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Evaluation of noise pollution level from traffic for Sivas city using GIS-based noise indexes

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Abstract

In this study with the purpose of determining the noise pollution originating from traffic in Sivas city center, noise measurements were performed in 14 different points that represent the city for 5 days in morning, noon and evening. Based on the measurement results, GIS based noise pollution spatial distribution maps were created and also the noise levels and orbits that change according to the time as time-wise and spatial were determined. Also, noise pollution level of city is revealed with calculating indexes such as traffic noise pollution index (NI), noise climate (NC), noise exposure index (NEI) and level of noise pollution (Lnp). Level of equivalent continuous noise (Leq) value is above limit values in all regions and its mean determined for morning, noon and evening hours as 75.19, 73.72 and 75.92 dB respectively. The highest Lnp values are calculated as 96,8 dB for morning, 98,7 dB for noon and 97 dB for evening. The highest NC values are calculated as 18,7 dB for morning, 21,3 dB for noon and 21 dB for evening. Almost all of the NEI values were more than 1 and this shows that the level of noise exposure of all measuring points is at excessive level. The NI value which is calculated according to the measurements is usually above 74 dB. The areas affected by noise within the boundaries of Sivas city were revealed by using the noise distribution maps obtained with the help of GIS. When all of the results are evaluated, it is seen that there is a serious noise pollution problem around the traffic way of city. Noise pollution is the most important factor that disrupts environmental quality and environmental health in the city center.

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1. Introduction

Noise is described as unwanted sound [1]. At the same time, it noise is an important pollutant which consists of unwanted sounds that are affecting humans' sense of hearing negatively: breaking their physiological and psychological balance, decreasing their performance at work and having random spectrum [2].

Noise pollution has recently been one of the main factors affecting quality of life in urban areas around the world. In an urban environment, noise pollution is can be differentiated because of it can diffuse from other sources that can adversely affect the public health and environment quality [3]. Due to rapid increase in industrialization, urbanization and other communication and transportation systems, noise pollution has reached as uncomfortable level in years [4]. Urban areas are experiencing environmental stresses which increaseing in the form of especially excessive noise and traffic jam congestion. Road traffic is considered as one of the most important noise pollution sources which that has negative effects on human health [5, 6].

The World Health Organization (WHO) has identified traffic-related noise as the most important source of noise in terms of the number of people who are exposed to it and where the noise is widespread [7]. Among the factors, that affects the traffic-related noise levels, there are the features of the vehicles; their speed, tyre types, the road is whether one-way or two-way, lane number, whether there is a presence of bar in median, the texture of road covering materials, void ratio, density, whether the surface is dry or wet road surface[8]. The running speeds of the vehicles in the traffic are among the important variables [9].

Alongside the domestic and industrial noise sources, the noise related to motor vehicle traffic is adversely affectings daily life and human health in modern cities [10].The effects of noise on human health and comfort

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are divided into four categories depending on the duration and volume of noise. These are: (i) physical effects such as hearing problems (ii) physiological effects such as high blood pressure, irregularities in heart rhythms and ulcer (iii) psychological effects such as insomnia and late sleeping, irritability and stress and (iv) effects on work performance such as decrease in performance and misunderstanding on the thing that heard [11].

The most common one among physiological effects is hearing loss [12]. Hearing loss due to noise is very common in industrialized societies and one of the factors which affects life quality adversely [13]. Among the other physiological effects, there are high blood pressure, acceleration in heartbeats, muscle reflexes and sleep disorders. Long exposure to the noise can cause disruption in the order of the blood pressure by way of increase in the circulatory system's hormones such as adrenaline, noradrenaline and cortisol [14]. That is why, the assessment of the problem and programming for noise and its side effects are become an urgent need for the society.Even though the effects of the noise differs from person to person, the limit values are defined as a result of research. Noise levels and the discomforts they caused are presented in Table 1 [15].

Table 1. The noise levels and the discomforts they caused.

Level	Noise Level dB(A)	The Discomforts They Caused
1	30-65	Discomfort, disturbance, anger, furiousness, sleep disorder and concentration disorder
2	65-90	Physiological reactions, high blood pressure, acceleration in heartbeats and respiration, decrease in the pressure of cerebral fluid, sudden reflexes
3	90-120	Increase in physiological reactions, headaches
4	120	Continuous damage in inner ear, disruption of the balance
5	140	Severe brain damage

Many types of noise vary depending on with time and the response of people to these noises depends on the noise level and the temporal characteristics. The Leq (level of equivalent continuous noise) noise indicator was developed to represent the effect of time on noise. Leq is the A-weighted sound pressure level of continuous noises with equal energy over a certain time period [16, 17]. The L10, L90, Leq single number evaluation systems are used to define the average sound pressure level in a given time period. L10 is the A-weighted sound pressure level that is exceeded for 10% of the measurement time. The L90 is the A-weighted sound pressure level that is exceeded for 90% of the measurement time, and is often used for background noise measurement. Lmax is the maximum sound level obtained for a very short period of time during the measurement period and Lmin is the minimum sound level obtained for a very short period of time during the measurement period [18].

The main purpose of this study is evaluation of noise pollution level from traffic for Sivas city by GIS-based noise indexes. In this study with the purpose of determining the noise pollution originating from traffic in Sivas city center, noise measurements were performed in 14 different points (Fig. 1) that represent the city for 5 days in morning, noon and evening. Based on the noise measurement in 14 different points of the city center, GIS-based noise pollution spatial distribution maps were created. Also, the city's noise pollution level is revealed with calculating indexes such as traffic noise pollution index (NI), noise climate (NC), noise exposure index (NEI) and level of noise pollution (Lnp). In the studies performed, noise was generally evaluated according to noise indices (Lmax, Lmin, L90 and Leq). In this study, noise indexes (NI, NC,NEI and Lnp) were calculated and noise evaluations were made on these indexes.

2. Materials and Methods

Sivas province is located in the Yukarı Kızılırmak Basin of Central Anatolian Region, between 36^o - 39^o eastern longitudes and 38^o - 41^o northern latitudes with 28.488 km^2 acreage, as the second largest province of Turkey after Konya. Sivas province has the general geographical view of a plateau, which consists of valleys between single mountains and mountain chains, sunken plains and highlands. Sivas Basin is a sedimentary area starting from the provincial center of Sivas and west of Erzincan (east-west direction), and lying on the NE-SW direction until Kayseri basin, 250 km in length and 50 km in width, consisting of metamorphic, magmatic and ultramafic rocks.

In this study with the purpose of determining the noise pollution originating from traffic in Sivas city center, noise measurements were performed in 14 different points (Fig. 1) that represent the city for 5 days (Monday-Friday) in morning (07.30-09.00), noon (12.00-13.30) and evening (17.00-18.30). The reason of the noise measurement period is considered as 5 days; no significant changes in noise levels were observed in the morning, lunch and evening hours for 5 days. Noise measurements were carried out with the IKON 72 noise measurement device according to the Environmental Noise Measurement and Evaluation Manual of the Ministry of Environment and Urbanization. The noise meter is calibrated before each measurement. Measurements were made at A (low) equivalent noise level in 15 sec intervals and the measurement results of 5 min were recorded for each noise source. Each measurement was repeated 3 times and the standard deviation was determined as "≤ % 3".

As a result of the measurements the noise values of the indexes Lmax, Lmin, L10, L90 and Leq were recorded. The coordinates of the measured points were determined by the Magellan hand GPS and a GIS based database containing noise and coordinate information was prepared. Using the measured noise values, NI values were calculated with noise index values such as NC, Lnp, NEI. Using the IDW (Inverse Distance Weighted Interpolation) interpolation method included in the Spatial Analyst Module of ArcGIS 10.2 software, spatial distribution maps of the calculated noise indexes and calculated NI values for the morning, lunch and evening hours were created. The obtained noise measurements and generated spatial distribution maps are evaluated within the scope of WHO and the Organization for Economic Cooperation and Development (OECD) standards and the Regulation on Assessment and Management of Environmental Noise.

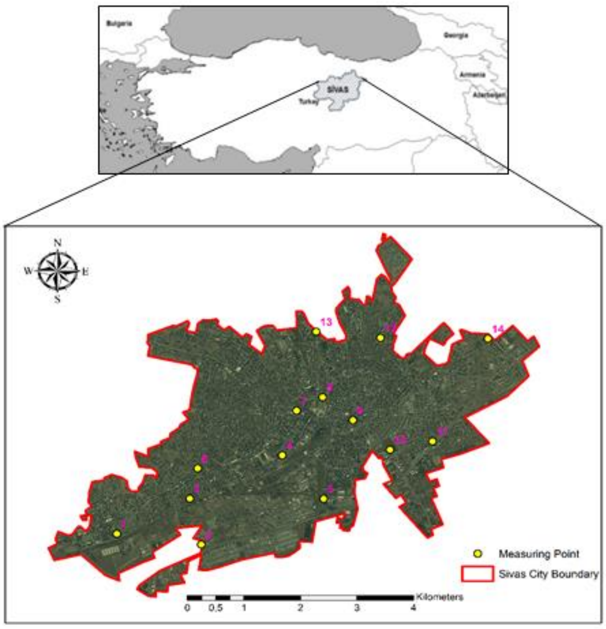

Figure 1. Study area and noise measurement points.

Various noise pollution indices can be calculated using the Gaussian percentage to obtain noise pollution levels. The L10 and L90 indexes are used in the evaluation of NC, Leq and Lnp [19]. Equation 1-3 was used to calculate the noise pollution indices [20].

$$NC = L10 - L90 \tag{1}$$

$$Lnp = Leq + NC \tag{2}$$

$$NEI = (t1/T1) + (t2/T2) + \cdots + (tn/Tn) \tag{3}$$

Here t1…tn = is the actual exposure limit at corresponding noise levels, T1…Tn = is the permissible exposure limits on corresponding noise levels.

NI (dB) is a measure of the distress behavior of people exposed to environmental noise and is calculated with the following mathematical expression (Equation 4) [21, 22]:

$$NI = 4\,.\,(L10 - L90) + (L90 - 30) \tag{4}$$

2.1. IDW (inverse distance weighted interpolation) method

The known example is an interpolation technique used to determine cell values of non-sampled points with the help of the values of the sampled points. The cell value is calculated according to the various points that move away from the relevant cell and due to the increase in distance. The predicted values are a function of the distance and magnitude of the surrounding points, and with the increase in distance, the importance and impact on the cell to be estimated are reduced [23]. The effect of known data points in this interpolation is inversely proportional to the distance from unknown points to be estimated. Although the IDW interpolation technique is practically applicable, more time is required to calculate the distances if the number of dots is greater. This method creates concentric shapes in the height curves created in the method. In the IDW method, the relationship between the two points and the similarity is assumed to be proportional to the distance between them [24]. IDW is expressed in equation 5 [25]:

$$Z\,(Xo) = \frac{\sum_{i=1}^{n} Z(Xi).\,d_{i0}^{-r}}{\sum_{i=1}^{n} d_{i0}^{-r}} \tag{5}$$

Here the Xo location where the predictions are made is a function of the adjacent measurements n [Z(Xi) and i=1,2,…,n,], r is the exponent determining the assigned weight of each of the observations and d is the distance between the observation location Xi and the prediction location Xo. As the exponent grows, the assigned weight of the observations at a distance from the prediction location becomes smaller. The increase in the exponent indicates that the estimates are very similar to the nearest observations [26].

3. Results and Discussions

Table 2 shows the averages of the measurement results in 14 points for 5 days at the morning, noon and evening hours. Spatial distribution maps for noise indexes for morning, noon and evening measurements are given in Figure 2-4 and the spatial distribution map for NI values is given in Figure 5. The average Leq was determined as 75.19, 73.72 and 75.92 dB for morning, noon and evening hours, respectively. According to the standard values set by the WHO and OECD (Table 3), if the equivalent noise level is greater than 65 dB, this region is defined as «black area and serious discomfort». In this context, it is seen that all of the Leq values are over 65 dB in the morning, noon and evening hours (Table 2). Highest Leq values were measured in the morning hours at points 7 and 11 (Fig. 2), in the noon hours at points 10, 11 and 12 (Fig. 3) and in the evening hours at points 4, 12 and 13 (Fig. 4). Generally the noise levels in the north of the city are higher than the noise levels in the west of the city. This is due to the fact that there is movement of settlement towards the north of the city and traffic mobility due to the increase of connection roads.

Table 2. Measured and calculated noise index values in the study area.

Time	Measuring Point	Measured Indexes (dB)					Calculated Indexes (dB)			
		L10	**L90**	**Leq**	**Lmax**	**Lmin**	**NC**	**Lnp**	**NEI**	**NI**
Morning (07.30-09.00)	1	75,1	61,1	70,9	82,5	52,2	14	84,9	1,04	87,1
	2	74,3	60,9	70,8	84,3	56,1	13,4	84,2	1,04	84,5
	3	78,9	67,1	75	88,9	62	11,8	86,8	1,10	84,3
	4	78,2	64,6	74,2	85,9	60,3	13,6	87,8	1,09	89
	5	76,5	63,5	72,6	84,8	57,4	13	85,6	1,07	85,5
	6	79,1	65,3	76,4	92,2	62,9	13,8	90,2	1,12	90,5
	7	83,7	68,6	80,1	94,5	66,1	15,1	95,2	1,18	99
	8	79,4	66,4	75	84,8	63,1	13	88	1,10	88,4
	9	77,6	62,6	73,7	87,1	55,1	15	88,7	1,08	92,6
	10	80,2	69,2	76,2	85,2	66,5	11	87,2	1,12	83,2
	11	85,2	69,4	81	93,4	66,5	15,8	96,8	1,19	102,6
	12	76,6	64,5	72,9	82,6	61,3	12,1	85	1,07	82,9
	13	80,1	66,5	76,8	93,7	62,5	13,6	90,4	1,13	90,9
	14	80,7	62	77,1	95,6	56,6	18,7	95,8	1,13	106,8
	Average	78,97	65,12	75,19	88,25	60,61	13,85	89,04	1,11	90,52
Noon (12.00-13.30)	1	74,9	57,5	71,4	84,7	47	17,4	88,8	1,05	97,1
	2	78,1	61,1	73,6	87,4	55,3	17	90,6	1,08	99,1
	3	79,4	59	75,5	89,8	51,4	20,4	95,9	1,11	110,6
	4	79,3	66,6	75,2	86,8	61,1	12,7	87,9	1,11	87,4
	5	76,6	65,3	72,8	86,2	60,7	11,3	84,1	1,07	80,5
	6	78,6	62	74,9	87,8	58	16,6	91,5	1,10	98,4
	7	69	64,2	67	74,4	61,8	4,8	71,8	0,99	53,4
	8	75,5	62,7	71,3	82,5	60,8	12,8	84,1	1,05	83,9
	9	73,3	55,4	68,4	80	49,6	17,9	86,3	1,01	97
	10	80,1	67,7	77	89,5	61,7	12,4	89,4	1,13	87,3
	11	81	64,3	77	90,5	57,5	16,7	93,7	1,13	101,1
	12	83,6	65,3	80,4	96,2	59,7	18,3	98,7	1,18	108,5
	13	76,3	60,2	72,3	84,3	53,6	16,1	88,4	1,06	94,6
	14	78,4	57,1	75,3	89,7	50,9	21,3	96,6	1,11	112,3
	Average	77,44	62,03	73,72	86,41	53,36	15,41	89,13	1,08	93,66
	1	76,4	60,3	72	81,6	48,9	16,1	88,1	1,14	94,7
	2	76,7	60,1	72,3	80,8	49,3	16,6	88,9	1,15	96,5
	3	80,1	62,9	75,7	88,8	57,1	17,2	92,9	1,20	101,7
	4	83,9	70,9	80,5	93,2	65,9	13	93,5	1,28	92,9
	5	78,2	66,3	75,2	88,1	59,6	11,9	87,1	1,19	83,9
	6	79,8	66,2	76,1	89,9	64,2	13,6	89,7	1,21	90,6
	7	79,2	66,2	76,4	91,6	65	13	89,4	1,21	88,2

Evening (17.00-18.30)	8	70	62,4	66,8	78,4	61	7,6	74,4	1,06	62,8
	9	80,2	61,4	76	90,6	54,4	18,8	94,8	1,21	106,6
	10	82	70,3	78,4	89,9	67,4	11,7	90,1	1,24	87,1
	11	80,5	67,4	77,5	94,8	59,5	13,1	90,6	1,23	89,8
	12	84,1	69	80,1	96,4	63,9	15,1	95,2	1,27	99,4
	13	83,6	68,8	79,9	94	62,7	14,8	94,7	1,27	98
	14	80,2	59,2	76	88,5	53,9	21	97	1,21	113,2
	Average	79,64	65,10	75,92	89,04	59,49	14,54	90,46	1,21	93,24

Table 3. Noise levels and exposure situation according to WHO and OECD.

Noise Level	Leq (morning)	Exposure
<55	White Zone	No disturbance
55-60	Gray zone	There is discomfort
60-65	Gray zone	Discomfort significantly increases
>65	Black Zone	Serious discomfort and behaviors are affected

In the Regulation on the Assessment and Management of Environmental Noise[27], road environmental noise limit values are much more restrictive in the areas of noise-sensitive areas of use in education, culture and health (Table 4). In terms of Highway Environmental Noise Boundary Values, Leq limit values were determined to be 68 dB during the day and 63 dB at evening time from in the areas where commercial buildings and noise-sensitive uses utilities co-exist to the highly densed housing facilities areas where the houses are densely exists. Nearly all of the measurements made within the scope of the study are above this limit value (Table 2).

Table 4. Highway environmental noise limit values.

Areas	Planned/Refurbished/ Repaired roads		Existing Roads	
	$L_{morning}$ (dB)	$L_{evening}$ (dB)	$L_{morning}$ (dB)	$L_{evening}$ (dB)
From noise-sensitive areas, the areas of education, culture and health areas and summer and camping	60	55	65	60
From areas where commercial structures and noise-sensitive uses co-exist, the areas where houses densely exists	63	58	68	63
From areas where commercial structures and noise-sensitive uses co-exist, the areas where workplaces densely exists	65	60	70	65
Industrial areas	67	62	72	67

The highest Lmax measured in the study area was measured at the point 14 (95.6 dB) in the morning (Fig. 2), and in the noon and in the evening at the point 12 were measured as 96.2 dB and 96.4 dB, respectively (Fig. 3 and Fig. 4). The reason for measuring the high values at point 12 is the density of the settlement areas located in the north of Sivas city due to traffic at the junction that provides connection to Sivas city center. The reason is that the noise values measured in the morning reached the highest level at point 14 the specified measuring point is on the Sivas-Erzincan highway, there is an organized industrial zone on this route and the traffic mobility increases due to the intersection of this route with the ring road. Lmin was measured at point 1 in the morning, noon and evening (52,2 dB, 47 dB, 48,9 dB respectively) (Fig. 2, Fig. 3, Fig. 4). At this point, the noise level is very low, there is no density of traffic in this region.

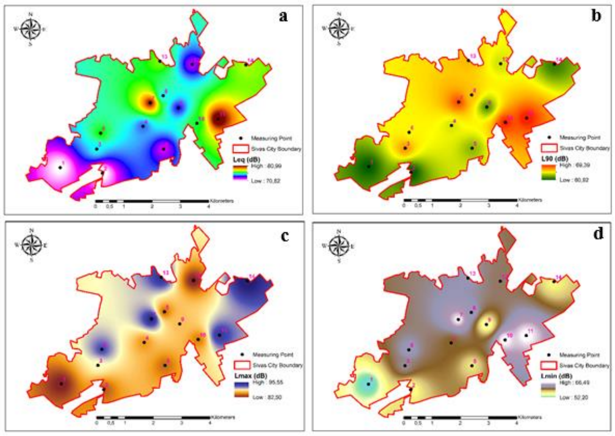

Figure 2. Spatial distribution of **a** Leq, **b**L90, **c** Lmax, **d** Lmin in the morning times in the study area.

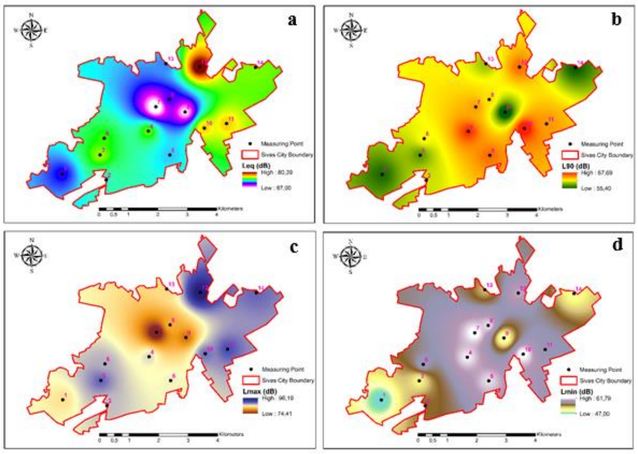

Figure 3. Spatial distribution of **a** Leq, **b**L90, **c** Lmax, **d** Lminat noon in the study area.

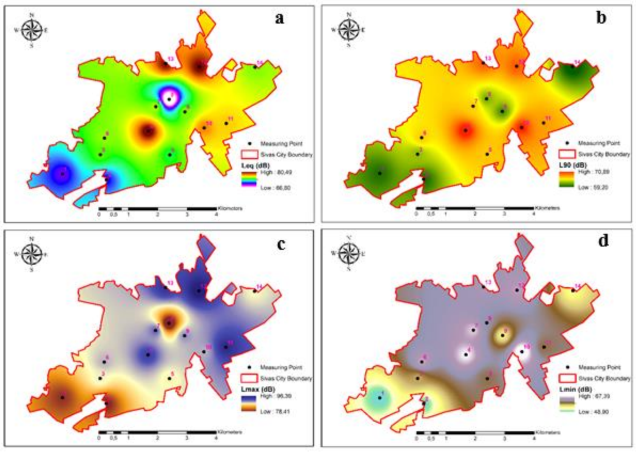

Figure 4. Spatial distribution of **a** Leq, **b**L90, **c** Lmax, **d** Lminin the evening in the study area.

The Lnp value takes into account both the NC and Leq indexs. This index is considered to be the best indicator of the physiological and psychological impact of noise while giving an idea of noise level fluctuations and noise pollution. NC values also show larger fluctuations in noise levels [20]. Highest Lnp values in the workspace were measured in measuring points 11 (96,8 dB) and 14 (95,8 dB) in the morning, measuring points 12 (98,7 dB) and 14 (96,6 dB) in the noon and measuring points 12 (95,2 dB) and 14 (97 dB) in the evening. Highest NC values in the measurement points were measured in measuring points 7 (15,1 dB) and 14 (18,7 dB) in the morning, measuring points 3 (20,4 dB) and 14 (21,3 dB) in the noon and measuring points 9 (18,8 dB) and 14 (21 dB) in the evening. Considering the Lnp and NC values it is seen that the measurement point with the largest fluctuations in noise level is at the measuring point 14.If the NEI value is greater than 1, the noise exposure level is considered excessive [20]. Since almost all of the NEI values calculated for the study area are greater than 1, the noise exposure level of all measurement points is excessive (Table 2).

In studies and social surveys, an NI value of 74 dB (A) has shown that less than 3% of those who are exposed suffer from it [22]. The NI value which is calculated according to the measurements made in this study is usually above 74 dB. The measuring point with the highest values is point 14. In general, noise-related disturbances occur in the places where it is measured (Fig. 5).

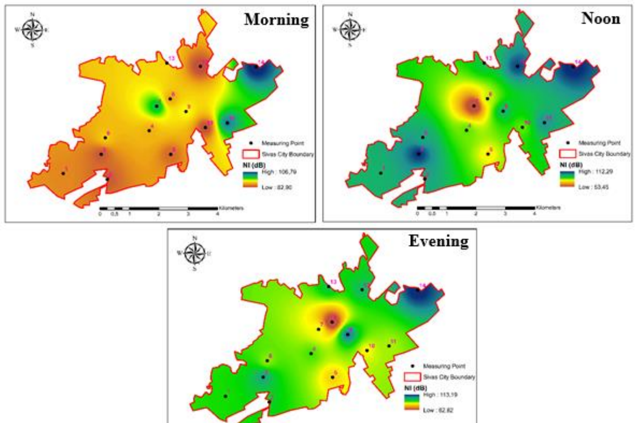

Figure 5. Spatial distribution of NI at certain times in the study area.

The comparison of the morning, noon and evening noise measurement results with WHO and OECD (> 65 dB) and Highway Environmental Noise Limit Values (Lmorning 68 dB and Levening 63 dB) are presented graphically in Figure6. Because WHO and OECD only set a standard for daytime measurements, evening measurements (Fig. 6c) were compared with the Highway Environmental Noise Limit Values only.

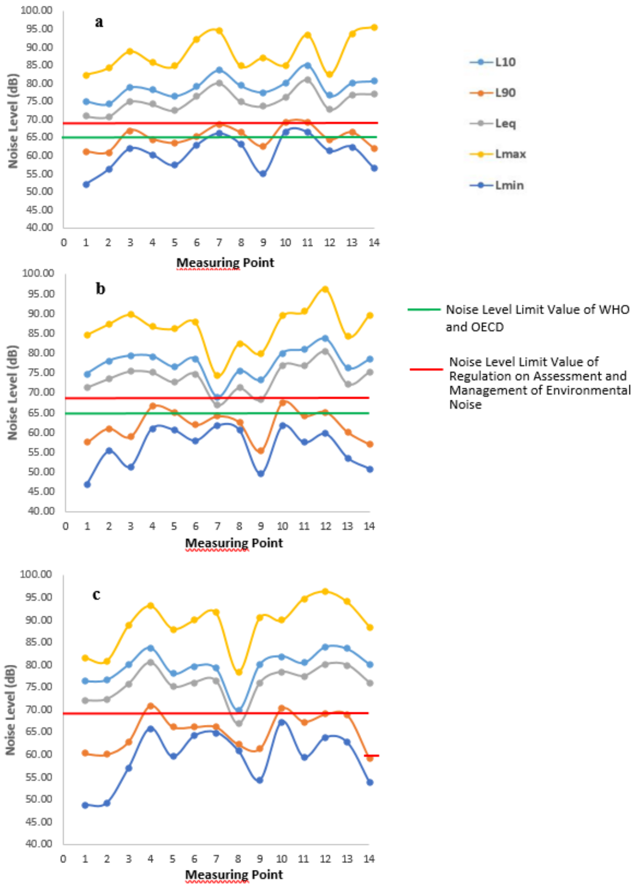

Figure 6.a Morning **b** noon and **c** evening noise measurement results graph.

As seen in Figure 6, L90 and Lmin values were below both standards in morning and noon measurements (Fig. 6a, Fig. 6b), while L10, Lmax and Leq values exceeded the standards. In the evening measurements (Fig. 6c), only the Lmin value remains below the standard while the other values are above the standard. This shows that the noise caused by traffic at the places where the measurement is taken is disturbing at morning and evening hours.

The results of this study were similar to many previous studies on noise pollution. Cai *et al*.[28], have created daytime and night traffic noise maps for the Guangzhou (China) region with the help of GIS. The noise limit values in this region are 70 dB and 50 dB respectively for day and night. In this region, while 6.56% of the noise in the daytime is above 70 dB, 44.96% of the noise is between 50 dB and 70 dB. At night time, 6.56% of the noise is above 70 dB, while 44.96% of the noise is between 50 dB and 70 dB. at night, 44.49% of the noise is higher than 50 dB and 7.61% of the noise exceeds 70 dB. According to the researchers, the results were thought to help to control traffic noise. In the study conducted by Alesheikh and Omidvari [29], it was aimed to measure the urban traffic noise levels in Tehran and to analyze the temporal and spatial dynamics of urban traffic-related noise pollution. Measurements were made at times when traffic was dense and low. In this study Index values such as Leq, L10, L50, L90, Lmax and Lmin were measured. The results showed that most of the commercial and residential areas surrounding the main streets were affected by serious noise pollution. Mahdi *et al*.[30], evaluated the traffic noise caused by road traffic as spatial and temporal in Karachi City (Pakistan), and found that noise levels were generally higher in mornings and evenings. Researchers emphasized that the average noise level is over 66 dB and this noise level may cause serious distress in accordance with the World Health Organization (WHO) outdoor noise guidelines.

4. Conclusions

In this study, noise pollution in the city center of Sivas was evaluated based on GIS based noise indexes. With the purpose of determining the noise pollution originating from traffic in Sivas city center, noise measurements were performed in 14 different points that represent the city for 5 days (Monday-Friday) in morning, noon and evening. The evaluation was made by taking the averages of the measurements made at the same time for 5 days. According to the standard values set by the WHO and OECD, if the Leq is greater than 65 dB, this region is defined as “black area and serious discomfort”. In terms of Highway Environmental Noise Boundary Values, Leq limit values were determined to be 68 dB during the day and 63 dB at evening time from the areas where commercial buildings and noise-sensitive uses co-exist to the areas where the houses are densely exists. Almost all of the measurements were above the limit values and ranged between 70-80 dB. If the NEI value is greater than 1, the noise exposure level is considered excessive. Nearly all of the NEI values calculated according to the measurements are greater than 1, and this shows that the level of noise exposure of all measuring points is excessive. In studies and social surveys, an NI value of 74 dB (A) showed that less than 3% of those who were exposed were uncomfortable. The NI value which is calculated according to the measurements made in this study is usually above 74 dB. In general, noise-related disturbances occur in the places where it is measured. This study showed that traffic noise can cause environmental pollution everywhere in the modern world.When all of the results are evaluated, it is seen that there is a serious noise pollution problem around the city’s traffic roads. The lack of alternative roads of transportation for the city and partly due to presence of intercity main roads in the city's residential areas, raises the problem of traffic and accompanying noise. The main roads that provide intercity transportation should be moved out of the urban settlements. Thus, the noise caused by large vehicles such as bus trucks cannot affect settlements. In addition, alternative routes should be created for the city, thus reducing the number of vehicles on the roads. Priority should be given to the control of traffic vehicles to prevent noise pollution at the source. Efforts should be made to reduce environmental noise to reduce exposure to noise pollution.

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