

Research Article

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Modeling and mapping of traffic noise pollution by ArcGIS and TNM_{2.5} techniques

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Abstract: The aim of this study was to map and model the noise pollution level (NPL) of a highway in Iran by using statistical techniques, geographic information system (GIS) Software, and the Traffic Noise Model version 2.5 (TNM_{2.5}). The equivalent noise level in A weighting network ($L_{eq(A)}$) was measured in 28 stations in different seasons using the sound level meter of the TES-1358 model. The traffic noise data and indices L_{eq} (equivalent noise level), L_{max} and L_{min} (the maximum and minimum time-weighted noise levels), L_n (noise pressure level exceeded for n percent of the time), NPL, and TNI (traffic noise index) were measured and calculated to determine the daily sound level. They were then statistically analyzed by SPSS and Sigma Plot Software. Finally, the GIS software and TNM_{2.5} techniques were used to map and predict the traffic NPL in the region and the distribution of noise levels. The highest noise level was measured at about 80 and 79.61 dB in Kouhsangi and Abadgaran stations, respectively. The lowest level was measured at around 58 dB in the Hafez Square station. In addition, the results show that the highest and lowest L_{eq} were almost in the same range (81–85 dB). It appears that the TNM_{2.5} model can reasonably predict traffic noise levels as well as the dispersion and nature of noise pollution on the highway.

Keywords: traffic noise pollution, TNM_{2.5} model, $L_{eq(A)}$, vehicles, GIS software, highway

1 Introduction

Like air, soil, and water pollution, noise pollution is one of the environmental problems that threatens human health and even the survival of living organisms. Therefore, noise pollution is an important criterion for determining the quality of life in countries [1]. The World Health Organization (WHO) introduces noise pollution in large cities as the third most dangerous type of pollution after air and water pollution, in which urban traffic is the main cause of this type of pollution [2].

Thus, the importance of the issue becomes more colorful when we know that the physiological and psychological effects of noise pollution on humans usually appear gradually and in the long term have a direct effect on the human nervous system and reduce general health [3]. One of the reactions of the human body to noise pollution is the secretion of the hormone adrenaline, which changes the heart rate and blood pressure, and immorality, violence, and lack of concentration [4,5]. Road traffic, public transport vehicles, and industrial and construction workshops are some of the most important sources of noise pollution in cities and residential environments [6]. However, traffic is the most important source of noise pollution in cities. Moreover, numerous studies have reported that most of the traffic noise pollution in cities arises from motor vehicles [7–10]. Another study in Iran has reported that the main reasons for traffic noise in Tehran are worn-out cars, the old technology of car manufacturers, high traffic density, lack of modern traffic control equipment, lack of planning, and lack of monitoring policy [11]. A study on traffic noise pollution in Kerman showed that noise levels are in the range of 66–79.5 dB, which is higher than the standard, and it has a negative effect on the citizens of Kermani, such as mood swings, insomnia, concentration problems, and headaches [12]. Like many other cities, Mashhad City has also encountered the problem of traffic and different kinds of environmental pollutants due to the irregular increase of vehicles and lack of effective mechanisms and infrastructures to apply limits for using personal vehicles. Mashhad City, the center of Khorasan Razavi

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Province, with an area of 328 m² and a population of 3,372,660, is the second most populous city in Iran after Tehran City. Based on the latest information from the statistical yearbook of transportation in 2019, the number of the commuting of residents of Mashhad by vehicle one day and night is around 6.65 million and the number of travelers by vehicle in the rush hours in the morning is 816,000 commuting.

Traffic noise assessment is one of the appropriate solutions to predict situations to reduce the burden of pollution in urban environments [13]. Traffic noise modeling is one of the most common methods to predict the pollution level, effects, and control of traffic noise [14]. There are many statistical tools to model noise pollution such as the Traffic Noise Model version 2.5 (TNM_{2.5}), sound plan, and SPreAD-GIS (System for the prediction of Acoustic Detectability Geographic Information System). Numerous studies have shown that the TNM_{2.5} model is a more suitable option for assessing traffic noise pollution, especially in urban highways of Iran, compared with other tools, which are often expensive or designed for specific purposes [5]. In the study of traffic noise in Thessaloniki city in Greece, Begou *et al.* concluded that modeling based on Geographic Information System (GIS) was more capable than conventional methods of analyzing ambient noise [15]. However, many studies have confirmed that the TNM_{2.5} model is a more suitable option for assessing traffic noise pollution in most cities with high traffic noise pollution all around the world. There is no study in the field of traffic noise pollution modeling in Iran, and most of the studies have been conducted based on the models of other countries [13]. Hence, considering the effective role of traffic on the rate of noise pollution in Iranian cities and also the lack of comprehensive studies in this field in Iran, the aim of this study was to evaluate, map, and model the noise pollution level (NPL) of Shahid Kalantari Highway in Mashhad using statistical techniques, GIS software, and TNM_{2.5} model.

2 Methods

2.1 Study process

The process of the current study was organized into three stages including investigation, data collection, and data analysis and modeling. The investigation stage included the specifications of the city passages network, the relevant maps, and information layers, considering the type of the composition of the highway axis, identifying the type of

traffic information required for operating in the research and planning for the traffic statistics, identifying the locations to establish sound record stations along the highway axis and collecting sound data, organizing GIS data, identifying the factors affecting the sound emission along the highway axis, and considering the models of traffic noise prediction. In the data collection stage, the map of the study area in GIS was prepared based on the information collected regarding the traffic volume, the traffic composition, the speed of the vehicles, sound data in the stations of the study area, the specifications of the highway (e.g., the route slope). The stage of data analysis and modeling included the data precision, transferring information to the GIS software, statistical analysis of the collected data, modeling the NPL of the highway using the statistical techniques, GIS software, and the model of TNM_{2.5}. Meanwhile, the sound level equation maps were prepared for the index of $L_{eq(A)}$ in all stations in the studied time intervals. The process of the study is presented in Figure 1.

Investigating the noise pollution of a part of the highway network of Mashhad City was the subject of the current study. Shahid Kalantari Highway starts from the interchange of Azadi (north) and is extended to the interchange of Ghadir (south) for around 11 km. Figure 2 shows the parts of the Shahid Kalantari Highway.

2.2 Data collection

To collect data, considering the route map, environmental conditions, intersections, and the density of sensitive points, 28 stations were selected as the sampling stations for recording data. The sound measurements were done, and the specifications of the through traffic were determined in four seasons of spring, summer, autumn, and winter, in one working day and in the rush hours (time intervals: 7:30–9:30, 12:30–14:30, 18:30–20:30, 23:30–1:30, and 3:30–5:30). The measurement duration in each station was 5 min, which was also repeated for three times. The sound level meter of TES-1358 was used to measure $L_{eq(A)}$. The device was set on A frequency weighting network to act based on the sensitivity of human ears, the fast speed, and the spectrum of 30–130 dB. It was calibrated before the measurement, at the time of sound measurement, it was located on a stand with the height of 1.5 m from the ground and a distance of 1.5 m from the street curb, and a spongy protector was put on the device sensor to minimize the effect of airflow. To prepare data, statistical analysis was conducted on the data of different stations, in the hours of morning, noon, evening, and night, and the

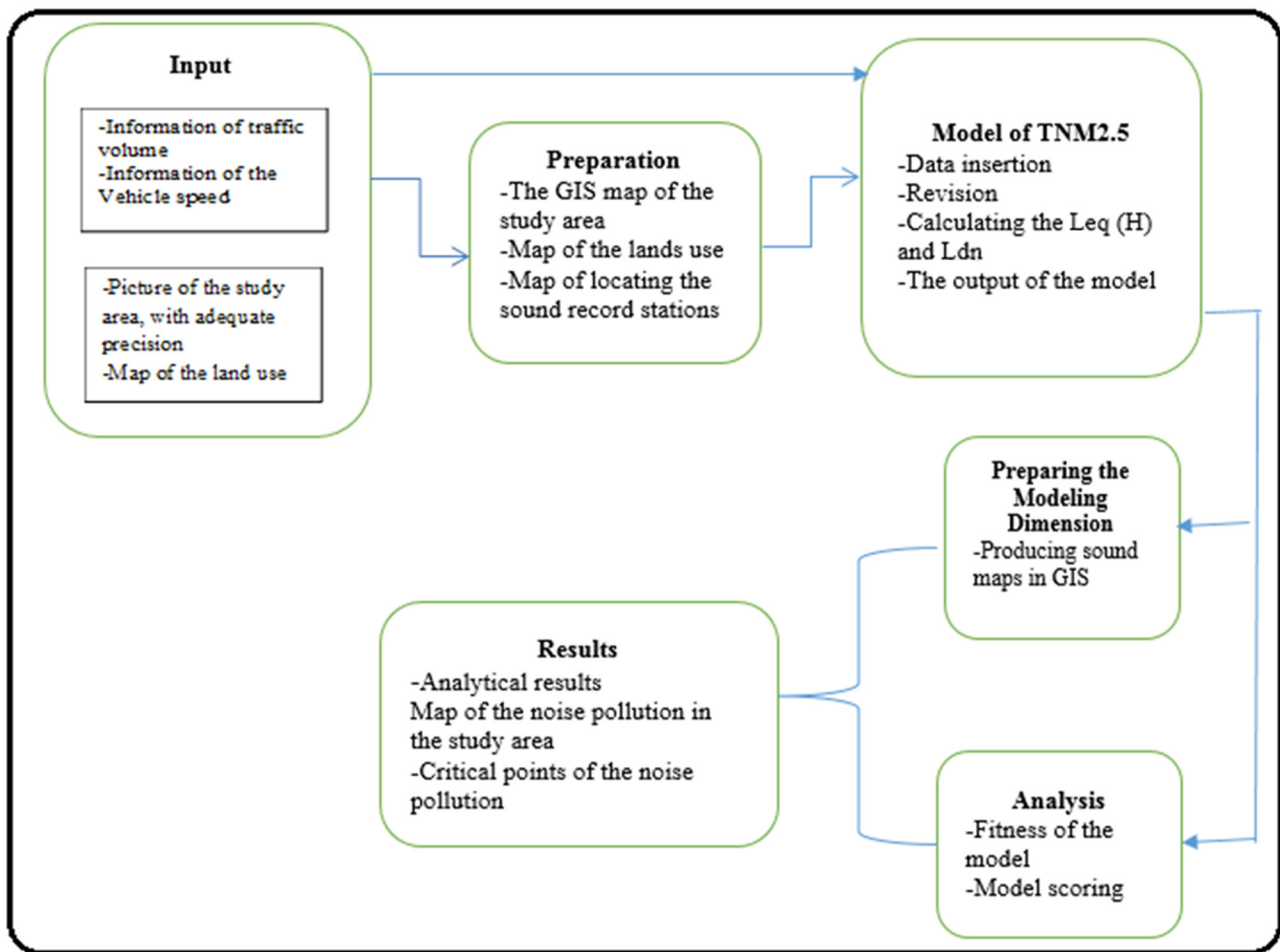


Figure 1: The process of research execution.

entered data were ready to be used in the $TNM_{2.5}$ model. Then, based on the inserted information, the lines of the street were drawn on the map, and in the final stage, the values of $L_{eq(A)}$ were determined considering sound barriers in each station, for various types of vehicles, based on the information. Figure 3 shows the map of the study area and the location of measuring sound pressure levels in 28 stations.

2.3 Mapping the traffic noise pollution

The collected data were entered into the GIS software, and the information layers were identified to provide the level of pollution in the region and to determine the distribution of noise pollution in the region. The sound contour maps of Shahid Kalantari Highway were drawn using sound levels measured in 28 stations around the highway, in five time intervals using IDW interpolation in ArcGIS software. The areas with low sound pollution dispersion were

demonstrated by cool colors and the areas with high sound pollution dispersion by warm colors. Table 1 presents the time intervals of the measurement of equivalent noise levels on the highway as input data in ArcGIS.

2.4 Structure of Traffic Noise Model version 2.5 ($TNM_{2.5}$)

In the current study, noise mapping of the sound level, identifying the critical points, analysis of the sound indices, and prediction and modeling of the noise pollution in the highway were conducted using the $TNM_{2.5}$ model. The systemic interpolation model of $TNM_{2.5}$ was used to predict the amount of the traffic noise in the highway. $TNM_{2.5}$ is the highway model of the United States and is certified by the United States Environmental Protection Agency (USEPA). In this model, five types of vehicles are defined, including automobiles, semi-heavy trucks, heavy trucks, buses, and motorcycles. In the $TNM_{2.5}$ model, in addition to the



Figure 2: The parts of Shahid Kalantari highway.

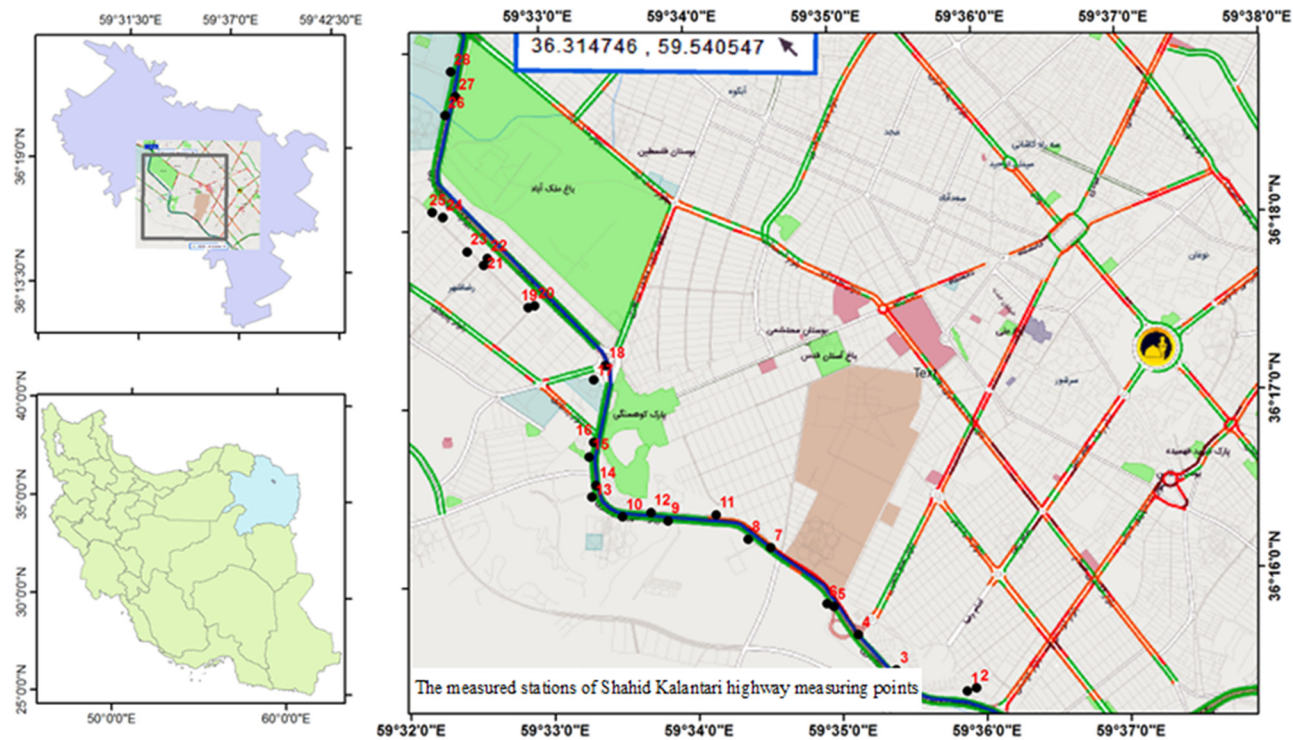


Figure 3: The map of the study area and the location of measuring sound pressure levels in 28 stations.

Table 1: Measurement intervals of the equivalent noise level on the highway as input data in ArcGIS

Autumn and Winter		Spring and Summer	
Part of the day or night	Time	Part of the day or night	Time
Morning	7:30–9:30	Morning	7:30–9:30
Noon	12:30–14:30	Noon	12:30–14:30
Night	18:30–20:30	Evening	18:30–20:30
Midnight	23:30–1:30	Night	23:30–1:30
Dawn	3:30–5:30	Midnight	3:30–5:30

mentioned vehicles, the user might define a new vehicle, and it is also capable of designing the sound barriers and obstacles. The $TNM_{2.5}$ model determines the intensity of the noise resulted from the traffic volume of vehicles in the street and highway, considering the barriers, trees, the material of the ground, slope of the street, and other parameters. The model uses algorithms to calculate the intensity of sound, and sometimes, the algorithms are very complicated [16,17]. The $TNM_{2.5}$ model uses the algorithm equation (Eq. (1)) to estimate L_{Aeq1h} .

$$L_{Aeq1h} = EL_i + A_{traffic(i)} + A_d + A_s, \quad (1)$$

where the EL_i indicates the total sound emission level of the whole vehicle, based on the type of the vehicle; $A_{traffic(i)}$ is the coefficient of the traffic flow; A_d is the modification of sound intensity for the distance from the road and the road length; and A_s is the modification of the noise intensity for the barriers, ground and trees. $A_{traffic(i)}$ is calculated based on Eq. (2):

$$A_{traffic(i)} = 10 \log_{10} \left(\frac{V_i}{S_i} \right) - 13.2 \text{ dB}, \quad (2)$$

where V_i indicates the vehicle flow per unit of time (h) and S_i indicates the speed of vehicles in k/h. It is noteworthy that in the current study, the average speed in highway for all vehicles, in a free-of-traffic condition, is supposed to be 80 k/h.

The model of $TNM_{2.5}$ modifies the amount of sound intensity based on the distance between the road and the receiver, transversely, which is calculated according to Eq. (3):

$$A_d = 10 \times \log_{10} \left[\left(\frac{15}{d} \right) \left(\frac{a}{180} \right) \right] \text{ dB}, \quad (3)$$

where A_d is the sound intensity modification coefficient for the distance from the road, d is the vertical distance between the road and the receiver, in meters, and a is

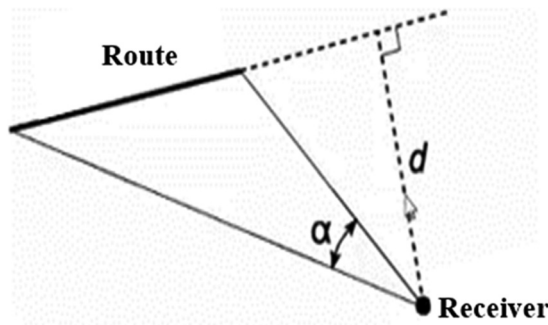


Figure 4: The angle of the intersecting line with the vertical distance between the road and the receiver.

the angle of the intersecting line with the vertical distance between the road and the receiver, which is suggested at most 10 degrees (Figure 4).

The $TNM_{2.5}$ model considered and modified the effects of the ground and barriers between the receiver and the source of sound production on the amount of the reduction of traffic noise, by the A_s coefficient, in a way that the sound emitted from the source is influenced by different factors such as trees and plants, sound barriers, buildings, material of the ground, asphalt, and the climatic conditions. In the model employed, the number of each of the mentioned factors is separately calculated, as a correction factor. It should be noted that in the traffic model of $TNM_{2.5}$, the atmospheric effects such as wind speed and the temperature gradient were not calculated. The $TNM_{2.5}$ model considers buildings as barriers, except that to consider the possibility of the sound crossing through the buildings, once the model assumes a complete barrier and once no building, and then it takes an average. If there is not enough space between the buildings, they are considered as a complete barrier. The model considers only one row of buildings, and for each additional row of buildings, the model takes into account a 1.5 dB decrease in the sound intensity. The minimum decrease in the sound intensity due to the existence of buildings is 10 dB. The effect of sound on the ground surface is also different, in a way that the hard ground is not able to absorb the sound; rather, it reflects the sound and results in increasing the sound intensity. The soft ground decreases the intensity of the sound hitting the ground and results in the absorption of the sound energy. The decrease or increase in the sound intensity should be explained for each frequency, separately, because the decrease in the sound intensity is different for each frequency. It should be noted that in the current study, the material of the road is considered to be ordinary asphalt and hard ground. Precipitation, particularly in the form of

snow, affects greatly the results, too, because it increases the amount of sound energy absorption by the ground. Moreover, snow causes the creation of a positive temperature profile around the ground surface, which leads to the increase of sound on the ground surface [18].

The data input to the model of $TNM_{2.5}$ included the location of the station (latitude and longitude), street width, road slope, barriers, row of buildings, ground lines, green spaces, traffic volume (the volume of different vehicles crossing the passage), the vehicle speed, and also the measured values of $L_{eq(A)}$ in 28 stations. The volume of vehicles crossing the passage is recorded based on the number of vehicles in 1 hour, for different kinds of vehicles including five groups of automobiles, semi-heavy trucks, heavy trucks, buses, and motorcycles.

3 Results

3.1 Collected data

Table 2 shows the input data required to develop the $TNM_{2.5}$ model in 28 stations on the highway for different hours and seasons. These data include the location of the station (longitude and latitude), height above sea level of the studied area, traffic volume (passage volume of different vehicles on the road), vehicle speed, and sound pressure equivalent level in A weighting network ($L_{eq(A)}$).

3.2 Model validation

In the current study, the $TNM_{2.5}$ model was developed based on the information from the measured samples in the stations, and the results of the model were evaluated with the measured data. To evaluate the model, the independent two-sample mean test, one of the frequently used tests in the statistical analyses, was used. By this test, the mean of two independent samples might be compared and decisions could be made about their statistical difference. When the data of samples follow the normal distribution, t -test and t -statistics are adequate to compare the mean of two samples. In other words, in the current study, the measured $L_{eq(A)}$ (mean) was compared with the $L_{eq(A)}$ predicted by the models in stations, using the paired sample t -test. The null hypothesis (H_0) in the present study was that there was no difference between the values of means in two paired samples.

Table 2: The input data of the $TNM_{2.5}$ model for predicting the traffic noise emission in the highway (Sample: Rush Hour in the Morning, Spring)

Station	Coordinates X	Coordinates Y	The Vehicles Volume per Hour in the Passage					Vehicle Speed (km/h)	$L_{eq(A)}$ (dB)
			Bus	*Sedan	Motorcycle	Heavy Truck	Semi-Heavy Truck		
1	4021983.494	728007.668	9	331	23	2	13	80	74.90
2	4022092.783	727687.612	18	609	33	6	43	80	79.43
3	4022190.604	727395.720	23	635	64	7	41	80	77.80
4	4022445.822	726668.440	20	648	34	5	48	80	78.85
5	4022711.736	725923.858	15	754	47	9	46	80	76.87
6	4022935.123	725291.837	23	769	43	6	43	80	80.30
7	4023221.600	724478.540	10	296	19	1	19	80	79.39
8	4023426.520	723901.878	14	704	57	7	40	80	78.28
9	4023680.277	723192.834	16	652	61	5	41	80	78.07
10	4024017.822	722761.952	17	704	37	7	37	80	78.39
11	4024234.111	721627.283	20	738	33	6	47	80	77.72
12	4025059.275	719059.922	23	789	30	5	44	80	77.36
13	4024456.957	720788.033	33	759	25	8	39	80	76.57
14	4024193.326	721551.973	30	842	22	6	34	80	76.90
15	4024049.679	720315.136	14	313	72	0	28	80	76.39
16	4023916.953	722292.936	20	405	41	2	32	80	76.56
17	4023814.693	722634.219	16	683	47	4	37	80	79.73
18	4023603.022	723210.991	30	645	43	3	38	80	80.67
19	4023467.530	723598.074	25	667	40	5	35	80	80.34
20	4023364.361	723859.462	7	320	54	0	16	80	85.63
21	4023104.826	724600.150	34	343	43	6	42	80	75.26
22	4022911.508	725151.397	26	750	47	6	40	80	79.31
23	4022846.861	725321.486	22	687	33	7	41	80	77.45
24	4022427.233	726508.994	27	637	30	5	34	80	77.32
25	4022060.437	727513.245	17	569	39	6	31	80	76.53
26	4022846.861	725323.460	29	823	43	6	33	80	76.80
27	4022427.233	726528.987	26	782	40	8	32	80	77.20
28	4022062.437	727534.234	6	313	42	0	12	80	76.00

*Sedan: A sedan is a passenger car in a three-box configuration with separate compartments.

3.3 Traffic noise pollution maps

The output of ArcGIS for sound contour maps is illustrated in five time periods in Figures 5–9. These figures depict the scattering of the emission of $L_{eq(A)}$ on the Shahid Kalantari Highway at the peak of pollution from 7:30 to 9:30. The maximum $L_{eq(A)}$ in spring was measured around 86–88 dB. Figure 5 demonstrates that the amount and dispersion of noise pollution in spring is highest, and the critical areas are the northwestern, west, and center of the highway. The minimum $L_{eq(A)}$ was 74–78 dB. The reopening of schools in this season, commuting to reach organizations and offices, and huge traffic from 7:30 to 9:30 have increased the amount of sound level in this region. Moreover, the average $L_{eq(A)}$ has sometimes increased due to the motorcycle passing and the instant noise they make and also the traffic of heavy vehicles.

Figure 6 shows the scattering of the emission of $L_{eq(A)}$ on Shahid Kalantari Highway from 12:30 to 14:30. The maximum $L_{eq(A)}$ is around 85–87 dB. The amount of $L_{eq(A)}$ in

spring was highest in terms of pollution emission in all stations, and $L_{eq(A)}$ was around 85–87 dB. In summer, the amount of $L_{eq(A)}$ was around 80–82 dB and the critical areas of emission were the south and southeastern parts of the highway. In autumn, the amount of $L_{eq(A)}$ was around 83–85 dB and the critical areas of emission were the south and southwestern of the highway. In winter, the amount of $L_{eq(A)}$ was around 81–82 dB and the critical area was the southeastern of the highway.

Figure 7 shows the scattering of the emission of $L_{eq(A)}$ on Shahid Kalantari Highway from 18:30 to 20:30. The maximum $L_{eq(A)}$ was around 85–87 dB in spring. It demonstrates that the critical areas were the western and northwestern of the highway. In summer, the amount of $L_{eq(A)}$ was around 80–82 dB, and in some parts, it is increased to around 85 dB, which might be due to the instant passing of cars with high speed and high sound levels. In autumn, the amount of $L_{eq(A)}$ was around 76–83 dB, and the critical areas were the south and southwestern of the highway.

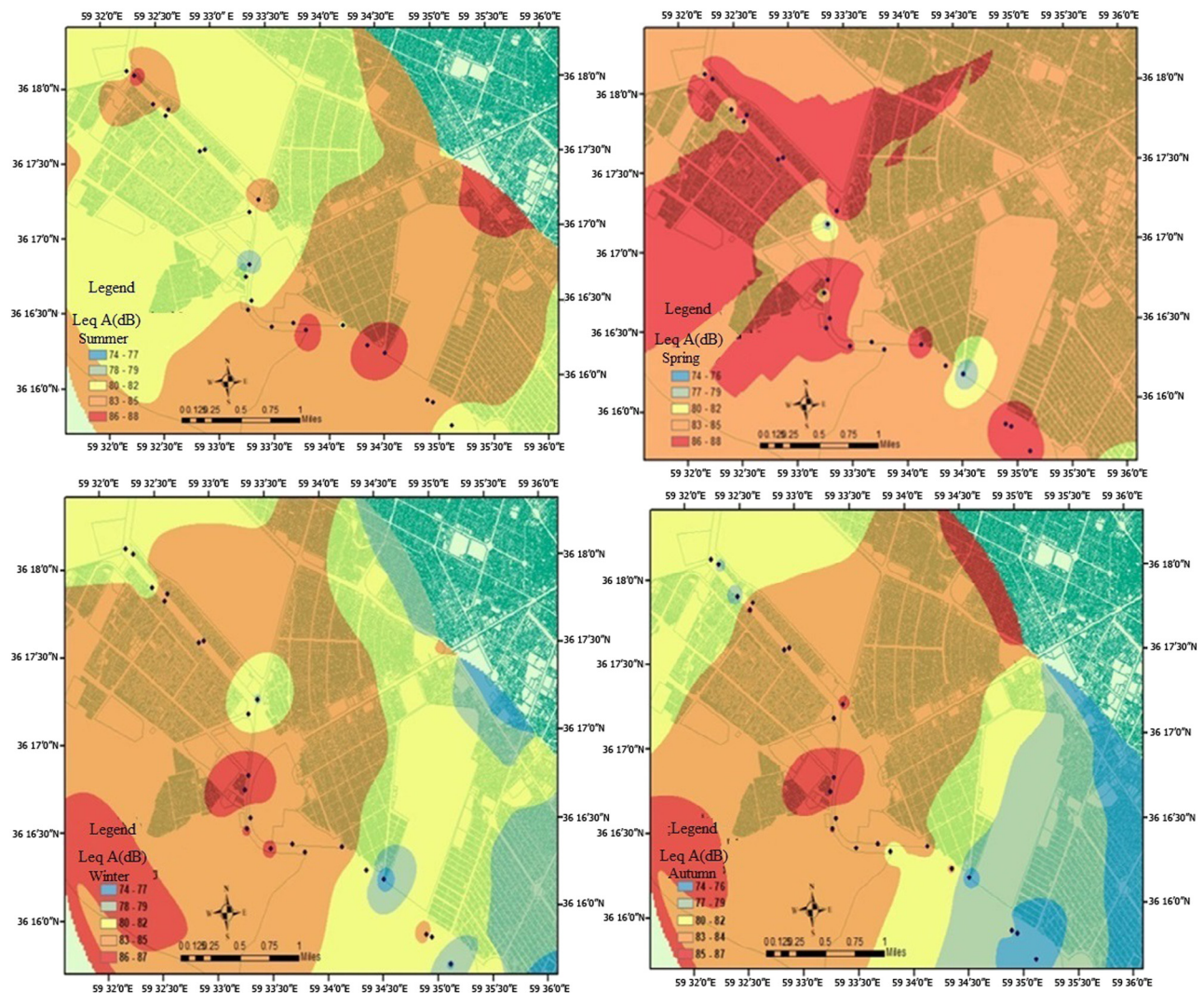


Figure 5: Maps of the scattering of the emission of $L_{eq(A)}$ on Shahid Kalantari highway from 7:30 to 9:30.

In winter, the amount of $L_{eq(A)}$ was around 83–85 dB and the critical area is the southwestern part of the highway.

Figure 8 shows the scattering of the emission of $L_{eq(A)}$ on Shahid Kalantari Highway from 23:30 to 1:30. The maximum intensity of noise pollution was around 85–87 dB in spring. It shows that the amount of noise pollution intensity in spring was around 85–87 dB, and the critical areas were the west and northwestern parts of the highway. In summer, the amount of $L_{eq(A)}$ was around 80–82 dB in all measurement points. In autumn, the amount of $L_{eq(A)}$ was around 83–84 dB, in all measurement points. However, in winter, the amount of $L_{eq(A)}$ was around 65–72 dB, in all measurement points.

Figure 9 shows the scattering of the emission of $L_{eq(A)}$ on Shahid Kalantari Highway from 3:30 to 5:30. The maximum intensity of noise pollution was around 82–87 dB in

spring and the critical areas were the west, southwestern, and center of the highway. It shows that the amount of noise pollution intensity in spring was around 82–87 dB, indicating the highest pollution. In summer, the amount of $L_{eq(A)}$ was around 76–78 dB in all measurement points. In autumn, the amount of $L_{eq(A)}$ was around 79–81 dB, and the critical areas were the south and southwestern parts of the highway. In winter, the amount of $L_{eq(A)}$ was around 82–86 dB, and the critical area was the southwestern part of the highway.

3.4 The results of model validation

Figure 10 and Table 3 present the results of the developed $TNM_{2.5}$ model in comparison with the results of measured

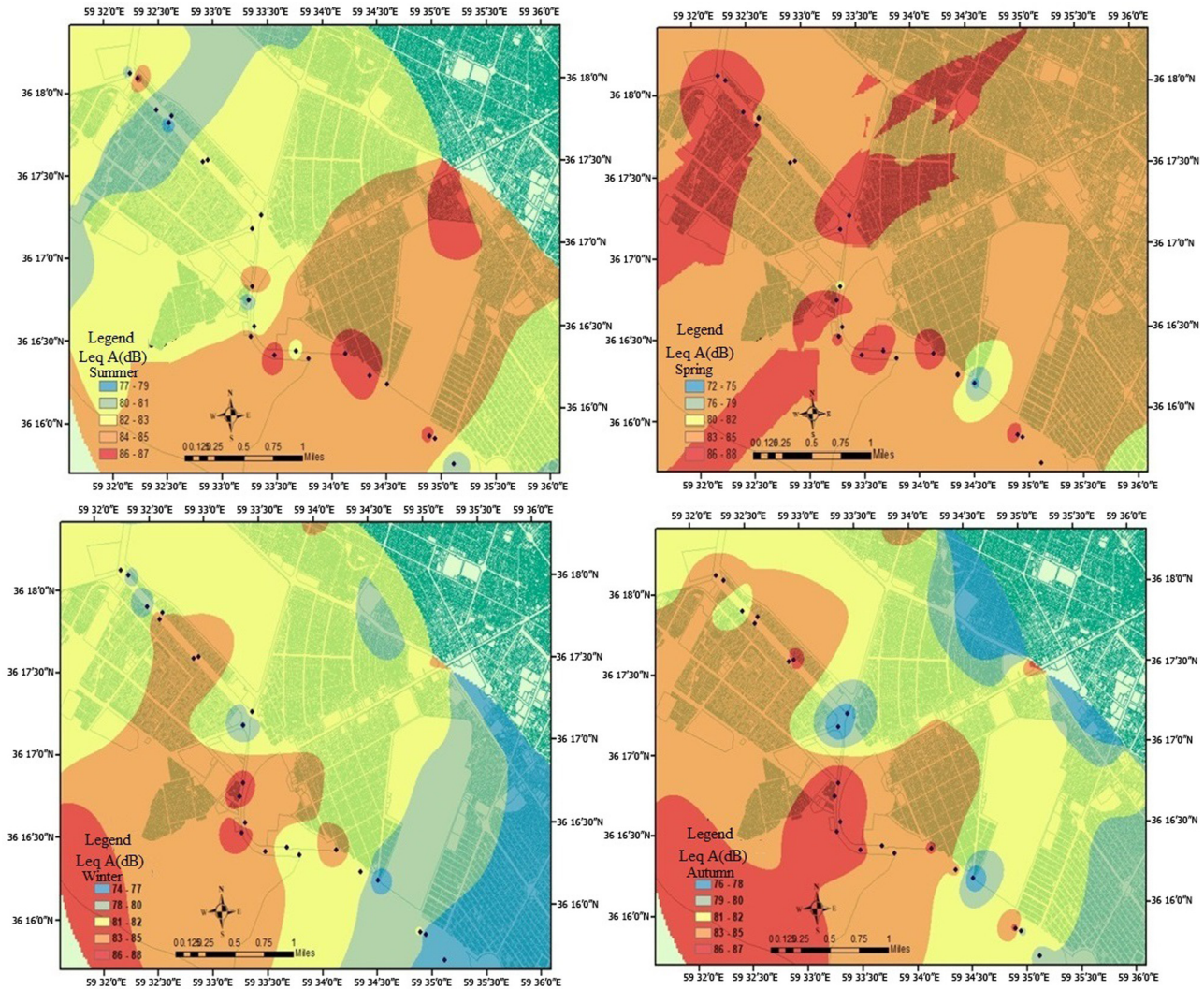


Figure 6: Maps of the scattering of the emission of $L_{eq(A)}$ on Shahid Kalantari highway from 12:30 to 14:30.

$L_{eq(A)}$ in 28 stations, in different seasons, and different time intervals of days and nights. As shown, for example, there is an almost good agreement between the data of the measurement stations and the results of modeling from 7:30 to 9:30 a.m.

As can be seen in Table 3, the prediction model of $TNM_{2.5}$ is comparable or equal to a method that produces the real measured values. According to the $TNM_{2.5}$ model, $L_{eq(A)}$ on the Shahid Kalantari Highway was estimated at about 65 to 85 dB. A comparison of measured and modeling values of $L_{eq(A)}$ with the standard of open-air sound during the day (55 dB) and night (45 dB) is illustrated in Figure 11.

The standard of open-air sound in residential areas is 55 and 45 dB per day and night, respectively. The measured values and equivalent sound level of the $TNM_{2.5}$ model were compared with the standard values. According to

the model, the highest values of $L_{eq(A)}$ in the four seasons were estimated at stations 8 (Piroozi Boulevard, 80.29 dB), 9 (Kuksangi gas station, 78.68 dB), 18 (the bus terminal, 77.73 dB), and 19 (gas station, 74.48 dB).

4 Discussion

A comparison of the average parameters of noise pollution in different stations of Shahid Kalantari Highway at a significant level of 5% showed that the highest amount of noise pollution was in the stations of the Piroozi Boulevard (86.87 dB), gas station (86.87 dB), Kuksangi (85.42 dB), and Abadgaran (84.23 dB). High noise pollution in these stations might be due to the junction of the streets at the end of the

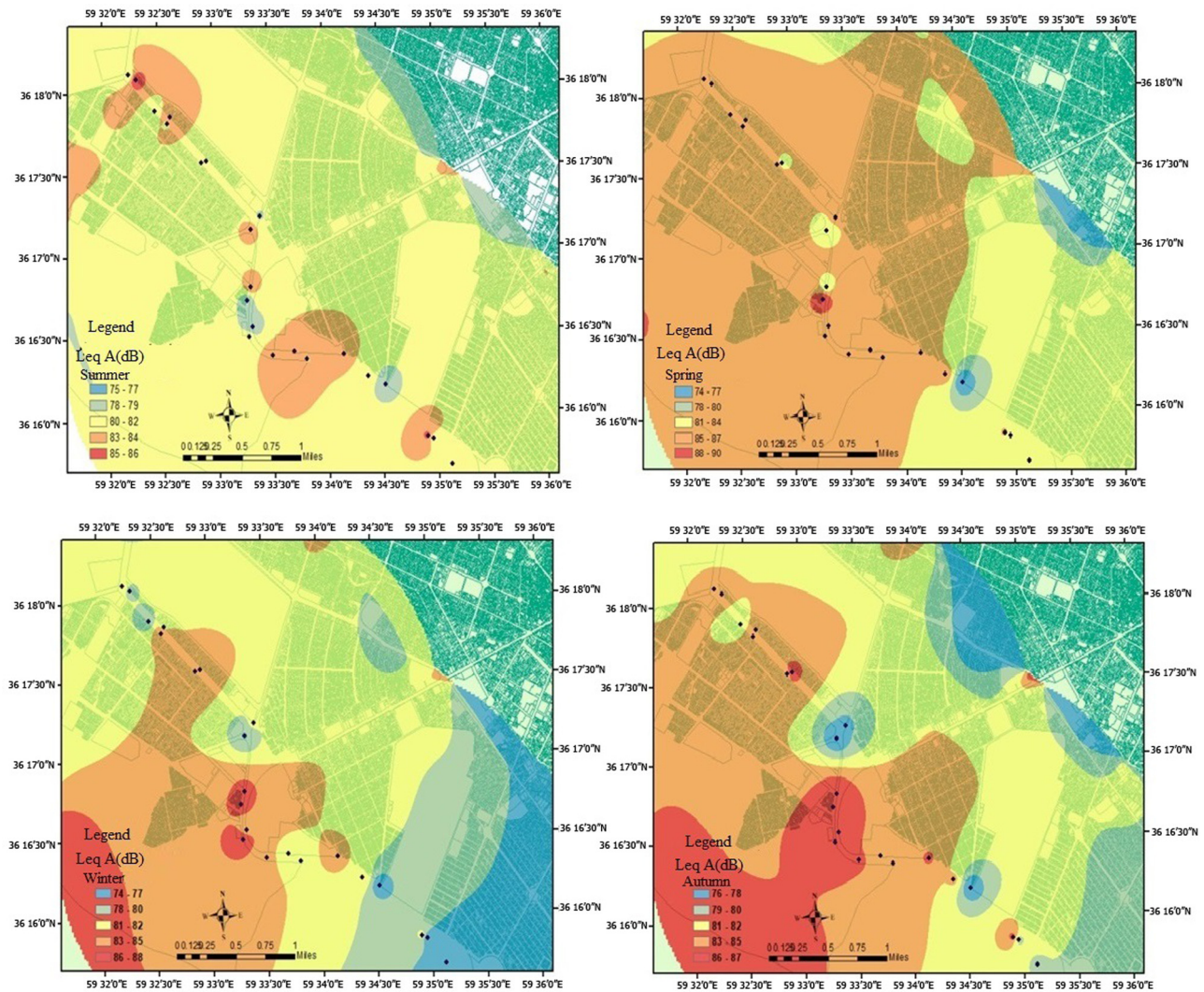


Figure 7: Maps of the scattering of the emission of $L_{eq(A)}$ on Shahid Kalantari highway from 18:30 to 20:30.

stations leading to the surrounding estates, the relatively high accumulation and traffic of motor vehicles on the highway side, the movement of vehicles by low gear especially in rush hours, and the high traffic of public transportation vehicles and motorcycles. Moreover, considering the results obtained from the research, in all seasons off the year, the average $L_{eq(A)}$ in all stations was higher than the daily environmental sound level recommended by the standard of sound in ambient air in Iran so that the highest amount of $L_{eq(A)}$ was measured in autumn (80.23 dB) (Figures 4–8). The high amount of $L_{eq(A)}$ can be due to the re-opening of schools and universities in autumn, the change in the traffic volume, and the increase in the traffic of such vehicles as passenger car, buses, and mini-buses in autumn. Furthermore, in all the time intervals of

morning, noon, evening, and night, $L_{eq(A)}$ was higher than the recommended daily limits (60 dB) for the residential-commercial areas. The highest $L_{eq(A)}$ was related to the morning, which was 86.87 dB, and it is noticeable due to the high traffic of vehicles and start of offices and educational centers in the first hours of the day.

Studying the traffic composition and comparing the minimum and maximum measured indexes and the traffic load show that in all cases, the increase in the traffic load has not led to the increase in the level of sound indexes. It indicates that there is not necessarily a direct relationship between such parameters. Moreover, in some cases, despite the increase or decrease in the traffic load, contradictory results were observed in the measured indexes, and definite proportions were not observed among the parameters. It

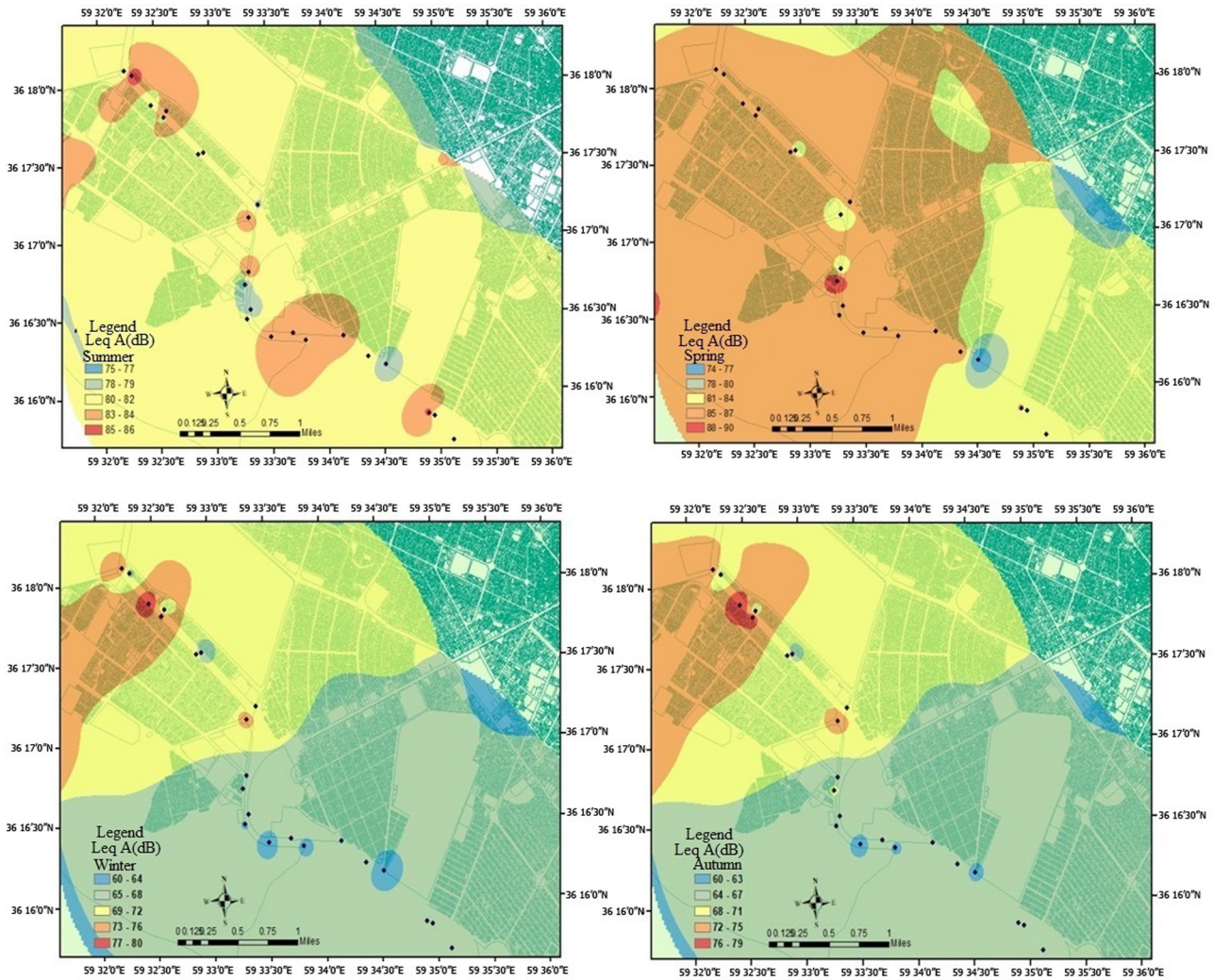


Figure 8: Maps of the scattering of the emission of $L_{eq(A)}$ on Shahid Kalantari Highway from 23:30 to 1:30.

could be attributed to the effect of all other effective environmental parameters on the amount of noise pollution, such as type of the vegetation, different speed and manufacturing technology of vehicles, the quality of asphalt, speed bumps, and the measurement time, which are not taken into consideration in the current study [4].

Moreover, the noise mapping showed that the level of noise pollution on the Shahid Kalantari Highway is higher than the allowable limit. The high level of noise pollution on the highway was caused by the proximity of the NAJA specialized training center, the bus parking lot, garages, the sports complex, and the bus terminal. Therefore, it requires the attention of authorities and employing the management and noise pollution control strategies. Some of the effective factors in this regard are the factors of urban development and traffic engineering. In line with this, the results of a research on noise mapping in

Taiwan showed that 90% of the people living in the area under study were under unacceptable noise pressure, and it was necessary to employ immediate strategies to control the noise [10]. In another study in Yazd City in Iran, it was reported that through calculating $L_{eq(A)}$ in some streets and developing the interpolation method of Kriging, the noise mapping contour lines could be used as some basic important data for future studies and monitoring [19]. In a study in Leipzig City in Germany, Weber *et al.* [20] concluded that the level of noise pollution depends on the type of urban structure determined by the landscape criteria. Moreover, according to Fiedler and Zannin [21], in Curitiba City in Brazil, by 50% decrease in traffic, the noise decreases around 3 dB. Therefore, to prevent the negative effects of noise pollution, the implementation of technical and management plans for noise control in crowded areas with huge traffic in cities is necessary.

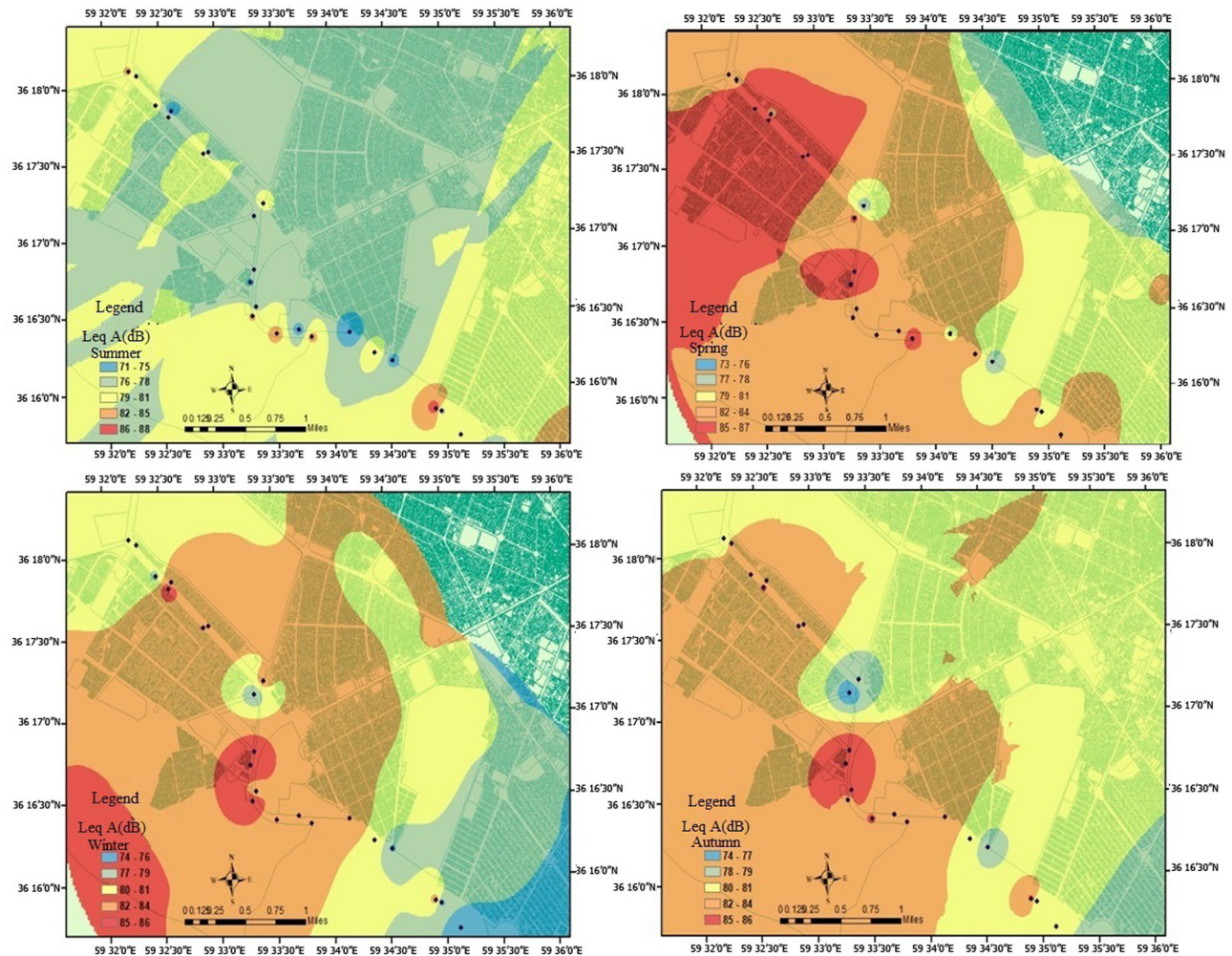


Figure 9: Maps of the scattering of the emission of $L_{eq(A)}$ on Shahid Kalantari Highway from 3:30 to 5:30.

The results of this study also showed that the $TNM_{2.5}$ model is a valuable approach to predicting traffic noise pollution on highways in large cities. Overall, the evaluation of the traffic noise on Shahid Kalantari Highway using the $TNM_{2.5}$ model indicated that the model shows the same rating between the low and high sound-polluted areas and the measured values in the real environment. Models are usually formed based on the information obtained from the measured samples and are validated and calibrated by statistical tests using records and field-based data. The results of the current study also showed that the average calculated $L_{eq(A)}$ by the $TNM_{2.5}$ model in the evaluated stations was 6.51 dB less than the recorded values by the sound level meter in the real environment. Therefore, since the permissible difference limit between the measured values in the real environment and the predicted values by the $TNM_{2.5}$ model is equal to 1–7 dB, it seems

that the $TNM_{2.5}$ model might adequately predict the amount of $L_{eq(A)}$, traffic noise pollution, noise emission, and the manner of noise. In line with this study, Khayyami *et al.* [22] have confirmed that the $TNM_{2.5}$ could provide a reasonable prediction of traffic noise volume and its distribution of the pollution on the highways. Furthermore, Chang *et al.* [23] developed a prediction model of traffic noise in a Taiwanese city considering motorcycle traffic. They found that the $TNM_{2.5}$ model is applicable to predict the noise exposure in the urban environments.

In general, some review and systematic studies also consider the importance of modeling methods for traffic noise to save time and money; the prerequisite for using them is to pay attention to the type of model, the differences, and assumptions required before using the model [24]. In addition, another review has reported that in recent years, many studies emphasize the use of regression

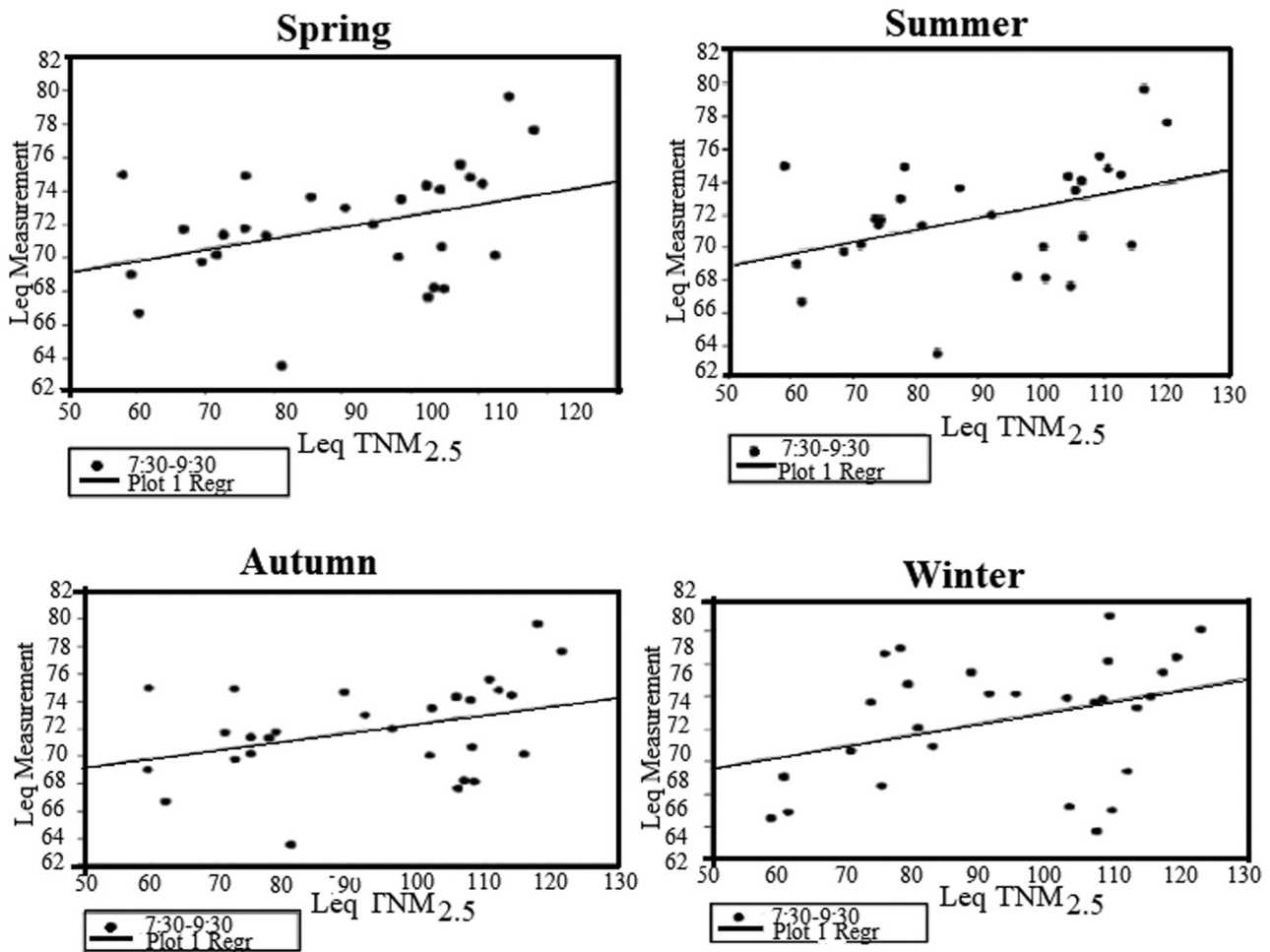


Figure 10: Scatter plots of measured equivalent sound level $L_{eq(A)}$ versus predicted equivalent sound level by the $TNM_{2.5}$ model in the four seasons from 7.30 to 9.30 a.m.

Table 3: Measured equivalent sound level in comparison to predicted values by the $TNM_{2.5}$ model in the four seasons from 7.30 to 9.30 a.m.

Time	Measured $L_{eq(A)}$			Predicted $L_{eq(A)}$			P-value
	Mean	SD	MD	Mean	SD	MD	
Spring	90.36	18.62	11.33–25.66	72.85	4.83	11.19–25.83	<0.001
Summer	91.08	18.82	11.97–26.48	72.85	3.47	11.82–26.63	<0.001
Autumn	92.87	19.40	13.51–28.46	72.88	3.50	13.36–28.61	<0.001
Winter	93.96	19.62	05.76–20.91	80.62	3.80	05.61–21.06	<0.001

MD: Mean difference.

modeling methods for traffic noise, which is due to the lack of attention to the optimal use of modeling methods such as genetic algorithms, fuzzy systems, and neural networks for model development. The results of this study clearly show the superiority of modeling methods such as $TNM_{2.5}$ in predicting traffic noise [25].

5 Conclusion

In general, it can be concluded that the noise pollution in the studied highway is higher than the permissible limit. In addition, according to the results, providing a report on noise pollution in highways and urban areas based on

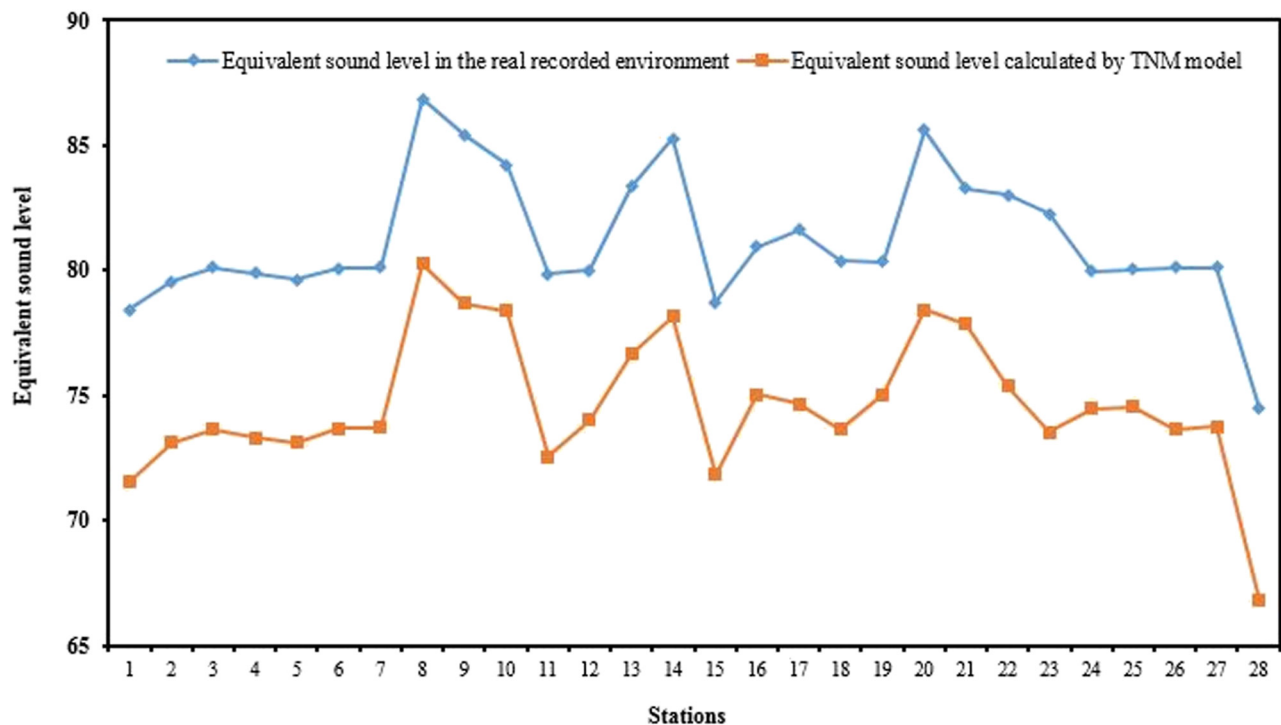


Figure 11: Comparison of measured values of equivalent sound level values and predicted values by the $TNM_{2.5}$ model.

GIS maps can be an accurate and optimal approach to express the amount of traffic noise pollution, which provides complete information about noise pollution indicators and temporal and spatial changes in densely populated urban areas. It seems that the $TNM_{2.5}$ model can reasonably predict traffic noise levels as well as the dispersion and nature of noise pollution on the highway, and it has relatively acceptable accuracy in changing the amount of sound emission compared to other modeling methods. Analyzing and predicting traffic noise pollution on highways can be considered an important aspect of a city management program for controlling noise pollution.

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