Environmental Engineering and Management Journal September 2021, Vol. 20, No. 9, 1415-1423
http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu

"Gheorghe Asachi" Technical University of Iasi, Romania

TRAFFIC INDUCED NOISE POLLUTION PREDICTION USING TRAFFIC NOISE MODEL (TNM) IN RASHT, IRAN

Ali Ahmadi Orkomi*, **Khashayar Mahdiani Bora**

Department of Environmental Sciences, Faculty of Natural Resources, University of Guilan, Sowmeh Sara, Guilan, Iran

Abstract

In this survey, the traffic noise model (*TNM*) has been applied for traffic-induced noise prediction. District 4 of Rasht was chosen as the study area, and three pavement types on the *TNM* model were examined to select the best one for the study area. The model predictions satisfied well with the measured ones by using the *RMSE* statistical parameter and *ANOVA* test. The *DGAC* pavement type proved to have the least *RMSE* = 2.8. *ANOVA* test results showed the measured equivalent A-weighted sound levels ($L_{A,eq}$) and the predicted ones are statistically the same (*P-value*=0.64>0.05 and $F=0.22<F_{critical}=4.04$), meaning that the usage of *DGAC* leads to lower noise level prediction error. After that, the $L_{A,eq}$ induced from traffic have been predicted using the traffic load time series data. The daytime averaged noise levels in the north-eastern parts of district 4 are much higher than the Iranian standard. The nighttime $L_{A,eq}$ contour map also showed that the residential areas around the main roads have sound levels between 55 *dBA* to 60 *dBA* during nighttime, which is unhealthy for human, and the L_{DN} contour for the day-night time indicated that the residential areas have sound levels between 60 to 65 *dBA* that is about 5 to 10 *dB* more than the *EPA* noise pollution standard. Also, the results showed that the cumulative contribution of heavy trucks and different types of bus on the noise level at residential areas is about 43% in average. In this regard, redirecting the heavy trucks and buses traffic routes reduces the L_{DN} value about 2.5 *dBA* in the most polluted parts of the study area.

Key words: noise pollution, pavement type, sound level, TNM model, traffic noise

Received: November, 2020; Revised final: February, 2021; Accepted: March, 2021; Published in final edited form: September, 2021

1. Introduction

Noise pollution is defined as the dispersion of noise or unwanted sound in a level that affects the quality of human and animal life or interferes with routine activities (Jain et al., 2016). It may be generated by vehicles, trains, any electrical appliances, music systems, noisy machinery, horns, airplanes, and even the people. Noise pollution is the third most perilous pollution for human health after air and water pollution (Rahimi Moghadam et al., 2018).

Not only noise pollution is harmful due to the abovementioned reasons, but it also can cause disorders such as hearing disabilities, permanent hearing loss, ear discharge, eardrum damages, blood pressure increase, stroke, abortion, dementia, sleep disturbance, cardiovascular disease, and impairment of cognitive performance in children, etc. (Basner et al., 2014; Sørensen et al., 2017; Yang et al., 2018). In this regard, Wu et al. (2019) studied the effects of traffic noise in different floors of high-rise buildings along the main roads in Guangzhou city using $L_{A,eq}$ measurement results and questionnaires. They concluded that at least 60% of participants suffer from the noise level, physically and psychologically.

Traffic noise has much more adverse effects, disruptions, and disturbances than the other noise types (Shalini and Kumar, 2018). New ecological studies have also shown the substantial impacts of noise pollution on biodiversity and all life forms on Globe (Hempton and Grossmann, 2009; Sordello et al., 2019; Warren et al., 2006). Traffic noise is known

* Author to whom all correspondence should be addressed: e-mail: Orkomi@guilan.ac.ir, Phone: +989124785336. Fax: +981333516042

as one of the most important sources of noise pollution globally, and many kinds of research have been carried out based on that. Industrialization and urbanization have led to increased traffic noise, especially in developing countries (Morillas et al., 2018).

Noise pollution studies have a short history in Iran, although the need to do them is sensed more than at any time. Several studies have been carried out in Iran, especially in the capital, Tehran, to investigate, evaluate, and to predict sound levels (Mehravaran et al., 2011), and most of these studies have shown that the equivalent sound levels are higher than standards in many districts of the city (Mohammadi, 2009). In similar research conducted in Yazd, the researchers investigated noise pollution in urban environments using Arc-GIS and eventually concluded that the equivalent noise level exceeded the standard limits (Ehrampoush et al., 2012).

Perhaps the first traffic noise model in the history of acoustics had been proposed by Beranek (1952), where the model was designed and recommended to use for speeds between 55 to 70 kilometers per hour and distances greater than six meters. During the last decades, the model forms were developed, and gradually further variables, including vehicle percentages and pavement types, were introduced and added to the models (Quartieri et al., 2009). Three of those advanced models are Federal Highway Administration (*FHWA*) Traffic Noise Model (Barry and Reagan, 1978), the *CNR* model in Italy (Cannelli, 1983), and the SonRoad model in Switzerland (Heutschi, 2004; Tachibana, 2000).

One of the most significant *Arc-GIS*-based traffic noise prediction models was developed by Zhu et al. (2015) in China, who used the data obtained from Beijing highways and concluded that the traffic noise predictions performed by the ASJ-2013 model have more accuracy than those of other models. Colorado Department of Transportation carried out a three-step research including; validation of *TNM* model with field data in Colorado, analyzing the sensitivity of *TNM* results to all affecting parameters, and comparing the accuracy of *TNM 2.1*, *TNM 2.5*, and *STAMINA* models. The results showed that the prediction error of *TNM 2.5* was lower than that of *TNM 2.1* and *STAMINA 2*. (Hankard et al., 2006; Menge et al., 2001). Jamrah et al. (2006) applied the road traffic noise prediction model (*CTRN*) to evaluate traffic noise pollution in Amman, Jordan. They calculated and analyzed lower noise levels of 90% and 10% of measuring time (*L90* and *L10*). The study disclosed that the *CTRN* model was efficient at predicting sound levels in that study area.

Kim et al. (2011) evaluated noise level variations by using different pavement types and concluded that noise mitigation would be feasible by replacing the Arizona *ARFC* pavement type. Ece et al. (2018) applied *SoundPLAN* to predict noise pollution in Antalya, Turkey. They studied the effects of some preventing scenarios with *SoundPLAN*. They concluded that the noise exposure would be reduced by 25-63% by considering the alternative routes for heavy vehicles. Also, the effects of the porous asphalt surface and barrier installation have been studied separately.

2. Material and methods

The question that made us begin our study was, "has the city of Rasht been influenced by noise pollution due to the development of technology and the rise in the number of cars since the last couple of years?" Considering Rasht as a metropolitan city and the most populated city in the north of Iran, it has heavy traffic, which leads to some urban issues like air and noise pollution (Foroutan, 2018). According to the history of Rasht, it was believed in the past that most types of pollution, especially air pollution, did not have a significant impact on the environment, simply because of the high rate of precipitation in the north of Iran. However, the influence of technologies was neglected, and no one could imagine that the rapid development of urban areas would become a contributing factor to all environmental problems. According to the census data, the population of the urban regions of Rasht is around 680000 (GPSIS, 2018), and it is divided into five districts. In this study, District 4 of Rasht is considered the study area (Fig. 1b) to evaluate the *TNM* model's performance for predicting traffic-induced noise level. District 4 is the most populated Rasht district (population is around 194000). It is also located in the second-most densely populated section of the city (108 persons per hectares). In this regard, *TNM* 2.5 version has been utilized.

The most important parameters in *TNM* are hourly traffic data, surface air temperature, relative humidity, and pavement type. The general governing equation to predict the hourly averaged sound level in *TNM* is as below (Hastings, 2019),

$$L_{A,eq} = EL_i + A_{traffic(i)} + A_d + A_s \tag{1}$$

where: EL_i, $A_{traffic(i)}$, A_d and A_s are emission noise level of the vehicle type *i*, the adjustment factor for the volume and speed of the vehicle type *i*, the adjustment for the distant between the road and the receiver and for the length of the road, the adjustment for all types of shielding between the source and the receiver. Since there is no mechanized traffic monitoring system in Rasht city, the traffic data are gathered by a camera mounted on a stand. The meteorological parameters are obtained from the surface meteorological station at Sardar-Jangal airport in Rasht. In the validation stage, some different road pavement types have been utilized to select the best one with the minimum sound level predicting error. The average pavement type is the default pavement typeset on *TNM*. It consists of Reference Energy Mean Emission Level (*REMEL*) data that was measured on the combination of Dense-graded asphalt concrete pavement (*DGAC*) and Portland cement concrete (*PCC*) pavements (Beranek, 1952).

In the model validation stage, the $L_{A,eq}$ is measured by a digital sound level meter (MODEL *TES 1353H*) licensed by the *ISO* 3746. The measurement speed of sampling was 'slow weighting', which calculated an $L_{A,eq}$ in each second. The receivers were always placed with a height of 1.50 meters, and the octave band was 1/3. Meanwhile, the traffic data of the nearby roads are monitored. On each traffic data sampling, traffic was recorded by a camera, and the numbers of heavy trucks, medium trucks, automobile, buses, and motorcycles were extracted. Sampling was carried out in November and December 2018 at some parts of district 4 of Rasht, and the sampling time ranged from early morning (07 *AM*) to 19 *PM*, which consisted of 12 consecutive hours. A portable *GPS* device has been used to record the location of sampling points. The coordinate system was set on Metric. Since weather parameters such as temperature, humidity and precipitation did not have a significant impact on noise variation; the weather parameters were assumed constant (Lau et al., 2004). The study area's base map is prepared in *Arc-GIS* as a shape file and introduced to the *TNM* model. After that, the roads and the building blocks have been sketched in the *TNM* environment. The constructed map in the *TNM* environment is depicted in Fig. 2.

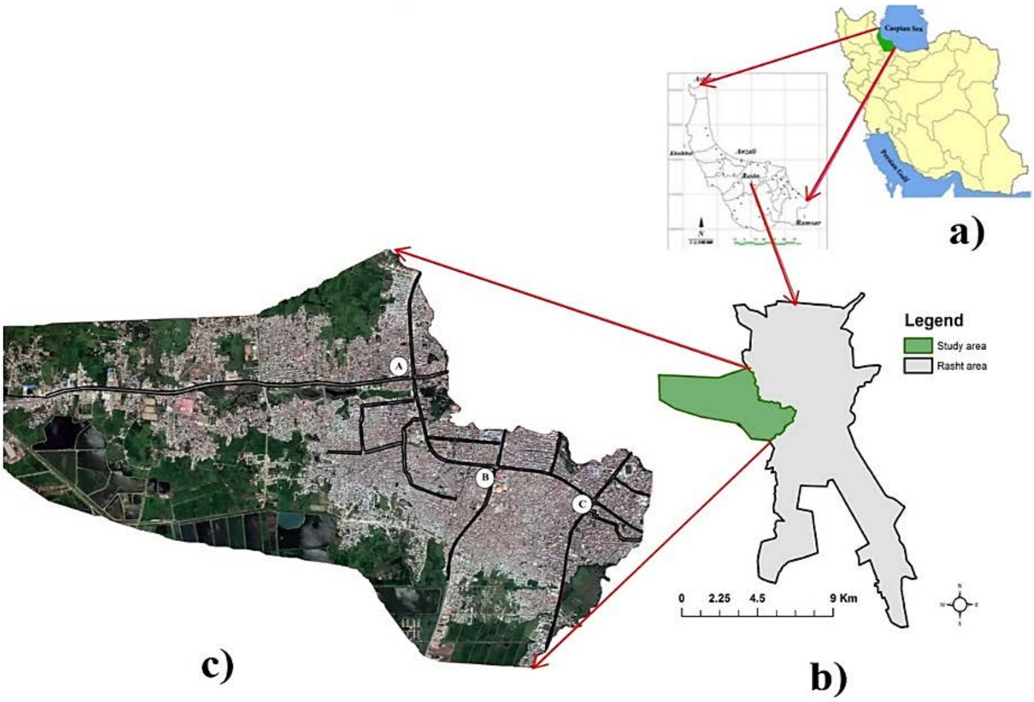

Fig. 1. The schematic map of (a) Iran geographical domain, (b) Rasht city and the study area, (c) Road distribution in the study area

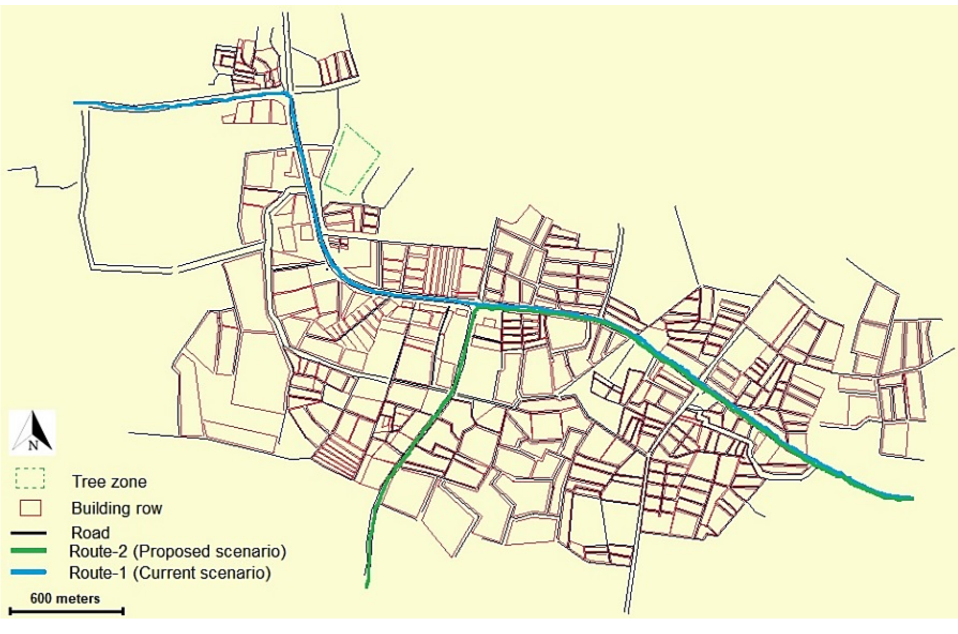

Fig. 2. Roads and building blocks in *TNM* software for some parts of the study area

3. Results and discussion

3.1. Model validation

A-weighted sound level and the traffic data at some points of district *4* of Rasht have been monitored at different times of days November and December simultaneously. In this regard, 25 receptors have been considered, and the $L_{A,eq}$ measured at these receptors in the morning, noon and afternoon during November and December in 2018. It should be noted that the model has been run three times with different pavement types. The measured $L_{A,eq}$, along with the predicted ones by the *TNM* model, are summarized in Table 1.

To assess the most suitable pavement type, the statistical parameter root means square error (*RMSE*) has been calculated for three sets of predicted $L_{A,eq}$ values and the results are reported in Table 2. According to Table 2, the *RMSE* of the predicted $L_{A,eq}$ with *DGAC* pavement is lower than the *RMSE* of other types of pavements. It can be concluded that the *DGAC* pavement is more suitable than other types of pavement in *TNM* for traffic-induced noise prediction in Rasht city. Furthermore, the analysis of variances (*ANOVA*) test with a confidence level of 95% ($\alpha = 0.05$) has been performed in Excel software to statistically analyze the significant difference between the observed and the predicted $L_{A,eq}$. The *ANOVA* test results are also introduced in Table 2.

The *ANOVA* test results show that the null (H_0) hypothesis cannot be rejected for all three modeling data sets. It means that the differences between measured $L_{A,eq}$ and the predicted ones are not statistically significant (all P-values are lower than α). To reveal the accuracy of the modeling results, the quantile-quantile (q-q) plot of measured SPLs versus the predicted ones with *DGAC* pavement is depicted in Fig. 3.

As shown in Fig. 3, the q-q plot also satisfies the accuracy of *TNM* model in predicting the SPLs induced by traffic in Rasht. Although there are some disagreements between the predicted and measured sound levels (Fig. 3), prediction error may be reduced by introducing the building blocks distribution and their elevations accurately. However, it may be a time consuming job and some unwanted disturbances effects on the prediction results cannot be removed.

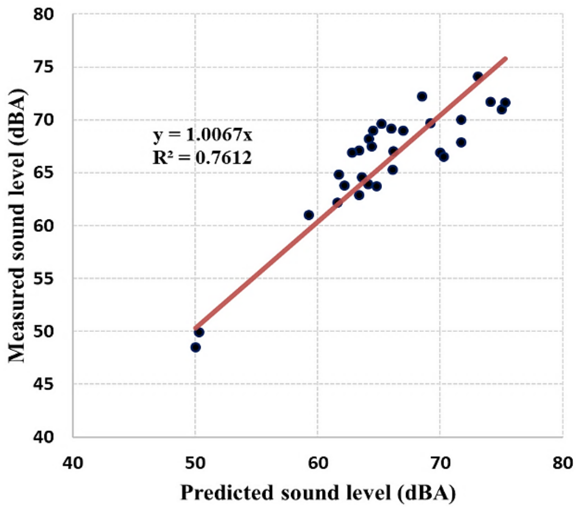

Fig. 3. Quantile-quantile plot of measured and predicted sound levels

Table 1. Observed and predicted $L_{A,eq}$ at receptors

Rec.	*X(m)*	*Y(m)*	*Time*	*Pave*	*Measured $L_{A,eq}$ (dBA)*	*Predicted $L_{A,eq}$ (dBA)*	*Pave*	*Predicted $L_{A,eq}$ (dBA)*	*Pave*	*Predicted $L_{A,eq}$ (dBA)*
1	373031.2	4125253.4	7:00	Average	75	71.5	DGAC	71	PCC	72.2
2	374551.1	4124923.0	7:30	Average	64.1	64.8	DGAC	63.9	PCC	65.5
3	374505.4	4124797.4	8:00	Average	64.8	64.7	DGAC	63.7	PCC	65.9
4	372110	4126379.1	8:30	Average	75.3	72.8	DGAC	71.6	PCC	73.1
5	372159.7	4126383.0	9:00	Average	68.5	70.1	DGAC	72.2	PCC	70.9
6	373213.5	4125168.7	7:00	Average	64.2	66.1	DGAC	68.2	PCC	69.8
7	372266.8	4126366.3	7:30	Average	74.1	70.5	DGAC	71.7	PCC	70.9
8	372411	4125415.6	8:00	Average	71.7	68.3	DGAC	67.9	PCC	68.6
9	372440.2	4125392.1	8:30	Average	70	66.5	DGAC	66.9	PCC	67.2
10	373922.5	4125180.0	9:00	Average	66.1	64	DGAC	65.3	PCC	66.9
11	372440.2	4125392.1	10:45	Average	70.3	66.8	DGAC	66.5	PCC	67.2
12	372730.1	4125371.3	11:00	Average	62.2	67.1	DGAC	63.8	PCC	67.4
13	372856.3	4125269.3	11:30	Average	71.7	69.8	DGAC	70	PCC	70.1
14	372698.4	5125160.8	11:45	Average	63.6	64.1	DGAC	64.6	PCC	65.5
15	374520.6	4124926.7	12:00	Average	63.4	62	DGAC	62.9	PCC	63.8
16	374070.8	4125015.4	12:30	Average	63.4	67.5	DGAC	67.1	PCC	67.9
17	372245.8	4126065.4	12:45	Average	62.8	67.4	DGAC	66.9	PCC	68
18	374655.6	4125059.9	13:00	Average	61.6	61	DGAC	62.2	PCC	62.8
19	373392.6	4125165.0	13:15	Average	64.4	66.6	DGAC	67.5	PCC	68
20	371949.7	4126293.7	13:30	Average	69.2	70.5	DGAC	69.7	PCC	71
21	372302.5	4125872.8	15:00	Average	65.2	70.5	DGAC	69.6	PCC	70.8
22	372358.8	4125627.7	15:30	Average	67	71.8	DGAC	69	PCC	72
23	372754.4	4125225.1	16:00	Average	66	69.8	DGAC	69.2	PCC	69
24	373219.8	4125233	16:30	Average	73.1	74.4	DGAC	74.1	PCC	74.8
25	372906.5	4125179.96	17:00	Average	64.5	69.7	DGAC	69	PCC	66.2

Table 2. Statistical analysis parameters

Pavement	*RMSE*	*ANOVA test parameters*			
		α	*P-value*	*F-critical*	*F*
Average	3.1	0.05	0.56	4.04	0.35
DGAC	2.8	0.05	0.64	4.04	0.22
PCC	3.0	0.05	0.2	4.04	1.65

3.2. Noise level prediction

In the preceding section, the accuracy of the *TNM* in the sound level prediction of traffic in Rasht city has been validated. This section has tried to predict the $L_{A,eq}$ at all Arterials, collectors, and local roads in district 4 of Rasht city. The most critical parameter in *TNM* is the hourly rate of traffic. Road distribution in district 4 of Rasht is depicted in Fig. 1c. Referring to the gathering of traffic data at an annual scale by our research team in the city of Rasht, it was concluded that the traffic load has the same behavior at different months in Rasht except for weekends, holidays and before national holidays in which it was so slightly different; hence, in order to carry out an unbiased traffic sampling, sampling was done on seven random days of a month strategy basis. In Fig. 4.a, the monthly average hourly rate of gathered traffic data for two links in the study area (Links *AB* and *BC* in Fig. 1c) is depicted.

As shown in this figure, the traffic rate is almost the same for different months. Therefore, November's traffic data is applied for *TNM* modeling instead of modeling the whole year *2018*. Furthermore, In *TNM*, hourly data is required. Since the day's traffic rate is not the same for different hours, the hourly distribution of traffic data should be obtained. The traffic data have been gathered on six-time intervals of 06-10 *AM*, 10-14 noon, 14-18 *PM*, 18-22 PM, *22-02* midnight and 02-06 *AM* based on a seven-random-day strategy. It has been assumed that the traffic load is almost constant in each mentioned time interval. As an instance, the temporal distribution of traffic in two sample links of the study area is shown in Fig. 4b.

The required data for *TNM* modeling in each time interval have been introduced into the model, and the $L_{A,eq}$ have been predicted for almost 250 receptors through the study area. Finally, the average hourly $L_{A,eq}$ of 250 receptors have been computed by *TNM* model. Eq. (2) has been used to calculate the daytime or nighttime average $L_{A,eq}$ by using the values of the six-time interval (Oyedepo and Saadu, 2010):

$$L_{A,eq} = 10\log\left(\frac{\sum_{i=1}^{N} t_i \times 10^{SPL_i/10}}{\sum t_i}\right) \qquad (2)$$

where: t_i, SPL_i are time interval *i*, and the equivalent A-weighted sound level at time interval *i*.

In this study, the daily averaged, nighttime averaged, and day-night averaged sound levels have been calculated based on the Iranian national and United States environmental protection agency (US-EPA) standards for noise exposure. To have a comprehensive mapping of the predicted sound levels through the study area, the calculated $L_{A,eq}$ are mapped in the *Arc-GIS* environment and depicted in Figs. 5-7.

According to the Iranian national environmental noise pollution standards, the maximum permitted equivalent noise levels in residential areas are 55 *dBA* at daytime (07 *AM* -10 *PM*) and 45 *dBA* at nighttime (10 *PM* -07 *AM*) (Golmohammadi et al., 2010). Besides, to check the situation of the noise pollution during 24 hours, the EPA recommended day-night noise level (L_{DN}) is also calculated. The L_{DN} is an energy averaged noise level with an extra emphasis (10 *dBA*) on the noise generated from 10 *PM* to 07 *AM* (Barron, 2002). Values of L_{DN} greater than 55 decibels outdoors are identified as preventing activity interference and annoyance. The levels up to 55 decibels are considered those which will permit daily routines (US-EPA, 1974).

According to the daytime $L_{A,eq}$ contour, shown in Fig. 5, the areas with sound levels exceeding 55 *dBA* are mostly concentrated around the ring roads with surrounding residential parts, and briefly, all residential areas at the north-eastern part of the study area suffer from unhealthy noise level at daytime. The nighttime $L_{A,eq}$ contour lines in Fig. 6 show that the $L_{A,eq}$ level has been reduced compared to daytime, but according to the national standards ($L_{A,eq}$ <45 *dBA*), the extent of unhealthy areas at night is greater than the unhealthy regions at daytime. The L_{DN} contour indicates that the main roads experience dangerous sound levels of more than 70 *dBA* through day-night time and in most residential areas at the north-eastern part of the study area, sound levels are between 60 to 70 *dBA*, about 5 to 15 *dB* more than the EPA noise pollution standard.

The L_{DN} value at residential areas in the western parts of district 4 is below the standard limit. Comparing Fig. 5 and Fig. 7 reveals that the unhealthy areas in both situations are almost the same, but in the daytime (Fig. 5), the areas with $L_{A,eq}$ > 60 *dBA* are greater than those in the day-night point of view. Moreover, the unreported results revealed that the averaged $L_{A,eq}$ at the morning time period is much higher than the Iranian daytime noise pollution standard and the EPA standard in comparison with the averaged $L_{A,eq}$ at noon and afternoon periods, meaning that the morning time (between 06-10 *AM*) is the noisiest time interval in the studied area. To calculate the contribution of different types of vehicle in total noise emitted from the traffic during morning rush hours, the sound level of different vehicle types at some selected receptors are calculated throughout the study area.

The averaged energy-based relative contribution of automobiles, medium trucks, heavy trucks and buses are 0.45, 0.20, 0.22 and 0.13, respectively. However, the motorcycles' average contribution can be ignored. Due to the high traffic of automobiles, their role in noise emission is greater than other cars. But the limiting issue in noise emission control is heavy trucks' traffic. Because their number is much less in transit routes and their traffic can be controlled and directed to outer ring roads or limited access roads. In this regards, the effect of redirecting buses and heavy trucks' traffic from route-1 (current scenario) to route-2 (proposed scenario) in Fig. 2 is examined. This restriction is applied as a control strategy in *TNM* and the new L_{DN} contours have been depicted in Fig. 8.

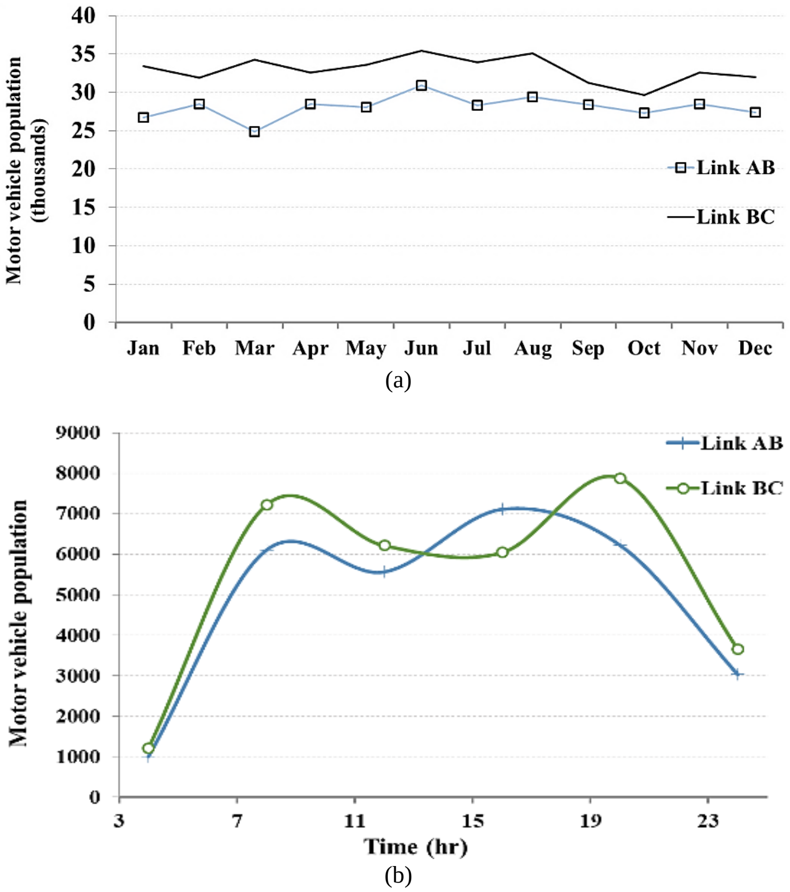

Fig. 4. (a) Temporal variation of hourly motor vehicle population during the calendar year 2018 (b) hourly change of the traffic during a sample day in October at two links

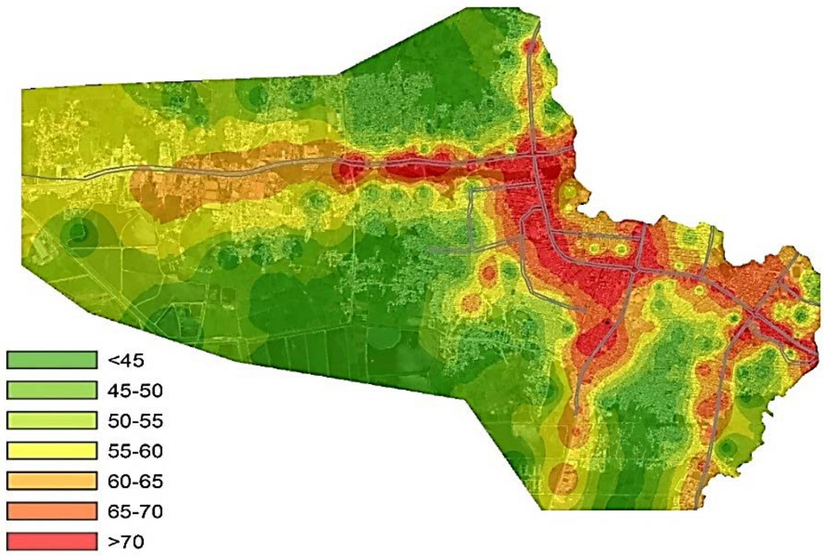

Fig. 5. Daily-averaged predicted $L_{A,eq}$ throughout the district 4 of Rasht

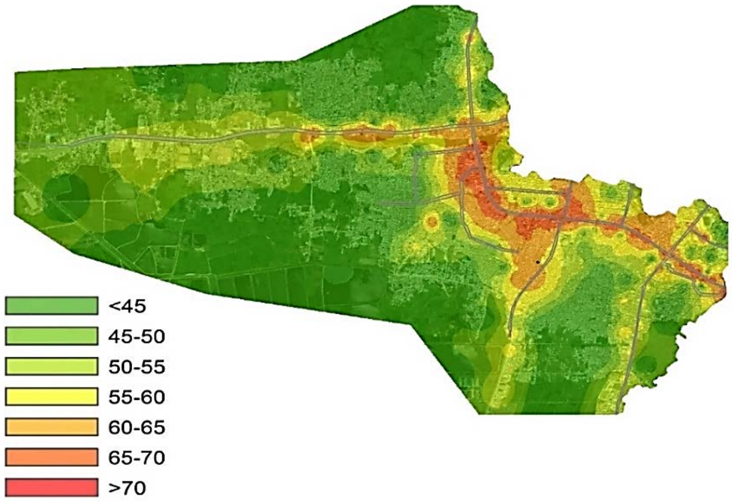

Fig. 6. Nighttime-averaged predicted $L_{A,eq}$ throughout the district 4 of Rasht

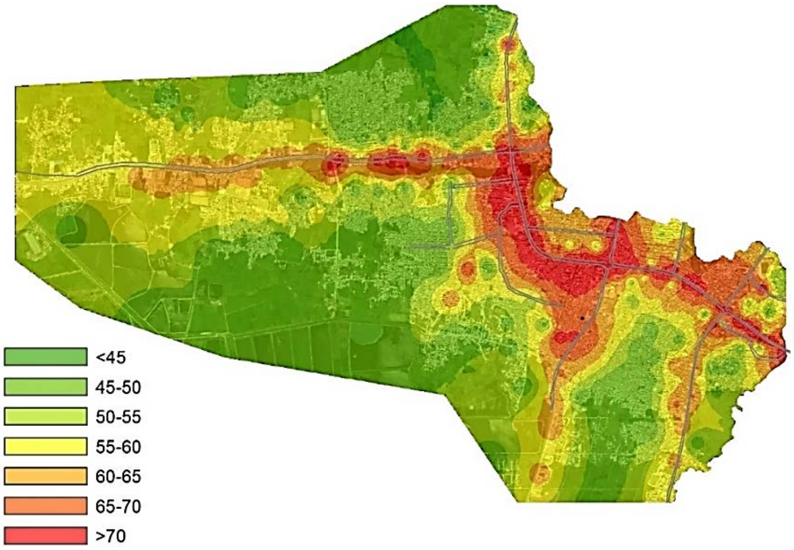

Fig. 7. Day-Night averaged of the predicted $L_{A,eq}$ throughout district 4 of Rasht

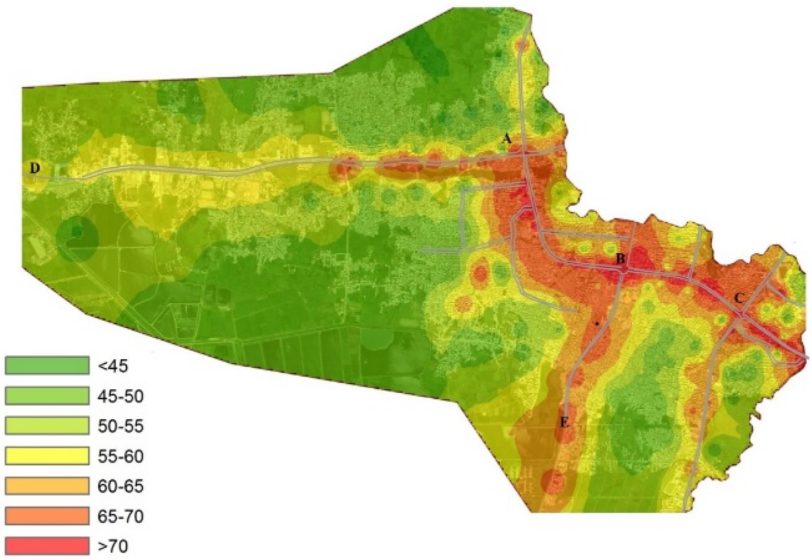

Fig. 8. Predicted L_{DN} throughout district 4 of Rasht for the proposed traffic scenario

According to the calculated sound levels which are not reported in the text, the L_{DN} values have been reduced almost 2.5 *dBA* in the north-eastern part of the studied area. As shown in Fig. 7 and Fig. 8, the unhealthy residential areas between points A and B are reduced by applying the proposed traffic restriction, where the areas with L_{DN} greater than 70 *dBA* have been almost disappeared. Meanwhile, the L_{DN} values have been increased around the B-E path due to the new traffic restriction. Since the population density around B-E path is much lower than the A-B and A-E path, the health effect of the proposed scenario is reduced noticeably.

4. Conclusions

It has been concluded that the *TNM* model is successful in evaluating and predicting the noise levels accurately in the study area. It is also demonstrated that the district 4 of Rasht is highly polluted due to the increasing number of transportation vehicles. According to the national and international standards, most residential areas (especially in north-eastern parts) in district 4 have $L_{A,eq}$ at least 5 *dBA* more than the permitted limits. As a result, noise mitigation plans are required to mitigate the noise problem regarding that the main roads of the studied areas are adjacent to populated residential spots.

A new traffic route is proposed for heavy trucks and buses to mitigate the noise level at the most polluted part of the study area with high population density. By redirecting the heavy vehicles traffic to the proposed route (route-2), the L_{DN} values in the residential areas around A-B path (the most polluted area in the current scenario) has been reduced below 70 *dBA*. It is highly recommended that urban management of Rasht city implements more useful plans to address the traffic-induced noise problems. Also, replacing the flashlights with the traffic lights at major intersections can have safer road traffic and reduce irregularities' noise.

Other control methods such as installing acoustic barriers, asphalt pavement improvement, and reducing the traffic congestion may be used to reduce the health effects of noise on residents.

References

Barron R.F., (2002), Industrial noise control and acoustics, *CRC Press*.

Barry T.M., Reagan J.A., (1978), FHWA highway traffic noise prediction model.

Basner M., Babisch W., Davis A., Brink M., Clark C., Janssen S., Stansfeld S., (2014), Auditory and non-auditory effects of noise on health, *The Lancet*, **383**, 1325-1332.

Beranek B., (1952), *Handbook of Acoustic Noise Control*, Wright Air Development Center.

Cannelli G.B., Glück K., Santoboni S., (1983), A mathematical model for evaluation and prediction of the mean energy level of traffic noise in Italian towns, *Acta Acustica United with Acustica*, **53**, 31-36.

Ece M., Tosun İ., Ekinci K., Yalçındağ N.S., (2018), Modeling of road traffic noise and traffic flow measures to reduce noise exposure in Antalya metropolitan municipality, *Journal of Environmental Health Science and Engineering*, **16**, 1-10.

Ehrampoush M.H., Halvani G.H., Barkhordari A., Zare M., (2012), Noise pollution in urban environments: a study in Yazd City, Iran, *Polish Journal of Environmental Studies*, **21**, 1095-1100.

Foroutan Z., (2018), Evaluation of the distribution of urban landscapes (Case Study: Rasht City), *Specialty Journal of Geographical and Environmental Science*, **2**, 13-26.

Golmohammadi R., Ghorbani F., Mahjub H., Daneshmehr Z., (2010), Study of school noise in the capital city of Tehran-Iran, *Iranian Journal of Environmental Health Science and Engineering*, **7**, 365-370.

GPSIS, (2018), Management and planning organization of Guilan Province. Statistical information system of Guilan province, Guilan Province Statistical Information System (in Persian).

Hankard M., Cerjan J., Leasure J., (2006), Evaluation of the FHWA traffic noise model (*TNM*) for highway traffic noise prediction in the state of Colorado, Report No. CDOT-2005-21, Colorado Department of Transportation, Research Branch, On line at: https://www.codot.gov/programs/research/pdfs/2005/tnm.pdf

Hempton G., Grossmann J., (2009), *One Square Inch of Silence: One Man's Quest to Preserve Quiet*, Free Press/Simon & Schuster, New York City.

Heutschi K., (2004), SonRoad: New Swiss road traffic noise model, *Acta Acustica united with Acustica*, **90**, 548-554.

Hastings A.L., (2019), Traffic Noise Model 3.0: Technical Manual (No. FHWA-HEP-20-012), United States. Federal Highway Administration.

Jain R.K., Cui Z., Domen J.K., (2016), *Chapter 4-Environmental Impact of Mining*, In: *Environmental Impact of Mining and Mineral Processing: Management, Monitoring, and Auditing Strategies*, Butterworth-Heinemann, Oxford, UK.

Jamrah A., Al-Omari A., Sharabi R., (2006), Evaluation of traffic noise pollution in Amman, Jordan, *Environmental Monitoring and Assessment*, **120**, 499-525.

Kim J., Shu N., Koo D.D., (2011), Noise impact analysis using the traffic noise model (TNM) comparing different pavement types–average vs. ARFC, On line at: http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=5B27ACB5382031DE55B7EEFFA37A6700?doi=10.1.1.685.5943&rep=rep1&type=pdf

Lau M.C., Lee C.S., Rochat J.L., Boeker E.R., Fleming G.G., (2004), FHWA Traffic Noise Model user's guide. (version 2.5 addendum).

Mehravaran H., Zabani S., Nabi B.G.R., Ghousi R., Keshavarzi S.H., (2011), Noise pollution evaluation method for identification of the critical zones in Tehran, *International Journal of Environmental Research*, **5**, 233-240.

Menge C.W., Anderson, G.S., Barrett D.E., (2001), Experiences with USDOT'S traffic noise model (TNM), *Inter-noise 2001-Abstracts from International Congress and Exhibition on Noise Control Engineering*, On line at: https://trid.trb.org/view/722331

Mohammadi G., (2009), *An Investigation of Community Response to Urban Traffic Noise*, In: *Global*

Perspective for Competitive Enterprise, Economy And Ecology, Springer, London.

Morillas J.M.B., Gozalo G.R., González D.M., Moraga P.A., Vílchez-Gómez R., (2018), Noise pollution and urban planning, *Current Pollution Reports*, **4**, 208-219.

Oyedepo O.S., Saadu A.A., (2010), Evaluation and analysis of noise levels in Ilorin metropolis, Nigeria, *Environmental Monitoring and Assessment*, **160**, 563-577.

Quartieri J., Mastorakis N.E., Iannone G., Guarnaccia C., D'ambrosio S., Troisi A., Lenza T.L.L., (2009), A review of traffic noise predictive models. Recent advances in applied and theoretical mechanics, *5th WSEAS International Conference on Applied and Theoretical Mechanics (MECHANICS'09*), Puerto De La Cruz, Tenerife, Canary Islands, Spain December, 14-16.

Rahimi Moghadam S., Tizabi L., Naser M., Khanjani N., Emkani M., Taghavi Manesh V., Mohammadi A.A., Delkhosh M.B., Najafi H., (2018), Noise pollution and sleep disturbance among Neyshabur Hospital staff, Iran, *Journal of Occupational Health and Epidemiology*, **7**, 53-64.

Shalini K., Kumar B., (2018), Development of traffic noise model (*TNM*) using regression analysis in Varanasi city, India, *International Journal of Civil Engineering and Technology*, **9**, 70-76.

Sordello R., De Lachapelle F.F., Livoreil B., Vanpeene S., (2019), Evidence of the environmental impact of noise pollution on biodiversity: a systematic map protocol, *Environmental Evidence*, **8**, 8-14.

Sørensen M., Wendelboe Nielsen O., Sajadieh A., Ketzel M., Tjønneland A., Overvad K., Raaschou-Nielsen O., (2017), Long-term exposure to road traffic noise and nitrogen dioxide and risk of heart failure: a cohort study, *Environmental Health Perspectives*, **125**, 1-8.

Tachibana H., (2000), Road traffic noise prediction model "ASJ MODEL-1998" proposed by the acoustical society of Japan-Part 1: Its structure and the flow of calculation, *Proceeding of Inter-Noise*, 3075-3080.

US-EPA, (1974), Information on levels of environmental noise requisite to protect public health and welfare with an adequate margin of safety, Supt. of Docs., US Govt. Print. Off. 74 (4), United States Office of Noise Abatement and Control,

Warren PS., Katti M., Ermann M., Brazel A., (2006), Urban bioacoustics: it's not just noise, *Animal Behaviour*, **71**, 491-502.

Wu J., Zou C., He S., Sun X., Wang X., Yan Q., (2019), Traffic noise exposure of high-rise residential buildings in urban area, *Environmental Science and Pollution Research*, **26**, 8502-8515.

Yang W.T., Wang V.S., Chang L.T., Chuang K.J., Chuang H.C., Liu C.S., Bao B.Y., Chang T.Y., (2018), Road traffic noise, air pollutants, and the prevalence of cardiovascular disease in Taichung, Taiwan, *International Journal of Environmental Research and Public Health*, **15**, 1707-1717.

Zhu L., Li X., Jiang C., Liu L., Wu R., Wang W., Zhang, B., (2015), Rapid modeling method for road traffic noise sources: A case study in Beijing, *Noise Mapping*, **2**, 31-39.