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INVESTIGATING URBAN TRAFFIC BASED NOISE POLLUTION IN THE CITY OF KIRIKKALE, TURKEY

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Abstract. The study presents an investigation into traffic based noise pollution in the city of Kırıkkale, Turkey. For this purpose, traffic noise levels were measured at 15 intersections across the city during three peak times – morning (08:00–09:00), noon (12:30–13:30) and evening (17:00–18:00) hours. The comparison of L_{eq} values against the limit values of the Turkish Noise and Control Regulations for Settlement Zones showed that L_{eq} values exceeded the limits at all stations. A linear regression analysis performed between the L_{eq} and logarithm of total traffic volume (log Q) produced a coefficient of determination of 0.52. A multi regression analysis carried out between the L_{eq} and four different vehicle types resulted in a correlation coefficient of 0.74. The correlation matrix indicated that the highest correlation was found for trucks/buses with r = 0.92. The spatial maps of traffic noise created by the Kriging method under ArcView GIS displayed that there seemed to be significant differences in the spatial variation of traffic noise across the city. In order to reduce traffic based noise levels within the city some useful suggestions were presented.

Keywords: traffic based noise, equivalent noise level, regression analysis, noise maps, GIS.

1. Introduction

Loss of work performance and various hearing and psychological problems are the most common aspects among numerous questions resulted from noise pollution. Traffic based noise pollution in urban areas has become a major environmental problem not only for big cities but also for small-scale towns such as Kırıkkale. Rapid population increase, unplanned urbanization and more important development of transportation projects without environmental effect evaluations can be listed as the main reasons behind traffic noise industrial development (Abdel Alim *et al.* 1983; Ayvaz 1994; Morillas *et al.* 2002; Homburger 1992).

As a spot sound source (SSS) vehicles cause traffic based noise pollution due to noise resulted from engine, friction between tires and roads and air friction. Also, low road standards and vehicles without regular maintenance contribute to traffic noise pollution. As a matter of fact, an increase in traffic density in roadway results in a logarithmic increase in noise level. For example, while a vehicle causes 64 dB(A) noise, a traffic volume of 2000 vehicles per hour causes 66 dB(A) noise and a traffic volume of 6000 vehicles per hour causes 71 dB(A) (Can 2000). The study of Pakman (1990) showed that 80% of sound energy is resulted from traffic noise.

Different types of vehicles cause different noise levels. Heavy vehicles, trucks in particular, are the most noise producing vehicles because of axle loads. If axle load of a truck is reduced from nearly 2000 kg to 500 kg, a 15 dB(A) decrease in noise level is obtained. Vehicle speed is another major factor in generating traffic based noise. The faster a vehicle travels the more noise it generates because of the friction between tires and pavement. Actually, as the speed increases the friction noise surpasses the motor noise (Homburger *et al.* 1992).

The pavement type and road slope are also important factors for traffic based noise. Porous pavement types, for example, produce less noise than the other pavement types. When a vehicle travels upslope, its engine and exhaust noise levels gradually increase (Magrab 1998).

In Turkey, a rapid increase in the number of motorized vehicles results in a serious traffic based noise pol-

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lution. According to the official records at national level, there was a 14% increase in the number of motorized vehicles in just 3 years between 1998 and 2000 (The Summary of… 2002). In addition, improper maintenance of roads, lack of coordination among signalized intersections and negligence of traffic rules create a significant amount of traffic based noise pollution in the cities.

The objective of this study is to explore traffic based noise pollution in the city of Kırıkkale. The effect of traffic density and composition on the traffic noise level in the city was investigated using a multi regression model. The evaluation of study results would be very useful to develop new strategies to reduce traffic based noise in the city.

2. Literature review

Several studies investigating traffic based noise pollution and its environmental effects have been presented in literature. A number of selected research studies have been reviewed in the following paragraphs.

Morillas *et al.* (2002) conducted a noise survey in the city of Caceres, Spain. The obtained results indicated that the sound levels in the city were quite high with 90% of the measurements surpassing an L_{eq} of 65 dB(A) during working hours. They established relationships between the equivalent noise level, traffic flux and main noise level percentiles and found out their results broadly agreed with those of other researchers mentioned in literature.

Pamanikabud and Vivitjinda (2002) formulated a model of highway traffic noise based on vehicle types with free-flow traffic conditions in Thailand. They developed a reference energy mean emission level for each type of vehicles based on direct measurement of L_{eq} from the real running condition of each type of vehicles.

Li *et al.* (2002) performed a study to analyze traffic noise levels along three main roads in Beijing, China. They discovered that the selected roads were overloaded by traffic flow during daytime. Due to road traffic, noise levels were above relevant environmental standards by 5 dB(A).

Ali and Tamura (2003) performed a traffic noise study in Greater Cairo, Egypt, and carried out an extensive measurement in 21 sites. They measured the degree of annoyance by questionnaire. The received results revealed that there was a strong relationship between road traffic noise levels and the percentage of highly annoyed respondents.

Filho *et al.* (2004) analyzed the effects of traffic composition on the traffic noise generated by typical Brazilian roads. They made a total of 149 measurements from Monday to Friday between 06:00 and 10:10 a.m. on the selected roads. They plotted L_{10} and L_{eq} values against the composition of traffic and obtained empirical expressions with reasonably good correlation indexes.

Kumbur *et al.* (2003) studied the urban traffic based noise in the city of Mersin, Turkey. Using the traffic noise records between 1998 and 2003, the authors compared the noise levels at various intersections against the Turkish Noise and Control Regulations for Settlement Zones

Table 1. Traffic based noise criteria for settlement zones (The Turkish Noise… 1986)

Zone	Zone Definition	Basic Criteria L_{eq}: 35–45 dB(A)
I	Rural area housing (far from traffic)	0
II	City outskirts	+5
	City center housing (100 m. from traffic)	+10
	City center housing, main streets, office buildings (60m. from traffic)	+15
III	City center housing, main streets, office buildings (20m. from traffic)	+20
IV	Industrial Zones and Heavy vehicle traffic areas	+25
	Daily Time Periods	
	Daytime (06:00-19:00)	0
	Evening (19:00-22:00)	-5
	Night (22:00-06:00)	-10

(Table 1) and detected that the noise levels at all stations exceeded the national limit by at least 20 dB(A).

Uysal *et al.* (2004) investigated the traffic noise levels in the centre of three major towns (Çorlu, Lüleburgaz and Çerkezköy) in the Trakya region of Turkey. They found that the equivalent noise levels ranged from 70 to 85 dB(A) during 06:00–24:00 in the inspected areas.

Bazaras (2006) is investigated the internal noise modelling problems of transport power equipment. Using *ANSYS/Multiphysic* software acoustic noise of different power units in the engine sector was simulated. In this paper the author presents the modelling results of the locomotive internal noise.

By Bazaras *et al.* (2008), traffic flows in cities, especially in city centres, are intensive and uneven, moreover, registered noise levels exceed allowable limits. Noise levels have been measured at K. Mindaugo ave. and Birštono street crossing in Kaunas (Lithuania) and data of automated traffic flow registration equipment have been used. A constant reduction of noise level from the beginning till the end of the green light has been identified – "hot starts" generated noise dominates. To make estimates of noise and traffic flow interdependency, mathematical statistical models have been applied. Parameter distribution patterns have been analysed, prediction models have been composed.

3. Area of study

The city of Kırıkkale is located in the Central Anatolia region of Turkey with a population of about two hundred thousand. The climate of the area is characterized by hot summers with low humidity and cold winters with moderate rain and snow. Although the city was first found as a small village in the early 20th century, its economic and social development began with the establishment of country's main public mechanical and chemical industry by 1925. The rapid industrialization in the following years resulted in an uncontrolled population increase in the area with serious urbanization problems including traffic based noise pollution.

Today's city is among the most densely populated places in the country with an insufficient road network. Currently, there are nearly 25 000 registered motorized vehicles, 53% of which are passenger cars in the city. However, this should be increased by approximately 17% since the city is very close to Ankara, the capital of Turkey, and there are some people owning cars registered in Ankara but residing in Kırıkkale. In addition to that, there is a daily traffic load of nearly 16 000 cars (40% heavy vehicles) through two major intercity highways which connect 44 provinces to all directions of the country. All these combined together create a serious traffic noise in the area (1996–2000 inventory… 2001).

4. Analysis of measurements

The traffic noise measurement and traffic count for the study period were carried out at 15 stations across the city as depicted in Figure 1. 12 stations are intersections located in the city center, while the remaining 3 are intersections located on the Ankara–Samsun Highway. Data gathering was performed on weekdays for one hour periods at three peak times – morning (08:00–09:00), noon (12:30–13:30) and evening (17:00–18:00).

Traffic noise was recorded using the Jetronl (S4001) sound measuring device which has A and C functions and both quick and slow modes with measuring capacity from 30 to 130 dB(A). During the noise measurements, the Turkish standards of acoustic environment and traffic noise measurement requirements were taken into account. In this respect, the microphone of the device was located at a distance of 3.5 m from the road edge at a height between 1.2 and 1.5 m from the ground. In order to eliminate the effect of interference due to reflections from buildings, the measurements were made 1 m away from constructions.

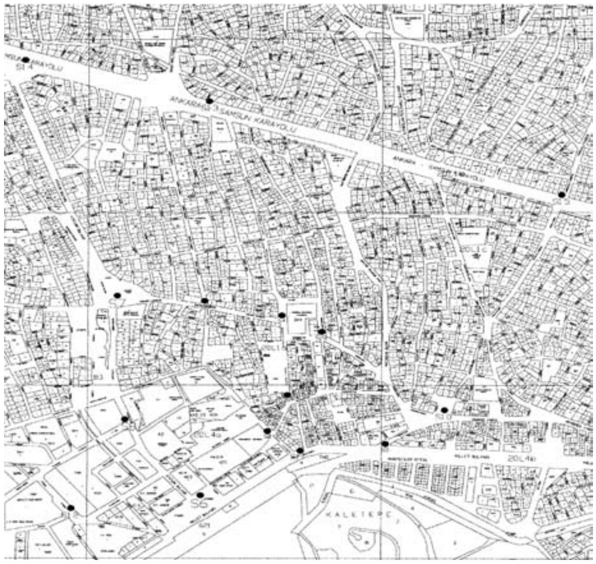

Fig. 1. Area of study with the measurement stations

The maximum, minimum and equivalent noise (L_{eq}) values for the morning, noon and evening periods were tabulated in Table 2. Here, L_{eq} was calculated using Eq. (1) as follows

$$L_{eq} = 10 \log \left(\frac{1}{n} \right) \sum_{i=1}^{n} 10^{\left(\frac{L_i}{10} \right)}, \quad (1)$$

Table 2. The maximum, minimum and equivalent (L_{eq}) noise levels

a) in the morning hours

Station	Morning (8:00–9:00) Min. dB(A)	L_{eq} dB(A)	Max. dB(A)
1	60.9	74.6	92.6
2	59.7	76.2	97.8
3	31.8	75.3	86.7
4	60.8	78.2	98.3
5	50.2	82.2	100.6
6	69.7	86.2	102.3
7	63.6	82.5	99.2
8	61.3	76.9	89.6
9	57.9	75.2	86.7
10	70.0	82.7	97.1
11	60.8	78.0	91.3
12	62.1	82.9	96.7
13	64.0	80.6	96.0
14	61.0	80.4	98.5
15	65.3	81.9	95.7
Average	59.9	79.6	95.3
Standard Deviation	9.1	3.5	4.8

b) at noon

Station	Noon (12:30–13:30) Min. dB(A)	L_{eq} dB(A)	Max. dB(A)
1	60.7	73.8	87.5
2	59.3	77.0	93.5
3	59.8	77.8	99.6
4	62.1	77.6	93.7
5	50.9	81.2	96.3
6	66.0	84.7	104.7
7	64.6	79.9	91.3
8	59.9	76.8	91.7
9	57.0	72.3	86.2
10	67.0	80.9	98.2
11	59.0	73.4	86.1
12	50.7	72.4	84.5
13	62.2	81.2	99.9
14	66.7	84.9	81.5
15	64.8	82.6	96.9
Average	60.7	78.4	92.8
Standard Deviation	5.0	4.2	6.6

c) in the evening hour

Station	Evening (17:00–18:00) Min. dB(A)	L_{eq} dB(A)	Max. dB(A)
1	60.3	77.6	100.2
2	60.9	78.1	100.8
3	60.6	73.2	94.9
4	60.5	80.1	103.2
5	65.7	83.5	109.1
6	66.1	84.2	100.6
7	65.5	82.1	97.2
8	57.8	77.4	94.8
9	60.1	79.3	98.3
10	66.6	79.5	95.5
11	62.3	78.6	93.8
12	64.6	79.7	91.3
13	59.0	74.5	98.8
14	66.6	82.2	94.6
15	65.7	80.5	94.2
Average	62.8	79.4	97.8
Standard Deviation	3.1	3.0	4.5

Table 3. The average traffic composition for the peak times during the study period

Station	Auto	Van/Lorry	Bus/Truck	Motorcycle/ Others	Total
1	1 305	477	37	31	1 850
2	1 141	303	46	31	1 521
3	1 083	315	46	31	1 475
4	1 503	401	6	35	1 945
5	1 270	689	107	87	2 153
6	1 116	558	112	72	1 858
7	711	292	38	16	1 057
8	894	278	39	22	1 233
9	686	267	26	34	1 013
10	1080	609	14	68	1 771
11	2043	806	149	90	3 088
12	314	131	2	10	457
13	910	371	106	27	1 414
14	781	337	121	27	1 266
15	630	242	85	34	991
Average	1 031.1	405.1	62.3	41.0	1 539.5
Standard Deviation	413.7	186.2	46.8	25.3	618.9

Table 4. Traffic noise limits for vehicle types by the Turkish Noise and Control Regulations (1986)

Vehicle Type		Max. Noise Level dB(A)
Automobile		75
Bus	Urban	85
	Rural	80
Trucks and other heavy vehicles (at 80 km/h velocity)		85
Inside of a locomotive (at full power and windows are locked)		85
Electrified locomotives		80
Inside of a wagon		70

where L_i is the noise level for i^{th} measurement and n is the number of measurement.

The analysis of results showed that L_{eq} values exceeded the limits stated by the Turkish Noise and Control Regulations for Settlement Zones (Table 1) at all stations by 5 to 20 dB(A). This can be explained by the following important factors:

a) The number of vehicles in the city is continuously increasing as a result of population increase. However, the current road network is not able to sustain this trend without additional roads,
b) Street widths are not proportional with building heights and thus, traffic noise increases due to reflections,
c) Lack of road and vehicle maintenance contributes to excessive traffic noise,
d) The inadequate signalization system of the city, insufficient pedestrian crossings and traffic violations cause extra traffic noise.

5. Model development

A regression analysis was performed to investigate the relationship between L_{eq} and logarithm of traffic volume (log Q) using the total average traffic volume (Table 3) similar to the previous studies reviewed by Morillas *et al.* (2002). The analysis disclosed that the coefficient of determination (R^2) made 0.52 which is relatively lower than those presented in Morillas *et al.* (2002) research. This can be due to additional noise producing factors in the city such as pedestrians and technical conditions of vehicles. More specifically, although L_{eq} values at some stations (e.g. station 7 is close to a playground, station 9 appears in a commercial area, station 12 is near to three major hospitals) were relatively high, the traffic volumes at the same stations were relatively low.

The field observations also showed that some vehicles, especially domestic and old ones, generated much higher noise levels than the limits stated by the Turkish Noise and Control Regulations for Vehicle Types (Table 4).

The correlation between the equivalent noise level and different vehicle types was also examined in this work. For this purpose, a multi regression model was developed using the equivalent noise level as the dependent variable and the vehicle types as the independent variable. The model classified the vehicles as automobiles, vans/lorries, buses/trucks and motorcycles/others (Table 3). The result of fit given by Eq. (2) showed that there was a 74% correlation (i.e., $r = 0.74$) between L_{eq} and vehicle types.

$$L_{eq} = 80.92 + 0.007x_1 + 0.01x_2 + 0.019x_3 + 0.03x_4, \quad (2)$$

where: x_1 is the number of automobiles, x_2 is the number of vans/lorries, x_3 is the number of trucks/buses and x_4 is the number of motorcycles/others. The correlation matrix indicated that the highest correlation was found for trucks/ buses ($r = 0.92$) as expected. It was followed by vans/lorries ($r = 0.63$), motorcycles ($r = 0.48$) and automobiles ($r = 0.30$).

6. Traffic based noise maps

In order to examine the spatial variation of traffic noise during the peak time periods, noise maps were prepared using the Kriging method under Arcview GIS. Figures 2a–c displays the spatial variation of traffic noise in the morning, noon and evening hours during the study period. Referring to the figure, there are considerable differences in the spatial variation of traffic noise representing variations in the traffic composition and fluctuation within the day. More specifically, traffic noise in the northern and southern parts, where the Ankara-Samsun highway and the Millet Boulevard pass through, respectively, seems to be relatively higher than that in the central part of the city. The two major reasons behind that

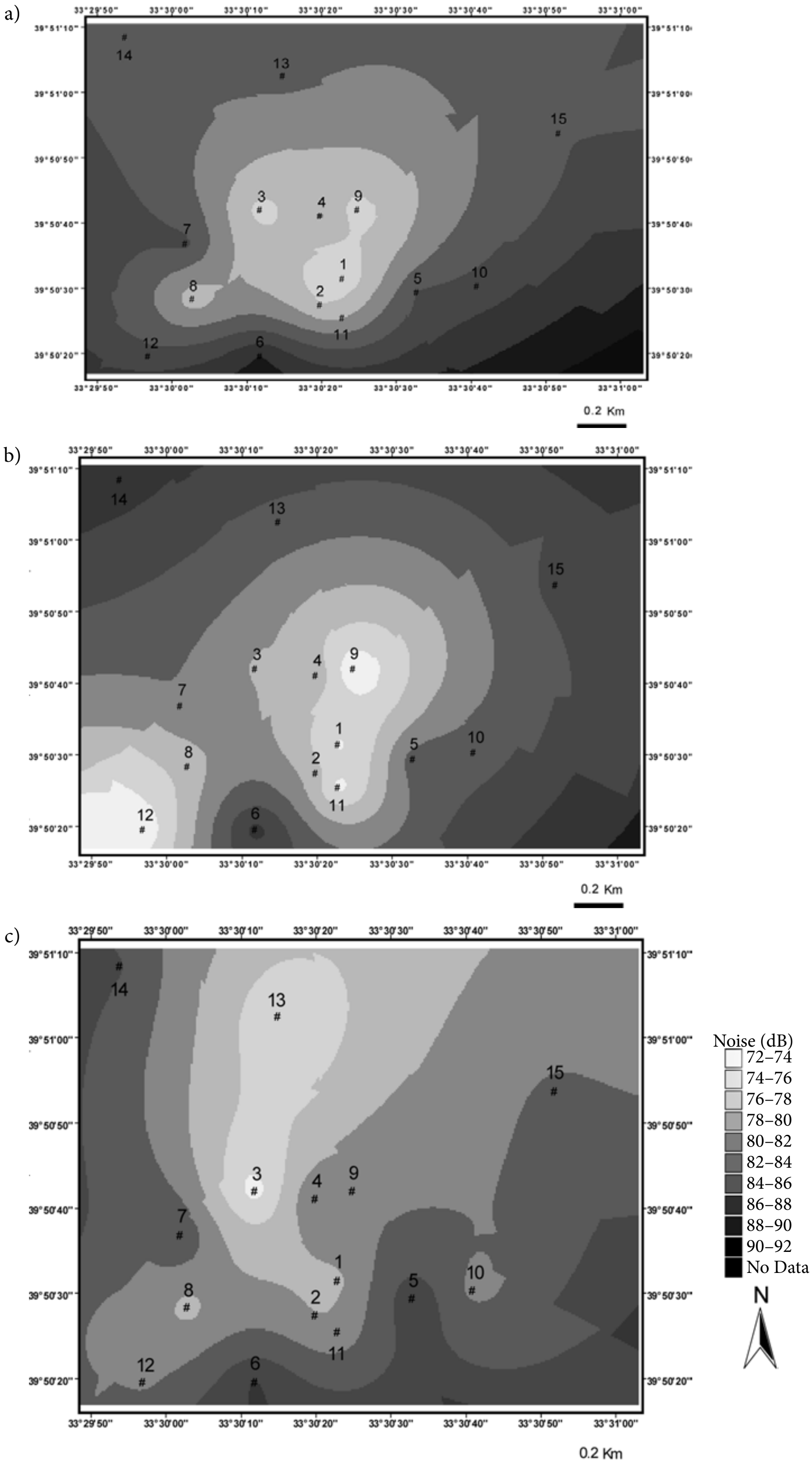

Fig. 2. Spatial maps of traffic based noise: a – in the morning hours; b – at noon; c – in the evening hours

are traffic composition and overall speed i.e. traffic is dominated by heavy vehicles in the northern and southern parts with relatively higher overall speed whereas passenger cars are mainly used in the central part.

7. Conclusions and suggestions

This work presented a traffic based noise pollution study in the city of Kırıkkale, Turkey. For this purpose, traffic noise measurements were carried out at 15 stations across the city. The study results indicated that equivalent noise levels at all stations exceeded the upper limits of the Turkish standards by as much as 20 dB(A) at some places.

A regression analysis performed between L_{eq} and logarithm of total traffic volume (log Q) produced a relatively low correlation (r = 0.72) and coefficient of determination (R^2 = 0.52). As a further study, a multi regression analysis carried out between L_{eq} and vehicle types resulted in a correlation coefficient of 0.74. The model indicates that the highest correlation was found for trucks/buses with a correlation coefficient of 0.92. The evaluation of the spatial maps of traffic noise revealed notable differences in the spatial variation of traffic noise. Traffic noise in the northern and southern parts, where traffic is dominated by heavy vehicles, was relatively higher than that in the central part of the city.

An important outcome of this study was that the city of Kırıkkale faces serious traffic based noise pollution. In order to reduce excessive traffic noise levels, which can cause serious health problems, and to create a better living environment in Kırıkkale, the following suggestions are believed to be useful:

- the current road network should be supported by additional roads,
- the current signalization system should be replaced with a more efficient one,
- the national noise and control regulations should be enforced more strictly,
- local citizens should be educated about adverse effects of noise pollution.

In the light of this research study, further studies can be performed to investigate adverse effects of noise pollution on public health in the city of Kırıkkale.

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