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Research article

Noise levels associated with urban land use types in Kigali, Rwanda

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ABSTRACT

Noise pollution poses a serious threat to public health and continues to grow in extent, frequency, and severity due to the rapid population growth and urbanization, and this is of particular concern in developing countries such as Rwanda. However, data on noise pollution levels, noise laws and regulations are, however, lacking in Rwanda. We assessed the effect of land-use type during a two-month period at nine sites: three commercial sites, three passenger-car parking sites, two road junction sites, and one reference site (Car-Free Zone) in Rwanda. We collected data on noise pollution during weekdays (Monday, Wednesday, and Friday) and Weekends (Saturday and Sunday) in the morning (7h00–10h00), around noon (11h00–14h00), and in the evening (15h00–18h00). The mean noise levels were higher during weekdays (60–80) A-weighted decibels (dB) (A)) than during weekends (50–70 dB (A)). We recorded the lowest noise level at Kigali car-free zone in the morning (34.4 dB (A)) and the highest noise level at Nyabugogo passenger-car parks in the evening (111.2dB (A)). Spatial variation of noise levels interpolated for Kigali City shows higher noise levels (hotspot) in the outskirts of Kigali, Remera and Kimironko. Noise levels recorded in Kigali exceeded the World Health Organization permissible daytime limits during both weekdays and weekends at all land-use types except the car-free zone site. Our results indicate that Kigali residents are exposed to high levels of noise, and urgent development of noise pollution monitoring programs and control measures in Rwanda is required.

1. Introduction

Urbanization is accompanied by several environmental problems, including air pollution, biodiversity loss, the heat island effect, and noise pollution, which poses a serious threat to public health [1, 2, 3]. Exposure to high levels of noise pollution negatively affects human health by causing, among others, cardiovascular disease [4], diabetes [5], hypertension, ischemic heart disease [6], learning impairment [7], metabolic syndrome [8, 9], obesity [10], and sleep disorders [11]. Noise pollution is generally higher in urban areas where its effects depend on land-use types [12]. The characteristics of the surfaces reached by sounds, such as road materials, structures of buildings, and tree species, for instance, play a significant role in sound absorption, reflection, and transmission during sound propagation [13, 14, 15]. Due to demographic and economic growth, urban areas are rapidly expanding. However, there is a lack of a comprehensive understanding of the impact of land-use types on noise pollution in major cities of developing nations, such as Kigali and Rwanda in general.

Noise pollution is one of the most basic forms of pollution, and it has increased due to the recent development of transport systems [16]. Transport systems, such as airports [17], railway traffic [18], and roads [19, 20], are large sources of noise pollution in cities. Traffic noise in metropolitan areas depends on the gradient and number of lanes, pavement ageing, percentage of heavy vehicles, road pavement conditions, road surface, road texture, speed of cars, and traffic congestion [21, 22, 23]. High noise levels in cities are attributed to traffic congestion resulting in honking and noise generated during the movement of vehicles [24, 25]. Thus, economic growth, demographic profile, and poor traffic planning contribute to traffic noise, severe environmental and health effects. Levels of noise pollution in cities are influenced by the design of urban areas; urban density, urban morphology, street distribution, street environment, and urban land use are critical factors in noise pollution [26]. Cities with larger green spaces have, for instance, lower day-evening-night noise levels [26, 27, 28]. The day-evening-night levels of noise pollution also depend largely on commuting patterns [29, 30]. Furthermore, noise pollution is higher in areas with a higher density

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Table 1. Land-use types and coordinates of sampling sites in Kigali, Rwanda.

Land-use Types	Sampling sites	Coordinates
Passenger-car park sites	Nyabugogo car parks	-1.9423° S,30.0440° E
	Downtown car parks	-1.9433° S,30.05511° E
	Kimironko car parks	-1.9505° S,30.1259° E
Commercial sites	Biryogo market	-1.9658° S,30.0627° E
	Nyamirambo market	-1.9752° S,30.0489° E
	Nyarugenge market	-1.9405° S,28.7588° E
Road junction sites	Kigali City Plaza	-1.9441° S,30.0544° E
	Gisimenti (Remera)	-1.9601° S,30.1089° E
Reference site	Car-free zone	-1.9477° S,30.0555° E

of buildings and roads, such as commercial and street junction areas, while car-free zones experience lower noise levels [31]. Business zones record high levels of noise pollution, and the noise levels in mixed land use are higher than in single land use areas [32]. Thus, land use type affects noise pollution in urban settings, and many countries are working towards improving noise pollution.

Different organizations have established and published environmental noise directives to avoid or reduce the adverse effects of noise pollution [12]. For example, the European Commission published the Environmental Noise Directive, which recommends project-based methods to calculate, assess, and reduce traffic noise, including the E.U project [33]. The World Health Organization (WHO) has recognized noise pollution as an epidemiological concern and has set noise guidelines of 45 dB (A) for quiet areas, 55 dB (A) for residential areas, and 65 dB (A) for industrial areas [34, 35]. While developed countries such as Australia, Japan, and the U.S. have set noise pollution standard levels [36]. For example, some developed countries have developed their own traffic models, such as the Federal Highway Administration in the U.S., Richtlinien für den Lärmschutz a Straben in Germany, and Calculation of Road Traffic Noise in the United Kingdom [33]. China published a report on the prevention and control of noise pollution in 2016 [12], and several countries have established noise maps to provide detailed information about the noise environment and visualize noise levels in different places in colour [33, 37]. According to the U.S. Environmental Protection Agency (U.S.E.P.A.), noise pollution levels from 60 –<65 dB (A) are classified as highly risky, 70–<75 dB (A) as dangerous and >80dB (A) as extremely dangerous [38].

On the other hand, noise pollution is under-studied in developing countries such as Rwanda. For instance, no country has noise regulation standards in sub-Saharan Africa. However, noise pollution may rise in those countries due to population expansion, poor urban planning associated with urban sprawl, and increased use of vehicles. To our knowledge, this is the first study on noise pollution in Kigali and in Rwanda at large. Recognition of the factors contributing to noise pollution in urban areas is of paramount importance for urban planning and renewal to reduce and mitigate noise pollution, particularly regarding its effects on schoolchildren, in developing countries. This study assessed noise pollution levels in different land use types between weekdays and

Figure 1. Figure showing the noise data sampling sites topography and site characteristics.

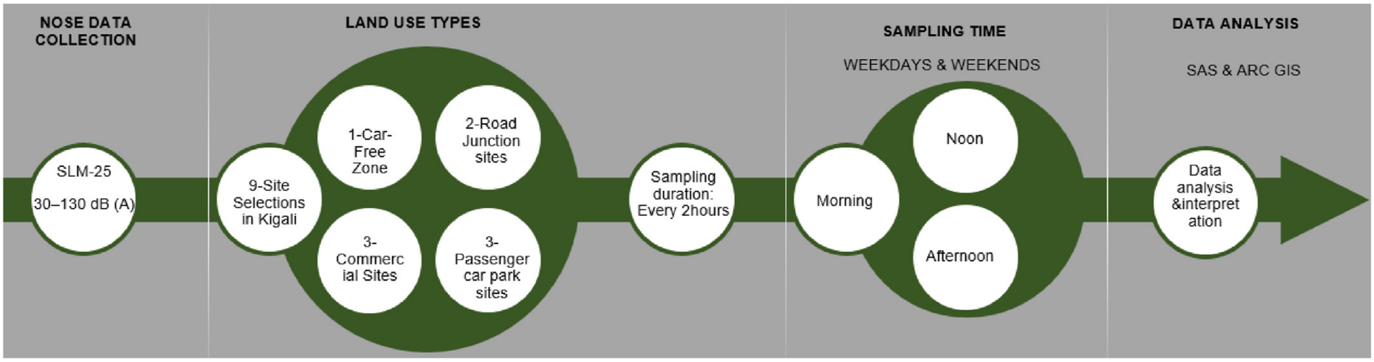

Figure 2. General workflow for the experimental design, showing how noise data were collected at different land-use types.

weekends for a period of months in Kigali, Rwanda. We provided the first preliminary data on noise levels at different land use types in Rwanda and will serve as the basis for the development of noise standards and regulations by the Rwanda Environmental Management Authority REMA responsible for noise pollution control in Rwanda.

2. Material and methods

2.1. Study site

We studied the effects of land-use types on noise pollution in the city of Kigali. Kigali is the capital and the largest city in Rwanda and is divided into three districts: Gasabo, Kicukiro, and Nyarugenge. Kigali has a surface area of 730 km^2, a population of ~1,132,686 people, and, thus, a population density of ~1,552/km^2. Kigali is located at 1°56′38″S, 30°3′34″E and an elevation of 1,567 m. Since its independence from Belgium in 1962 and the genocide against Tutsi in 1994, Kigali has become a cultural, economic, and transport hub in Rwanda. Population expansion, urban sprawl, and development in the transport sector make Kigali an area vulnerable for noise pollution. This study investigated noise pollution at four land use types in Kigali: three passenger-car parking sites, three commercial sites, two road junction sites, and a car-free zone, a reference site (Table 1, Figure 1A). Due to the limitation of equipment and logistic difficulties, data were collected in rotation from one site to another. We choose the sampling sites because these places have the daily largest numbers of people compared to other sites in Kigali (due to services offered there).

2.2. Data collection

We collected data on noise levels using a Sound Level Meter (SLM-25 Sound Level Meters, Gain Express Holdings Ltd., Hong Kong and China) logged at 1-minute intervals. The manufacturer calibrated the SLM-25 instruments before shipping them to Rwanda. The SLM-25 devices have a measurement range of 30–130 dB (A) with an error of <1.5 dB (A) Type 2 Sound Level Meter standards and have been previously used for noise studies [35]. The S.L.M. was mounted on a wooden tripod stand of 1.5 m above the ground to maintain the stability of the Sound Level Meter (S.L.M. 25) (Figure 1). S.L.M. was connected to the TOSHIBA Laptop computer (Intel® Celeron(R) CPU 925 @ 2.30GHz with a disk of 86.1GB and Os Type: 32-bite) fitted with data logging software of Sound Level Meter. We sampled each site three times per day: in the morning (7h00–10h00), around noon 11h00–14h00, and in the evening (15h00–18h00) (Figure 2)each Monday, Wednesday, Friday, Saturday, and Sunday every week in rotation over two months from September–October 2019. In addition, we used Geographical Information Systems (G.I.S.) to map the noise exposure in different land-use types between weekdays and weekends. A T-test was used to compare the mean noise level between weekend days and weekdays, and an ANOVA test was used to compare mean noise levels between morning, noon and afternoon at each sampling site. We applied spatial interpolation techniques using geostatistical approaches to fit a spatial model to the data, which enabled us to generate a prediction value of noise level at unsampled locations (like deterministic methods) and to provide users with an estimate of the accuracy of this prediction. All other analyses

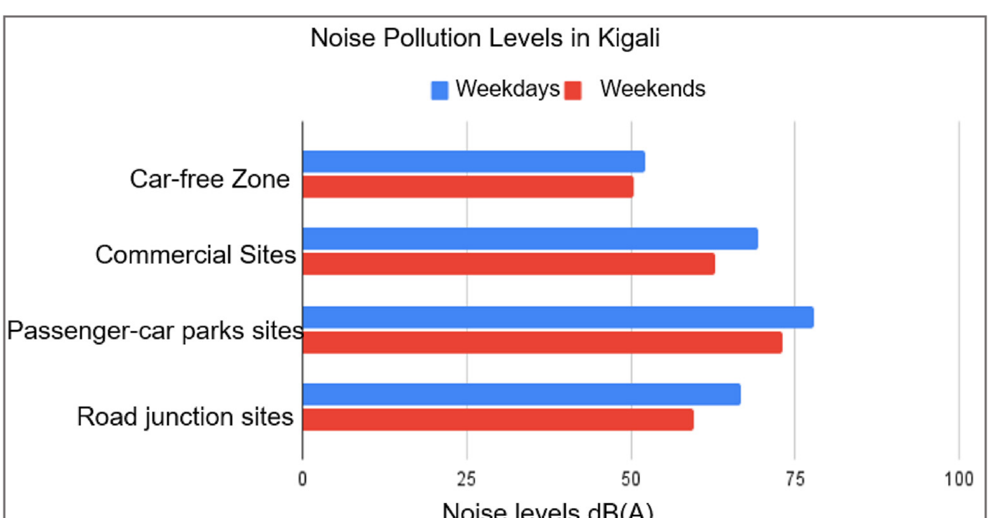

Figure 3. Average of noise levels between weekdays and weekends for different land-use types in Kigali.

Table 2. Comparison of noise pollution between weekdays and weekends for various land-use types.

Study site	Weekday	Weekend	p-value	Sensitivity
Passenger-car park sites	76.6 ± 7.6	71.8 ± 8.2	<0.01	Highly dangerous
Commercial sites	70.0 ± 7.1	63.1 ± 7.7	<0.01	Dangerous
Road junction sites	69.6 ± 8.4	63.9 ± 9.1	<0.01	High risky
Car-free zone site	47.3 ± 8.3	49.3 ± 3.7	<0.01	Safe

were computed using S.A.S (version 9.4 by S.A.S. institute Inc. Cary.INC. U.S). and we used ArcGIS version 10.8.1 software (E.S.R.I. Inc. Canada).

3. Results and discussion

The mean noise levels were higher in passenger-car parking sites during weekdays (76.6 dB (A)), followed by commercial sites (70.0 dB (A)) and road junction sites (69.6 dB (A)), while the lowest mean noise level was measured at the car-free zone site (47.3 dB (A)) (Figure 3 & Table 2). Except for the car-free zone, the mean noise level for all other sites was in a dangerous zone (>70 dB (A)). Noise levels recorded in Kigali exceeded the WHO's guideline permissible daytime limits for all land use types (55 dB (A)) for daytime passenger-car parks, and (60 dB (A)) for daytime commercial noise levels, and (70 dB (A)) for daytime industrial noise levels [35, 36]. A t-test showed that mean noise levels during weekdays were significantly higher than those recorded during weekends ($p < 0.01$) (Table 2) at the passenger-car park sites, commercial sites, and road junction sites. In contrast, in the car-free zone, mean noise levels were higher over the weekends than on weekdays, and both weekday and weekend levels were classified as safe, as their levels were below the WHO noise guideline daytime limit value of 50 (dB(A)) [35].

Weekdays showed higher noise pollution values because of road traffic and business activities. The noise pollution in the car-free zone was greater on weekend days than on weekdays. The car-free zone of Kigali is a site of many sports activities during the weekend, which may be the reason the level of noise pollution at this site was higher during the weekend than during weekdays. During weekdays, the car-free zone receives many people who are busy using free Wi-Fi, making the area quieter. However, we still need long-term studies addressing temporal noise pollution in Kigali, spanning different seasons. The bus station at Nyabugogo is about 2 km north of the city centre and the largest bus station in Kigali, with a lot of traffic that could explain the highest level of noise recorded in this area. During weekends, the highest levels of noise are in the markets of Biryogo and Nyamirambo. These markets are located in the busiest areas of Kigali, with heavy traffic, especially over weekends. According to the WHO guidelines, average noise levels of 50 dB (A) can cause moderate annoyance, and 55 dB (A) can induce serious disturbance [29, 39]. The thresholds to reduce the risk of cardiovascular diseases and prevent hearing loss recommended by WHO is 55 dB (A) and 70 dB (A) [39]. Thus, land-use types drive noise pollution, and residents of Kigali are exposed to noise levels that could cause serious health issues. However, more studies in Rwanda are needed to understand noise pollution levels in places with large crowds of people, such as schools. The minimum level was recorded in the Kigali Car-free zone reference site during the morning (34.4 dB (A)), while the highest levels were recorded at Nyabugogo passenger car parks at noon and in the evening (111.2 dB (A)). Noise pollution was higher around noon than in the morning in the car-free zone, while for business areas, noise pollution

Table 3. Summary statistics of noise pollution level between weekdays and weekends during the morning, around noon, and in the evening at different land-use types in Kigali, Rwanda.

Site Type	Site	Time	Weekday (dB (A))			Weekend (dB (A))		
			Min	Mean	Max	Min	Mean	Max
Reference site	Car-free zone	07h00–10h00	34.4	44.5	83.1	35.4	49.6	88.3
		11h00–14h00	37.1	47.0	65.7	43.3	51.0	82.8
		15h00–18h00	36.5	50.4	79.0	44.6	51.0	69.7
Commercial site	Biryogo	07h00–10h00	55.7	74.2	90.3	0.0	61.6	78.5
		11h00–14h00	49.2	62.3	83.2	52.7	67.0	89.6
		15h00–18h00	47.2	65.0	92.6	36.5	63.2	84.3
	Nyamirambo	07h00–10h00	61.4	70.4	88.9	36.7	58.3	77.4
		11h00–14h00	61.4	76.6	97.1	39.1	67.6	79.7
		15h00–18h00	57.3	68.3	91.9	36.4	59.2	87.2
	Nyarugenge	07h00–10h00	57.3	71.6	84.4	36.1	61.8	84.7
		11h00–14h00	61.9	72.7	87.0	38.5	62.8	83.2
		15h00–18h00	58.7	67.8	93.1	45.7	64.4	91.3
Passenger parks	Kimironko	07h00–10h00	60.9	71.1	84.2	63.1	73.6	92.8
		11h00–14h00	63.2	75.9	97.1	45.0	66.7	85.9
		15h00–18h00	64.9	77.0	98.8	61.8	76.1	99.4
	Nyabugogo	07h00–10h00	57.6	72.0	88.4	36.1	69.0	89.1
		11h00–14h00	62.5	78.6	98.4	37.6	70.2	98.7
		15h00–18h00	62.4	85.8	105.0	63.1	80.4	111.2
	Downtown	07h00–10h00	34.4	44.5	83.1	na	na	na
		11h00–14h00	57.6	64.0	86.3	na	na	na
		15h00–18h00	61.4	69.9	89.7	na	na	na
Road junctions	Remera	07h00–10h00	62.5	72.5	90.7	61.7	73.8	97.2
		11h00–14h00	64.0	73.6	89.5	45.9	62.7	79.6
		15h00–18h00	58.1	69.4	93.2	na	na	na
	Rubangura	07h00–10h00	51.7	57.6	79.5	36.3	61.1	89.4
		11h00–14h00	64.3	74.8	93.8	37.5	59.3	83.9
		15h00–18h00	54.3	63.8	85.5	44.6	58.2	78.2

n/a: not data available.

Table 4. Comparison of ANOVA test of noise pollution between morning, noon, and afternoon during weekdays and weekends for various.

Land-use types	Times	Morning	Noon	Afternoon	P Value
Car-free zone site	Weekdays	49.7 ± 8.2	55.6 ± 11.4	52 ± 7.3	0.113
	Weekends	49.5 ± 5.0	51 ± 7.2	51 ± 7.2	0.851
Commercial sites	Weekdays	65.3 ± 7.6	73.6 ± 9.5	69.7 ± 8.2	0.083
	Weekends	61.7 ± 6.8	62.8 ± 6.5	64.3 ± 5.3	0.185
Passenger-car park sites	Weekdays	75.0 ± 11.2	81.6 ± 13.6	77.5 ± 13.2	0.001
	Weekends	69.1 ± 9.7	70.4 ± 10.3	80.6 ± 16.7	0.003
Road junction sites	Weekdays	59.0 ± 7.3	72.1 ± 6.8	69.4 ± 7.9	0.345
	Weekends	61.5 ± 6.8	59.2 ± 5.9	58.1 ± 6.7	0.432

was higher in the morning and afternoon than in the evening (Table 3). Noise pollution was higher at noon than in the morning and afternoon at road junction sites (Table 3). The ANOVA results showed that the noise levels were significantly higher at noon compared to morning and afternoon (Table 4). In contrast, during weekends, noise levels were significantly higher in the afternoon than in the morning and noon at the Passenger-car park sites (Table 4). No significant difference was observed between morning, noon and afternoon during weekends and weekends at car-free zone, road junctions and commercial areas (Table 4). These levels recorded during the morning, noon and evening in Kigali were lower than those recorded in Nigeria in the morning (74.01 dB (A), afternoon (72.31 dB (A), and evening (73.23 dB (A)) (Baloye and Palamuleni, 2015). Noise levels recorded in Kigali during the morning, noon and evening were comparable to 63.2 ± 5.5 dB (A) in Montreal, 65.1 ± 7.4 dB (A) in Atlanta, 61.1 ± 6.4 dB (A) in Basel, 63.9 ± 6.2 dB (A) in Girona, 64.5 ± 6.7 dB (A) in Grenoble, 75.7 ± 1.6 dB (A) in New York, and 66.4 ± 4.6 dB (A) in Los Angeles [40, 41, 42, 43].

The spatial variations in mean noise levels in Kigali for weekdays and weekends were mapped to show the level of noise sensitivity associated with the various land use types [Figure 4 (A, B)]. For example, Nyabugogo, Kimironko and Remera, central transportation hubs in the city, fall within the hazardous zone of noise sensitivity during weekdays and the high-risk zone during weekends, which could be attributed to people moving to and from Kigali.

Three noise level hotspots (Remera, Nyamirambo and Kigali City centre) were observed during weekdays (37–85 dB (A)), while two noise hotspots sites (Kimironko and Remera) were observed during weekends (60–77 dB (A)) (Figure 4). In contrast, car-free zone areas show the mean noise sensitivity level falling within safe limits during weekdays but being risky during weekends at noon [Figure 5(A-F)]. This is because Rwanda has recently moved small businesses (supermarkets and bars) to the outskirts of Kigali city centre, such as Remera, and these zones are car-free during weekends. Figure 5 (A-F) shows high levels of noise levels in these hotspot zones (Remera, Kimironko) during weekdays and weekends from morning to afternoon. These results support the influence of human activities on the increase of noise levels, and immediate attention is required to reduce noise pollution levels in these hotspots.

Passenger-car parks and road junctions showed high noise levels, assumingly, because of the high density of vehicles and people. Road traffic seems to be the major source of noise pollution in Kigali, as found in other cities [34] where the average noise level increases with increased road network density and vehicles per km^2 [44]. Moreover, commercial land use, mostly with many streets for pedestrians and/or large shopping malls, often produces crowds of people and noisy entertainment, resulting in a high-noise environment [45, 46]. Commercial land use produces more noise pollution than open space with hard pavements or residential land use [12]. In Kigali, commercial areas have higher noise levels because of the number of people and the use of loudspeakers to attract clients to shops. In terms of land use, commercial land use poses a significant concern because people spend significant amounts of time doing business or shopping in those areas.

Commercial areas should be concentrated in cities, and a green barrier or buffering zone should be installed to minimize the impact of noise on surrounding land uses, such as residential areas [12]. A high concentration of commercial land use can reduce the number and distance of shopping trips and, thus, the noise and other types of pollution produced by vehicles. Increasing vegetation cover, mainly in the form of forest and grassland, can be a sustainable way to alleviate noise pollution in urban settings [47, 48]. A mixed and overlying arrangement of forest and grassland is recommended to help reduce urban noise, such as planting different species of trees on grassland [49]. Car-Free Zones can be an effective land use to reduce noise pollution, as the Car-Free Zones in this study showed the lowest noise level. Car-Free Zones should also be introduced in secondary cities, such as Huye, Muhanga, Musanze, and Rubavu, in Rwanda. However, care should be taken while paving a car-free zone because hard pavement reduces the capacity to mitigate noise pollution.

This study provided useful noise data for epidemiological studies on the nature of noise levels at different land-use types in Rwanda. This comprehensive dataset will be a key tool for policymakers in providing vital information for conducting epidemiological health studies and setting up practical noise level exposure limits. Furthermore, exposure to

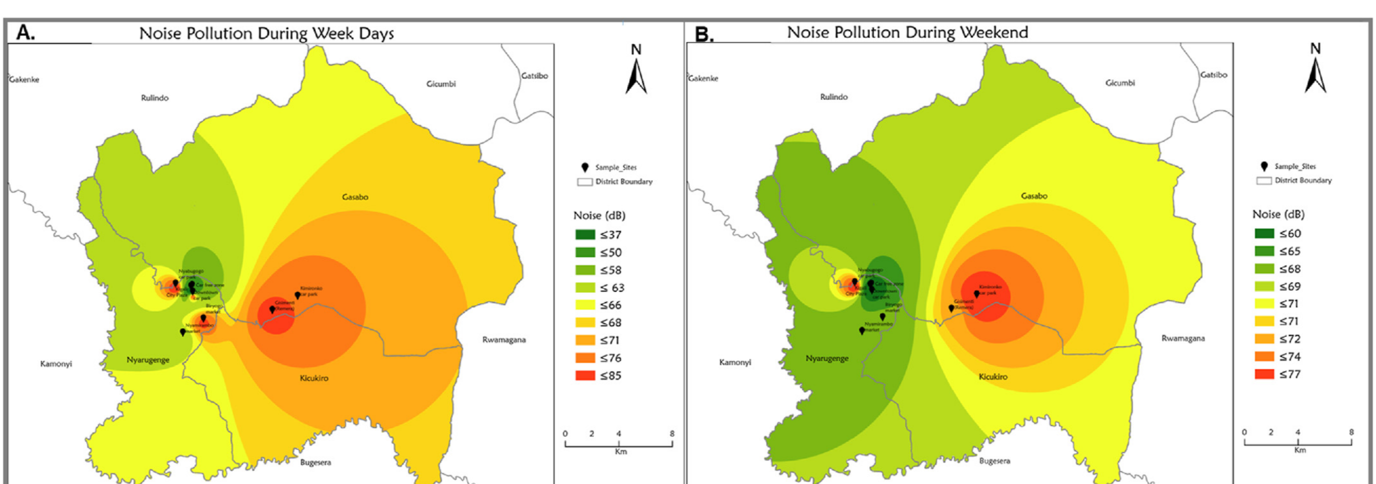

Figure 4. Spatial distribution of noise pollution within the sampling sites on weekdays (A) and weekends (B).

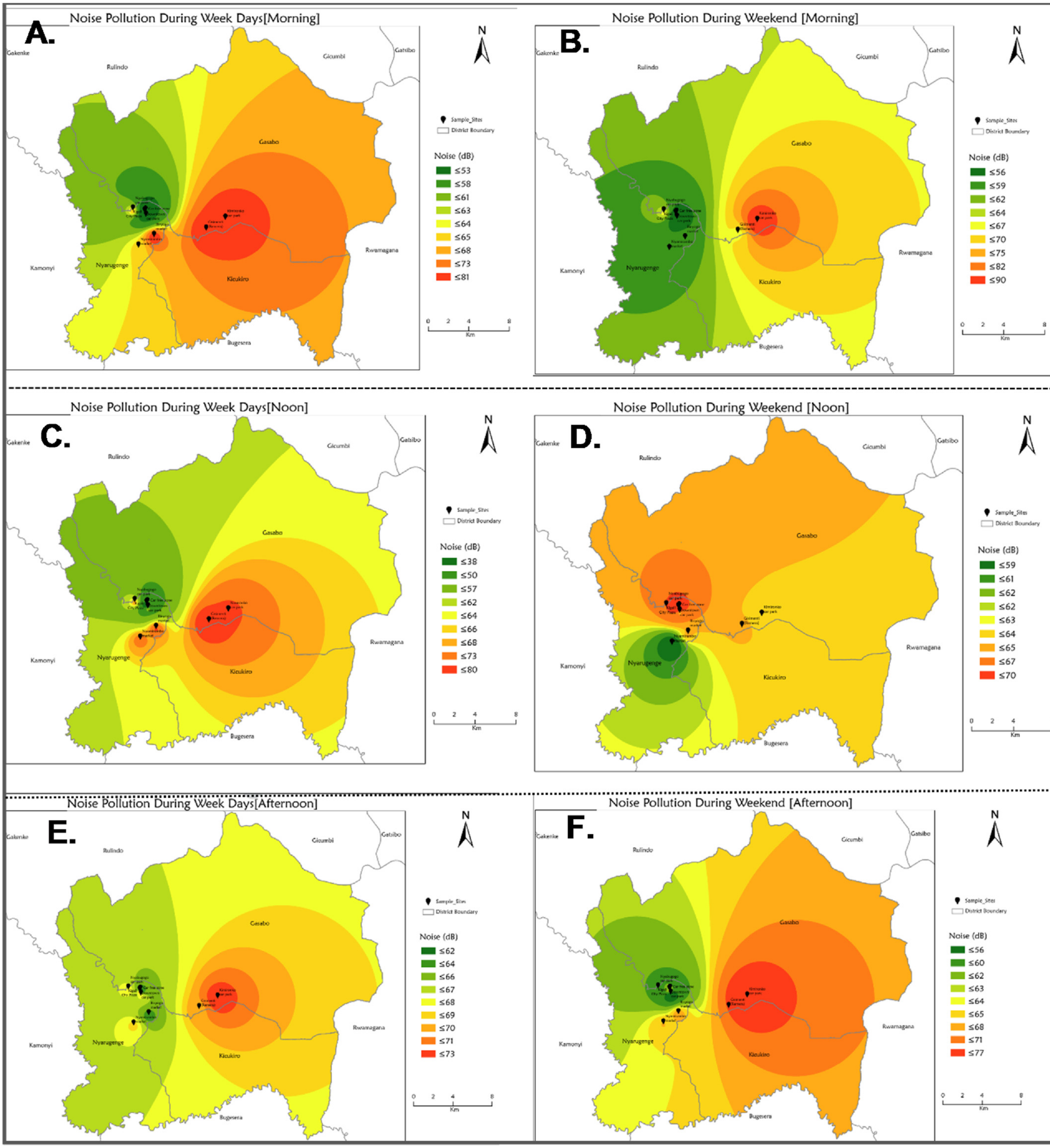

Figure 5. Spatial distribution of noise pollution within the sampling sites during morning (A and B), noon (C and D) and afternoon (E and F) between weekdays and weekends.

noise pollution is a global problem. Therefore, the findings of this research conducted in Rwanda are relevant worldwide.

4. Limitation of this study

This study focussed only on measuring noise data during two months of the wet season. Due to the logistic complexity of noise, data were not collected simultaneously at all sites, and the study period was limited to one season and lacked long-term monitoring data spanning dry and wet seasons. Future studies should conduct long-term data collection and modelling analysis at various sites in Rwanda (urban and rural areas) necessary for setting up regulation laws on noise pollution control in Rwanda.

5. Conclusion

This study investigated the impact of land-use types on noise pollution in the city of Kigali. Land use type affected noise pollution in Kigali;

noise pollution was higher for other land use types than recommended by WHO, except for the car free-zone site. In addition, only car free-zone had higher noise pollution during the weekend than on weekdays, while noise pollution was higher during weekdays than at the weekend for other land use types. Thus, residents of Kigali are exposed to dangerous noise pollution. More long-term studies are needed in Kigali, and secondary studies and areas frequently crowded with people, such as schools. Schoolchildren are more vulnerable to noise pollution than adults, and their exposure to noise pollution in their schools and commuting to and from school require immediate attention. The findings of this study will help to formulate and implement effective policies targeting noise pollution mitigation and ensure sustainable development in urban settings. Furthermore, our results provide evidence-based recommendations to help to reduce noise pollution and enhance public health, especially in Kigali and secondary cities in Rwanda. However, there is a need for more data to establish a noise map of the city of Kigali.

Declarations

Author contribution statement

Egide Kalisa: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Elisephane Irankunda: Performed the experiments; Wrote the paper.

Eulade Rugengamanzi: Analyzed and interpreted the data.

Mabano Amani: Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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