrial zone west of Guayaquil, exceeded the regulated 75 dB. Finally, the noise levels in 2021, the residential-industrial zone west of the city, exceeded the permissible limit of 65 dB.

There were two limitations during the development of this study: the decrease of participants and the use of smartphones. The decrease in the number of participants in 2021 caused the sample size to drop during that year. In addition, the group of students and volunteer teachers that took the measurement points in 2020 differed from 2021, which partially altered the location of said points. It is important to note that the data availability for 2020, compared to the following year, allows for a more representative and discretized interpolation in the respective maps. On the other hand, when analyzing the technological aspect, the application of smartphones for sound data collection represents a low-cost solution easily replicable in other cities where local governments still do not consider noise an environmental problem. Therefore, this initiative makes it possible to consider noise as a variable to control during urban development.

5. Conclusions

In this study, the crowdsourcing application, during a period of partial mobility restriction, allowed to obtain noise measurements of the same time periods for 2020 and 2021. A descriptive and inferential statistical analysis made it possible to determine an increase in noise levels in Guayaquil. Furthermore, the noise maps made it easier to identify in which neighborhoods of the city such increases occurred. The analysis by time slots determined that the night time (8:00 p.m.) showed a more significant change. On the other hand, when comparing noise levels monthly, June presented the most significant increase, but August reached the highest noise levels. In general, the neighborhoods located west of the city had the highest noise pollution levels. In addition, there were few areas with decreasing noise levels in all time slots.

Future studies could extend the implementation of this methodology, seeking correlations with health effects related to problems for the surveyed population, such as, increased stress level, loss of sleep quality, and decreased concentration level, to offer different solutions to medical specialists. Finally, adapting wireless noise sensors for automated data collection makes this research attractive for local governments by showing real-time noise maps for every city.

Declaration of Competing Interests

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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