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Effect of cycling development as a non-motorized transport on reducing air and noise pollution-case study: Central districts of Tehran

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ABSTRACT

The aim of this study was to investigate the possible reduction of air and noise pollution due to the substituent of motorcycles and personal vehicles with bicycles by the theoretical phase and to compare the exposure of a cyclist to noise pollution in using different modes of transportation in the field phase. In the theoretical phase, different scenarios were designed based on a 25% and 50% reduction in the volume of motorcycles and personal vehicles separately, as well as a simultaneous reduction of 50% for motorcycles and personal vehicles. The effect of running these scenarios on reducing air pollution was investigated using emission inventory model and on noise pollution by CadnaA software according to DIN 45687 and ISO 17534 Series. In the field phase, the exposure of a cyclist to noise pollution in the use of different modes of transportation was investigated in two main and secondary routes based on the weighted-time average method. Considering the 64% share of passenger cars in the total volume of motor vehicle traffic in Tehran, the highest noise reduction is expected to occur in the scenario of 50% replacement of private cars with bicycles under which, the average sound level near the main thoroughfares and highways will decrease by 1.8 dBA and $PM_{2.5}$ and NO_2 emissions by about 11 and 1196 t/y, respectively. According to the field investigations, noise levels for motorcyclists, cyclists, drivers, and public transport passengers were far higher than for car drivers, which may be attributed to the loud background noise and lack of a control system such as a proper cabin. By replacing cars and motorcycles with bicycles, air and noise pollution will definitely be reduced and cyclists will be less exposed to pollution. Accordingly, exposure to air and noise contaminants should be considered as effective decision-making criteria when locating bicycle lanes.

1. Introduction

The use of bicycles, as one of the modes of public transport, is expanding in many cities in North America, Canada, and Europe.

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Tehran and other metropolitan cities of Iran, with a vast and complex network of roads and highways and heavy traffic loads, have recently begun to build and develop cycling infrastructure. Tehran also has a relatively advanced Public Bike Share (PBS) scheme. Despite the growing popularity of the scheme, the share of cycling in the total volume of traffic in the city is still very low. According to the Tehran Transport and Traffic Organization (TTTO), out of 20.3 million trips per day, only 0.3% is made by bicycle (TTTO, 2017).

Urban planners are increasingly pushing for the use of bicycles, the expansion of bicycle networks in cities, and the launch of PBS projects (Buehler and Pucher, 2012). There is now a debate about the benefits of cycling on the health and well-being of people in urban areas. Cycling allows people to increase their level of physical activity and improve their cardiovascular fitness (Oja et al., 1998). It also helps improve quality of life by reducing the risk of chronic diseases (diabetes, cardiovascular disease, and certain types of cancer), overweight, and obesity (Bassett et al., 2008), as well as increasing mental health (Daley, 2008).

Despite these benefits, cycling in the city center on shared routes with motor vehicles or cycling lanes may pose some health and safety hazards due to the exposure to air and noise pollution and severe traffic congestion on the streets (De Hartog et al., 2010). Numerous studies have been conducted on the exposure of cyclists to air pollutants. There is conflicting evidence about the exposure of people who use bicycles compared to those use other modes of transportation. In the cycling mode, despite the increase in physical activity, the risk of health outcomes also increases due to the close exposure to traffic (Park et al., 2017). Many studies have linked health outcomes such as hypertension, infarction, and deaths from cardiovascular disorders to the exposure to traffic noise (Beelen et al., 2009; De Kluizenaar et al., 2007; Peters et al., 2004).

Guariso and Malvestiti (2017) in Milan, Italy, analyzed and compared the outputs of the Health Economic Assessment Tool (HEAT) model for cycling and PM_{10} inhalation (RR model) and showed that the benefits of using bicycle are far greater than its potential damage in all scenarios (change in travel time, working days, age group 20 to 64, etc.).

Cyclists are just as physically at risk as pedestrians, so the chance of injury and death among them is higher than those using public transport (Elvik, 2009; Pucher and Dijkstra, 2003). In the city of Boston, the effect of proximity to the street on cyclists' NO_2 and black carbon (BC) intake was examined. The amount of NO_2 and BC measured in the bike lanes (attached to vehicle traffic) was 33% higher than the bike path (away from traffic; MacNaughton et al., 2014).

Another research, by measuring UFP (Ultrafine Particle) and BC along 450 km of Montreal-Canada streets showed that the emission concentration had the strongest relationship with the type of streets (main and secondary; Farrell et al., 2015).

In another study conducted in Toronto in 2018, the average personal exposure to UFP, BC, and LAeq along the different bike paths was 23.487 part/cm^3, 1754 g/m^3, and 72.7 dBA, respectively (Mineta et al., 2018).

Cycling has positive effects on the environment of urban areas and promoting the use of bicycles significantly reduces air and noise pollution (Hatzopoulou et al., 2013; Rojas-Rueda et al., 2011).

In a study by Apparicioa et al. (2016) in Montreal, Canada, it was found that cyclists in the central suburbs were exposed to noise level of about 54.6 to 87.6 dBA during the trip, which is much higher than the daytime permissible limit of 55 dBA recommended by World Health Organization (WHO). The study also showed that the cyclists were exposed to an average NO_2 level of 76 μg/m^3 in the routes, which was less than the WHO recommends for hourly NO_2 exposure (200 μg/m^3). Apparicioa et al., 2018in a research showed that noise exposure was significantly higher for public transport passengers and cyclists than for car drivers. Although the amount of NO_2 exposure was not much different between the three modes of transport, the inhaled doses of NO_2 were three times higher for cyclists than for car drivers. Air and noise pollution in recent years have become one of the most important problems in the city of Tehran (Hosseini and Shahbazi, 2016). According to air quality assessment reports, various types of

particulate matter (MP), especially those with a diameter less than 2.5 μm ($PM_{2.5}$) have been assigned as criteria pollutants for more than 85% of the days in Tehran during the years 2014–2018 (Torbatian et al., 2020). Motor vehicles are the most important sources of air and noise pollution in large cities (Shahbazi et al., 2016a, 2016b; Tobías et al., 2015), the control of which is one of the priorities of modern life today.

Replacing some modes of motor transportation with bicycles will not only increase the physical activity of the community and reduce the consumption of fossil fuels, but also reduce air (Shahbazi et al., 2019a, 2019b) and noise pollution, which are the most important environmental problems of large and densely populated cities.

According to car registration information, 6,232,861 vehicles were registered by the end of 2017, of which passenger cars and motorcycles, with 3,434,868 and 2,410,019 units, accounted for the highest shares, respectively (Traffic Police, 2017). Based on the TTTO statistics, the share of personal vehicles and motorcycles in the morning traffic peak hours is 73.5% and 10.8%, respectively (TTTO, 2020).

As reported by Tehran Air Quality Control Company (AQCC), motorcycles with a noise emission of about 83 dBA have a share of 49% in noise pollution of Tehran City, followed by passenger cars with a share of 30% (AQCC, 2017).

In terms of air pollution, according to car registration data, 80% of motorcycles had Euro-I and earlier air pollution standards. The fuel system in 99.3% of the motorcycle fleet is carburetor and 0.7% is injector. The number of hybrid and electric motors is less than 700 units. According to the vehicle age standard in Iran, 63.5% of the motorcycle fleet is worn out and motorcycles have the largest share of worn-out vehicles in the transport fleet. It should be noted that 37.8% of private cars have Euro III emission standard certificate. Carburetor and injector fuel systems account for 5.8% and 94.2% of all vehicles, respectively. These statistics highlight the importance of paying attention to the replacement of personal vehicles and motorcycles with bicycles in the form of different scenarios.

Currently, due to the low capacity of the public transport fleet in Tehran, many people use private vehicles. In addition, due to heavy traffic on the roads and traffic restrictions imposed in the central districts of the city (traffic plan), motorcycles are used for most intercity trips. Also, the use of motorcycles is very common for courier services (e.g. delivery of food or goods), especially in the central parts of the city where the main city market is located (District 12).

Therefore, replacing vehicles with bicycles on short distances can make a significant contribution to reducing noise and air emissions. To analyze the costs and benefits, the modeling technique was used. Controlling pollution at source has always been considered as one of the important environmental pollution mitigation strategies.

As the literature reviews show, although most recent studies have examined the impact of biking on exposure to air and noise emissions, the role of "promoting" the use of bicycle in reducing air and noise pollution has not been studied, seriously. This study is the first in Iran to investigate this issue. The study focuses on the extent to which replacing a personal car and motorcycle with a bicycle can reduce air and noise pollution. The use of scenario building and comparison of the effect of source control in reducing air and noise pollution is one of the innovations of this research compared to other previous studies. In general, the main objectives of this research can be summarized in two cases: 1) Determining the level of exposure to air and noise pollution during the use of different modes of transportation, 2) Investigating the impact of replacing personal cars and motorcycles with bicycles on reducing air and noise pollution under different scenarios by the use of modeling and simulation techniques. For this purpose, the metropolis of Tehran as the most crowded and polluted city of Iran was selected.

2. Material and methods

2.1. Study area

The metropolitan city of Tehran, as the capital of Iran, has 22 districts and with an area of more than 700 km^2 has a population of about 8.7 million people. Tehran is the 24th most populous city in the world and the second in the Middle East (Torbatian et al., 2020). The length of highways in the city is 900 km and the number of urban trips during the day is about 20.3 million trips (TTTO, 2017). Although the use of bicycles in a city like Tehran with a large area and steep slopes in some districts alone cannot be a substitute for motor transportation; however, it can be a very efficient means of communication between the origin and public transport networks such as metro and BRT (Bus Rapid Transit). Tehran Municipality has developed a shared bicycle scheme with priority in the central crowded districts (6, 7, 11, and 12). Accordingly, the scope of this study was limited to the districts where the project is being implemented (see Fig. 1).

2.2. Field investigation

2.2.1. Measurement of noise exposures based on the weighted-temporal average method in one of the passages of the study area

First, two routes were selected to compare noise exposure in the use of bicycles and other modes of transport. Main route: The main

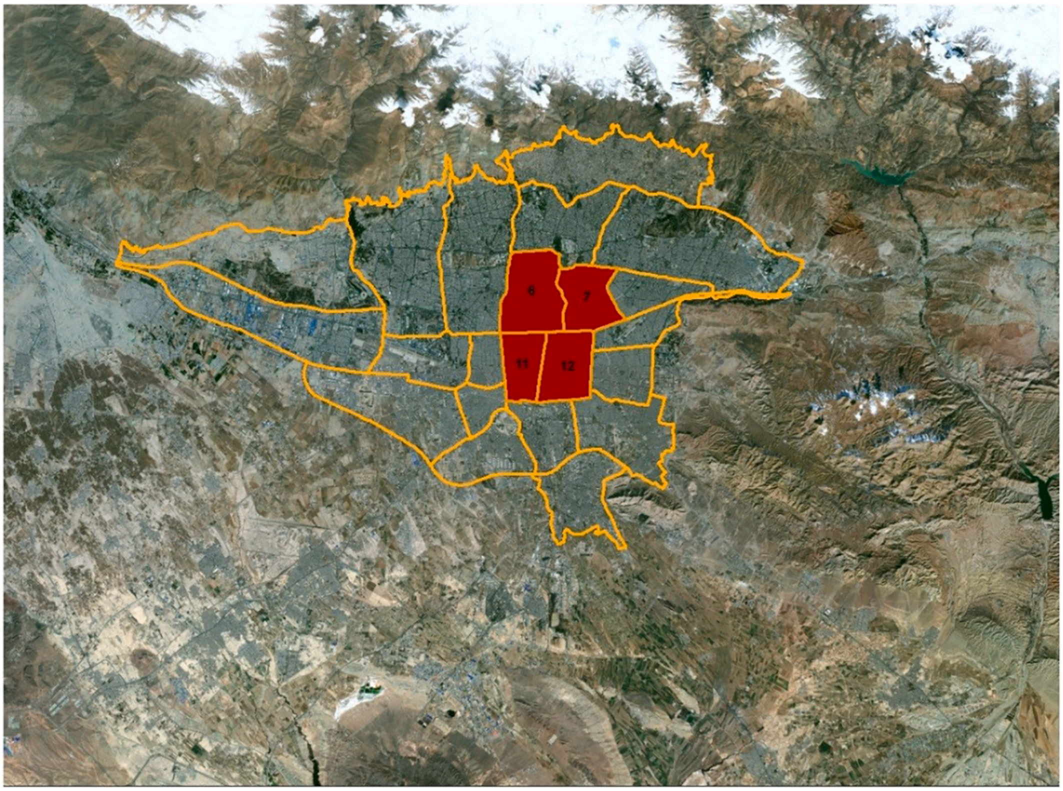

Fig. 1. Target districts of Tehran Municipality for the development of cycling.

route was between Districts 8 and 7 of Tehran Municipality, stretching from Resalat Square (origin) to Ali Akbari Street (destination) with a length of approximately 5.30 km. This is the route that all measurements were taken due to the access to all modes of transport in a single route (see Fig. 2). b) Side route: To compare the cyclist's exposure on side and main roads, another low-traffic route was selected with the same origin and destination crossing alleys and passages parallel to the main route, which was approximately 5.71 km in length. The cycling route on the main and side streets is shown in Fig. 3. Inevitably, in some parts of the route, the main and secondary passages overlapped and it was not possible to choose an alternative route. The average sound level along the route was measured by B&K Portable Sound Level Meter, model 2250, calibrated by a calibrator, model 4231. The measurements were taken in the morning at peak hours in the morning (6,50) on working days in different modes of transportation such as bicycles, cars, buses and motorcycles. Rubber was used to prevent the transmission of vibration to the sound level meter while moving (see Fig. 4).

To increase the accuracy and reduce the effect of impact sounds, instead of sound pressure level (SPL), the equivalent continuous sound pressure level, LAeq, was measured in one-minute intervals. Since the goal was to evaluate spatially the route in terms of the level of sound exposure, taking a time interval of longer than one minute would also cause the loss of location points. When cycling along the route, attempts were made to pass through smooth and unobstructed places. The placement of the device in different modes of transport was as similar as possible and at the height of human ear.

The bicycle used in this study was an electric gear shift bike (with a rechargeable battery). Also, Peugeot 405 (model 2013), carburetor motorcycle CC125 model 2010, and Shahab SLF bus were other transport modes used in this study. The vehicles all had a valid technical inspection certificate and were without any technical problems. Attempts were made to do the measurements in the same traffic conditions. There are 5 traffic lights and 10 bus stops on the selected route. Despite the high variety of motorcycles, efforts were made to select the most widely used and high-frequency type in the transport fleet. The measurements were done in May and June 2020 under relatively stable weather conditions (no precipitation, wind speed less than 2 m/s). While capturing sound levels by a portable sound level meter, "geographical coordinates", "maximum speed", "average speed", and "mileage" were also recorded by GPS Essentials App. (2020 updated version) installable on android systems. To coordinate the points recorded in the GPS with the outputs of the sound meter, the GPS tracking unit was also set to one minute. To coordinate the GPS recorded points with the output of the sound level meter, the time interval of the GPS device was also set to one minute. Accordingly, the coordinate of points and average sound level were recorded along the route every 1 min.

2.2.2. Measurement of PM2.5 by a fixed-site air quality monitoring station

Due to the lack of access to portable measuring instruments for direct measurement of air pollutants along the route, the results of a fixed air monitoring station, namely Setad Bohran (in District 7 of Tehran) were used. The location of this station relative to the selected route is shown in Fig. 5. At this station, the concentration of $PM_{2.5}$ (as the most important air pollutant in Tehran) was

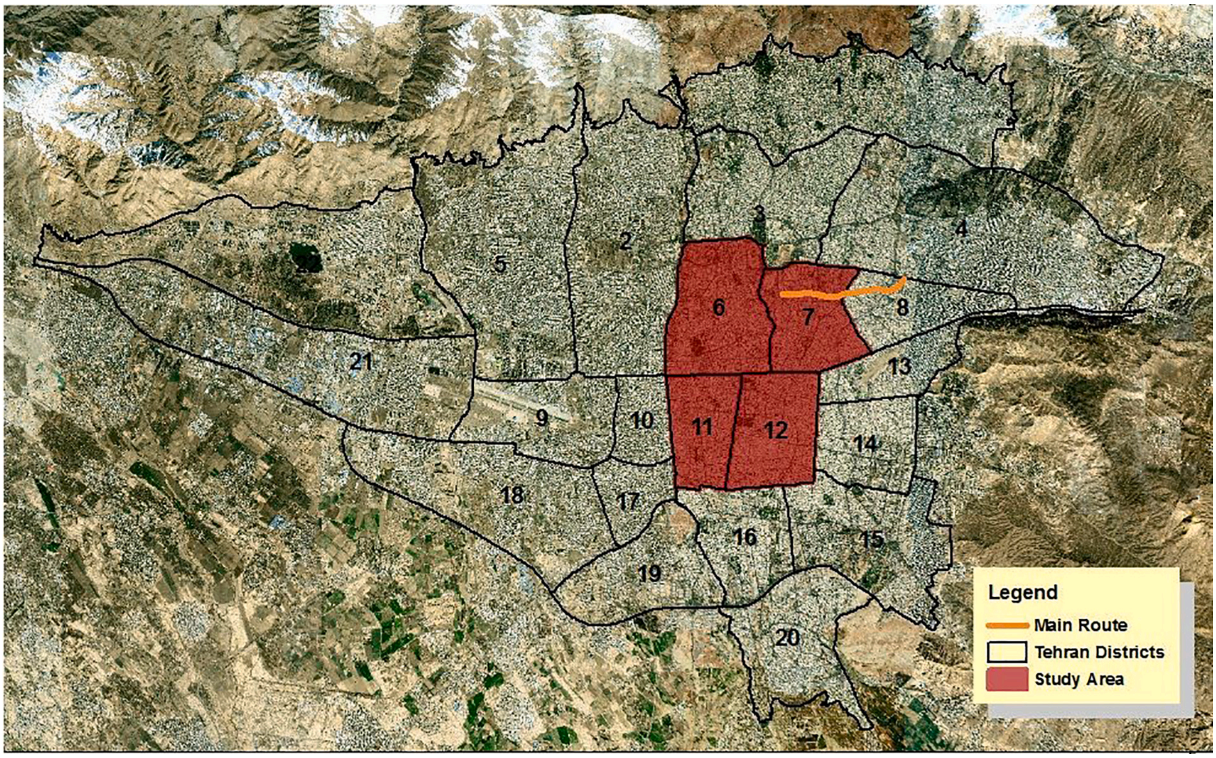

Fig. 2. Location of the route under study.

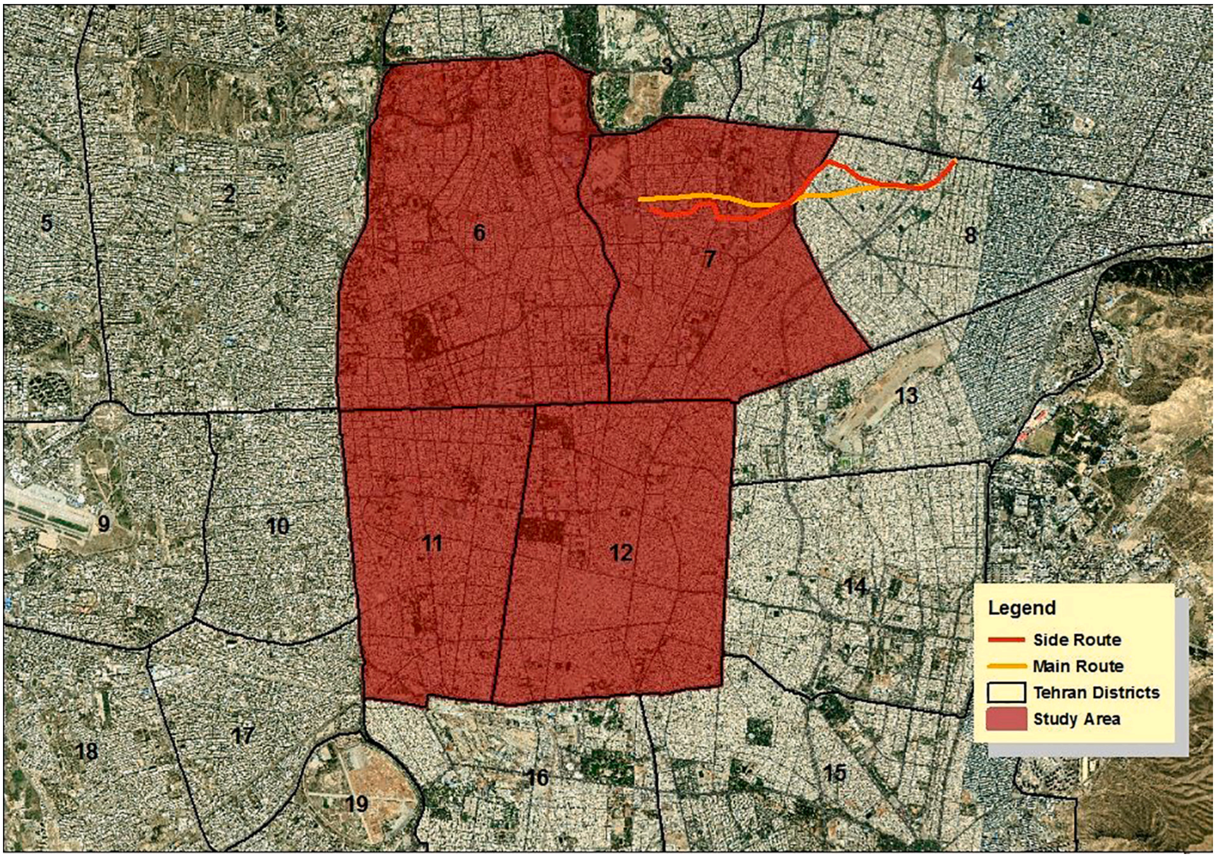

Fig. 3. Bicycle lane through the main and side crossings on the map.

Fig. 4. Portable sound level meter, B&k 2250 model.

examined on the same days that noise pollution was measured. According to the standard of the Iran Ministry of Health and Medical Education, $PM_{2.5}$ permissible limit is 35 $\mu g/m^3$ per day.

2.3. Modeling approach

2.3.1. Noise pollution theory

After examining the current situation and direct measurements, the effect of cycling development on reducing noise pollution was investigated. First, different scenarios were defined based on the reduction of the share of motorcycles and personal vehicles in the transport fleet. These scenarios include a 25% and 50% reduction in the volume of motorcycles and personal vehicles separately, as well as a 50% simultaneous reduction in motorcycle and personal vehicles. The reason for choosing the above scenarios is the

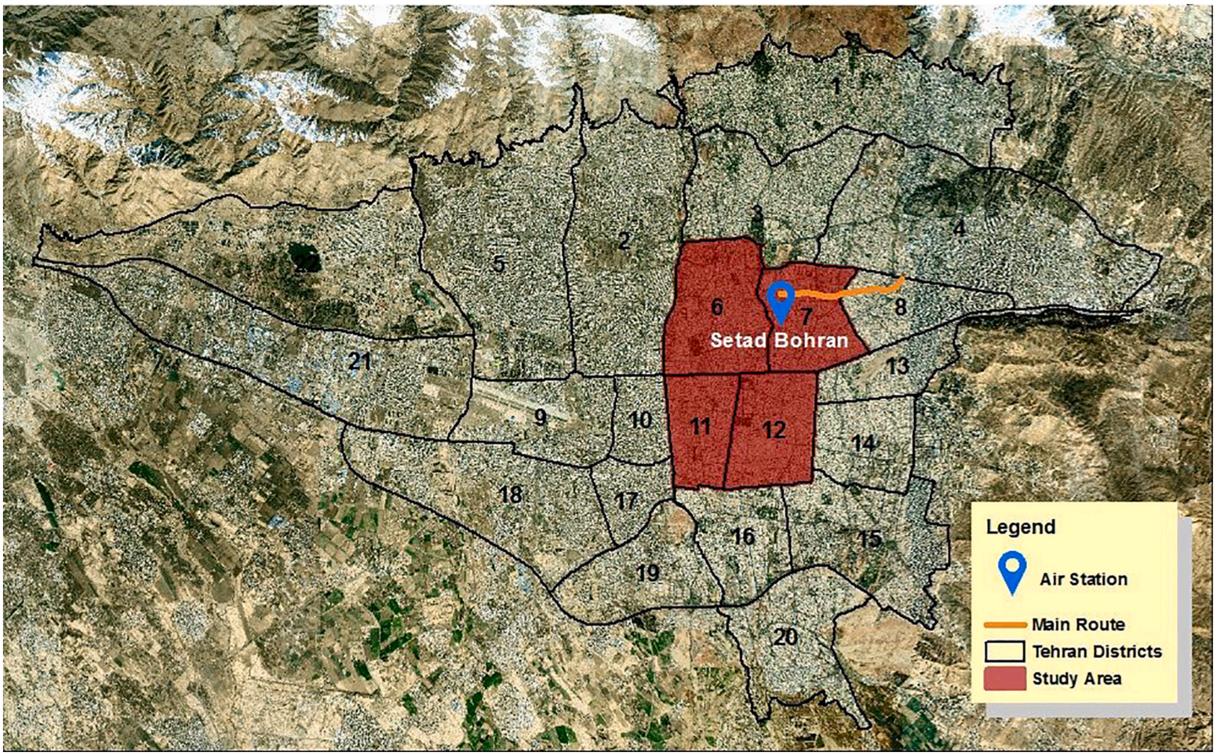

Fig. 5. Position of the fixed air monitoring station relative to the main route.

assumption that source control is effective in reducing noise pollution. Studies have shown that if the volume of motor vehicles is reduced by half, the sound level is reduced by only about 3 dBA (Bendtsen et al., 1998).

The selected scenarios, although not possible in reality, were defined to show the effect of reducing the number of vehicles on reducing noise pollution. To model noise pollution, the specialized software of CadnaA 2017 (Computer Aided Noise Abatement) was used, which is run under DIN 45687 and ISO 17534. As recommended in the software instruction, only the traffic data of one day as a representative of the whole year (DTV: Durchschnittlicher täglicher Verkehr a German abbreviation for Average daily traffic) was used. The premise behind this is that, the average sound level of different days does not differ significantly (AQCC, 2017). Based on different scenarios, the intended changes were applied in the 2017 traffic data (as the latest available traffic data) of the RLS90 traffic model and together with other inputs (topography, buildings, and vegetation cover) were imported to the modeling software. The traffic model was originated from to Germany and the reason for choosing the model was the similarity of its format with the traffic data of Iran. The traffic volume data included the number and speed of vehicles, their distribution during the day and night, and the percentage of heavy vehicles during the day and night. To validate the model outputs, the modeled average sound levels were compared with direct sound measurements at the fixed noise monitoring stations (see Fig. 6).

Since road traffic was supposed to be the only source of noise emission in the model, the receivers were positioned at a distance of 20 m from each other and 20 m from the edge of the main thoroughfares and highways, at a height of 1.5 m from the road surface (at height of the human ear). Then, the average sound level at the receiver points (42,667 receivers) was calculated before and after runningthe scenarios. The modeling was done only for the daytime period (7 am to 10 pm) because bicycles are not usually used beyond this period.

2.3.2. Air pollution modeling

To investigate the impact of cycling development, 5 scenarios of replacing personal cars and gasoline motorcycles with bicycles were considered and the amount of reduction of air pollutants due to the implementation of each scenario was examined. Accordingly, the effectiveness of each of the following scenarios was examined, separately:

1. Reduction of 25% of passenger car traffic in the target district by replacing urban trips with bicycles
2. Reduction of 50% of passenger car traffic in the target district by replacing urban trips with bicycles
3. Reduction of 25% of gasoline motorcycle traffic in the target district by replacing urban trips with bicycles
4. Reduction of 50% of gasoline motorcycle traffic in the target district by replacing urban trips with bicycles
5. Simultaneous reduction of 25% of passenger car and gasoline motorcycle traffic in the target district and replacement of urban trips with bicycle

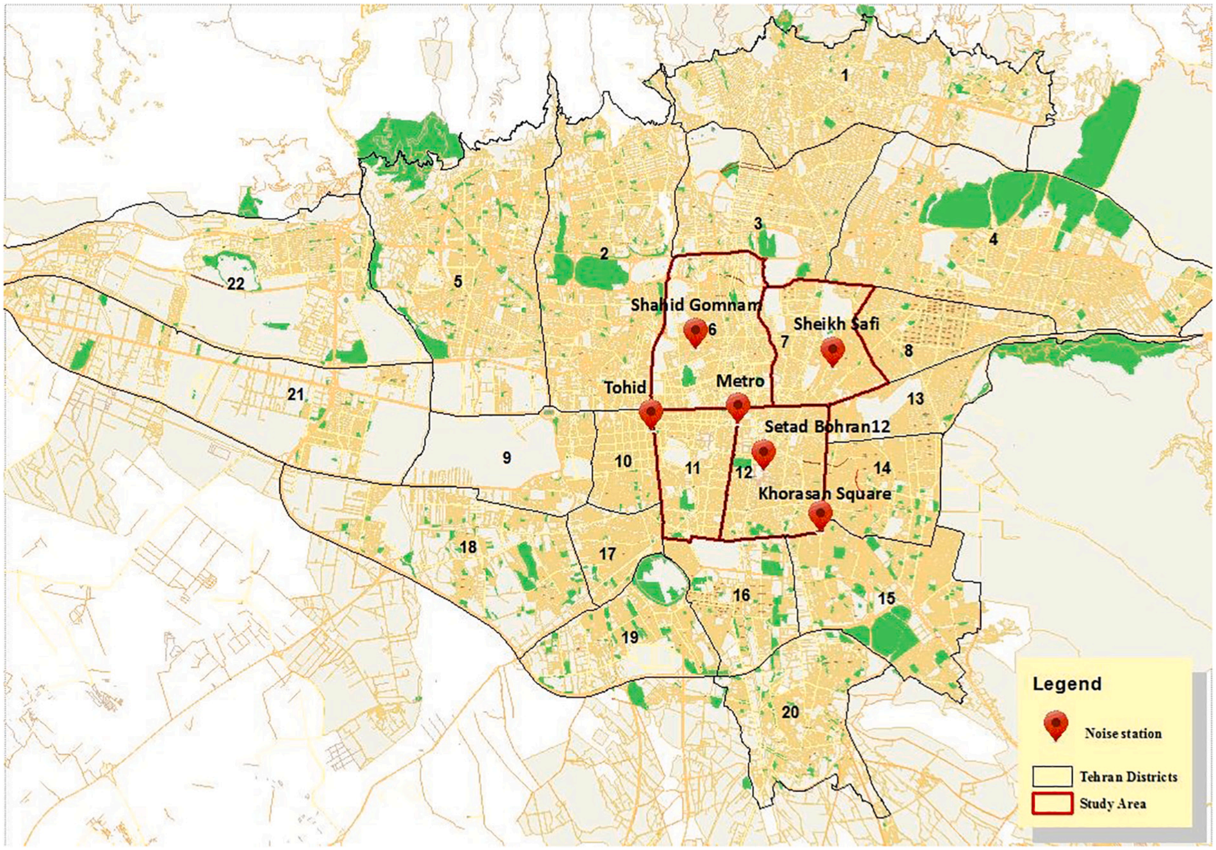

Fig. 6. Location of the noise monitoring stations in the target districts, Tehran.

Emission inventory method was used to calculate the effect of implementing these scenarios in reducing air pollution emissions in Tehran. The city pollution rate of was calculated separately for gaseous pollutants and suspended particles during 2017. The calculation method was the same method used by Shahbazi et al. to develop Tehran mobile source emission inventory.

Based on the latest emission inventory of Tehran (Shahbazi et al., 2016a, 2016b), vehicles (as the main source of emissions in the city) are responsible for emitting 85% of total CO, NOx, VOCs, and SOx and 70% of PM emissions in the city. Accordingly, this study examined the emission rate of two groups of vehicles in Tehran, including passenger cars and motorcycles, from three primary sources, including exhaust, non-exhaust, and evaporative emissions.

To prepare activity data, the traffic data were gathered from the relevant authorities. Based on the travel demand model of Tehran, the traffic model of the city road network in 2017 (from October to November) was prepared for the two categories of vehicles during the morning rush hours (7:30–8:30 AM). Tehran traffic model specifies the number of vehicles for about 18,112 connections located in Tehran and its suburbs during rush hour.

To generalize the modeled traffic data to the entire year, hourly, daily, and monthly traffic profiles, which was prepared from traffic measurements, were used. For this purpose, traffic counting and monthly gasoline sale data of the city were used.

To calculate exhaust and evaporative emission factors for different vehicle categories and different pollutants, IVE model were used. The inputs of the IVE model, including fleet composition, I/M information, fuel quality, driving characteristics, and ambient data of the city were prepared.

Tehran fleet information for passenger cars and motorcycles were prepared from car registration data prepared by Iranian Traffic Police and classified into IVE vehicle technologies. The gasoline and diesel fuel quality data was obtained from the fuel analysis report published by Tehran AQCC. The local ambient conditions (as one of the inputs of IVE model), including temperature and relative humidity was prepared from Mehrabad Meteorological Station. To calculate the emissions from friction processes (brake, tire, and road), the emission factors of the European Environmental Agency guidelines were used.

After calculating the annual emission rate in the baseline scenario, the changes in atmospheric emissions under different scenarios were calculated and compared with the baseline. Since all the policies envisaged in this study are immediate or short term (2–3 years), the changes in the composition of the vehicle fleet and number were ignored.

3. Results

Based on the results recorded by the portable sound level meter, the total personal exposure when using different modes of transportation in the main and secondary routes was determined as presented in Table 1.

According to the standard of the Department of Environment (DoE) of Iran, the average sound level in residential areas should be 55 and 45 dBA during the day- and night-time, respectively. Also according to the WHO guideline, sound levels above 70 dBA in urban traffic can cause significant health outcomes (hearing impairment; Berglund et al., 2000).

Based on the measurement results (Table 1), due to the loud background noise and the lack of a control system such as a suitable cabin, the amount of noise exposure for motorcyclists, cyclists, drivers, and passengers of public transport is significantly higher than that among car drivers. As shown in the table, the maximum travel time is 22:23 min belonging to the bus transportation mode. The longer travel time can be attributed to bus stops at bus stations to carry passengers.

The next longest trip belongs to the side road crossing by bicycle, which is due to the longer length of the route. The shortest time belongs to the crossing by bike in the main route. The large difference between the maximum and minimum noise (SNR: *Signal-to-noise ratio*) indicates greater annoyance. As shown in Table 1, this difference is greater for motorcyclists and bicyclists than in other modes of transport. The large difference between the minimum and maximum exposure levels in the bike passing through the side-route is due to the overlap of part of the route with the main street. This point should be considered in designing new bike routes.

The LC-LA difference indicates sound quality and shows the person is exposed to bass traffic noise. Although bass means less annoyance; however, the large difference between the minimum and maximum sound levels in the route acts reversely and causes more annoyance.

In addition to the total personal exposure along the route, for more accuracy, the amount of exposure per minute was also recorded along the route. The results are presented in Fig. 7. The figure shows how the use of different modes of transport for a given route will change a person's exposure to noise pollution.

According to Fig. 7, the longest travel time belongs to the bus and the highest exposure to noise is related to motorcycles. The next highest personal exposure belongs to the use of bicycles varying between 64.8 and 79.69 dBA along the route. Therefore, along with the development of cycling and the design of new routes, special attention should be paid to the issues of “cyclists' health” and “cyclists' exposure to air and noise pollution”. Using cycling routing apps to suggest routes with the least amount of noise pollution can also be very helpful.

As shown in Fig. 7, a noticeable decrease in the sound level is observed in all modes in the time frame of 6:55 min. This is due to the presence of two consecutive red lights at a distance of 3 to 4 m from each other, which causes a stop for about 3 to 5 min (depending on the traffic volume) behind the light.

The cyclist's exposure along the route at one-minute intervals is shown in Fig. 8. According to the measurements, the rider in the side and main routes was exposed to the sound levels of 72.35 and 76.2 dBA, respectively. As shown in the graph, although sub-route selection increases the journey time by about 7 min, it reduces the exposure by about 4 dBA. A reduction of 4 dB means a 60% reduction in the sound pressure level. This means that by choosing a side route with less traffic, instead of the main and busy streets, 60% of the sound pressure level received by the cyclist will be reduced. Due to the logarithmic nature of noise pollution, this rate of reduction hardly occurs in noise control. Therefore, 4 dB is a significant reduction and is approximately equivalent to halving the sound energy.

The sound level measurements by the bicycle could determine the trend of sound level fluctuations along the main and side- routes and thus help to select low-noise-emission cycling routes. Usually to measure the ambient sound level, the sound level meter is fixed next to the passage. This was for the first time in Iran that the sound level was measured in a more realistic and mobile way (by cycling along the route). People, as sound receivers, do not have a fixed place and are exposed to different sound levels during the day. This method can show the average amount of exposure to environmental noise.

The equivalent sound level map of the target districts for daytime hours of 7 am to 10 pm is shown in Fig. 9. As can be seen in the figure, the average sound level near the main thoroughfares and highways is very high and the adjacent residential areas are exposed to noise beyond the standard limit. The white spots on the map are the missing data points due to the unavailability of the building data in District 11. To validate the model outputs, the results were compared with direct measurements (Fig. 10).

The difference between the direct measurements and the modeling outputs fell almost within an acceptable range at all stations, except for Tohid. This was mainly due to changing traffic conditions on the street adjacent to the station (operation of BRT station and construction of Tohid underpass tunnel).

The traffic data used in the sound level modeling was based on a traffic model (EMME/2) that certainly, like any other model, is

Table 1
Results of direct measurements by sound level meter.

Max speed	AV speed	L10-L95	L10	L90	L95	LC-LA	LAeq (dBA)	length of the trip (min)	Type of vehicle
30.6	21.2	15.24	79.75	65.77	64.54	10.74	76.2	13:46	Bicycle (main route)
25.7	17.1	16.46	75.56	60.83	59.1	12.18	72.35	20:31	Bicycle (side route)
49.7	18.5	19.37	88.5	70.66	69.13	11.12	84.29	16:29	Motorcycle
48.7	18.1	10.09	69.24	58.34	56.9	25.18	65.91	17:02	Private car (opened window)
46	19.1	12.62	67.06	55.19	54.44	25.21	63.97	16:52	Private car (closed window)
24.7	13.07	11.07	72.99	62.45	61.29	16.71	69.79	22:33	Urban bus (opened window)

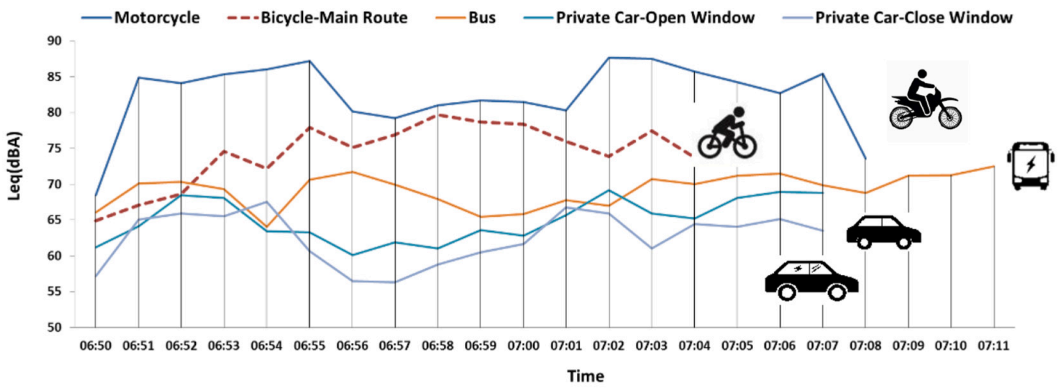

Fig. 7. Comparison between the personal exposure levels in the use of different modes of transportation in the main route.

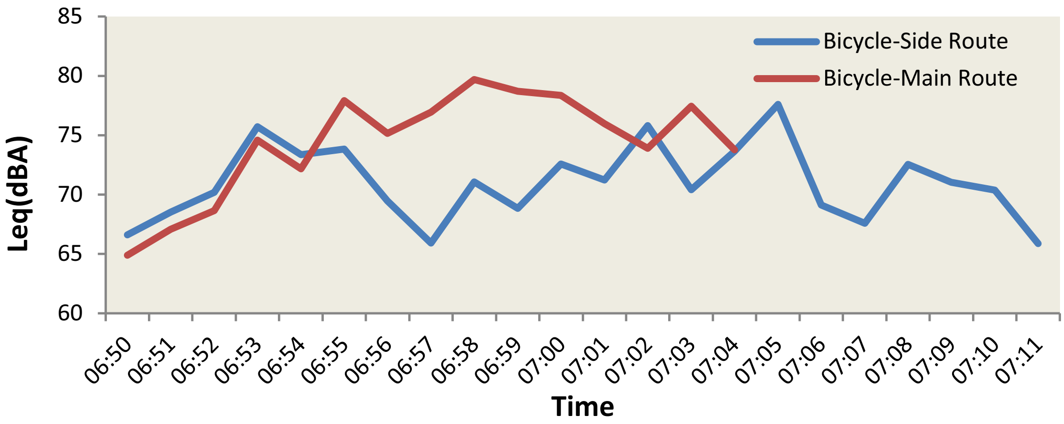

Fig. 8. Comparison of the bicycle rider exposure to noise pollution in the main and side route.

subject to uncertainty. Because the stations were located on highway and the accuracy of traffic data was high, the difference between the modeling and measurement results was negligible.

According to the modeling results, with a reduction of 25 and 50% in the volume of motorcycle traffic, the average noise level along the roads decreases by 0.33 and 0.57 dBA, respectively. Running the same scenario for private cars showed a decrease of about 0.52 and 1.8 dBA. If the number of private cars and motorcycles each decreases by 25%, the average sound level near the roads will decrease by 0.86 dBA. The latest statistics of the Traffic and Transport Deputy Office of Tehran Municipality (2017) show that private cars and motorcycles make up about 64% and 11% of the city's traffic volume, respectively. Obviously, the application of the above scenarios in the case of private cars will show a further reduction. It should also be borne noted that the noise pollution of motorcycles is much higher than private cars, and the difference in their share of daily traffic leads to differences in their impact on noise pollution. As expected, controlling the sources of noise pollution alone will not have a significant effect on reducing noise pollution. Reflective surfaces such as building facades, hard asphalt surfaces, and unsuitable urban structures play an important role in the control of noise pollution, so mitigation programs should be multifaceted and take into account all the influencing factors.

The concentration of $PM_{2.5}$ was recorded at the fixed air quality monitoring stations on the days when the noise pollution level was investigated. Table 2 shows the average daily concentration of $PM_{2.5}$, which was measured during the study period at the monitoring station. The measured values were lower than the daily standard of $PM_{2.5}$ concentration in Iran (35 μg/m^3). It should be noted that these results belong to an episode in the spring when the concentrations are lower than standard. The maximum daily concentration of $PM_{2.5}$ at the station, ranging 40–70 μg/m3, occurs in the cold seasons of the year.

Based on the reports, the concentration of CO, volatile organic compounds (VOCs), NOx, SOx, and PM emissions in Tehran in 2017 was 478, 91, 102.7, 19, and 10.4 thousand tons, respectively.

The share of mobile sources (vehicles) from the total emissions was about 83% (equivalent to 579 thousand tons) and stationary sources about 17% (equivalent to 122 thousand tons).

CO emissions from mobile vehicles in 2017 was about 463,446 tons, of which the share of private cars, motorcycles, taxis, pickups, and trucks was 46%, 25.1%, 12.3%, 12.1%, and 3.2%, respectively.

Out of a total of 36,150 tons of NOx released, the share of personal passenger cars, trucks, taxis, pickups, motorcycles, minibuses, urban buses, and service buses equals 44.9%, 14.8%, 9.8%, 8.5%, 7.5%, 5.2%, 4.7%, and 4.6%, respectively.

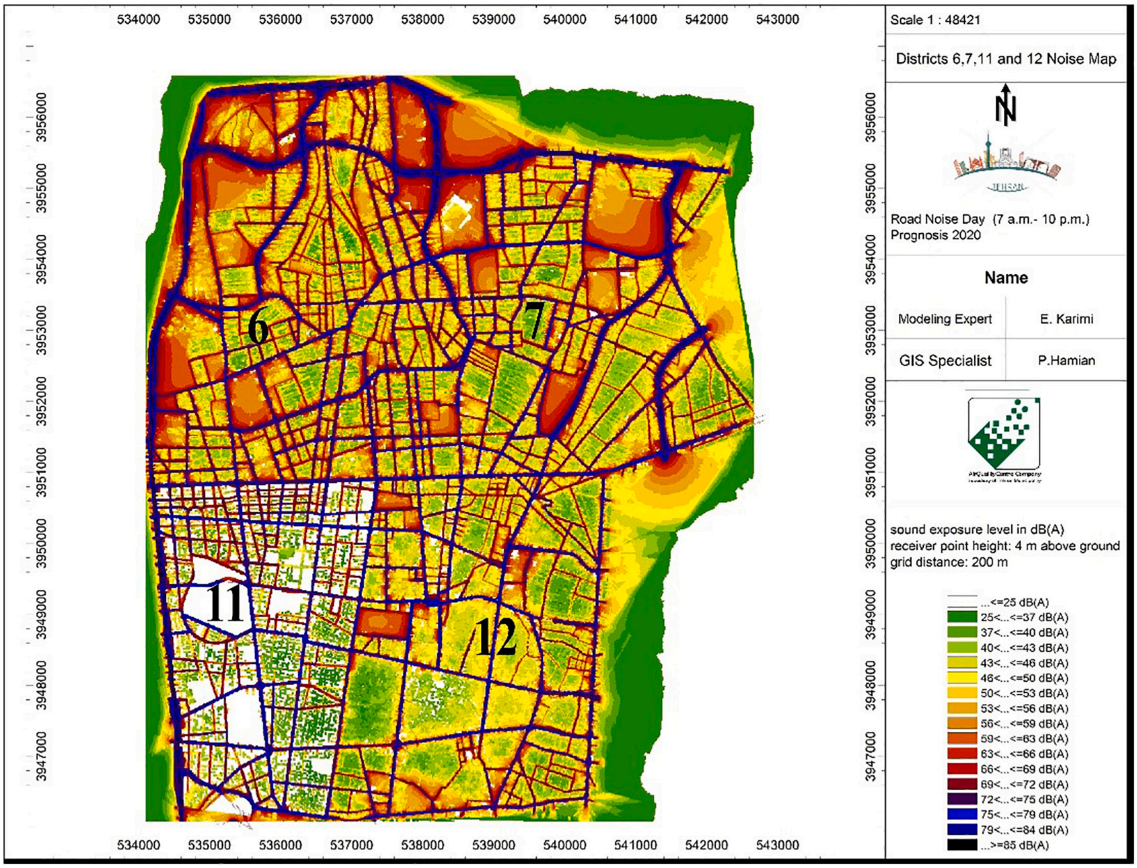

Fig. 9. Equivalent sound level map of the target districts for daytime hours.

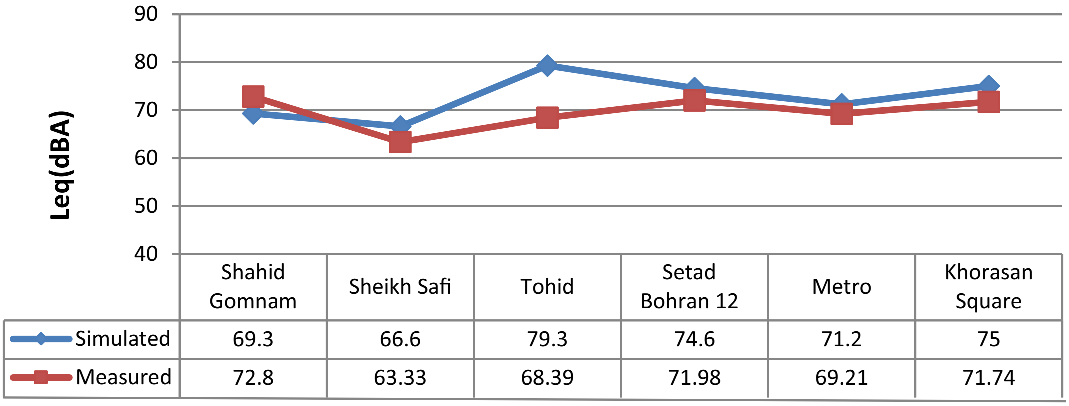

Fig. 10. Comparison of modeling results with direct measurements (the daytime period).

Table 2
Daily average of PM2.5 pollutant in the Setad Bohran station of District 7.

Pollutant	2020/5/11	2020/5/16	2020/5/18	2020/6/7	2020/6/9	2020/6/10
$PM_{2.5}$ μg/m^3	26	33	23	18	15	17

The annual emission of VOCs from mobile vehicles in 2017 was 71,882 tons, of which 75.1% were released from vehicle exhaust and 24.9% from evaporative processes. The SOx emission in 2017 was about 1127 tons, which was mainly emitted from private cars, pickups, taxis, and motorcycles with a share of 82%, 8%, 4.2%, and 3.7%, respectively. The annual PM emission from mobile sources is 6338 tons, of which 68.8% is due to combustion processes and 31.2% due to abrasion. Also, from the total PM emission including exhaust and non-exhaust particles, the share of trucks, personal passengers, motorcycles, service buss, urban buses, minibuses and pickups, taxis, and pickups are equal to 25.9%, 22.9%, 16.6%, 2.12%, 49%, 6.5%, 3.4%, and 2.9% respectively.

Table 3 shows the annual rate of emission reductions due to different substituent scenarios. As observed, reducing the number of motorcycles and personal vehicles does not have the same effect on different pollutants, except for CO. As the results show, all 5 scenarios have almost the same effect on reducing CO emissions.

Reducing traffic and replacing car trips with cycling has a greater impact on reducing NOx compared to the scenario of gasoline motorcycle substituent. According to the Euro 4 gasoline fuel quality standard in Tehran, applying different scenarios has little effect on reducing SOx emissions in Tehran. The effect of scenarios 1 and 2 on reducing PM emission is different from scenarios 3 and 4. Substituting personal cars with bicycles causes a further reduction in non-exhaust PM emissions than exhaust PM. This is the opposite for the motorcycle substituent scenario. In general, substituting the motorcycle fleet has a greater impact on reducing particulate matter emissions than passenger cars. The same is true for VOC pollutants, and the impact of motorcycle fleet substituent on reducing VOC emissions is greater than in passenger cars.

According to Scenario 5, if a combination of Scenarios 1 to 4 is considered, the CO, NOx, SOx, PM, and VOC emissions will be 16,741, 796, 41, 130, and 3665 tons per year, respectively.

The implementation of the scenarios had a more significant effect on reducing air pollution than noise, which indicates the important role of control at the source in reducing air pollution. Therefore, in planning for mitigation strategies, the focus should be directly on source control, while the orientation of noise control programs should be more on the path and receivers. "Use of absorbents in the facades of buildings", "installation of standard multi-glazed windows", "porous asphalt coating of passages", "Observance of buffer zone between residential houses and roads", "planting vegetation", "modification of urban structures and traffic laws", and "prohibition of on-street car parking to prevent traffic jams" are other noise control solutions recommended.

4. Conclusion

Cycling not only helps people's health as a sport but also solves problems such as traffic jams and air and noise pollution. One of the requirements of urban management and planning is to examine the consequences of executive measures before implementing them in terms of effectiveness, benefit(s), and cost(s).

The results of modeling and direct measurements showed that cyclists are exposed to air and noise pollution beyond standard limits. By replacing cars and motorcycles with bicycles, air and noise pollution will definitely be reduced and cyclists will be less exposed to pollution. The effects of non-motorized transportation on increasing people's health and reducing fuel and energy consumption are among the other consequences that should be considered in the assessments. Accordingly, city managers should provide the ground for promoting bicycle use and improving the health of communities by locating and building cycling lines in accordance with environmental standards and reforming urban structures. Paris, for example, ranked 20th in the list of world-friendly cycling cities in 2019. According to the Paris Mayor's Office, during the year from September 2018 to 2019, the number of bicycle users increased by 50% and compared to 2010, the number of private car city trips decreased by 5%. This has been achieved by measures such as; "development of PBS schemes", "creation and development of exclusive cycling and walking lanes", "conversion of on-street parking spaces to exclusive cycling lanes and green space", "promotion of the use of electric bicycles to reduce city trips by car", and "vehicle traffic bans on certain streets, such as sidewalks near historic sites." Although these changes may initially increase the traffic load on adjacent streets, the problem will gradually be solved by altering people's habits and encouraging them to use non-motorized transportation systems.

The results showed that the cyclist's exposure on the side-route was about 4 dBA less than the main route, although in some parts of the trip, the two routes overlapped. With long-term planning to improve the urban structure, exclusive bicycle lanes can be located and implemented on less polluted routs. In addition, cycling apps can provide users with health routes to help them stay healthy by choosing less polluted routes. Also, to protect the health of cyclists and reduce their exposure to noise, the use of helmets with acoustic

Table 3
Annual emission reduction due to the implementation of the scenarios for the substitute of passenger cars and motorcycles with bicycles.

Scenario	Emission					
	CO	NOx	SOx	PM (exhaust)	PM (non-exhaust)	VOC
Pollution emission from private car (ton/year)						
25%	7859	598	38	5	45	1337
50%	15,717	1196	76	11	91	2673
Pollution emission from motorcycle (ton/year)						
25%	8882	198	3	72	8	2329
50%	17,765	396	7	144	15	4657
Pollution emission from private car & motorcycle (ton/year)						
%25–25	16,741	796	41	77	53	3665

properties is recommended. The filtered masks can also be helpful in reducing exposure to air pollution.

As the results showed, source control had a direct and significant effect on reducing air pollution. Although source control in noise pollution is not as effective as air pollution, its simultaneous use with other mitigation strategies will be very effective.

As observed, reducing the number of motorcycles and personal vehicles does not have the same effect on different pollutants, except for CO. As the results show, all 5 scenarios have almost the same effect on reducing CO emissions.

Reducing traffic and replacing car trips with cycling has a greater impact on reducing NOx compared to the gasoline motorcycle substituent scenario.

According to the Euro 4 gasoline fuel quality standard in Tehran, applying different scenarios has little effect on reducing SOx emissions in Tehran.

The effect of scenarios 1 and 2 on reducing PM emission is different from scenarios 3 and 4. Substituting personal cars with bicycles causes a further reduction in non-exhaust PM emissions than exhaust PM. This is the opposite for the motorcycle substituent scenario. In general, substituting the motorcycle fleet has a greater impact on reducing particulate matter emissions than passenger cars. The same is true for VOC pollutants, and the impact of motorcycle fleet substituent on reducing VOC emissions is greater than in passenger cars.

According to Scenario 5, if a combination of Scenarios 1 to 4 is considered, the CO, NOx, SOx, PM, and VOC emissions will be 16,741, 796, 41, 130, and 3665 tons per year, respectively.

The main purpose of this study was to use the modeling technique to investigate the effect of source control in reducing air and noise pollution. Therefore, personal exposure to noise pollution was assessed only to gain relative knowledge of the existing conditions and to compare the exposure levels in the use of different transportation modes under the same conditions.

Regarding the first goal, which was to obtain an overview of the level of exposure to the use of different modes of transportation, one of the limitations of the research was the lack of stability and uniformity of traffic load on different days and changing conditions due to traffic restrictions at the time of the corona virus outbreak. Lack of access to building data in part of the district and car and motorcycle emission data were among the causes of uncertainty in the model. However, since using the direct measurement method on a large scale requires a lot of time and money, the use of modeling in management decisions with a percentage of error will be very efficient. In monitoring air pollutants, portable equipment was not available and therefore, the data of the nearest fixed air quality monitoring station was used. Since PEMS vehicle direct pollution measurement information was not available for vehicles in Tehran, IVE diffusion model was used to calculate emission coefficients.

Obviously, for accurate and reliable results, measurements must be made at different times of the day and on different routes. Measuring sound levels while on the move (the method used in this research) makes it possible to measure the level of sound along bike exclusive lanes. By importing noise data in bike routing applications, cyclists can be helped choose better routes with less exposure. The data will also be very useful in locating new routes for the development of bike exclusive lanes.

To reduce the exposure assessment uncertainties in future research, it is recommended that direct measurements be made with a larger number of samples for a greater number of routes on several types of each vehicle and at different daytimes. Since the accuracy of input data is the most important factor in modeling, so the preparation and use of data with higher accuracy is recommended to obtain more reliable outputs. As the ultimate goal of this study, it is to estimate the profit and cost of the plan to replace personal cars and motorcycles with bicycles, the cost-benefit analysis of substituting motor vehicles with bicycles is proposed in future studies.

For a more accurate estimate of emissions, it is strongly recommended to scrutinize the data of environmental pollution measurements (for exposure assessment) by using portable devices and the traffic data and time profiles using PEMS test results. Projecting changes in the transport fleet and traffic loads in the coming years, new scenarios are proposed to be defined and evaluated to assess the exposure levels. The analysis of energy and greenhouse gases (global warming) is other field of concern for future research.

CRediT authorship contribution statement

Mohammad Reza Monazzam: Supervision. **Elham Karimi**: Conceptualization, Methodology, Software. **Hossein Shahbazi**: Data curation, Writing - original draft. **Hossein Shahidzadeh**: Funding acquisition, Writing - review & editing.

Declaration of Competing Interest

Elham Karimi reports equipment, drugs, or supplies was provided by deputy transportation of Tehran Municipality & Tehran air quality control Co.

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