**MARMARA UNIVERSITY**
**INSTITUTE FOR GRADUATE STUDIES**
**IN PURE AND APPLIED SCIENCES**

# EVALUATION OF AIR AND NOISE POLLUTION SOURCED FROM ROAD TRAFFIC IN TRABZON CITY AND EXAMINATION OF THE RELATIONSHIP BETWEEN THEM

MELİKE NEŞE TEZEL

**MASTER THESIS**

Department of Environmental Engineering

**Thesis Supervisor**

Prof. Dr. S. Sinan Keskin

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# MARMARA UNIVERSITY INSTITUTE FOR GRADUATE STUDIES IN PURE AND APPLIED SCIENCES

Melike Neşe Tezel, a Master of Science student of Marmara University Institute for Graduate Studies in Pure and Applied Sciences, defended her thesis entitled "**Evaluation of Air and Noise Pollution Sourced from Road Traffic in Trabzon City and Examination of the Relationship between them**", on 29.06.2017 and has been found to be satisfactory by the jury members.

**Jury Members**

Prof. Dr. S. Sinan KESKİN (Advisor).....

Marmara University

Yr. Doç. Dr. Rosa Muria Flores Rangel (Jury Member) .....

Marmara University

Prof. Dr. Neşe Y. Akdağ (Jury Member) .....

Yıldız Technical University

## APPROVAL

Marmara University Institute for Graduate Studies in Pure and Applied Sciences Executive Committee approves that Melike Neşe Tezel be granted the degree of Master of Science in Department of Environmental Engineering, Environmental Engineering Program on 06.07.2017. (Resolution no: 2017/14-02).

**Director of the Institute**

**Prof. Dr. Uğur YAHŞİ**

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June, 2017 Melike Neşe Tezel

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## ABSTRACT

### Evaluation of Air and Noise Pollution Sourced from Road Traffic in Trabzon City and Examination of the Relationship between them

Motor vehicles, which are heavily used in road traffic, are important parts of the modern industrial economy. Besides their advantages, they have side effects such as; environmental impacts, accidents and congestion. Road traffic related noise and air pollution can be classified as two important components which affect the human health in short and long term exposure. Epidemiological studies show that noise and air pollution could be the reasons of cardiovascular disease, myocardial infarction and hypertension. Due to the unfeasibility of exposure evaluation based on measurement, models are used to estimate noise exposures in road noise and health researches. Similarly, dispersion and/or simulation models are used to estimate concentrations of traffic-generated air pollution. In this study, a traffic emission inventory was prepared to determine the concentrations of air pollutants. $NO_x$ distribution, one of the main pollutants from road traffic, was modeled with AERMOD for the study area using emission inventory results. In addition, road traffic noise at many receptors was calculated as the equivalent continuous A-weighted sound pressure level ($L_{Aeq}$) in Trabzon by SoundPLAN. Model results were validated with measurement data by using different statistical tools. Separate and combined exposure of population from road traffic sourced $NO_x$ and noise was examined. Moreover meteorological and topographic effects on $NO_x$ and noise dispersion mechanisms were discussed. The relationship between $NO_x$ and noise pollution in study area was evaluated and results show that, road traffic sourced noise levels and $NO_x$ concentrations are highly correlated in Trabzon and therefore point out to their common source.

## ÖZET

### Trabzon İlinde Karayolu Trafiği Kaynaklı Hava ve Gürültü Kirliliği ile Aralarındaki Olası İlişkinin İncelenmesi

Karayolu trafiğinde yoğun olarak kullanılan motorlu araçlar, modern endüstriyel ekonominin önemli bir parçasıdır. Fakat birçok avantajının yanında, çevresel etkiler, trafikte kazalara ve tıkanıklığa neden olmaları gibi negatif etkileri vardır. Karayolu trafiği kaynaklı gürültü ve hava kirliliği, kısa ve uzun vadede insan sağlığını etkileyen iki önemli bileşen olarak sınıflandırılabilir. Epidemiyolojik çalışmalar gürültünün ve hava kirliliğinin kardiyovasküler hastalıklar, kalp krizi ve hipertansiyonun nedenleri olabileceğini göstermektedir. Ölçüm esasına dayalı maruz kalma değerlendirmesinin her zaman uygulanamaması nedeniyle, karayolu gürültüsü ve sağlık araştırmalarında gürültüye maruz kalma riskini tahmin etmek için modeller kullanılmaktadır. Benzer şekilde, trafik kaynaklı hava kirliliğinin yoğunluklarını hesaplamak için dağılım ve / veya simülasyon modelleri kullanılır. Bu çalışmada, hava kirleticilerinin konsantrasyonlarını belirlemek için bir trafik emisyon envanteri hazırlanmıştır. Karayolu trafiğindeki en önemli kirleticilerden biri olan $NO_x$'un çalışma alanındaki dağılımı, emisyon envanteri sonuçları kullanılarak AERMOD programı ile modellenmiştir. Buna ek olarak, çok sayıda alıcı noktadaki trafik gürültüsü, SoundPLAN programı tarafından Trabzon'da eş değer sürekli A ağırlıklı ses basınç seviyesi ($L_{Aeq}$) olarak hesaplanmıştır. Model sonuçları, farklı istatistiksel araçlar kullanılarak ölçüm verileri ile doğrulanmıştır. Nüfusun karayolu trafiği kaynaklı $NO_x$ ve gürültüden ayrı ayrı ve bir aradaki maruziyeti incelenmiştir. Ayrıca, $NO_x$ ve gürültü dağılım mekanizmalarında etkili olan meteorolojik ve topoğrafik etkiler tartışılmıştır. Çalışma bölgesindeki $NO_x$ ve gürültü kirliliği arasındaki ilişki değerlendirilmiştir. Sonuçlar, Trabzon'da trafik kaynaklı gürültü seviyeleri ile $NO_x$ konsantrasyonlarının korelasyonunun oldukça yüksek olduğunu ve dolayısıyla ortak kaynaklara işaret ettiğini göstermektedir.

## ABREVIATIONS

**BC:** Black carbon

**CO:** Carbon monoxide

**dB(A):** A weighted sound levels

**EEA:** European Environment Agency

**END:** European Noise Directive

**ENM:** Environmental Noise Management

**FAC2:** The factor of two

**HDV:** Heavy-Duty Vehicles

**IEA:** International Energy Agency

**IOA:** Index of Agreement

**$L_{Aeq}$:** The equivalent continuous A-weighted sound pressure level

**LCV:** Light Commercial Vehicles

**$L_{day}$:** The A-weighted long-term average sound level during all the day periods (07.00 to 19.00) of a year

**$L_{den}$:** The intensity of the long-term A-weighted average sound level during all the day (24 hr) of a year

**$L_{evening}$:** The A-weighted long-term average sound level during all the evening periods (19.00 to 23.00) of a year

**$L_{night}$:** The A-weighted long-term average sound level during all the night periods (23.00 to 07.00) of a year

**MoEU:** Republic of Turkey Ministry of Environment and Urbanization

**NMSE:** Normalized mean square error

**NMVOC:** Nonmethane volatile organic compounds

**$NO_x$:** Nitrogen oxides

**$O_3$:** Ozone

**OC:** Organic carbon

**PC:** Passenger cars

**PM:** Particulate matter

**$PM_{10}$:** Particulate matter with equivalent diameter between 2.5 and 10 μm

**$PM_{2.5}$:** Particulate matter with equivalent diameter less than 2.5 μm

**$SO_2$:** Sulfur dioxide

**USEPA:** United States Environmental Protection Agency

**$VOC_s$ :** Volatile organic compounds

**WHO:** World Health Organization

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# 1 INTRODUCTION

There has been a strong worldwide movement toward motorization since the end of World War II. The number of motor vehicles has increased up to ten times during the past 50 years (Cooper and Alley, 2011). According to the International Organization of Motor Vehicle Manufacturers' 2014 report, the number of motor vehicles in use has increased 38.5% since 2005 to 2014 and there are 1.236 billion motor vehicles in use all around the world (Figure 1.1). The report also shows that; motorization rate was 175 for thousand inhabitants in 2013 and 180 in 2014 (OICA, 2014). This increasing trend will also continue in the future because of the increasing urbanization according to the United Nations' projections (Cooper and Alley, 2011).

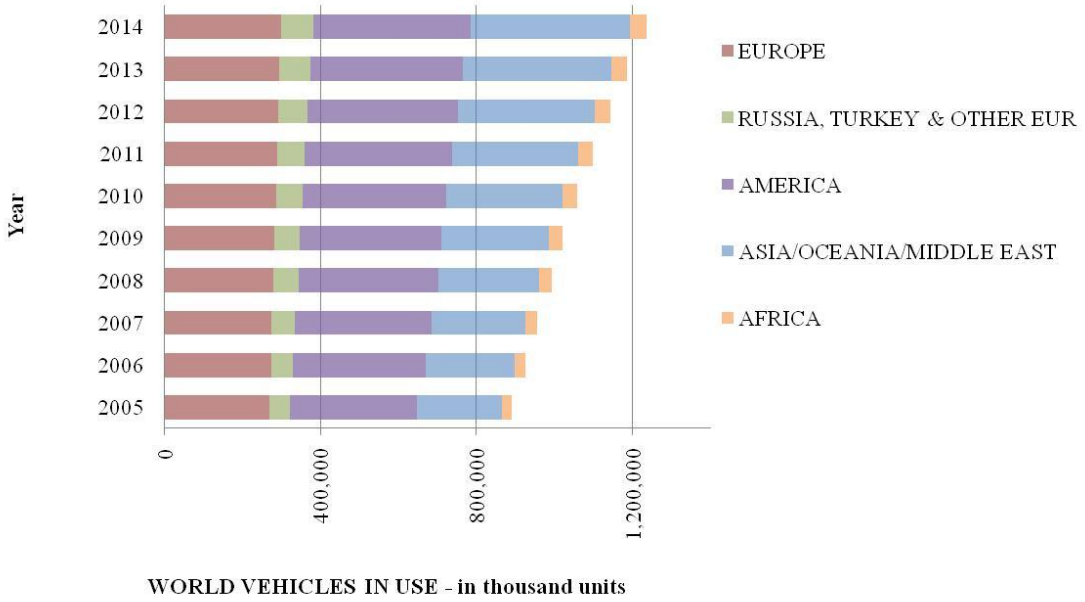


**Figure 1.1.** Motor vehicles in use all around the world (OICA, 2014)

Motor vehicles are important parts of the modern industrial economy which can serve rapid, reliable, convenient mobility and satisfy the demands of the ever-growing number of people in countries throughout the world (Winston and Virginia, 2003). Similarly, in Turkey, road transport covers 92% of passenger per km and 88% of tones per km in total transportation volume as shown in Table 1.1 (MoTMC, 2012). Road transport has the greatest emissions with respect to other type of transportation due to the fuel consumption (Soylu, 2007).

**Table 1.1.** Domestic Freight and Passenger Transport Rates According to Transportation Modes of Turkey (2010) (MoTMC, 2012)

| Transportation Type | Passenger–km | | Tonnes–km | |
|---|---|---|---|---|
| Road | 226,913 | 91.75% | 190,365 | 88.29% |
| Maritime | 1,575 | 0.64% | 12,568 | 5.83% |
| Rail | 5,491 | 2.22% | 11,462 | 5.32% |
| Air | 13,325 | 5.39% | 1,212 | 0.56% |
| **Total** | **247,304** | | **215,607** | |

Besides positive effects, unfortunately, most forms of transport also have side effects on society such as; accident costs, air pollution and noise. Side effects of transportation are named as external costs that are not caused by passengers. External costs are mainly related with road transport sector. These costs' details are explained in Table 1.2 (Maibach et al., 2008).

**Table 1.2.** Cost elements of cost components (Maibach et al., 2008)

| Cost component | Cost elements |
|---|---|
| Congestion costs (road) | Time and operating costs , Additional safety and environmental costs |
| Scarcity costs (scheduled transport) | Delay costs, Opportunity costs, Loss of time for other traffic users |
| Accident costs | Medical costs, Production losses, Loss of human life |
| Air Pollution | Health costs, Years of human life lost, Crop losses, Building damages, Costs for nature and biosphere |
| Noise costs | Rent losses, Annoyance costs, Health costs |
| Climate change | Prevention costs to reduce risk of climate change, Damage costs of increasing temperature |

Road traffic related noise and air pollution can be classified as two important components which affect the human health in short and long term exposure. Cardiovascular diseases, high blood pressure and sleep disturbances could be caused by noise exposure as has been shown in many epidemiological studies (Ross et al., 2011). The areas around the roads are severely affected by air pollutants. Cardiovascular mortality and atherosclerosis in these areas could be associated with this exposure (Foraster et al., 2011). In the United States, %75 of carbon monoxide was emitted from mobile sources in 2008 and over 100 million people were exposed to road traffic noise levels that is greater than limit values according to 1981 USEPA (United States Environmental Protection Agency) study (Cooper and Alley, 2011). Traffic sourced air pollution and noise can affect the human health individually but there could also be

their combined health effects. Epidemiological studies have shown that environmental noise and air pollution are associated with cardiovascular disease morbidity and mortality. The correlation between air pollutants and noise that are originated from road traffic are investigated by many researchers (Shu et al., 2014).

In this study, source concentrations (emission inventory) of air pollutants originating from vehicles in Trabzon city center were calculated with the help of the USEPA's guidelines, road vehicle counts, registered vehicle type statistics and road lengths in the study area. The most representative air pollutant of road traffic, $NO_x$ concentration at the receptor points was calculated by using AERMOD dispersion model. Besides, road traffic sourced noise emissions and exposures at many receptors were calculated by using noise simulation program; SoundPLAN. Moreover, correlation between $NO_x$ concentrations and road noise was examined by comparing the values found at the receptor points. In addition, the population affected by these two environmental factors in Trabzon city center has been determined.

## 1.1 Air Pollution

### 1.1.1 Air pollutants and their effects

Air pollution is any solid, liquid or gas substances that are present in air by a concentration that may affect human health, materials and ecosystems negatively. It is one of the major global problems which adversely affect millions of living organisms' health, ecological systems, atmospheric chemistry and global climate (Aggarwal and Jain, 2015). World Health Organization (WHO) reported that air pollution is one of the ten major risk factors affecting the global health. Particularly in highly populated urban areas and developing countries, the situation is expected to be getting worse (Lim et al., 2012).

Air pollution could be caused by natural (pollens, dust and volcanoes etc.) or anthropogenic sources (combustion, industrial facilities etc.). Air pollutants can stay in the atmosphere from minutes to years and cause local, national, regional or global problems. Primary pollutants and secondary pollutants are the two main classifications for air pollutants. Primary air pollutants are diffused directly from natural sources or anthropogenic activities. As a result of the chemical reactions between primary

pollutants and components in the atmosphere with the help of the sunlight, secondary pollutants could form (IEA, 2016).

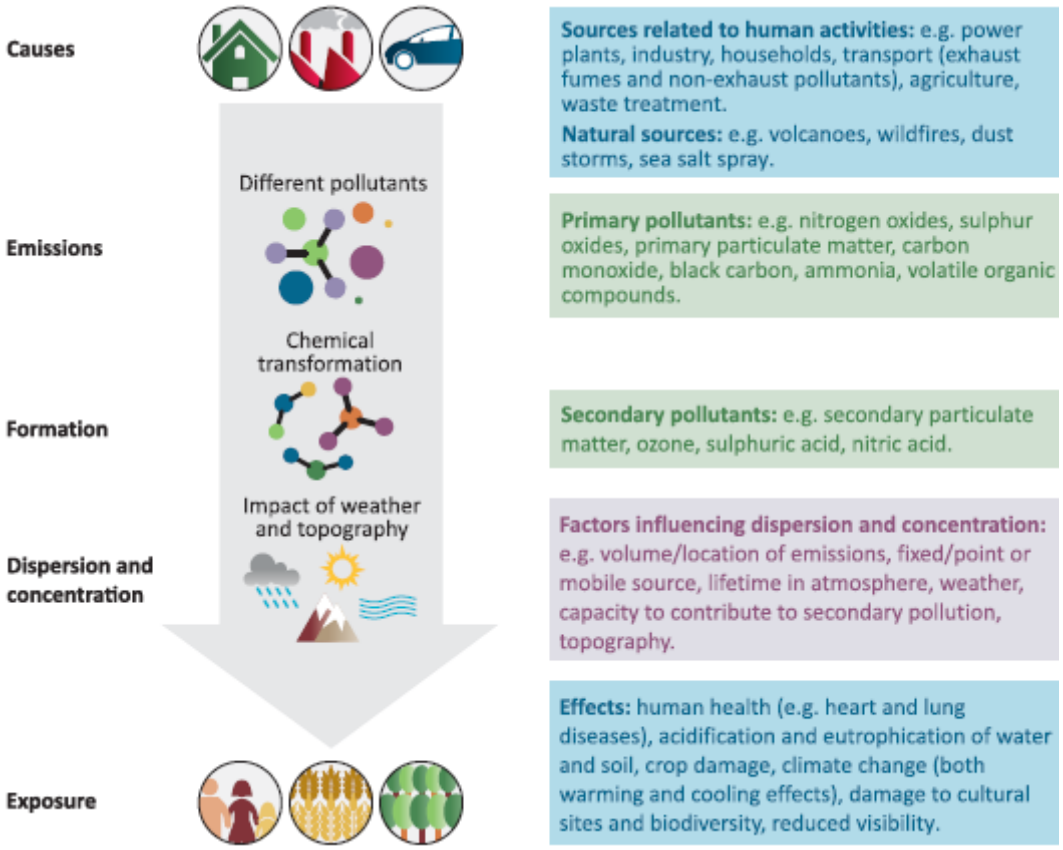


**Figure 1.2.** Flow diagram of air pollution problem (IEA, 2016)

The formation of pollutants and their release from the source, the atmospheric transport and transformation, the impact on population and environment are the sequential effects of air pollution phenomenon (Flagan & Seinfield, 1988). Type, concentration and location are the main specifications of air pollutants' sources. Major factors that affect the dispersion of air pollutants are; meteorological conditions and terrain of a region (Figure 1.2).

Short and long term exposure to air pollution can affect human health, animals, plants, materials and visibility (Schnelle and Brown, 2002). For example, particulate matter could be associated with lung cancer, chronic lung and heart diseases. Air pollution can be a reason of more than five hundred premature deaths. Statistics show that, there could be relevance between low birth weight, cataracts, throat cancers etc. and air pollution exposure (IEA, 2016).

Carbon monoxide (CO), sulfur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), ground-level ozone ($O_3$), particulate matter (PM) and lead (Pb) are classified as criteria pollutants by USEPA, that are or could be harmful to people (Mishra and Goyal, 2015).

*Nitrogen oxides ($NO_x$):* The major source of $NO_x$ is fuel combustion that is mainly emitted from transport and power generation. $NO_2$ is mostly formed by the oxidation of NO. The majority of $NO_x$ emission is NO, the rest of emissions is directly emitted as $NO_2$. The $NO_2/NO_x$ ratio of diesel vehicles emission is higher than in gasoline due to the oxidation of NO in diesel vehicles' exhaust after treatment systems. $NO_2$ can cause particulate matter and ozone formation; it contributes to acid deposition and eutrophication of soil and water with $SO_2$. $NO_2$ is associated with adverse effects on health: it can affect the liver, lung, spleen, blood and respiratory system (EEA, 2013; 2016; IEA, 2016). They also contribute to smog that is injurious to plants and animals (Cooper and Alley, 2011).

*Carbon monoxide (CO):* It is a colorless, odorless and toxic gas which is a product of incomplete combustion of road transport fuels, natural gas, coal, or wood (IEA, 2016). Motor vehicles, some industrial processes and incinerators could be the sources of this pollutant. Carbon monoxide emissions can affect cardiovascular, pulmonary, and nervous systems because, it influence negatively the ability of oxygen transfer from blood to tissues (USEPA, 2017b).

*Sulfur dioxide ($SO_2$):* It is a reactive, colorless and odorless gas at low concentrations that is emitted as a result of sulfur contained fossil fuels, coal and oil combustion (USEPA, 2017b). Power generation, industrial and household fuel combustion are the main sources of the anthropogenic emissions; volcanoes are the biggest natural source of $SO_2$ emissions (EEA, 2016). $SO_2$ emissions can be a precursor to the formation of sulfuric acid, which cause acidification of water bodies and visibility reduction (IEA, 2016; USEPA, 2017b). Emissions may cause breathing problems, respiratory illness and aggravation of existing cardiovascular disease (USEPA, 2017b).

*Ground-level ozone ($O_3$):* It is formed from $NO_x$ and $VOC_s$ with the help of heat and sunlight in the troposphere layer. Motor vehicles, landfills and industrial facilities are the sources of ground level ozone. It can cause coughing, asthma and irritation in the respiratory system and reduction in lung function. It may also reduce yield of

agricultural crops and can damages forests and other vegetation (IEA, 2016; USEPA, 2017b).

*Particulate matter (PM):* It is an organic and inorganic substance that might be a primary or secondary pollutant. "Coarse particles" have the diameter in the range between 2.5 and 10 micrometers and "fine particles" are smaller than 2.5 μm. Natural sources could be sea salt, pollen, volcanic ash etc. All kind of combustion (fuel combustion, waste incineration, residential heating etc.) are sources of anthropogenic PM which are dominant in urban zones (IEA, 2016). $SO_2$, $NO_x$, ammonia ($NH_3$) and volatile organic compounds ($VOC_s$) are the main forerunner for secondary PM formation. As a result of the reaction of these components in the atmosphere, ammonium ($NH_4^+$), sulphate ($SO_4^{-2}$) and nitrate ($NO_3^-$) compounds are formed that are called secondary inorganic aerosols (IEA, 2016). Particulate matter (PM) in the air can affect the cardiovascular system and other systems of the human body (Karagulian et al., 2015). Particulate matter exposure can cause eye, noise and throat irritation, decreased lung function, aggravated asthma, development of chronic bronchitis, and premature death. Visibility reduction and toxic metal carriage are other side effects of them (USEPA, 2017b).

*Lead (Pb)* is a heavy metal that is sourced from both natural and anthropogenic substances such as; soil, dust, paint, and fuel combustion. Brain and nervous system damage, negative effect on kidney function are the main health effects of lead (USEPA, 2017b).

*Other Pollutants:* Volatile organic compounds ($VOC_s$) are released from chemicals, solvents, or fuels. Methane ($CH_4$) is the main constituent of natural gas. Ammonia ($NH_3$) is emitted from land and waste management activities which reacts with nitrogen oxides and sulfur oxides to form secondary particles (IEA, 2016).

The effects of air pollutants are directly related to climate change and global warming, and they cause problems in short-term also. Black carbon (BC) (a component of PM) and ozone in the troposphere layer, are the two most important pollutants in the short term that have a large effect on global warming. The pollutants contributing to the global cooling are other PM components such as organic carbon (OC), ammonium, sulfate and nitrate. In addition, changes in meteorology as a result of climate change

affect the mechanisms of formation, transport and distribution of air pollutants in the atmosphere. For example, ground level ozone formation will increase in warmer climate and increased ozone levels at ground level will cause more warming (EEA, 2016).

### 1.1.2 Sources of air pollution

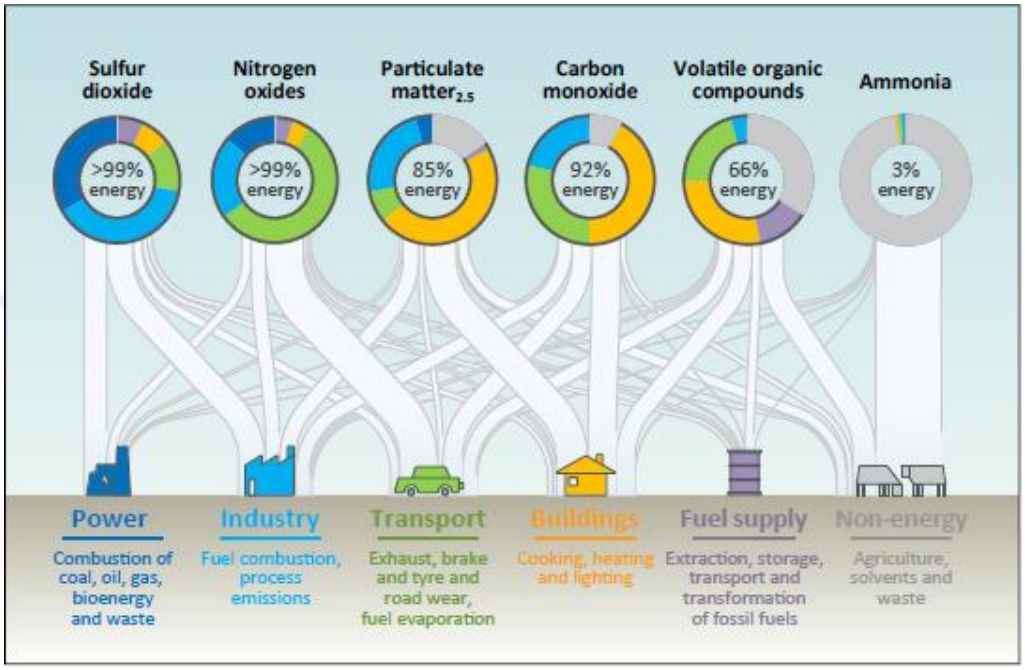


**Figure 1.3.** Sources of air pollutants in 2015 all over the world (IEA, 2016)

Sources of air pollution are either man made or natural. Man-made sources can be controlled by regulations (Schnelle and Brown, 2002). Because of the huge population in cities, there are so many human activities that cause various emissions (Karagulian et al., 2015). The most important anthropogenic air pollutants are sulphur dioxide, nitrogen oxides, $PM_{2.5}$, carbon monoxide and VOCs (Figure 1.3). They are sourced primarily from;

- Power production activities (combustion of coal, oil, gas, biomass, waste etc.)
- Industrial activities (process emissions etc.)
- Transportation (exhaust, brake, tyre and road wear, fuel combustion etc.)
- Buildings (Cooking, heating and lighting etc.)
- Non-exhaust emissions from the transport sector (road erosion etc.)

**Table 1.3.** U.S. Emissions from 1998 and 2008 (Mt/year) (Cooper and Alley, 2011)

| Source Category | CO | | $NO_x$ | | VOCs | | PM-10 | | $SO_2$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1998 | 2008 | 1998 | 2008 | 1998 | 2008 | 1998 | 2008 | 1998 | 2008 |
| **Mobile Sources** | | | | | | | | | | |
| On-road Vehicles | 73.24 | 38.87 | 8.62 | 5.21 | 5.86 | 3.42 | 0.26 | 0.17 | 0.30 | 0.06 |
| Non-road Vehicles* | 23.69 | 18.04 | 4.16 | 4.26 | 2.67 | 2.59 | 0.33 | 0.30 | 0.43 | 0.46 |
| SUBTOTAL MOBILE SOURCES | 96.93 | 56.91 | 12.78 | 9.47 | 8.53 | 6.01 | 0.59 | 0.47 | 0.73 | 0.52 |
| **Stationary Sources** | | | | | | | | | | |
| **Fuel combustion** | | | | | | | | | | |
| Electric Utilities | 0.45 | 0.70 | 6.23 | 3.01 | 0.06 | 0.05 | 0.23 | 0.12 | 13.42 | 7.55 |
| Industrial Furnaces | 1.15 | 1.22 | 3.05 | 1.84 | 0.17 | 0.13 | 0.23 | 0.19 | 2.74 | 1.67 |
| Comm., Res., and other | 2.73 | 3.37 | 1.10 | 0.73 | 0.89 | 1.27 | 0.38 | 0.07 | 0.59 | 0.58 |
| SUBTOTAL | 4.33 | 5.29 | 10.38 | 5.58 | 1.12 | 1.45 | 0.84 | 0.38 | 16.75 | 9.80 |
| **Industrial Processes** | | | | | | | | | | |
| Chemicals and Petroleum | 1.45 | 0.62 | 0.27 | 0.44 | 0.88 | 0.79 | 0.10 | 0.03 | 0.60 | 0.46 |
| Metals Processing | 1.71 | 0.95 | 0.09 | 0.07 | 0.08 | 0.05 | 0.15 | 0.02 | 0.41 | 0.20 |
| Other | 0.66 | 0.62 | 0.47 | 0.44 | 6.90 | 5.93 | 0.42 | 0.77 | 0.42 | 0.33 |
| SUBTOTAL | 3.82 | 2.19 | 0.83 | 0.95 | 7.86 | 6.77 | 0.67 | 0.82 | 1.43 | 0.99 |
| **Waste Disposal** | 3.12 | 1.58 | 0.16 | 0.12 | 0.54 | 0.37 | 0.49 | 0.23 | 0.03 | 0.03 |
| SUBTOTAL STATIONARY SOURCES | 11.27 | 9.06 | 11.37 | 6.65 | 9.52 | 8.59 | 2.00 | 1.43 | 18.21 | 10.82 |
| **Area Sources & Miscellaneous** | 7.19 | 11.73 | 0.18 | 0.26 | 0.72 | 1.33 | 20.30 | 9.97 | 0.01 | 0.08 |
| **TOTAL ALL SOURCES** | **115.39** | **77.70** | **24.33** | **16.38** | **18.77** | **15.93** | **22.89** | **11.87** | **18.95** | **11.42** |

*Non-road includes boats, planes, trains, construction equipment, lawn and garden equipment, and others.
Notes: Misc CO is almost all from fires; Misc PM-10 is almost all fugitive dust from paved and unpaved roads, construction sites, and agricultural sources.

Most proportion of sulphur dioxide emissions sourced from power production and industrial activities as seen from Figure 1.3. Transportation emissions are the main source of nitrogen oxides emissions besides industrial and power production activities. 85% of primary $PM_{2.5}$ is related with energy production and use which are mainly emitted from buildings and industrial processes. Transportation, industrial activities and residential sources are the main sources of carbon monoxide with 92% proportion in all $CO_2$ emissions. 66% of VOC emissions are attributable to energy production and use that are sourced from agriculture, buildings and transportation activities (IEA, 2016).

Sulfur oxides are caused by burning of sulphur or any sulphur containing material as can be seen from Table 1.3. Fossil fuel combustion for electric power generation is the main source of $SO_2$ emissions in U.S. in 2008. Petroleum refining and nonferrous metal smelting can be also important sources in specific locations (Cooper and Alley, 2011). All around the world, in 2015, it is estimated that 80 million tons (Mt) of $SO_2$ was emitted from the energy sector with over 45% from industry and one-third from the power sector. 22 Mt, over one-quarter of $SO_2$ emissions, which are related with energy, are sourced from China, where industrial activities are 64% of the total (Figure 1.4). The next main source of $SO_2$ emissions was India with 9 Mt in where one half of total emission is coal-dominated power sector. Power sector is responsible from almost half

of energy related $SO_2$ emissions in middle east, European Union, Africa and United States (IEA, 2016).

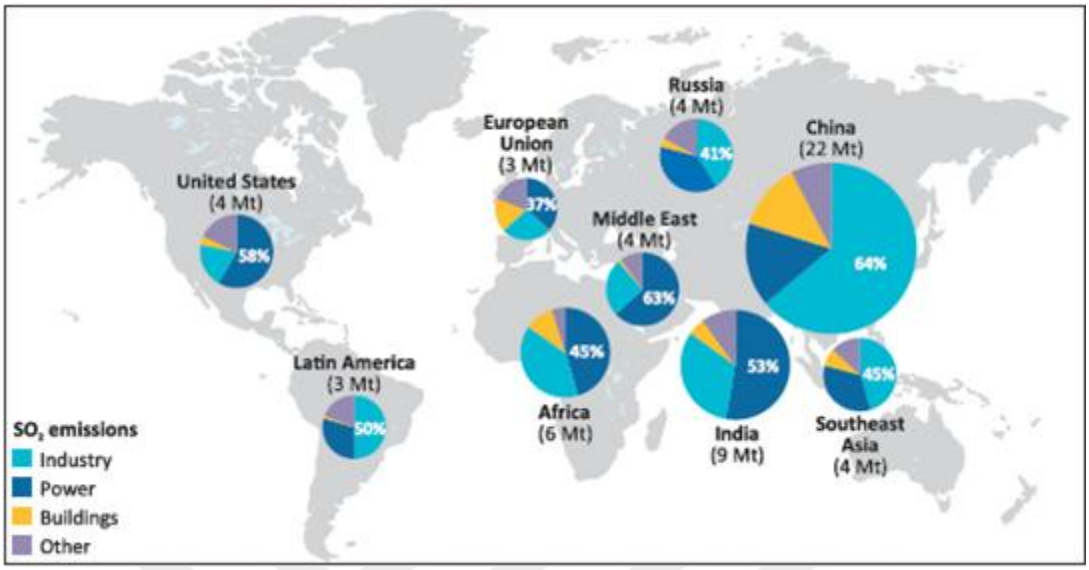


**Figure 1.4.** Regional $SO_2$ emission sources, 2015 (IEA, 2016)

According to International Energy Agency (IEA)'s report, anthropogenic emissions of nitrogen oxides continue to increase in all around the world. In 2015, 107 Mt $NO_x$ emissions are reported. Over half of these emissions are caused by transport, 26% of the emissions are sourced from industrial activities and power generation activities contribute with 14%. One-third of global energy-related $NO_x$ emissions (23 million tons) caused by China and the United States (13 million tons). In a global level, transportation is the main source of $NO_x$ emissions, the only exception is China; industry is the main source. In 2015, India's population has seen an increasing trend, reaching twice as much as Europe, while the $NO_x$ emission level is almost the same as in Europe. (Figure 1.5) (IEA, 2016). In 2011, European Environment Agency (EEA) reported that in Turkey, $NO_x$ emissions are produced from mainly energy use (48%) and road transport (45%) (Figure 1.6) (EEA, 2013).

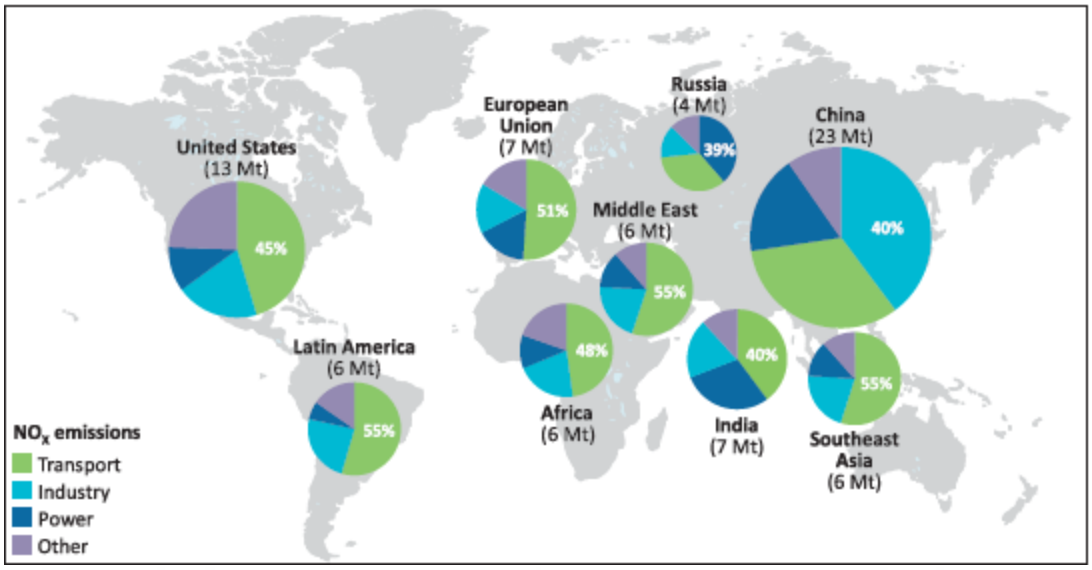


**Figure 1.5.** Regional $NO_x$ emission sources, 2015 (IEA, 2016)

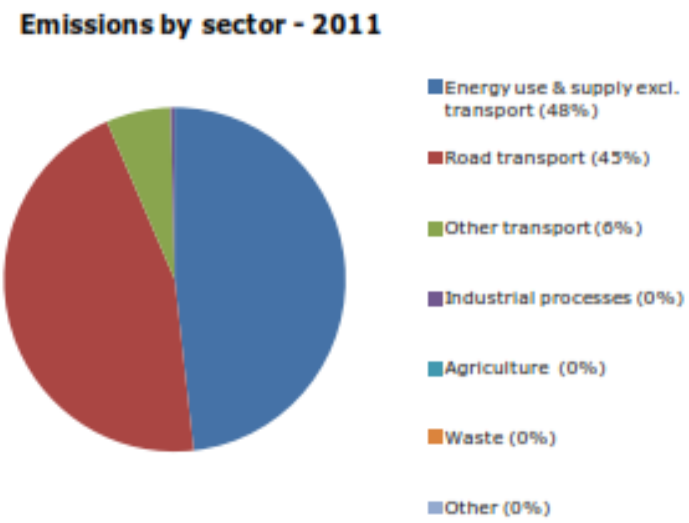


**Figure 1.6.** 2011 $NO_x$ emissions by sectors in Turkey (EEA, 2013)

Industrial processes, coal-oil burning electric power plants, residential fuel combustion and vehicle emissions are the main sources of particulate matter emissions (Cooper and Alley, 2011). In 2015, European Commission and WHO published the main sources of PM in 51 different cities all around the world. Traffic is the main source of air pollution, responsible from 25% of total $PM_{2.5}$, 15% caused by industrial sectors, 20% sourced from domestic heating, 22% from unspecified anthropogenic sources, and 18% from natural dust and salt (Figure 1.7). In Turkey, 30% of total $PM_{2.5}$ emissions are caused by industrial activities (Karagulian et al., 2015).

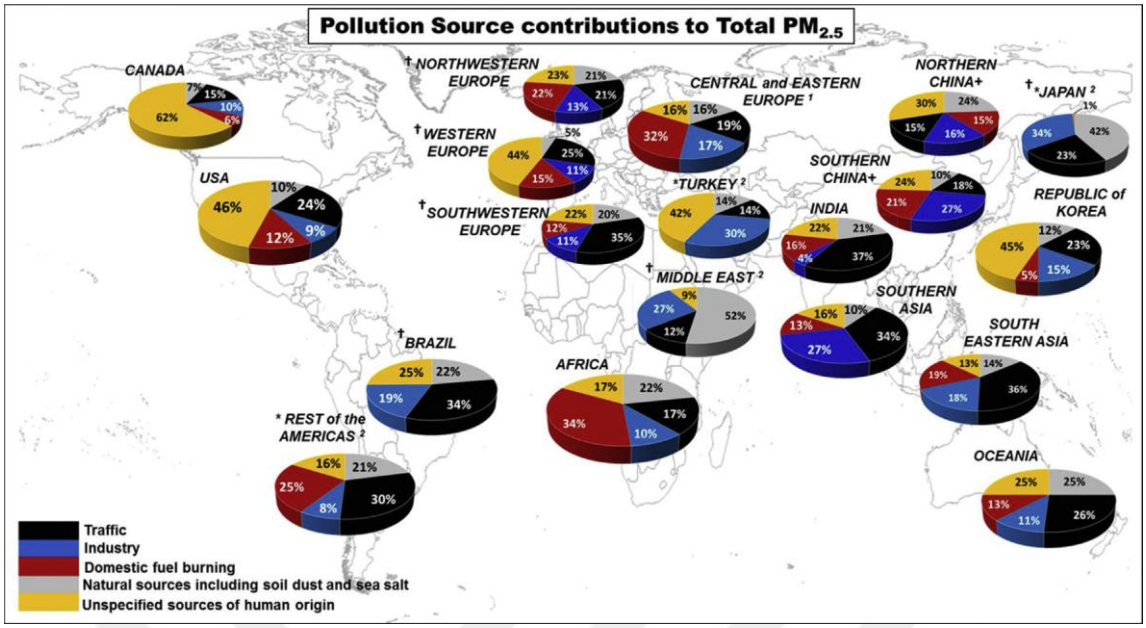


**Figure 1.7.** $PM_{2.5}$ sources in urban areas (Karagulian et al., 2015)

### 1.1.3 Air quality management

In spite of the fact that, clean air is a basic necessity for human health, air pollution remains a major threat to world population. Air quality guidelines were published by WHO in 2006 which will help to lead the reduction of air pollution. These guidelines are designed to inform decision-makers to determine goals for air quality management in all around the world. In the scope of this guideline, four common air pollutants are considered and limit values are defined; $SO_2$, $NO_2$, PM and $O_3$ (Table 1.4) (WHO, 2006).

According to the WHO's report, more than 2 million premature deaths per year may be related to exposure to open and closed air pollution from combustion of solid fuels in urbanized areas. More than half of this statistic constitutes people living in developing countries (WHO, 2006). In 2014, the population exposed to air pollution above the limits set by WHO for air quality constitutes 92% of the world. It is estimated that air pollution in urban and rural areas may be associated with 3 million premature deaths worldwide, according to the year 2012 data. Approximately 88% of these deaths occurred in low and middle-income countries (especially in Western Pacific and Southeast Asia) (WHO, 2017).

**Table 1.4.** Limit concentrations of PM, $NO_2$, $SO_2$ and Ozone (WHO, 2006)

| µg/m$^3$ | $PM_{2.5}$ | $PM_{10}$ | $NO_2$ | $SO_2$ | $O_3$ |
|---|---|---|---|---|---|
| Annual mean | 10 | 20 | 40 | - | - |
| 24-hour mean | 25 | 50 | - | 20 | - |
| 8-hour mean | - | - | - | - | 100 |
| 1-hour mean | - | - | 200 | - | - |
| 10-minute mean | - | - | - | 500 | - |

Air pollution rates in developing countries with low and middle income are well above the limit values set by WHO. As can be seen from Figure 1.8, there is a huge difference between the rate of air pollution observed in developed countries' cities with higher income levels and the amount of particulate matter observed in urbanized areas in developing countries. Especially in cities in China and India $PM_{2.5}$ pollution is above the limit values. In Istanbul, annual average fine particulate matter pollution exceeds the limit values.

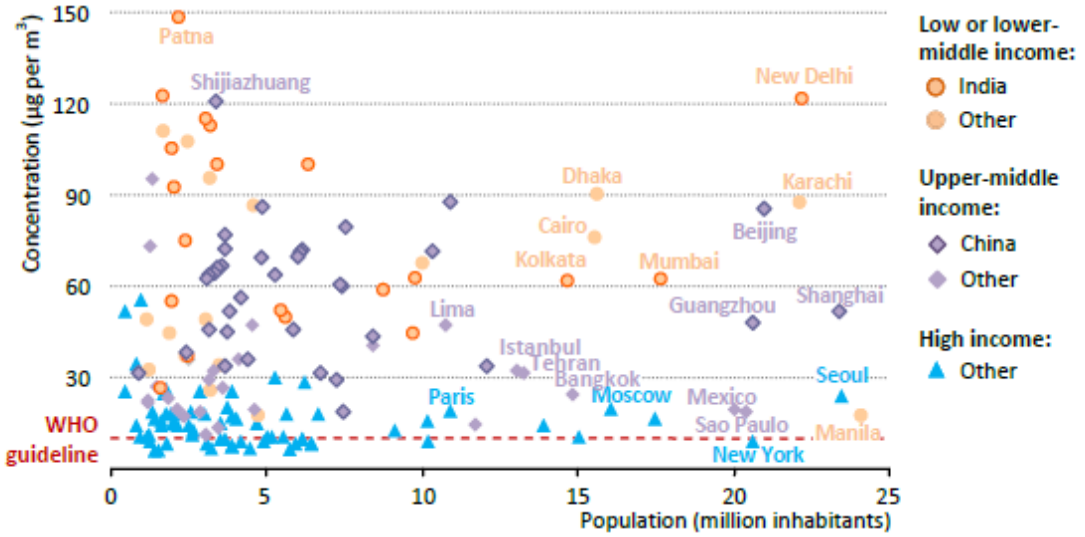


**Figure 1.8.** Average annual $PM_{2.5}$ concentrations in determined cities (IEA 2016)

High-income economies have significantly reduced their sulfur dioxide concentrations due to efficient pollution control. Very high concentrations of $SO_2$ can be observed in cities with high industrial activities which are placed especially in developing countries. Particularly at the ports in the coastal regions, high $SO_2$ concentrations in ship emissions are the greatest cause of total sulfur dioxide pollution. Since the middle of the 1990s, there has been increment in $NO_2$ concentrations in China, India and the Middle

East, while in the same period, the concentration of $NO_2$ in the majority of cities with high-income economies tended to decrease. In 2013, annual $NO_2$ concentrations were reported above the threshold values in almost all European Union cities with a population greater than 500,000, and were clearly above the goal in cities like Paris, London and Milan. Urban areas in developing middle- and low-income countries have high rates of air pollutants because of the increased number of vehicles, energy production increment and industrial growth (IEA 2016). It is necessary to establish various legal restrictions and control mechanisms in order to reduce these high pollutant emissions and to bring them below the limit values. That is, national governments should establish and implement air quality management programs.

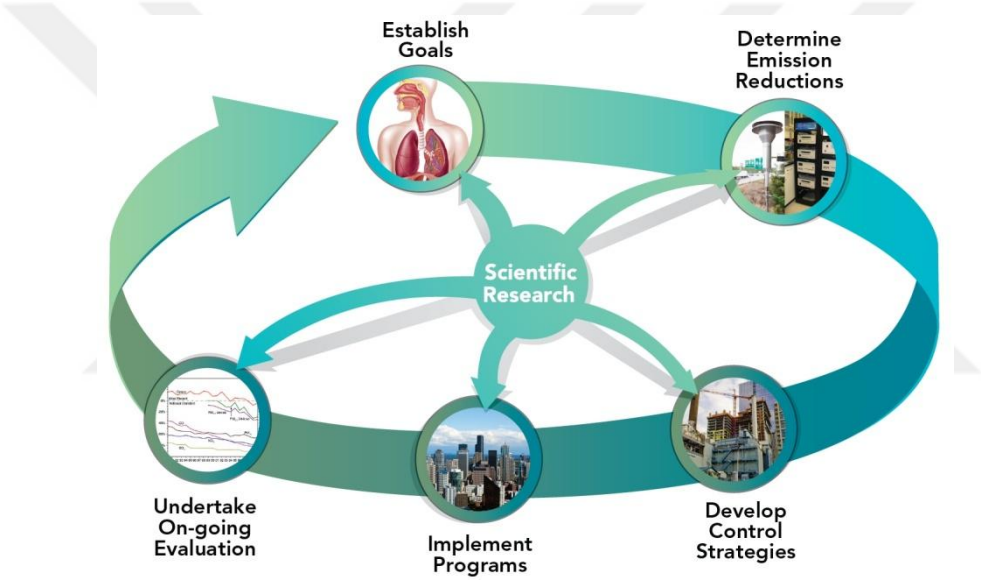


**Figure 1.9.** Air quality management cycle (USEPA, 2017a)

Air quality management is the whole of the planned and structured actions to reduce the harm that air pollution has on people and the environment. In order to improve the quality of the air, decision makers need to see the current situation, formulate action plans by setting realistic and effective strategies. Short and long-term causes of air pollution in urban areas must be considered in these strategies and action plans to achieve a sustainable growth model (Elbir et al., 2010). The process of managing air quality can be illustrated as a cycle of inter-related elements as shown in Figure 1.9 (USEPA, 2017a).

- First of all, government has to determine goals related about reducing the emissions of air pollutants to an acceptable level that will protect public health. They use emissions inventories, air monitoring, air quality modeling and other assessment tools for this purpose to understand the air quality problem fully.
- In developing control strategies, decision makers consider pollution prevention and emission control techniques which can be applied to achieve the goals.
- To successfully achieve the air quality goals, decision makers need to implement programs for pollution control strategies. Regulations or incentive programs have to be applied to lower emissions. Regulated industries need training and assistance in to comply the rules (USEPA, 2017a).

**Table 1.5.** Limit values for main air pollutants according to Turkish Regulations (MoEU, 2008)

| **Concentration µg/m$^3$** | **$PM_{10}$** | **$NO_2$** | **$SO_2$** | **$O_3$** |
|---|---|---|---|---|
| Annual mean | **40** | **40** | - | - |
| 24-hour mean | **50** (cannot be exceeded 35 times in a year) | - | **125** (cannot be exceeded 3 times in a year) | - |
| 8-hour mean | - | - | - | **120** |
| 1-hour mean | - | **200** (cannot be exceeded 18 times in a year) | **350** (cannot be exceeded 24 times in a year) | - |

In order to minimize the effects of air pollution on natural environment and human health in Turkey, Air Quality Assessment and Management Regulation has been published in Official Journal No. 26898 dated 6 June 2008. According to this regulation, limit values are given in Table 1.5 for main air pollutants. In addition, the Ministry of Environment and Urbanization has taken the necessary precautions for the sources causing air pollution (heating, industry, traffic) to regulate the control of air pollution caused by them (MoEU, 2010a).

#### 1.1.3.1 Road traffic emission inventory

Population density and energy use are generally directly proportional with air pollution factors because of the increasing requirement of the energy related activities. Nearly

four billion people (54% of the total population) accounting for around 80% of global economic activity live in urban areas. Cities that host a large population are compact areas to access energy services easily. However in urban areas, the intensive use of highways and the intense emissions of air pollutants due to the dense population are big problems. Excessive road networks in urbanized areas and heavy traffic, inadequate public transport planning, building density and height, topographic and meteorological dynamics are important factors in increasing air pollution load (IEA, 2016).

From emissions point of view, the anthropogenic sources are categorized namely point, area, and line source. The point sources represent industries and power plants. Area sources include household/domestic cooking, bakeries and restaurants, major construction sites and road dust. The line source represents the total vehicle over different types of road. Among these sources, the line sources are major contributors to the pollution load (Mishra and Goyal, 2015).

Emission inventories are important data sets which show the amount of air pollutants from different sources in a specified geographical area. Inventory data contains; pollutant type, amount of the emissions in a specific time (emission rate), source of emission and position of the source (Sari and Bayram, 2014). Emission inventories are the primary inputs of the air quality models with the meteorological conditions and topography that give very important outputs for policy–makers by quantifying the impact of various sources (Markakis et al., 2012; Sari and Bayram, 2014).

The levels of pollutant emissions from vehicles depend on vehicle specifications, operating conditions, maintenance level, fuel specifications, temperature and humidity. The pollutant's emission factor is defined as the estimated average emission rate of a particular vehicle category. Vehicle emissions are calculated by multiplying the distance taken by a specified vehicle type with an emission factor of pollutant that is sourced from that vehicle (Faiz et al., 1996). Motor vehicle emissions depend on:

1. Vehicle and Fuel Specifications
    - Engine type and technology
    - Exhaust and evaporative emission control systems in place
    - Engine’s mechanical condition and maintenance

- Fuel properties (aromatics, olefin content) and additives (lead)

2. Traffic Specifications
    - Vehicle composition (number and type of vehicles in use)
    - Usage of vehicles (kilometers per vehicle per year) by vehicle type
    - Age profile of the vehicles in use
3. Operating Characteristics
    - Altitude, temperature, humidity (for $NO_x$ emissions)
    - Vehicle use patterns - speed, driving behavior (aggressive or calm)
    - Traffic congestion ratio (Faiz et al., 1996).

Generally, the most preferred emission factor catalogues are; European Environment Agency's air pollutant emission inventory guidebook (EMEP/EEA, 2016), USEPA emission factors catalogue (USEPA, 2007) and Intergovernmental Panel on Climate Change Guidelines (IPCC, 2006). EMEP/EEA emission factors are preferred in this study because; there are a number of calculation options in any complexity that can be chosen depend on possessed data. Moreover there are methods which can be applicable for countries with older vehicle fleets.

Mishra and Goyal studied to explore total emissions from the different emission sources such as vehicular, power plants, industries, households and road dust for the year 2010 in Delhi. The inventory showed that the total emissions of CO, $NO_x$ and PM are 234.71 kt, 133.40 kt and 38.23 kt respectively over 26 km × 30 km region. The largest contributor of CO and $NO_x$ emissions are transport followed by the domestic sector, while vehicles, industries and power plants are approximately having equal contribution in PM emissions in Delhi (Mishra and Goyal, 2015).

Elbir was calculated the emission inventory of Turkey's primary air pollutants in Izmir, a region where the industry is concentrated. According to results, about 88% of the sulfur dioxide emissions in the study area is originated from industrial facilities, while domestic heating contributes to about 56% of the total PM emissions and 67% of $NO_x$ emissions sourced from road traffic (Elbir, 2004).

The hourly emissions of 23 large non-methane volatile organic compounds (NMVOC) and 16 gaseous and particle types were calculated for the Istanbul region in 2012. According to results, road traffic is the dominant source of CO, $NO_x$ and NMVOC. Combustion in the energy and industrial activities are the main sources of $SO_x$ emissions, while the cargo ships also make a remarkable contribution. While the main contribution to $PM_{10}$ emissions is the industrial activities, the fine particles are equally spread by the industrial processes and road transportation (Markakis et al., 2012).

#### 1.1.3.2 Air quality modeling

Especially in developing countries, there is an extraordinary growth in terms of the urban infrastructure, vehicular growth and the industrial activities for last decades. As a result of increasing urbanization rate, ambient air quality becomes the main environmental concern all around the world. The major sources of air pollutants can be classified as vehicular traffic, domestic, industrial and thermal power plants, etc. (Mishra and Goyal, 2015).

Urbanization cause changes in air quality by affecting local and regional climate with changing meteorological parameters. Widespread air quality measurements on correct places are extremely important to present the problem (Kindap et al., 2008). However, continuous air pollution monitoring is not feasible and applicable method due to the financial and practical limitations (Gibson et al., 2013). Because of these reasons, air quality modeling can be classified as a suitable way to understand the effects of urban air pollution. Detailed emission inventory studies should be carried out in order to make air quality models (Kindap et al., 2008).

Dispersion modeling systems can be used to estimate the atmospheric concentrations of defined air pollutants at receptors, in any climate, given emission source characteristics (type, point, line, volume and area sources), terrain, land use and meteorological conditions (Gibson et al., 2013). There are many dispersion models that have been developed and in use all around the world. There are so many studies of the USEPA about this issue. USEPA have developed various models to simulate air quality in different scenarios. AERMOD Modeling System, CALPUFF Modeling System, BLP, CALINE3, CAL3QHC/CAL3QHCR, CTDMPLUS, and OCD are preferred and recommended models for use by USEPA (USEPA, 2017c).

In capital of China, Beijing's mainland, AERMOD was used to calculate the air pollution concentration associated with traffic. The distribution of CO concentration was calculated to assess the effect of population exposure from traffic sourced air pollution. They found a correlation between traffic speed, traffic intensity and traffic related CO concentration. Moreover, the results also show that the CO concentration in the traffic is higher in morning and evening peak hours and shows higher impacts on public health in the case of calm wind condition (Pan et al., 2016).

A comprehensive emission inventory of the Kütahya city in Turkey was prepared for the year of 2014 to determine sources and distribution of the major pollutants including $SO_2$, $NO_x$, $PM_{10}$, and CO. The AERMOD dispersion model was used to calculate air concentrations and total emissions of $SO_2$, $PM_{10}$, $NO_x$, and CO. They were calculated as 64399, 9770, 24627, and 29198 tons/year, respectively. The results showed $SO_2$, $NO_x$, and $PM_{10}$ emissions were mainly emitted from industrial facilities. Domestic heating and road traffic were the most contributing sectors for CO emissions. Residential heating with high lignite consumption and road traffic in urban areas were the main contributors of total $NO_x$ and CO concentrations in the study area (Tuygun et al., 2017).

Emissions of five pollutants ($NO_x$, CO, $SO_2$, NMVOC and $PM_{10}$) were calculated and emission inventory was used to calculate dispersion of these pollutants in the atmosphere of the Izmir by using an air quality dispersion model that is called CALPUFF. According to study results, the total emissions given to the atmosphere during a week have been found as 108 tons for carbon monoxide, 14 tons for non-methane total volatile organic compounds, 48 tons for nitrogen oxides, 2 tons for particulate matter and 6 tons for sulfur dioxide for the winter season. For summer season, these values change as 107 tons for CO, 15 tons for NMVOC, 48 tons for $NO_x$, 2 tons for $PM_{10}$ and 7 tons for $SO_2$. Model results show that the maximum concentrations appear on the streets or just a few hundred meters away from the streets. It was also seen that the concentrations on summer days are higher than those of in winter (Elbir et al., 2008).

For the demonstration of air pollutants' concentrations at any region, USEPA prefers the steady-state model AERMOD and Lagrangian puff model CALPUFF in the near field (<50 km) and far field (>50 km), respectively. The AERMOD modeling system is

developed by the American Meteorological Society and USEPA (Rood, 2014). AERMOD uses the assumption of "non-gaussian probability density function" for cases where the air is unstable and the gaussian distribution when it is stable. The concept of "heat island" is taken into account in the urban areas modeling. It also gives more accurate results for areas with complex topography. In the model, the surface roughness length significantly influences the concentration results. According to previous studies, the AERMOD model shows high sensitivity to wind speed, wind direction and surface roughness length (Laffoon et al., 2005). Because of these reasons, AERMOD was used to calculate the distribution of the traffic sourced air pollutants in the city center of Trabzon.

*General information about AERMOD*

The AERMOD modeling system is developed by the American Meteorological Society and USEPA (Rood, 2014). According to USEPA definition; "AERMOD modeling system is a steady-state plume model that calculates the air distribution by processing boundary layer turbulence structure, simple and complex terrain information, and various sources" (USEPA, 2017c). Gaussian Model (A steady-state dispersion model), AERMET (meteorological data preprocessor) and AERMAP (a terrain data preprocessor) are three modules of AERMOD software which is an integrated system. Figure 1.10 shows the flow diagram of AERMOD. Calculation of the boundary layer parameters is processed by AERMET as an input dataset for AERMOD. The profiles of the required meteorological factors' are produced by the meteorological INTERFACE which is placed in AERMOD. Moreover, AERMET transfers all meteorological survey to AERMOD (USEPA, 2004).

Surface characteristics in the form of albedo (the fraction of the incoming solar radiation reflected and scattered back to the atmosphere), surface roughness and Bowen ratio (the ratio of heat energy used for sensible heating to heat energy used for latent heating), standard meteorological observations (wind speed, wind direction, temperature, and cloud cover), are input to AERMET. AERMET calculates hourly planetary boundary layer parameters which are then passed to the AERMOD. These parameters are used to calculate vertical profiles of wind speed, lateral and vertical turbulent fluctuations, potential temperature gradient, and potential temperature. AERMAP uses gridded terrain data to calculate the land height scale, which represents

the height of the land effect. The land height scale is uniquely identified for each receptor site. Grid data required by AERMAP is sourced from input data. The height of the specified receptors is automatically assigned by AERMAP. For each receptor, AERMAP transmits the following information to AERMOD: receptor position, mean altitude above sea level, and receptor-specific terrain height scale (USEPA, 2004).

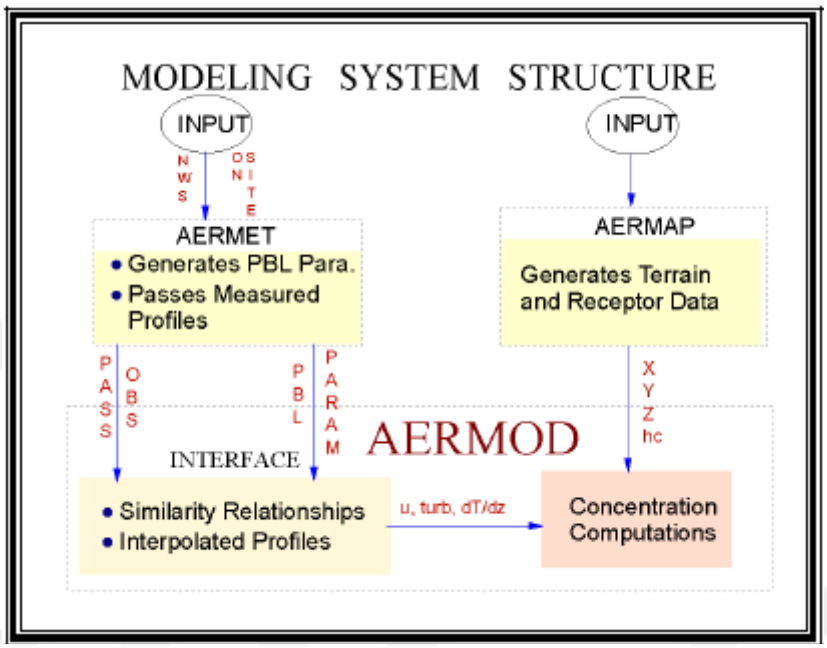


**Figure 1.10.** Flow diagram of AERMOD (USEPA, 2004)

## 1.2 Noise Pollution

### 1.2.1 Description of noise pollution

The vibrations of the material medium that create auditory sensation in the human ear are called sound. When a flickering object is separated from the static balance position, it pushes and compress the air in front it. At the same time, pressure decrement is formed behind the vibrating object and the space behind is quickly filled by air. By this way, the pressure changes are transmitted to far points (Hansen, 2017).

All sounds have three characteristics;

- frequency,
- amplitude,
- wavelength

The frequency of a wave, f, is the number of cycles per second and is expressed in Hertz [Hz]. The average healthy human ear can detect sounds from about 20 to 20,000 Hz. Sounds with higher frequency are generally heard as sounds with a higher 'pitch' and variations in pitch create a musical melody (Murphy and King, 2014). The voices that we hear contain different frequencies (vibrations in different thinness and thickness) . The time taken to complete one repetitive cycle is called the period, T, measured in seconds. The relationship between frequency and period is shown in Equation 1.1.

$$f = 1/T \text{ [Hz]} \tag{1.1}$$

The amplitude of a wave is represented by the maximum value of pressure in the vertical direction. It corresponds to the amount of energy in the wave. Sounds with higher amplitude have a greater intensity. The wavelength, l, is the distance (measured in meters) travelled by a wave during one oscillation. The wavelength can be measured between two successive positive peaks in the cycle and corresponds to the physical size of a wave (Murphy and King, 2014).

Acoustic pressure is the air pressure changes which are caused by the sound vibrations. Sound power is the propagation speed of acoustic energy. Noise intensity is defined as the average value of the sound energy passing through the unit area (1 $m^2$) perpendicular to the direction of propagation. In the theoretical analysis of acoustic phenomena, acoustic pressure, sound intensity and sound power are utilized. In practice, it is more appropriate to use these quantities in levels, especially in measurements. Decibel (dB) is the unit of level describing the ratio of two magnitudes with power. Level (dB) is a logarithmic magnitude (Rossing, 2007).

$$\text{Level (dB)} = 10\log (x / x_0)^{n} \tag{1.2}$$

X = current value in the environment in reference size

$X_0$ = reference size (eg 0,0002 μbar for sound pressure)

N = 2 for acoustic pressure, 1 for power and intensity

The human ear is not sensitive to all frequencies at the same time. We are more sensitive to high frequencies (high-pitched voices). Our hearing is sensitive to the changes of frequency and level. "A weighted sound levels dB(A)" has developed by

taking into account the auditory sensitivity of human ear. The dB(A) values consider the reduction of the sensitivity of the human ear to the deep voice. This means, it applies filter to the sounds like our ears do. Equivalent continuous sound level [Leq (dBA)] is defined as a weighted level of the stationary sound, which has the same acoustic energy as the sound whose level changes over time, during the measurement or observation. Sounds can be formed from regular (frequency can be specified), or irregular (noncyclical) vibrations. Physically irregular sounds are called noise. Noise is usually formed from more or less frequency components whose frequency and level distributions are random (Hansen, 2017).

Noise sources can be defined as point (e.g., a wind turbine blade, an air condition unit, a factory or a vehicle) and line (such as road) source. As the sound moves away from a source in the open air, it is weakened by various attenuation mechanisms. Noise at the building shell can be calculated by taking into account the sound levels of the sound source and the variations on the way to the receiver. Sound reduces with distance from the source to the receiver, and increases with absorption and reflection (Figure 1.11). Atmospheric events also have positive or negative effects on the sound that reaches the receiver (IoAP, 2017; Murphy and King, 2014).

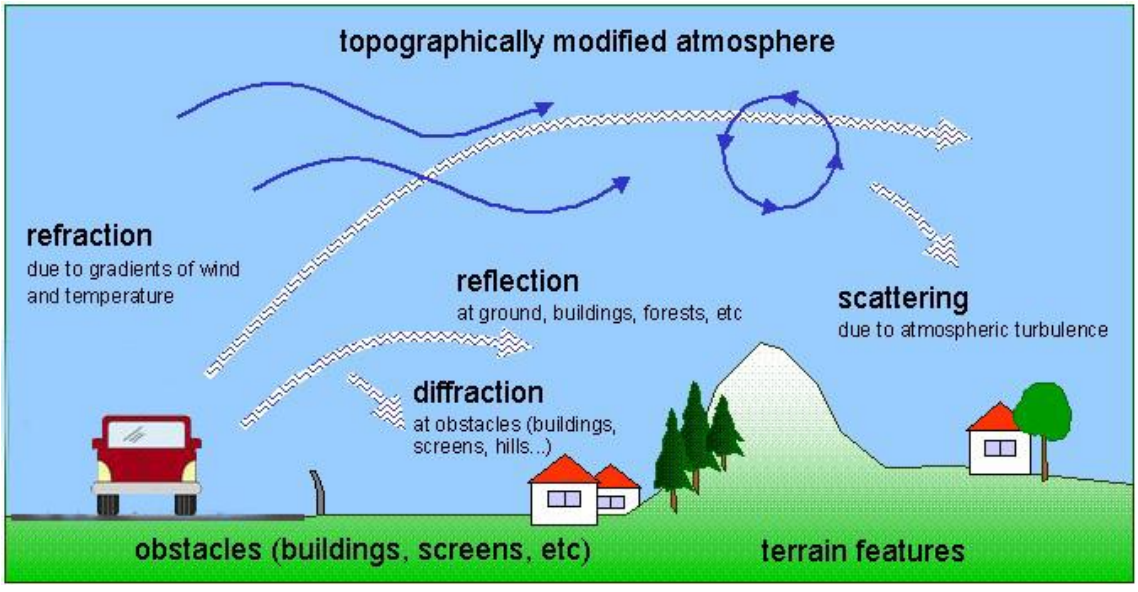


**Figure 1.11.** Noise propagation mechanisms (IoAP, 2017)

The calculation method is used for voice propagation mechanisms specifies the level of noise generated from the source and the procedures for determining attenuation as it moves away from the source of noise. If the receiver is sufficiently far away, the source may be accepted as a point source with a sound power $L_w$. The sound pressure level in the receiver, $L_p$, is simply formulated as below (where $A_{tot}$ represents the total attenuation);

$$L_p = L_w - A_{tot} \tag{1.3}$$

The total attenuation represents the sum of all forms of attenuation and may be calculated from:

$$A_{tot} = A_{div} + A_{atm} + A_{ground} + A_{diffraction} + A_{misc} \tag{1.4}$$

Where;

*Geometric Divergence ($A_{div}$)*; As sound propagates away from a source its energy is conserved – but it must be spread out over a wider area. In the case of a simple point source, propagating noise equally in all directions, the energy of the source is spread out over a sphere with surface area $4\pi r^2$.

*Atmospheric Absorption ($A_{atm}$);* As sound propagates through the atmosphere, its energy is gradually converted into heat through a number of molecular processes and this leads to a decrease in the sound level at a receiver point located some distance from the source. At distances close to the source the attenuation due to atmospheric absorption is negligible and only becomes obvious at great distances. Atmospheric absorption depends on four variables: frequency of the sound, atmospheric temperature, humidity and air pressure.

*Ground effect ($A_{ground}$);* Acoustic absorbent properties of a particular ground surface are directly related to its porosity. Compact grounds are generally reflective and porous ground types are generally absorptive. The acoustical properties of different ground surfaces are expressed through the use of a ground factor G, which is assigned a value of between 0 and 1, for which two types of ground surfaces are defined. A value of 0 corresponds to a reflective ground surface, a hard surface, while a value of 1 represents an absorbent ground surface, a soft surface.

*Diffraction ($A_{diffraction}$);* One of the most common measures for reducing noise is through the use of a noise barrier. A properly designed barrier will reduce noise propagating from source to receiver through diffraction over the top of the barrier or around its edges.

*Miscellaneous Other Effects ($A_{misc}$);*

- Temperature inversion: The speed of sound in air increases with temperature. Normally, the temperature of the air decreases with altitude. In special circumstances, a phenomenon known as temperature inversion may occur. In this case the temperature actually increases with altitude and sound waves are refracted towards the earth.
- Wind effects: If a receiver is downwind the wind will tend to bend the sound waves back towards the ground. However, when a receiver is located upwind from the source, the opposite occurs, and the sound waves tend to refract upwards (Murphy and King, 2014).

In humans, although emotional and physiological effects of exposure to the noise are often similar, they are subjective. We know that sensitivity to the noise of individual is changes. Two people who exposed to the same sound pressure may show quite different subjective responses in terms of annoyance and the psychological effects associated with them. In cities, rapid urbanization and the increased concentration of human settlement cause noisier environments, due to the high activities in relatively small areas. Noise has always been a problem especially for cities, but it is an environmental issue that is ignored. When compared to other environmental pollutants (for example air pollution), they are often not generally assessed in the same category and are of less importance (Murphy and King, 2014).

### 1.2.2 Sources and effects of noise pollution

#### 1.2.2.1 Sources of environmental noise

Environmental noise sources are generally compound sources, and there are many sources of noise at the same time. In this case, the priority is to analyze the noise emissions of each source, then calculate the total noise at which the sources at the same location on a given plane or line are at the same time. In the cities, some of the noises

that affect people originate from the inside of the building and the rest from the outside of the building (Kurra, 2009).

*Non-structural environmental noises;*

- Transportation noises: motor vehicle traffic, air and sea transportation
- Industry noises: all kinds of mechanical systems, equipment and manufacturing noises
- Production noises: road and building construction work and noise from machinery
- People and their activities, entertainment and commercial noise.

*Interior environmental noises;*

- Neighborhood voices in residential buildings
- Mechanical devices and equipment noises
- Electrical system noises

In practice, it is almost impossible to consider exposures from all sources because it is difficult to estimate exposure levels at population stage. For this reason, environmental noise management studies assess exposure to noise sources such as road, railway, air traffic, industrial and entertainment facilities (WHO, 1999; 2011).

#### 1.2.2.2 Effects of environmental noise

In the medical literature, there are two important ways to develop health effects that result from exposure to noise: direct and indirect arousal. Direct excitation is determined by the instantaneous interaction of the acoustic nerve with various structures of the central nervous system. The indirect path refers to the cognitive perception of voice as noise, the cortical activation and the emotional response associated therewith. The subjective effects of noise disturbance, not just noise itself, are associated with negative health effects. The indirect pathway begins with disturbances related with activities such as communication and sleep, which are caused by the noise (Murphy and King, 2014). Figure1.12 shows effects of noise exposure to health and well-being. In a population long-time noise exposure could be the reasons of stress reactions, sleep disturbances, and other biological and biophysical effects. For a relatively small portion of the population, subsequent changes may be converted to clinical indications such as

insomnia and cardiovascular disease, as a consequence, an increase in mortality rates may be observed (EEA, 2014).

*Sleep disturbance:* Noise can cause a change in sleep depth, making it difficult to fall asleep and causes a decrease in the rapid eye movement sleep (REM) rate, which is particularly important for health. Exposure to noise during sleep may result in increased blood pressure, increased heart rate, changes in respiration, and increased body movements.

*Cardiovascular and physiological effects:* Exposure to noise can increase blood pressure. Long-term exposures to noise may cause more permanent effects such as hypertension, heart problems and heart aging' in susceptible individuals.

*Mental health effects:* Exposure to environmental noise may cause anxiety, stress, irritability, nausea, headache, and mood swings. Research on the use of medicine such as sedatives, sleeping pills, and psychiatric symptoms suggests that environmental noise have implications for adverse effects on mental health (EEA, 2014).

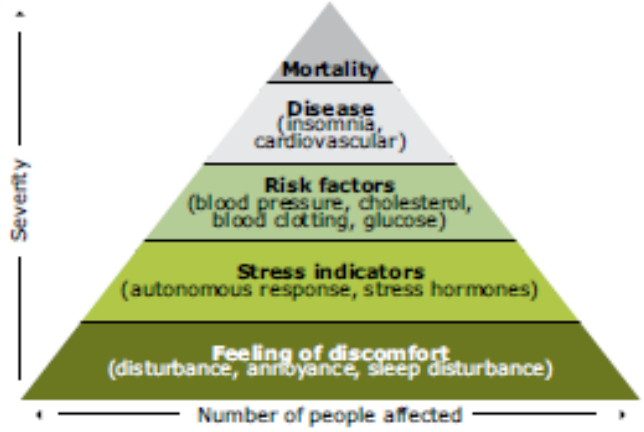


**Figure1.12.** Pyramid of noise effects (EEA, 2014)

*Annoyance:* It is defined as a sense of displeasure with a situation in which a person or group knows or believes that it is a negative factor. Short term annoyance effects may be observed such as communication and reduced school / work performance due to the exposure to environmental noise (Püschel and Evangelinos, 2012; WHO, 1999).

*Cognitive impairment:* The investigations have shown that noise from the airport and road traffic around the school is harmful to student's health, their reading ability and their cognitive abilities (Stansfeld et al., 2005).

*Economic impact:* The European Commission estimated that in 1996, the annual economic loss due to environmental noise potentially ranged from 13 million euros to 30 billion euros. Reduction in home prices, reduction in land use, increased medical costs, and decreased productivity at work are the examples of external costs which is related with environmental noise (EEA, 2014).

### 1.2.3 Environmental Noise Management

WHO studied about the environmental burden of the disease methodology for ischemic heart disease, cognitive impairment in children, sleep disturbance, tinnitus and annoyance that is caused by environmental noise. The results of this study show that at least one million years of healthy life disappear every year due to the traffic-related noise. Sleep disturbance and annoyance, mostly related to road traffic noise, constitute the fundamental burden of environmental noise (WHO, 2011).

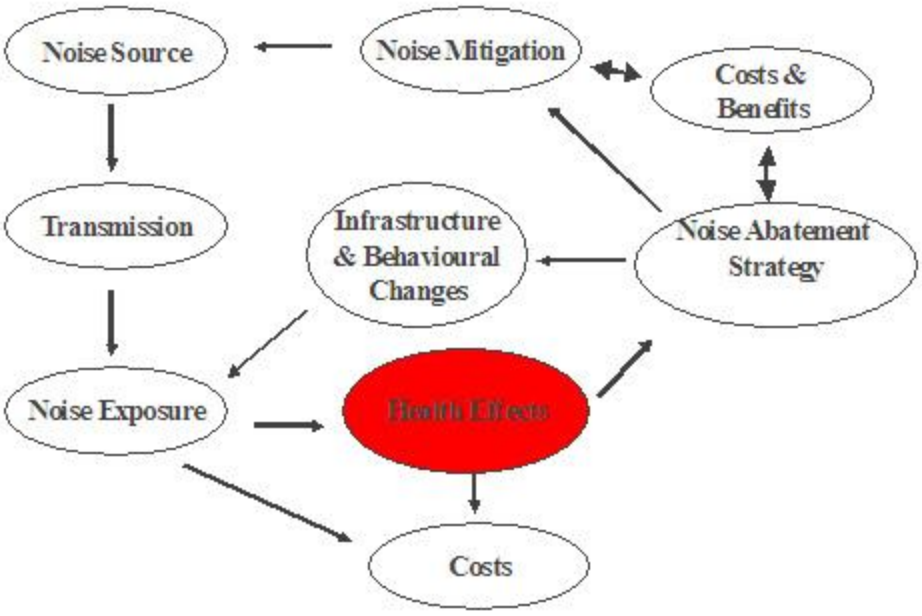


**Figure 1.13.** Environmental noise management process (Schwela et al. 2008)

Government officials, in co-operation with other partners, can determine the steps of the enforcement of Environmental Noise Management (ENM) process. An effective ENM includes, resource information, noise monitoring networks, noise estimation models, exposure and damage assessments, health-based standards and cost-effective exposure control measures, and legislative authorities and resources. Steps of environmental noise management process is shown in Figure 1.13 (Schwela et al., 2008)

The Environmental Noise Directive 2002/49 / EC (END) is the most important document of European Union which is used for the development of land-based noise emission monitoring and mitigation activities. This directive defines the environmental noise as unwanted or harmful open air sound caused by anthropogenic activities such as, transportation, road traffic, rail traffic, air traffic and industrial activities. To achieve END's objectives, three important issues are listed below:

- Determination of exposure to environmental noise
- Informing the public about environmental noise and its effects
- Prevent and reduce environmental noises.

The directive deals with the noise that people are exposed to in schools, hospitals and other noise sensitive buildings and areas, especially in public areas, public parks or other silent areas. Many calculation models can also be used to calculate exposure to noise for future scenarios based on estimated changes in noise sources. In assessing the exposure, best practice methods should be determined by assumptions and limitations for measurement or calculation. For example, in assessing exposure to transportation noise, the area where the noise exposure is highest is used for representation. However, this may not always be a good approach, because the rooms where people spend most of their time may not be on the most exposed side of the house. Noise exposure mapping is a widely used method for estimating the exposure of a population to noise. According to the END, it is necessary to prepare and publish noise maps and noise management action plans every 5 years for noise sources in agglomerations with more than 100,000 inhabitants. These noise sources are defined as main roads with more than 3 million vehicles per year, railways with more than 30 thousand trains per year, and airports with more than 50 thousand flights in a year (END, 2002; WHO, 2011). The authorities of

the member states should consult the relevant public while developing noise management action plans (END, 2002; MoEU, 2010b).

Many noise indicator definitions are identified for the representation of important noise levels such as $L_{den}$, $L_{day}$, $L_{evening}$ and $L_{night}$. Daytime, evening time, nighttime noise indicator ($L_{den}$): The intensity of the long-term A-weighted sound level, the level of influence used to express the daily total illness which is defined by the following formula:

$$L_{den} = 10\lg\frac{1}{24}\left(12*10^{\frac{L_{day}}{10}} + 4*10^{\frac{L_{evening}+5}{10}} + 8*10^{\frac{L_{night}+10}{10}}\right) \quad (1.5)$$

in which:

- $L_{day}$ is the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the day periods (07.00 to 19.00) of a year,
- $L_{evening}$ is the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the evening time periods (19.00 to 23.00) of a year,
- $L_{night}$ is the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over all the night periods (23.00 to 07.00) of a year (END, 2002).

WHO guidelines show health criteria for specific environmental conditions which is shown in Table 1.6. When guideline values are set, all adverse health effects are considered for the designated environments. A negative effect of intensity means a temporary or prolonged deterioration of the physical, psychological or social functioning associated with exposure to noise (WHO, 1999). Identification and reduction of noise sources exposed by citizens living in developed and developing modern cities are among the main subjects of politicians, administrations and technical-scientific institutions. Environmental noise management is a tool to identify targets for sustaining and reducing the impact on human health by creating a low-noise sound wave (Schwela et al., 2008). High noise levels are defined in the Seventh Environmental Action Program of Europe as noise levels for $L_{den}$ above 55 dB(A) and for $L_{night}$ above 50 dB(A). Exposure to high noise levels during the night causes sleep

disorders. Long-term exposure to noise above 55 dB (A) during the night may cause effects on the cardiovascular system (EEA, 2017a).

| Specific environment | Critical health effect(s) | $L_{Aeq}$ [dB(A)] | Time base [hours] | $L_{Amax}$ fast [dB] |
|---|---|---|---|---|
| Outdoor living area | Serious annoyance, daytime and evening<br>Moderate annoyance, daytime and evening | 55<br>50 | 16<br>16 | -<br>- |
| Dwelling, indoors<br><br>Inside bedrooms | Speech intelligibility & moderate annoyance, daytime & evening<br>Sleep disturbance, night-time | 35<br><br>30 | 16<br><br>8 | <br><br>45 |
| Outside bedrooms | Sleep disturbance, window open (outdoor values) | 45 | 8 | 60 |
| School class rooms & pre-schools, indoors | Speech intelligibility, disturbance of information extraction, message communication | 35 | during class | - |
| Pre-school bedrooms, indoor | Sleep disturbance | 30 | sleeping-time | 45 |
| School, playground outdoor | Annoyance (external source) | 55 | During play | - |
| Hospital, ward rooms, indoors | Sleep disturbance, night-time<br>Sleep disturbance, daytime and evenings | 30<br>30 | 8<br>16 | 40<br>- |
| Hospitals, treatment rooms, indoors | Interference with rest and recovery | #1 | | |
| Industrial, commercial shopping and traffic areas, indoors and outdoors | Hearing impairment | 70 | 24 | 110 |
| Ceremonies, festivals and entertainment events | Hearing impairment (patrons:<5 times/year) | 100 | 4 | 110 |
| Public addresses, indoors and outdoors | Hearing impairment | 85 | 1 | 110 |
| Music and other sounds through headphones/ earphones | Hearing impairment (free-field value) | 85 #4 | 1 | 110 |
| Impulse sounds from toys, fireworks and firearms | Hearing impairment (adults)<br><br>Hearing impairment (children) | -<br><br>- | -<br><br>- | 140 #2<br><br>120 #2 |
| Outdoors in parkland and conservations areas | Disruption of tranquillity | #3 | | |

#1: As low as possible.
#2: Peak sound pressure (not LAF, max) measured 100 mm from the ear.
#3: Existing quiet outdoor areas should be preserved and the ratio of intruding noise to natural background sound should be kept low.
#4: Under headphones, adapted to free-field values.

**Table 1.6.** Guideline values for community noise in specific environments (WHO, 1999)

Noise from road traffic alone is the second most harmful environmental stressor in Europe, behind air pollution, according to the WHO. More than half of the citizens of

the EU live in areas that cannot be provided acoustic comfort because of the transportation noise. On the roadsides where the traffic is heavy, the 24-hour equivalent sound pressure level can reach to 75-80 dB(A) levels (WHO, 1999). A survey of Agarwal and Swami was used to assess environmental noise disturbance with a questionnaire in Jaipur, India. Among all sources of noise, the road traffic was found to be the major source of noise with a rate of 65-85% (Agarwal and Swami, 2011).

In the 33 member countries of the EEA, around 100 million people are exposed to road traffic noise above 55 dB(A) and 32 million people are exposed to above 65 dB noise levels (Figure 1.14). Railways are the second largest environmental noise sources and 19 million people is exposed the railway noise above the limit values. Aircraft noise is the third main noise source, with more than 4.1 million people exposure in the close areas to major airports. Because of the industrial noise within urban areas, 1.0 million people is exposed to the noise levels above the limit values (EEA, 2017b).

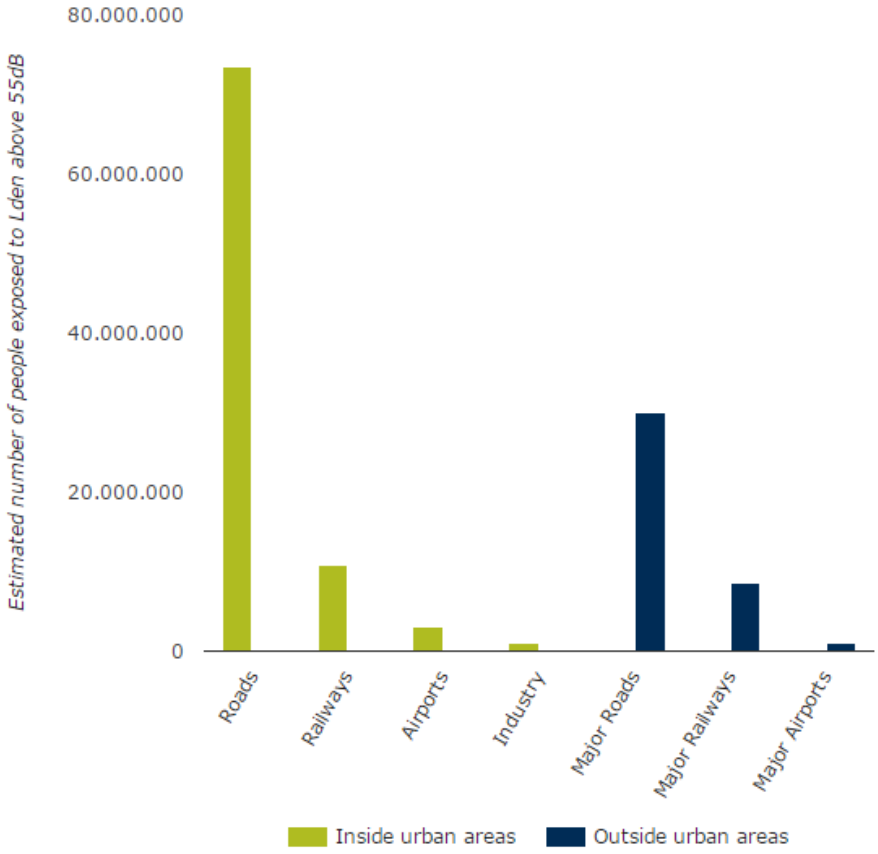


**Figure 1.14.** In 2012, Number of people in the EEA-33 member countries exposed to noise levels above 55 dB $L_{den}$ (EEA, 2017b)

WHO report shows that, in the EU, approximately 40% of the population during daytime hours is exposed to road traffic noise level of 55 dB(A) and above, 20% to 65 dB(A) and above, that is defined as unacceptable. At nighttime, 30% of the population is exposed to equivalent sound pressure levels that exceed 55 dB(A) value, and thus cause sleep disturbances (WHO, 1999).

Environmental noise that is caused from road traffic is also important problem in Turkey. Traffic noise levels were measured in 15 different measurement points in Sakarya line of highway D100 (E5). According to two months measurement results, limit values were exceeded in weekdays at all measurement points (Dal, 2016). Road traffic noise exposure was calculated in Malatya in 2016. As nearly 17,300 households with 4,700 buildings in the day-time, 32,900 households with 8,000 buildings in the evening time, and 36,500 households with 8,700 buildings at nighttime were exposed to noise levels that are above the limit values (Erdol et al., 2016).

**Table 1.7.** Environmental noise limit values for road traffic (MoEU, 2010b)

| **Areas** | **Planned / Renewed / Restored Roads** | | | **Existing Roads** | | |
|---|---|---|---|---|---|---|
| | **$L_{day}$ dB(A)** | **$L_{evening}$ dB(A)** | **$L_{night}$ dB(A)** | **$L_{day}$ dB(A)** | **$L_{evening}$ dB(A)** | **$L_{night}$ dB(A)** |
| Education, culture and health areas, as well as areas where summer camps and campsites are predominant, are sensitive to noise | 60 | 55 | 50 | 65 | 60 | 55 |
| Areas where commercial buildings and noise sensitive uses are concentrated in areas where houses are concentrated | 63 | 58 | 53 | 68 | 63 | 58 |
| Areas where workplaces are heavily involved in areas where commercial structures and noise sensitive uses coexist | 65 | 60 | 55 | 70 | 65 | 60 |
| Industrial areas | 67 | 62 | 57 | 72 | 67 | 62 |

In Turkey, Noise Control Regulation of 1986 has been revised within the framework of harmonization studies of European Union Directive 2002/49 / EC on Environmental Noise Management in the process of harmonization of the country with the EU and Ministry of Environment and Urbanization. "The Regulation on the Assessment and Management of Environmental Noise" has been prepared for this purpose. The limit values for different receivers are shown in Table 1.7. Environmental noise level caused by roads should not exceed these limits to protect the health of community (MoEU, 2010b).

#### 1.2.3.1 Road traffic noise emission inventory

Transportation; including road traffic, aircraft, and railway are the most common noise types among the environmental noise sources (Pearson et al., 2016). The most common and persistent noise in urban areas and settlements is the noise caused by the movement of motor vehicles on roads, which disturbs a large number of people. Today, the widespread use of highways has caused noise problems spreading over long distances in quiet areas outside the city. In the city, an integrated urban noise is generated by the contribution of various sources and motor vehicle traffic is dominant noise source in general. When a single vehicle is examined motor noise, exhaust noise, aerodynamic noise, tire-road surface friction sounds, brake sounds and horn sounds are the main sources of the total noise generated during stationary and in motion conditions (Kurra, 2009).

Classification of vehicles is important for the examination of the noise caused by motor vehicles. Vehicles are classified as heavy and light vehicles, depending on weight. Heavy vehicles with a weight greater than 3 tons like; large size trucks and buses are classified as heavy vehicles, automobiles and motorcycles are classified as light vehicles. According to the research results, noise emissions are increasing with; increased vehicle weight, outdated engines, increased motor speed and acceleration. Engine noise, which depends on engine speed, is higher in diesel engines. Generally, engine noise at low speeds, tire / road surface friction noise at high speeds, aerodynamic noise at medium speeds is important (Nelson, 1987; 1997).

When the spectral characteristics of road traffic noise are examined; noise levels were found to be higher at low frequencies. Reference loudness of heavy vehicles; it reaches

90 dB at low frequencies at 7.5 m from the roadside, but decreases to 45 dB at high frequencies. At about a "A" weighted total noise level, heavy vehicles have noise emissions around 80 dB(A) and light vehicles with around 70 dB(A) (Kurra, 2009).

The development of models to predict traffic noise started more than 50 years ago and, the results have often been very accurate. Usually these kind of models are developed taking into account mainly traffic flow, both of light and heavy vehicles, features of the road surface, distance between carriage and receivers. Moreover, several models have been developed all around the world in different countries. These models are; England standard: CoRTN procedure, German standard: RLS 90 model, Italian C.N.R. model and French model: NMPB – Routes. The predictions of NMPB-Routes-96 have been validated on a great number of experimental studies with various topography and meteorological conditions with founding a very good agreement with the measured noise data. Moreover, NMPB-Routes-96 actually represents the official standard traffic noise model adopted by the European community (Quartieri et al., 2009). Because of these reasons, this calculation method was preferred to calculate traffic noise emissions in Trabzon city.

#### 1.2.3.2 Noise modeling

Environmental noise maps are prepared to demonstrate the current or estimated noise levels caused by the noise sources (Licitra, 2013). The areas where noise limits are exceeded, affected the sensitive buildings (housing, school, hospital etc.) and population can be determined with noise maps. Noise maps are defined as layers of information which are added on geographic databases. In other words; it is the calculation of noise levels individually and the creation of noise contours for receiver points that are at a sufficient frequency in a specified region or area. The calculation points and the distances between them are determined in a specific order over the geographical maps and development plans of the land. For this reason, one of the most important steps in the preparation of noise maps is described as identification of physical environment data. Physical environment can be identified to the simulation software with many inputs such as the positions and heights of the buildings, the topographic situation, natural and artificial obstacles (TÜBİTAK, 2016b).

The noise mapping steps can be roughly summarized as follows:

1. Collecting, interrogating and arranging data so that they can become model inputs
2. Separate and integrated calculation for all noise sources with model software
3. Determination of noise contours
4. Identification and presentation of noise effects (Figure 1.15) (Kluijver and Stoter, 2003).

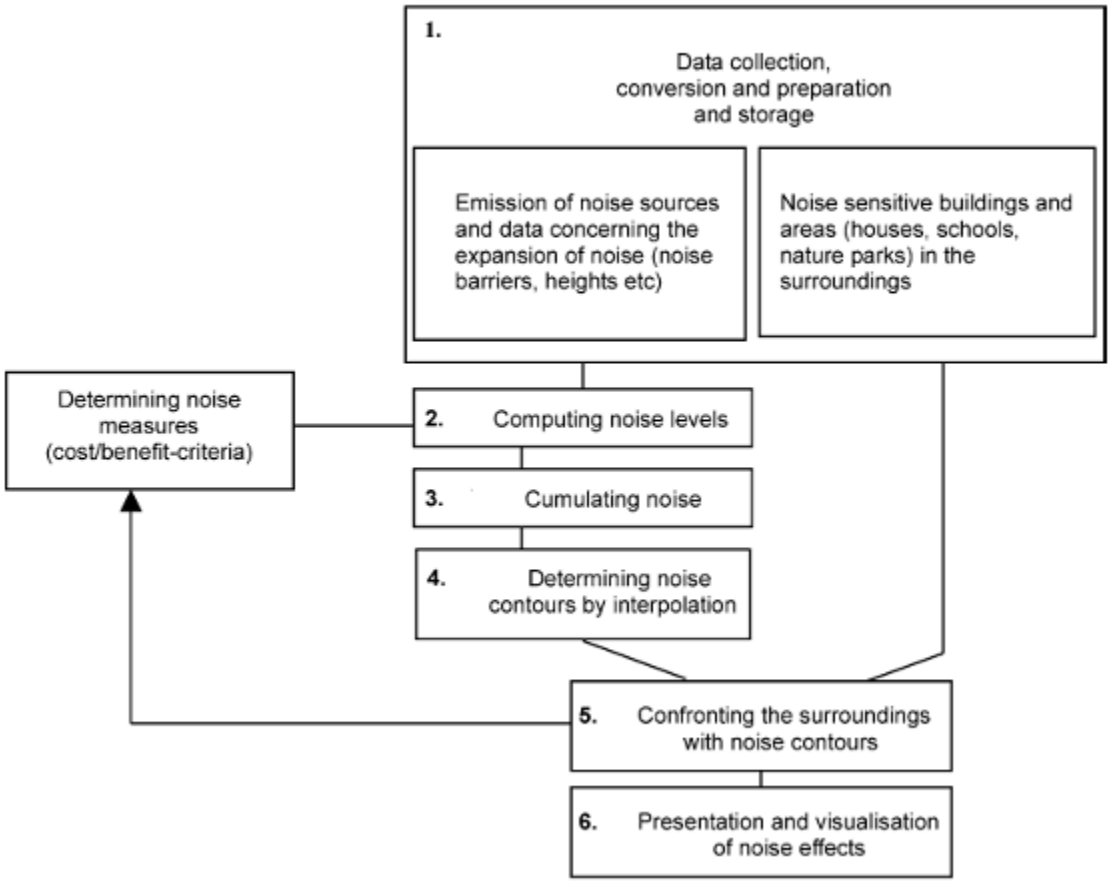


**Figure 1.15.** Schematization of the noise mapping process (Kluijver and Stoter, 2003)

Noise modeling harmonizes complicated noise spectrum and environmental noise evaluation in terms of cumulative noise exposure. Recognizing the environmental noise issues is very complicated and noise mapping could be defined as one of the easiest way for this. Noise maps consist of many receivers organized on a regular grid to show the spatial distribution of noise levels which is used for computing the exposed area, the

number of the critical buildings (house, hospital, school etc.) and the amount of people who are affected (Kluijver and Stoter, 2003; Ozkurt et al., 2015).

Simulation tools are especially useful in planning stages where measurement is not possible. CadnA and SoundPLAN softwares are widely used for noise mapping. In this study, the noise emitted by road was modeled by SoundPLAN in accordance with the standards in European Directive 2002/49/EC and Turkish Environmental Noise Assessment and Management Regulation.

*General information about SoundPLAN*

SoundPLAN is a software package created by qualified people that is specialized in the computer based simulation of noise pollution. Modeling package includes traffic, indoor and outdoor, industrial and aircraft noise. It contains more than 50 calculation standards to meet the needs of noise control programs (SoundPLAN, 2017).

The first step of the modeling is the simulation of the terrain with geographic database preparation. Coordinates, terrain elevations (x, y, z (height)) and building information system (purpose of the buildings, number of floors, number of flats in the building, living population etc.) are the main inputs of model. Information of population in the study area is processed as a secondary dataset. If there is population information in the building information system, population density is automatically calculated. If this is not the case, population is distributed to the residential areas and population density can be calculated. The third dataset describes the information about noise sources to be modeled. Sources can be classified as airports, highways and railways as well as industrial and entertainment facilities. Using the prepared noise source inventory, noise levels are estimated in the receiver points with the calculation methods which are among the standards specified in Turkish Environmental Noise Assessment and Management Regulation (TÜBİTAK, 2016b).

Noise distribution in London and the surrounding area was calculated by using a road traffic noise calculation method (CoRTN). The results showed that 12% of the population, or about 1.03 million people, are exposed to daytime traffic noise levels above 65 dB (A) and 1.63 million (19%) are exposed to night traffic noise levels above 55 dB (A) (Gulliver et al., 2015).

In Seoul, Republic of Korea, traffic noise levels were modeled with SoundPLAN and exposure to noise was estimated. It has been found that; 20% or more than in eight districts, 10% to 20% in eleven districts and less than 10% in the six districts' total population are exposed to higher noise levels than limit values in the daytime. In fourteen districts, it was estimated that more than 30% of the total population was exposed to higher noise levels than the night threshold (Lee et al., 2014).

Noise levels and exposed population was calculated in Mersin city center by TÜBİTAK Marmara Research Center with SoundPLAN software. According to road strategic noise map results; during a day, 47,300 people, 11 schools, 3 hospitals affected by noise level of 75 dB(A) or higher road traffic sourced noise levels and 596.600 people, 188 schools, 39 hospitals affected by 55 dB(A) or higher traffic sourced noise levels (TÜBİTAK, 2016a).

### 1.3 Correlation between Road Traffic Related Noise and Air Pollution

In urban areas, people are simultaneously exposed to both noise and air pollutants (King et al., 2016). It is obvious that noise and air pollution in combination is very important environmental hazard to public health (Vlachokostas et al., 2012). The health effects of noise and air pollutants related to traffic have been studied individually for many years (Shu et al., 2014). However in recent years, more interest have been shown on relationship between long term exposures to traffic-generated air pollutants and cardiovascular diseases, hypertension and mortality (Allen et al., 2009). Similarly, increasing association between road traffic noise and cardiovascular diseases is proved by many epidemiological studies (Bodin et al., 2009).

If cardiovascular diseases are associated with both traffic sourced air pollution and noise, there could be correlation between them (Allen et al., 2009). Combined effects of road traffic sourced air pollution and noise was studied in previous researches. It was found that both road traffic noise and nitrogen dioxide ($NO_2$) exposure were associated with a higher risk of myocardial infarction in single-pollutant models. In two-pollutant models, mainly noise was associated with myocardial infarction. Combined exposure to both pollutants was associated with the highest risk (Roswall et al., 2017). Combined effect of traffic related noise and air pollution was evaluated in other research. According to the data, each 10 dB(A) increase over the one year mean value of 42

dB(A) $L_{den}$, increase the risk of ischemic stroke for an individual by 16%. At the same time, 10 μg $NO_2$ per $m^3$ of air per year is increased the risk of this disease by 11%. $NO_2$-noise combination above 15.7 μg/$m^3$ and 62.1 dB(A) $L_{den}$, respectively, increase the risk of stroke by 28% (Sorensen et al., 2014).

In another research, the environmental annoyance of humans was examined according to air pollution and traffic noise levels with an integrated alternative approach to the Oslo traffic survey. The results showed that, if people are exposed to a higher level of air pollution, they are disturbed by road traffic noise at a higher level (Klaeboe et al., 2000).

The correlation between air and noise pollution originated from road traffic has been studied by many researchers. High correlations were found between 2-week average roadside nitrogen oxides ($NO_x$) concentrations and short term average noise levels ($L_{eq,5min}$) (Davies et al., 2009). There is a positive correlation between ultrafine particle number concentrations and noise levels, under downwind conditions (Shu et al., 2014).

In the fall of 2012, Equivalent sound pressure levels (Leq) was measured for 1 week in 56 New York locations where traffic and building density changed and combustion-induced air pollutants were routinely monitored. They found a high correlation between weekly NO, $NO_2$ and EC levels and equivalent continuous sound pressure levels (r = 0.61-0.68). A lower correlation was observed between $PM_{2.5}$ concentrations and noise levels (r = 0.45) (Kheirbek et al., 2014).

In recent years, population increase and unplanned urbanization, increasing trend in industrialization, coal usage for domestic heating purpose and high motor vehicle concentration in the city center have caused the increase of air pollutants in Trabzon. Because of the topographical structure, wind cycles are restricted and air pollutants are concentrated in the city center especially in stagnant atmospheric conditions. Besides the air pollution problem, environmental noise is also one of the major issues in the city center. According to the Provincial Directorate of Environment and Urbanization 2015 statistics, 39% of total received complaints are about environmental noise exposure in Trabzon (MoEU, 2016).

In this study, a traffic emission inventory in Trabzon was prepared to determine the concentrations of main pollutants ($NO_x$, $SO_2$, CO, PM and VOC). Calculated traffic

sourced $NO_x$ emissions were modeled for Trabzon city center by using AERMOD dispersion modeling system. The system contains three main modules: the meteorological model AERMET, a terrain pre-processor model AERMAP and the dispersion model AERMOD (Sari, 2011). Model results were evaluated with the help of the measurement data from four air quality stations of Ministry of Environment and Urbanization. In addition, noise levels sourced by road traffic for the day, evening and night time slices in Trabzon were calculated by SoundPLAN software according to the European Noise Directive (END). Trabzon road traffic statistics and road properties (slope, surface material), terrain and elevation data, number and location of residential buildings, hospitals and schools, population of the study area are the main inputs of the model. Model results were validated by site measurements in study area. Noise zones and the number of exposed people, households, schools and hospitals were estimated for study area in Trabzon. For both air pollution and noise models, many discrete receptors were defined on regular grid systems in the study area. Air pollutants' concentrations and noise levels were calculated for these receptors. The results were compared for three different time slices of a day. Comparison of outputs was used for the examination of relationship between air pollutants and noise exposure sourced from road traffic.

# 2 MATERIALS and METHODS

## 2.1 Study Area

In this study, Trabzon city center is selected as study area because of the intensity of road traffic in urbanized region. Moreover, air quality measurement stations are located very close to the road sections in city center which provide to observe road traffic sourced air pollution concentrations more clearly without other sources' effects.

There are four air quality monitoring stations of the Ministry of Environment and Urbanization in the city center of Trabzon which show the hourly emission measurements of the stations. These stations were used for air quality model validation. Moreover, eight measurement points were determined within the study area for the model validation of road traffic noises with 24 hours sound pressure level measurements.

Surface meteorological data were taken from Trabzon Airport Meteorological Station. Samsun Meteorological Station's upper air data is used for upper air meteorological observations.

Study areas' boundary layer, meteorological stations', noise level and air quality measurement points' locations and modeled roads in this study are shown in Figure 2.1.

### 2.1.1 General information

Trabzon is one of the important cities of Eastern Black Sea Region, which is located between 40° 33' and 41° 07' N latitudes and 39° 07' and 40° 30' E longitudes, occupies 0.6% of the country's territory with an area of 4685 $km^2$. The city of Trabzon's provincial border is surrounded by Giresun from the west, Gümüşhane from the south, Bayburt and Rize from the east. Black Sea is the northern neighbor of the city and the coastline of the Black Sea within the province borders is about 135 km (MoEU, 2016).

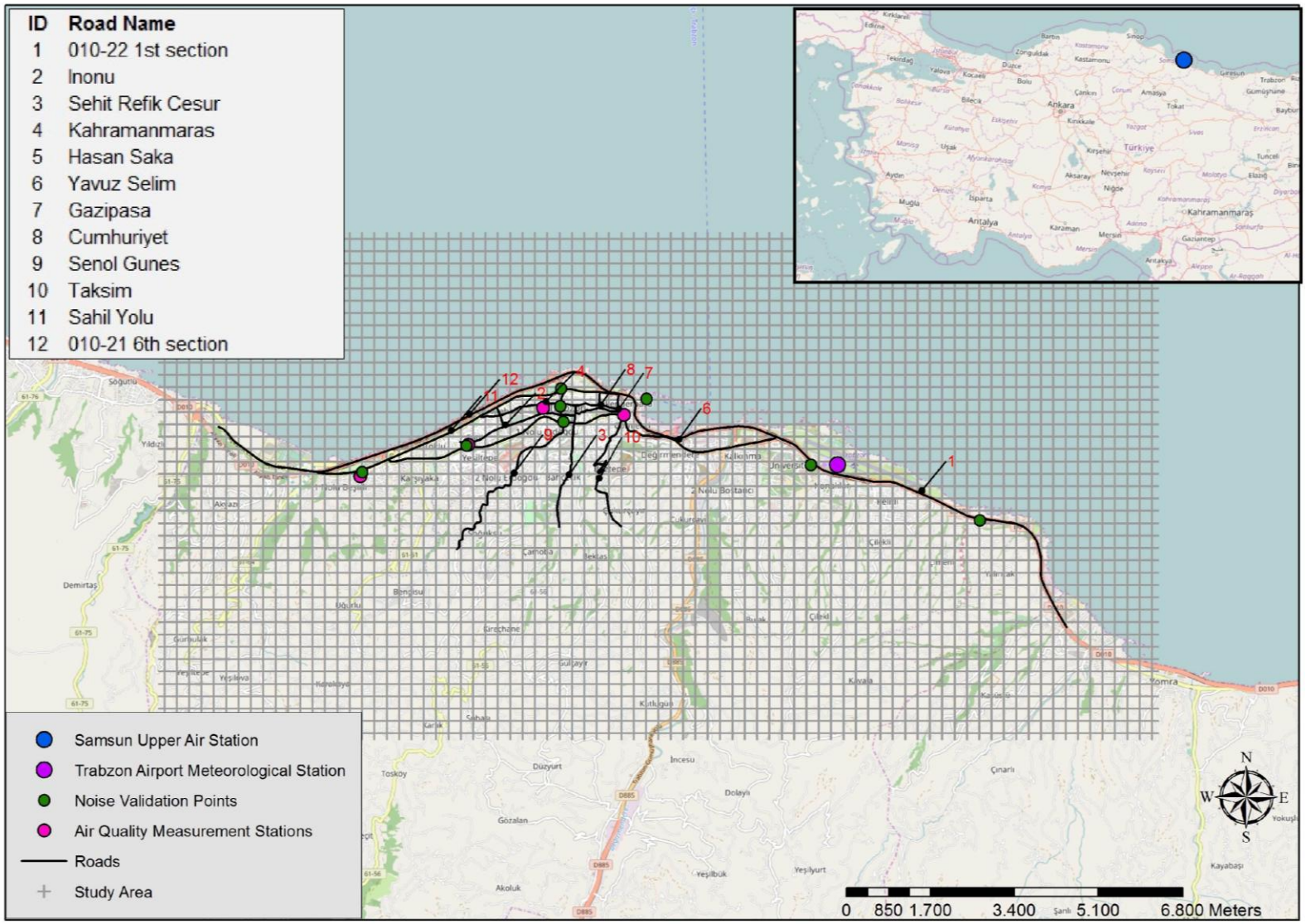


**Figure 2.1.** Study Area

Trabzon has mild climate which is affected by the sea. Summers are generally at moderate temperatures and winters are warm. Because of the depressions in the north-west direction, climate elements of the area change constantly. Due to its location, Trabzon has a distinctive feature all over Turkey in winter. The Caucasus Mountains surround the city all the way from the south and protect the city from the cold winds of the northwest. It also prevents the entrance of Siberia's cold air and the North East Anatolian plots' cooled air to the region. When monthly average rainfall amounts are examined, it is seen that August and November are dry (MoEU, 2016).

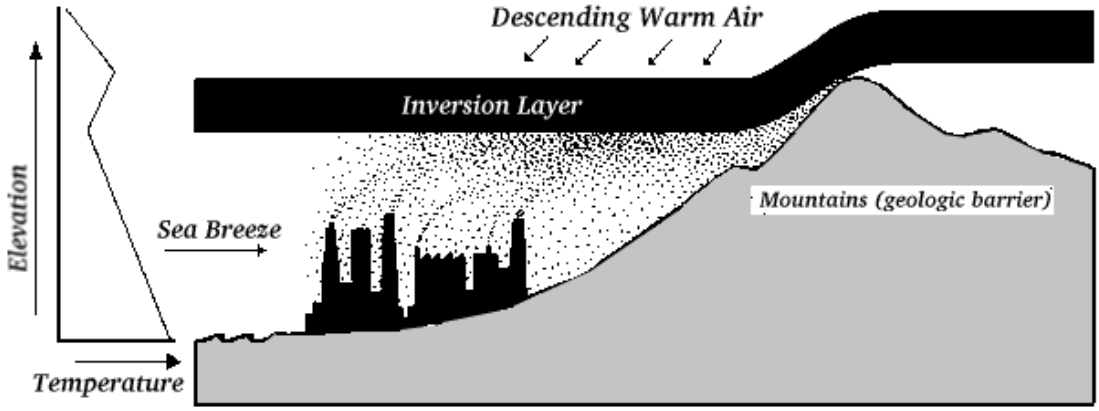


**Figure 2.2.** Inversion phenomenon in Trabzon city center (EarthSci, 2017)

Trabzon has elevated land structure and slopes are changing as going from coast to inland. Only 10% of the total area is flat and close to plain, 30% is mountainous. There are frequent cases of inversion in the city which affects the quality of the air in a negative way. Inversion frequently occurs in hillside and valley areas. Under high pressure conditions, in open air (in cloudless weather), in cold windy conditions, incoming cold air layer over mountain area or valley over the high elevation area gets jammed when descending from high elevation area. The jammed air mass heats up. This creates a hot air layer at a certain height from the ground. The ground-level air mass rises to the inversion layer. The inversion layer behaves like a lid, preventing air mass and contaminants from further rising and dispersing (Figure 2.2). Inversion occurs in the atmosphere in a few km from the ground. The altitude of the inversion layer is very important. If the inversion layer is formed at higher altitude, dilution rate of air in the atmosphere becomes higher. If the inversion layer's altitude is lower, removal time from

the environment will be longer. As a result, more severe effects of air pollution can be observed. In such mountainous regions, if poor quality fuels (sulphurous, ash and nematode, low calorie) are used for heating purposes in the winter months, the environmental impacts can be very harmful in inversion conditions (Kocaeli University, 2017).

Increasing concentration of motor vehicles in the city center and domestic heating are the main sources of air pollution in the city. In general, coal is used in urban areas and wood is used in rural areas for domestic heating purpose in Trabzon. Clean air programs for winter periods are being prepared within the scope of 2010/14 numbered Circular on "Control of Air Pollution", which was published in “Regulation on Control of Air Pollution Sourced from Heating” direction by Ministry of Environment and Forestry. Decisions regarding the fuels to be used in Trabzon were taken with the decision of the Local Environment Committee dated 6 December 2012, within the scope of this circular. Inspections are carried out at site / apartment and coal deposits in order to determine whether the use of high quality coal and burning boilers have been properly operated in order to reduce air pollution caused by heating. In order to reduce the air pollution problem especially in the city center, it is very important to use natural gas completely in the city and infrastructure works to achieve this goal are going on rapidly (MoEU, 2016).

### 2.1.2 Topography

Trabzon is a very mountainous region as other eastern Black Sea region cities. Altitude of the city is increasing from the sea to the south which reaches 3,000 meters on the southern border of the province. Mountains, hills and plains are usually located in region, except for the shoreline as shown in Figure 2.3. Trabzon Province, which is generally known as a plateau, is in the northern part of the 325 km long multi-terrain platform. In the area, mountains are extending parallel to the coast between Coruh Valley and Melet River. This platform was cut by the Coruh-Kelkit valley in the south. Zigana Pass that is placed in 2.000 m altitude connects Eastern Anatolia and Black Sea borders. Harşit and Coruh Valley and Kop Pass connect the region to Erzurum and Iran (MoEU, 2016).

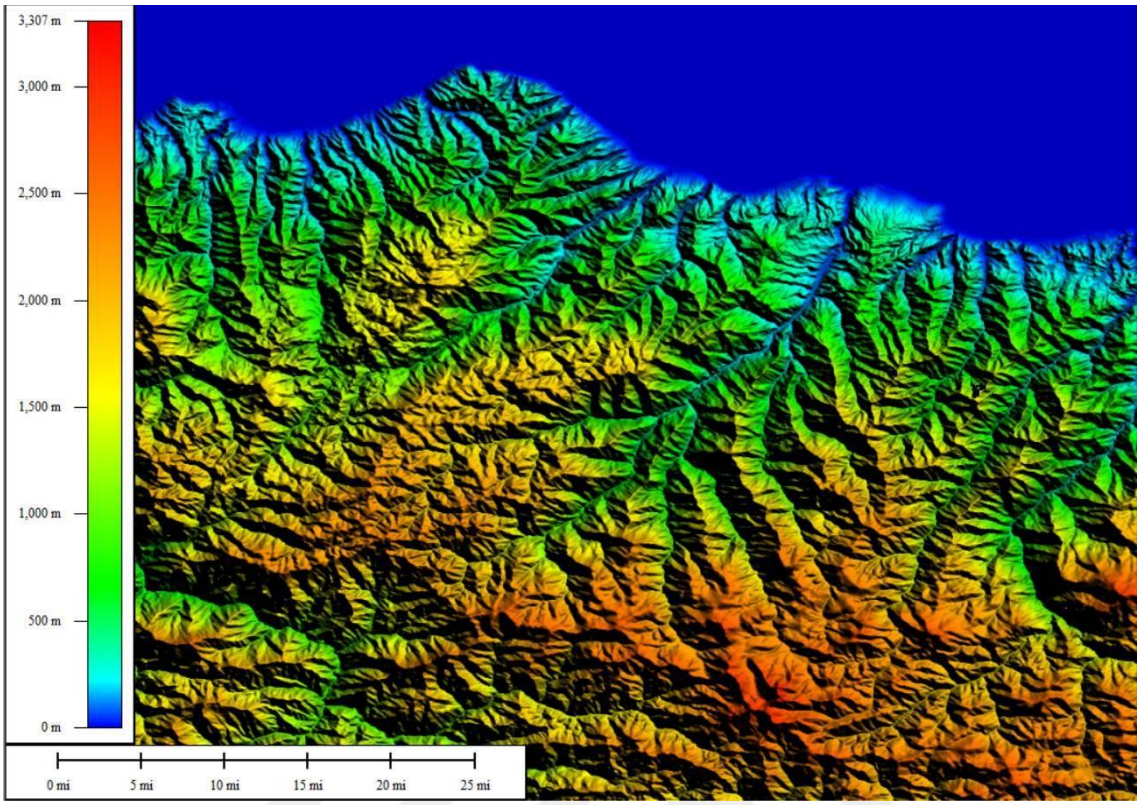


**Figure 2.3.** Topographical view of Trabzon city center

### 2.1.3 Land use

For the preparation of noise modeling and air quality modeling, land use information of the area was investigated. In this study, the Akcaabat and Ortahisar districts were discussed where the population is intense. Approximately 72% of the project area of Akçaabat province is in use for the purpose of agriculture. In Ortahisar province, about 84% of the project area is farmland. Land use information about Ortahisar district is given in Table 2.1.

### 2.1.4 Population

The increasing trend in the population of Turkey in 2016 is also observed in the population of the Eastern Black Sea Region. It has been detected 1.4 percent increment in Trabzon's population as of 31 December 2016 compared to the previous year. According to the results of population system based on address; the total population of the study area (city center) is 314,246 which contain 85 neighborhoods (TURKSTAT, 2016a).

**Table 2.1.** Ortahisar district's land use data (CORINE 2006) (TÜBİTAK, 2016b)

| Land Use (*) | Area ($m^2$) |
|---|---|
| Agriculture | 191,497,809 |
| Forests and semi-natural areas | 20,932,184 |
| City | 11,739,588 |
| Others | 2,795,417 |
| Airports | 1,363,319 |
| Harbors | 543,854 |
| Water bodies | 226,349 |
| Road, railway and related areas | 78,879 |
| **Total** | **229,177,399** |

(*) CORINE Land Classification System

### 2.1.5 Road traffic information

In this study, 53 km long roads were modeled. According to Trabzon Strategic Noise Map Report which was prepared by TÜBITAK, vehicle counts were carried out on a total of 12 road sections. Hourly vehicle counts were made at the busiest hours representing the time zone (day, evening and night) at these road sections. Vehicle counting data and length of the streets and highways under the responsibility of the General Directorate of Highways passing through the residential area are given in Table 2.2 for all time periods on an hourly basis (TÜBİTAK, 2016b). As shown in Figure 2.4

| | | Day (07:00-19:00) | | Evening (19:00-23:00) | | Night (23:00-07:00) | |
|---|---|---|---|---|---|---|---|
| **Road Name** | **Length (km)** | **Heavy Vehicle** | **Light Vehicle** | **Heavy Vehicle** | **Light Vehicle** | **Heavy Vehicle** | **Light Vehicle** |
| Sehit Refik Cesur Street | 2.5 | 163 | 367 | 122 | 319 | 94 | 319 |
| Kahramanmaras Street | 2.8 | 334 | 370 | 269 | 323 | 47 | 60 |
| Hasan Saka Street | 0.4 | 136 | 293 | 80 | 239 | 10 | 45 |
| Yavuz Selim Boulevard | 8.5 | 235 | 910 | 274 | 1,012 | 31 | 151 |
| Gazipasa Street | 0.3 | 375 | 678 | 239 | 716 | 74 | 277 |
| Cumhuriyet Street | 0.3 | 471 | 485 | 171 | 258 | 87 | 197 |
| Senol Gunes Street | 4.6 | 590 | 1,053 | 244 | 707 | 122 | 355 |
| Taksim Street | 3.4 | 409 | 734 | 400 | 831 | 86 | 321 |
| Sahil Yolu Street | 6.5 | 502 | 542 | 212 | 504 | 111 | 308 |
| Inonu Street | 3.4 | 322 | 490 | 221 | 404 | 69 | 206 |
| 010-21 6th section | 11.8 | 469 | 2,244 | 302 | 1,683 | 151 | 467 |
| 010-22 1st section | 8.6 | 628 | 2,636 | 240 | 2,149 | 122 | 584 |

, the maximum number of hourly vehicles can be observed during the daytime period.

**Table 2.2.** Hourly vehicle number counting data of the streets and highways (TÜBİTAK, 2016b)

| | | Day (07:00-19:00) | | Evening (19:00-23:00) | | Night (23:00-07:00) | |
|---|---|---|---|---|---|---|---|
| **Road Name** | **Length (km)** | **Heavy Vehicle** | **Light Vehicle** | **Heavy Vehicle** | **Light Vehicle** | **Heavy Vehicle** | **Light Vehicle** |
| Sehit Refik Cesur Street | 2.5 | 163 | 367 | 122 | 319 | 94 | 319 |
| Kahramanmaras Street | 2.8 | 334 | 370 | 269 | 323 | 47 | 60 |
| Hasan Saka Street | 0.4 | 136 | 293 | 80 | 239 | 10 | 45 |
| Yavuz Selim Boulevard | 8.5 | 235 | 910 | 274 | 1,012 | 31 | 151 |
| Gazipasa Street | 0.3 | 375 | 678 | 239 | 716 | 74 | 277 |
| Cumhuriyet Street | 0.3 | 471 | 485 | 171 | 258 | 87 | 197 |
| Senol Gunes Street | 4.6 | 590 | 1,053 | 244 | 707 | 122 | 355 |
| Taksim Street | 3.4 | 409 | 734 | 400 | 831 | 86 | 321 |
| Sahil Yolu Street | 6.5 | 502 | 542 | 212 | 504 | 111 | 308 |
| Inonu Street | 3.4 | 322 | 490 | 221 | 404 | 69 | 206 |
| 010-21 6th section | 11.8 | 469 | 2,244 | 302 | 1,683 | 151 | 467 |
| 010-22 1st section | 8.6 | 628 | 2,636 | 240 | 2,149 | 122 | 584 |

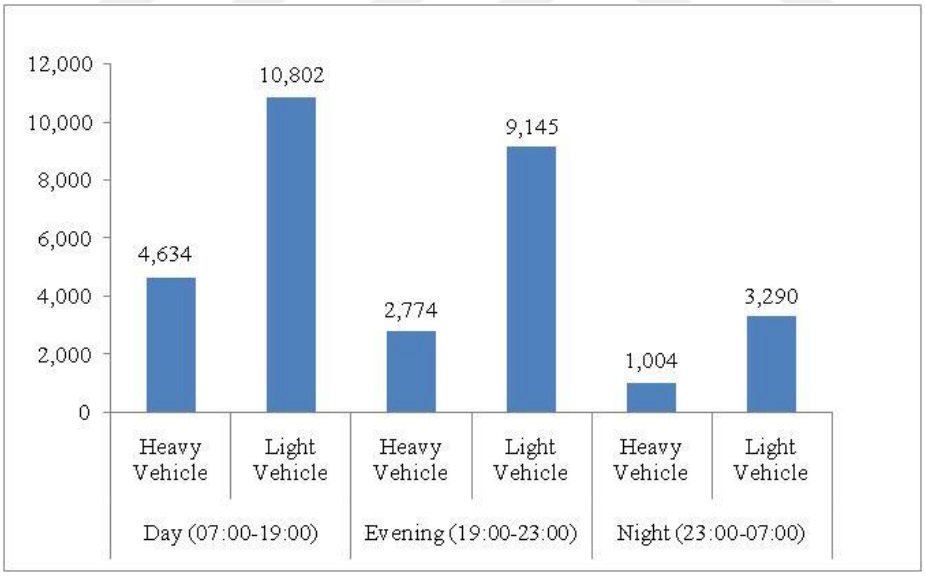


**Figure 2.4.** Comparison of total hourly vehicle numbers of three time slices of a day

In this study, TURKSTAT's report was used which shows the number of vehicles registered by their sizes and fuel types at the city center of Trabzon in 2015 (TURKSTAT, 2016b). According to this report, there are four main vehicle types in use with different sizes that are named as heavy duty vehicles (HDV), light commercial

vehicles (LCV), private cars (PC) and motorcycles (two-wheel). Gasoline, diesel and LPG are the main fuel types which are used in the city center of Trabzon. Percentages of the registered vehicle types and fuel types were calculated and values are shown in Table 2.3. Hourly average vehicle counts for three time periods (day, evening, night) was multiplied with this percentages to find number of vehicles in different sizes and fuel types on 12 road sections (Table 2.4, Table 2.5, Table 2.6).

**Table 2.3.** 2015 Vehicle type distribution in Trabzon

| | Heavy | | Light | |
|---|---|---|---|---|
| **Fuel** | **HDV***** | **LCV**** | **PC*** | **Two-wheel** |
| Gasoline | | 1.20% | 20.48% | 5.77% |
| Diesel | 19.26% | 79.53% | 41.66% | |
| LPG | | | 32.09% | |

(*) Passenger Cars, (**) Light Commercial Vehicles, (***) Heavy-Duty Vehicles

**Table 2.4.** Vehicle and fuel type categorization for daytime (07:00-19:00)

| **Day** | **Heavy Vehicle Number** | | | | **Light Vehicle Number** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Road Name** | **HDV Diesel** | **LCV Diesel** | **LCV Gasoline** | **Vehicle Number Per Hour** | **PC Gasoline** | **PC Diesel** | **PC LPG** | **Two-wheel Gasoline** | **Vehicle Number Per Hour** |
| Sehit Refik Cesur | 31 | 130 | 2 | 163 | 75 | 153 | 118 | 21 | 367 |
| Kahramanmaras | 64 | 266 | 4 | 334 | 76 | 154 | 119 | 21 | 370 |
| Hasan Saka | 26 | 108 | 2 | 136 | 60 | 122 | 94 | 17 | 293 |
| Yavuz Selim | 45 | 187 | 3 | 235 | 186 | 379 | 292 | 52 | 910 |
| Gazipasa | 72 | 298 | 5 | 375 | 139 | 282 | 218 | 39 | 678 |
| Cumhuriyet | 91 | 375 | 6 | 471 | 99 | 202 | 156 | 28 | 485 |
| Senol Gunes | 114 | 469 | 7 | 590 | 216 | 439 | 338 | 61 | 1.053 |
| Taksim | 79 | 325 | 5 | 409 | 150 | 306 | 236 | 42 | 734 |
| Sahil Yolu | 97 | 399 | 6 | 502 | 111 | 226 | 174 | 31 | 542 |
| Inonu | 62 | 256 | 4 | 322 | 100 | 204 | 157 | 28 | 490 |
| 010-21 6th section | 90 | 373 | 6 | 469 | 460 | 935 | 720 | 129 | 2.244 |
| 010-22 1st section | 121 | 499 | 8 | 628 | 540 | 1.098 | 846 | 152 | 2.636 |

**Table 2.5.** Vehicle and fuel type categorization for evening time (19:00-23:00)

| Evening | Heavy Vehicle Number | | | | Light Vehicle Number | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Road Name** | **HDV Diesel** | **LCV Diesel** | **LCV Gasoline** | **Vehicle Number Per Hour** | **PC Gasoline** | **PC Diesel** | **PC LPG** | **Two-wheel Gasoline** | **Vehicle Number Per Hour** |
| Sehit Refik Cesur | 23 | 97 | 1 | 122 | 65 | 133 | 102 | 18 | 319 |
| Kahramanmaras | 52 | 214 | 3 | 269 | 66 | 135 | 104 | 19 | 323 |
| Hasan Saka | 15 | 64 | 1 | 80 | 49 | 100 | 77 | 14 | 239 |
| Yavuz Selim | 53 | 218 | 3 | 274 | 207 | 422 | 325 | 58 | 1.012 |
| Gazipasa | 46 | 190 | 3 | 239 | 147 | 298 | 230 | 41 | 716 |
| Cumhuriyet | 33 | 136 | 2 | 171 | 53 | 107 | 83 | 15 | 258 |
| Senol Gunes | 47 | 194 | 3 | 244 | 145 | 295 | 227 | 41 | 707 |
| Taksim | 77 | 318 | 5 | 400 | 170 | 346 | 267 | 48 | 831 |
| Sahil Yolu | 41 | 169 | 3 | 212 | 103 | 210 | 162 | 29 | 504 |
| Inonu | 43 | 176 | 3 | 221 | 83 | 168 | 130 | 23 | 404 |
| 010-21 6th section | 58 | 240 | 4 | 302 | 345 | 701 | 540 | 97 | 1.683 |
| 010-22 1st section | 46 | 191 | 3 | 240 | 440 | 895 | 690 | 124 | 2.149 |

**Table 2.6.** Vehicle and fuel type categorization for nighttime (23:00-07:00)

| Night | Heavy Vehicle Number | | | | Light Vehicle Number | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Road Name** | **HDV Diesel** | **LCV Diesel** | **LCV Gasoline** | **Vehicle Number Per Hour** | **PC Gasoline** | **PC Diesel** | **PC LPG** | **Two-wheel Gasoline** | **Vehicle Number Per Hour** |
| Sehit Refik Cesur | 18 | 75 | 1 | 94 | 65 | 133 | 102 | 18 | 319 |
| Kahramanmaras | 9 | 37 | 1 | 47 | 12 | 25 | 19 | 3 | 60 |
| Hasan Saka | 2 | 8 | 0 | 10 | 9 | 19 | 14 | 3 | 45 |
| Yavuz Selim | 6 | 25 | 0 | 31 | 31 | 63 | 48 | 9 | 151 |
| Gazipasa | 14 | 59 | 1 | 74 | 57 | 115 | 89 | 16 | 277 |
| Cumhuriyet | 17 | 69 | 1 | 87 | 40 | 82 | 63 | 11 | 197 |
| Senol Gunes | 23 | 97 | 1 | 122 | 73 | 148 | 114 | 20 | 355 |
| Taksim | 17 | 68 | 1 | 86 | 66 | 134 | 103 | 19 | 321 |
| SahilYolu | 21 | 88 | 1 | 111 | 63 | 128 | 99 | 18 | 308 |
| Inonu | 13 | 55 | 1 | 69 | 42 | 86 | 66 | 12 | 206 |
| 010-21 6th section | 29 | 120 | 2 | 151 | 96 | 195 | 150 | 27 | 467 |
| 010-22 1st section | 23 | 97 | 1 | 122 | 120 | 243 | 187 | 34 | 584 |

## 2.2 Dispersion Model of Road Traffic Sourced $NO_x$ Emissions

AERMOD dispersion model was used for air quality modeling in this study. In order to calculate the effect of meteorological conditions on the distribution of air pollutants, the hourly meteorological data of the year 2016 were prepared in the AERMET pre-processor in the study area. The geographic database was also prepared with the AERMAP pre-processor. Vehicle counts were made in three time slices of the day [daytime (07:00-19:00), evening time (19:00-23:00) and nighttime (23:00-07:00)] for determined road sections and they were classified according to their weight and fuel types. Using this classification and emission factors, daily average emissions per hour were prepared for all road sections. AERMAP and AERMET in conjunction with grid-wise on-road vehicular emission loads were used to calculate daily and yearly average and maximum pollutant concentrations ($\mu g/m^3$).

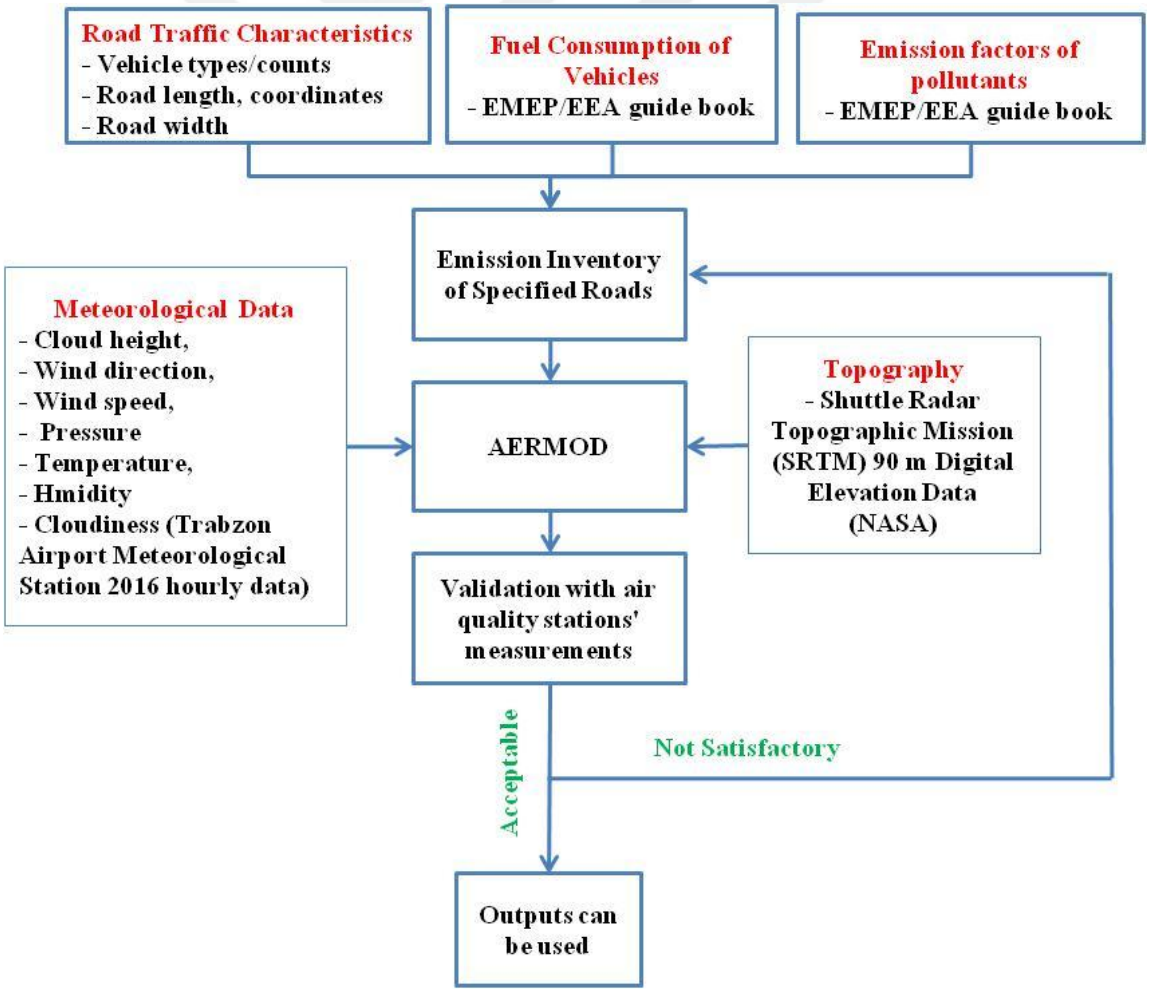


**Figure 2.5.** Flow diagram of the air quality modeling

Model was validated by comparison of the calculated model results with measurements performed at air quality measurement stations in the study area. Outputs of the model and affected population are determined with the help of the geographic information system (GIS) tools. Figure 2.5 shows the steps of air quality modeling.

### 2.2.1 Road traffic air pollutant emission inventory

Air pollution caused by road traffic is evaluated under the name of line sources. According to the EMEP / EEA guidebook, the main pollutants from these sources are; Particulate matter ($PM_{10}$, $PM_{2.5}$), sulfur dioxide ($SO_2$), carbon monoxide (CO), NMVOC and nitrogen oxides ($NO_x$). To calculate road traffic sourced emissions, gasoline and diesel fuel consumption data were collected from TURKSTAT's report which shows the number and properties of vehicles registered in 2015 (TURKSTAT, 2016b). The emission of sulfur dioxide sourced from combustion is estimated assuming that all of the sulfur in the fuel is converted to $SO_2$. $SO_2$ emissions per mass of "m" type of fuel can be calculated by using the following formula:

$$E_{SO_2,m} = 2 \times k_{S,m} \times FC_m E_{so_2,m} = 2 \times k_{S,m} \times FC_m \quad (2.1)$$

Where:

$E_{SO2,m}$ = mass of $SO_2$ emissions per mass of fuel type m used [g],

$k_{S,m}$ = weight related sulphur content in fuel of type m [g/g-fuel],

$FC_m$ = mass of consumed fuel type m [g-fuel].

Typical values for fuel sulphur content are given in Table 2.7. Since 1999, fuel specifications have been regulated to decrease the sulfur concentrations of fuel. In this study, Fuel 2009 sulphur content values are used for the calculation of $SO_2$ emission factor (EMEP/EEA, 2016).

**Table 2.7.** Typical sulphur content of fuel (EMEP/EEA, 2016)

| **ppm ($10^{-6}$ g/g-fuel)** | **1996 Base fuel (Market average)** | **Fuel 2000** | **Fuel 2005** | **Fuel 2009** |
|---|---|---|---|---|
| Gasoline | 165 | 130 | 40 | 40 |
| Diesel | 400 | 300 | 40 | 8 |

According to EMEP / EEA catalog, vehicles can be classified as; light vehicles that are lighter than 3.5 tones (Passenger cars, motorcycles and mopeds), and heavy vehicles which are heavier than 3.5 tons (light commercial, heavy duty vehicles and buses). Fuel types are; gasoline, diesel, LPG and natural gas. Table 2.8 shows consumed fuel types per kilometer for every vehicle category. The basis for this fractionation is; different countries' vehicle statistics and the annual fuel consumption (kg/km) estimates for different vehicle types (EMEP/EEA, 2016).

The combustion produces various byproducts resulting from the oxidation of incomplete fuel oxidation (carbon monoxide, hydrocarbons, particulate matter) or nonflammable substances in the combustion chamber as well as $CO_2$ and $H_2O$ as main products ($NO_x$ from air, $SO_x$ from sulfur in the fuel and lubricant, etc.). Vehicle manufacturers have developed a variety of technologies such as catalytic converters and diesel particulate filters (DPFs) to meet emission regulations and reduce pollutant emissions. However, such devices can also produce pollutants in small quantities such as $NH_3$ and $N_2O$ as a result of their process (EMEP/EEA, 2016).

**Table 2.8.** Typical fuel consumption per km, for different type of vehicles (EMEP/EEA, 2016).

| Vehicle category (j) | Fuel | Typical fuel consumption (g/km) |
|---|---|---|
| PC | Gasoline | 70 |
| | Diesel | 60 |
| | LPG | 57.5 |
| | E85 | 86.5 |
| | CNG | 62.6 |
| LCVs | Gasoline | 100 |
| | Diesel | 80 |
| HDVs | Diesel | 240 |
| | CNG (buses) | 500 |
| Two-wheel vehicles | Gasoline | 35 |

**Table 2.9.** Tier 1 mean emission factors (EMEP/EEA, 2016)

| | (g/kg Fuel) | CO | NMVOC | $NO_X$ | $PM_{10}$ | $PM_{2.5}$ | $SO_2$ |
|---|---|---|---|---|---|---|---|
| PC | Gasoline | 84.7 | 10.05 | 8.73 | 0.03 | 0.008 | 0.0056 |
| | Diesel | 3.33 | 0.7 | 12.96 | 1.1 | 0.275 | 0.0010 |
| | LPG | 84.7 | 13.64 | 15.2 | 0 | 0 | |
| LCVs | Gasoline | 152.3 | 14.59 | 13.22 | 0.02 | 0.005 | 0.0080 |
| | Diesel | 7.4 | 1.54 | 14.91 | 1.52 | 0.38 | 0.0013 |
| HDVs | Diesel | 7.58 | 1.92 | 33.37 | 0.94 | 0.235 | 0.0038 |
| | CNG | 5.7 | 0.26 | 13 | 0.02 | 0.005 | |
| Two-wheel vehicles | Gasoline | 497.7 | 131.4 | 6.64 | 2.2 | 0.55 | |

A tier in the EMEP / EEA guidance represents a level of methodological complexity. Usually tiers are given; Tier 1 is the simplest method; Tier 2, intermediate level; and Tier 3 represents the most data-intensive and complex method. The emission factors in Tier 1 are calculated on the basis of the Tier 3 (Tier 3 based on the results of Copert4, which was created using 1995 fleet and activity data). Since vehicle ages are high in Trabzon and couldn't have the chance to obtain complete data and statistics, this study has been performed using the Tier 1 emission factors given in the Table 2.9 (EMEP/EEA, 2016).

The average hourly exhaust emissions in all road sections for each pollutant was calculated by replacing the number of vehicles classified as vehicle and fuel type with the following equation:

$$FC_{j,m} = \sum \left( \begin{pmatrix} hourly\ number\ of\ vehicle \\ category\ j\ using\ fuel\ m \end{pmatrix} \times \left( \begin{matrix} Typical\ fuel \\ consumption\ \left(\frac{g}{km}\right) \end{matrix} \right) \times \left(\frac{kg}{1000g}\right) \times \begin{pmatrix} Road\ section \\ length\ (km) \end{pmatrix} \right) \quad (2.2)$$

$$E_i = \sum j \left( \sum m \left( FC_{j,m} \times EF_{i,j,m} \right) \right) \quad (2.3)$$

where;

Hourly number of vehicle category j using fuel m = Table 2.4, Table 2.5, Table 2.6

Typical fuel consumption (g/km) = Table 2.8

Road section length (km) = Table 2.2

$E_i$ = emission of pollutant i [g],

$FC_{j,m}$= fuel consumption of vehicle category j using fuel m [kg],

$EF_{i,j,m}$ = fuel consumption-specific emission factor of pollutant i for vehicle category j and fuel m [g/kg]. (Table 2.9)

Pollutant emissions in each road section were calculated by using Equations 2.2 and 2.3, for three time slices of the day. The hourly average emission value for a day is calculated according to the following formula;

$$\left(\begin{matrix}Hourly\ average\\ emission\ for\ a\ day\end{matrix}\right) = \frac{\left(\begin{matrix}Daytime\\ emissions\times 12\end{matrix}\right)+\left(\begin{matrix}Evening\ time\\ emissions\times 4\end{matrix}\right)+\left(\begin{matrix}Nighttime\\ emissions\times 8\end{matrix}\right)}{24} \quad (2.4)$$

### 2.2.2 Dispersion model meteorological data

AERMOD's meteorological pre-processor AERMET can calculate local surface characteristics such as boundary layer parameters, friction speed, temperature values, mixing heights, superficial heat flow, surface roughness, nocturnal albedo and bowen ratio. AERMET uses hourly radiosonde meteorological inputs to generate all the atmospheric information mentioned above. The structure and level of the atmospheric boundary layer depends on the momentum flow, which varies depending on the heat flow and earth effect (TÜBİTAK, 2013).

Inputs of AERMET preprocessor is one year surface meteorological data which are cloud height, wind direction, wind speed, pressure temperature, humidity and cloudiness that were taken from Trabzon Airport Meteorological Station. Samsun Meteorological Station's upper air data is obtained that includes upper air meteorological observations. The meteorological data and wind fields processed by AERMET meteorological module and results are used as input for AERMOD.

Hourly atmospheric temperatures are recorded in the meteorological stations of the State Meteorological Service. Daily average winter temperatures are in the range of 7.3–11.2$^{o}$C in Trabzon. Daily minimum value was observed in January as -2.5 $^{o}$C and the highest value is 34.8 $^{o}$C in July in 2016.

Generally humidity values in fall and spring seasons are higher than summer and winter as seen from Figure 2.6. The average maximum humidity value was recorded as 87.83%

during the fall and spring. The average minimum humidity value was observed as 58.81% in Trabzon station for all over the seasons.

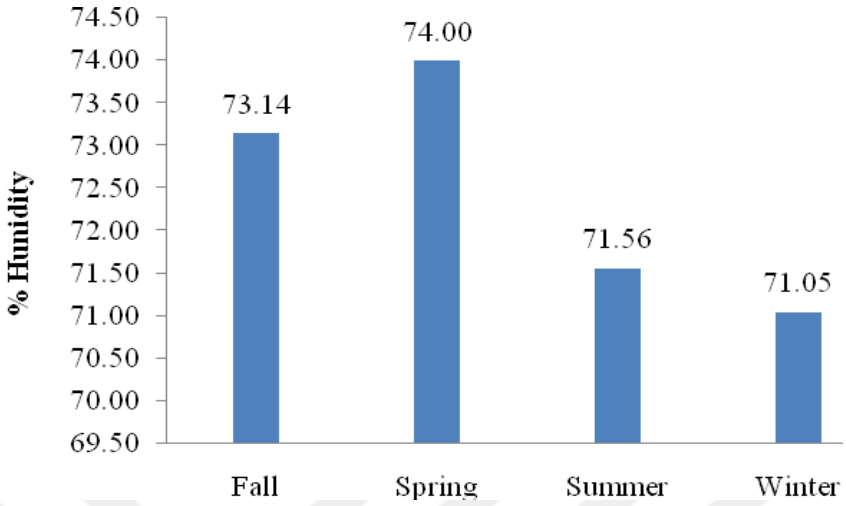


**Figure 2.6.** Seasonal daily average humidity values

Cloudiness values were observed between 0 and 10 in Government's Meteorological Stations' results. If the sky is open the value is given as 1 and 10 designates that the sky is fully cloudy. Vertical temperature profile of the atmosphere is affected directly from cloudiness level. Incoming solar radiation is scattered and reflected by clouds. Air pollutants' formation and dispersion mechanisms are directly affected from these changes. The maximum monthly average cloudiness value is 9 in Trabzon station.

Wind is the most important meteorological parameter affecting air quality. Wind speed affects the dilution mechanisms of pollutants and wind direction affects their transportation (Sari, 2011). Wind roses were plotted for daily average, daytime, evening time and night time periods using hourly wind speed and direction data of the year 2016 from the Trabzon Airport Meteorological Station. With the help of these wind roses, the dominant wind directions in selected periods were determined. These wind roses are given in Figure 2.7-2.10.

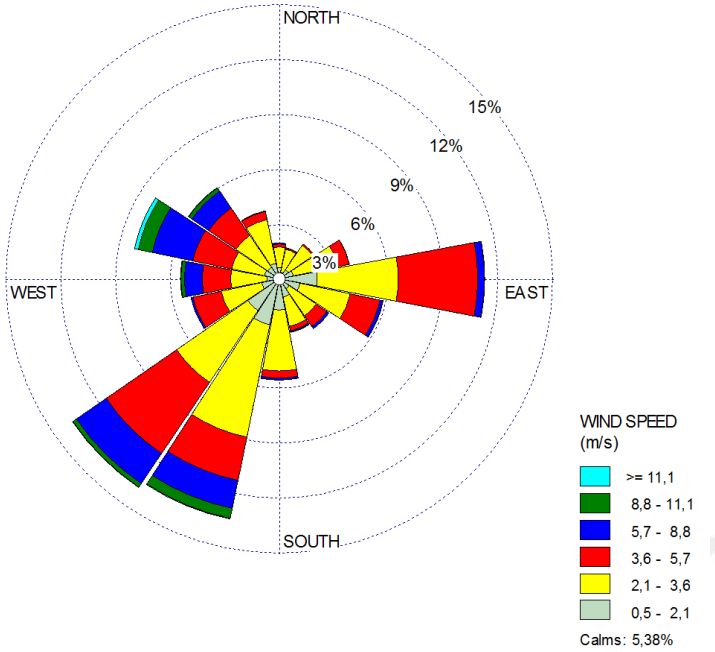


**Figure 2.7.** Daily (24hr) wind rose (2016 Annual Average)

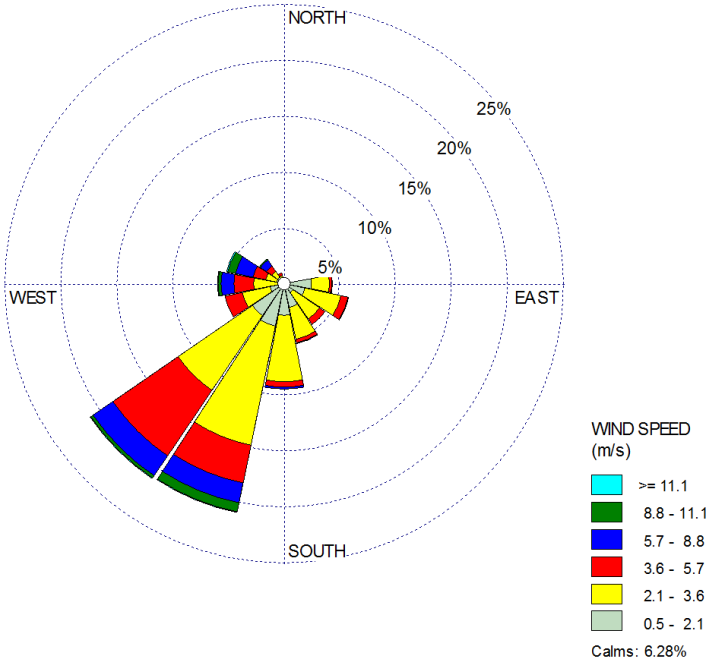


**Figure 2.8.** Daytime (07:00-19:00) wind rose (2016 Annual Average)

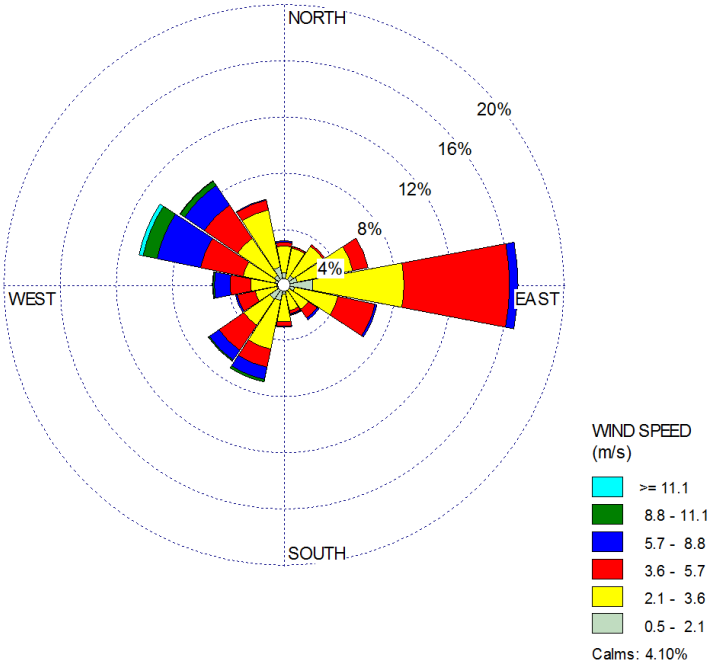


**Figure 2.9.** Evening time (19:00-23:00) wind rose (2016 Annual Average)

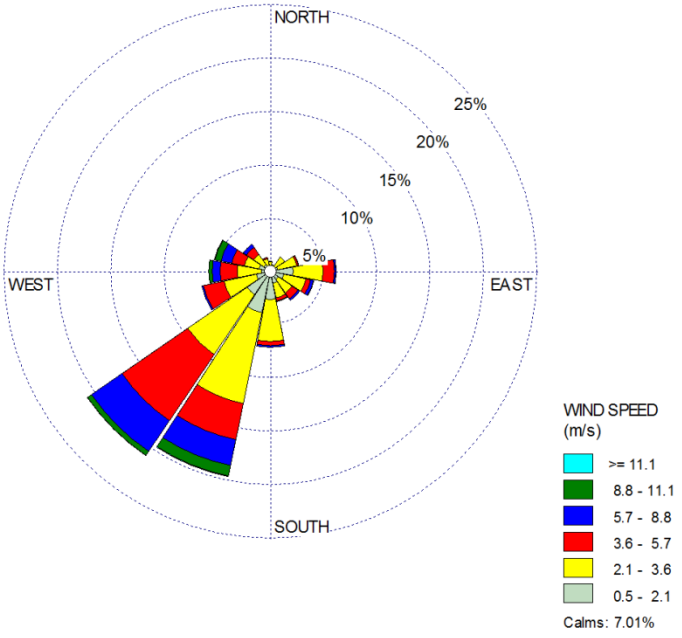


**Figure 2.10.** Nighttime (23:00-07:00) wind rose (2016 Annual Average)

### 2.2.3 Terrain data of dispersion model

Digital elevation preprocessing was performed by AERMAP module by utilizing the terrain data and topographical data at approximately 30 m resolution obtained from the USGS (U. S. Geological Survey). The topographical data of Trabzon was obtained from "Shuttle Radar Topographic Mission (SRTM) 90 m Digital Elevation Data" which is produced by National Aeronautics and Space Administration (NASA) for AERMOD. This input was used to determine surface elevation and slope for the study region. To better identification of complex terrain to model, a uniform 250 $m^2$ cartesian receptor grid was included besides individual receptors for all model runs (Michanowicz et al., 2016).

## 2.3 Road Traffic Noise Modeling

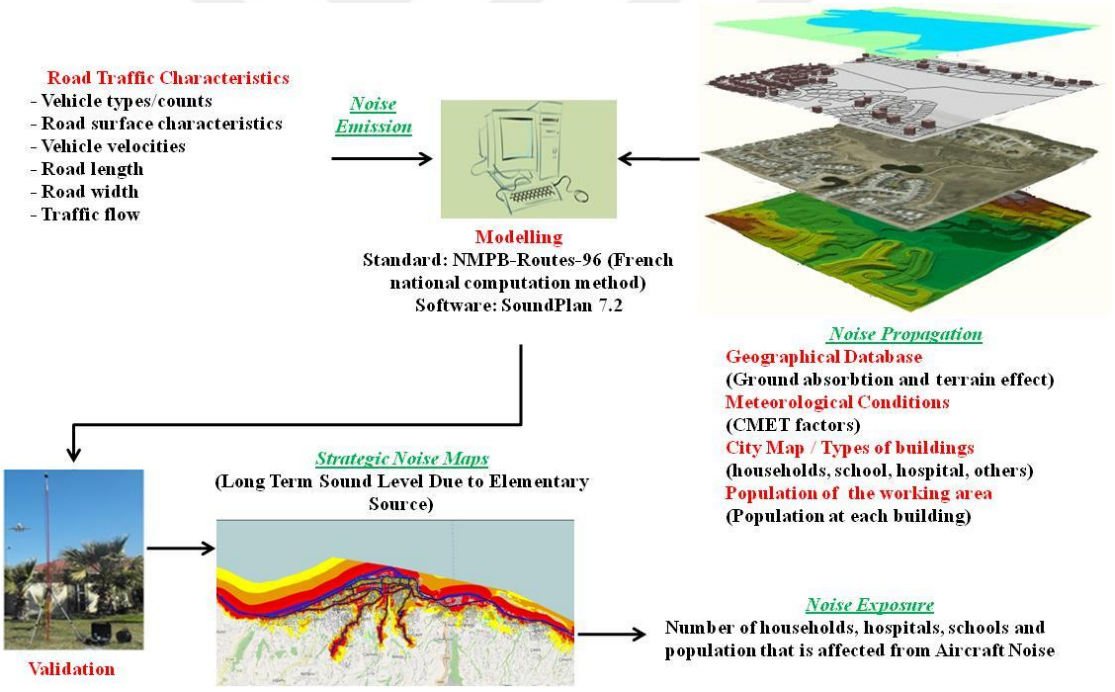


**Figure 2.11.** Flow diagram of noise modeling

Noise exposure was calculated for each residents, schools and hospitals in the study region by using SoundPLAN software which calculates road traffic noise in accordance with the standard of NMPB Routes 96 (NMPB, 1996). The main input variables for noise model included geographical database, meteorological conditions, and city map/types of buildings, population and traffic data on road lines. Road traffic noise was

calculated as the equivalent continuous $L_{Aeq}$, at the most exposed facade of the building for the day ($L_{day}$), evening ($L_{evening}$) and night ($L_{night}$), and expressed as $L_{den}$. Calculated sound pressure levels were validated with measured values at specified coordinates. After evaluation procedure, strategic noise maps were prepared with the help of the related module of SoundPLAN. Traffic related noise exposure was analyzed with the help of the results obtained from the model. Flow diagram of this procedure is shown in Figure 2.11.

### 2.3.1 Road traffic noise emission inventory

NMPB Routes 96 method has been developed by different French Institutes of Ministère de l'Equipement (CSTB, SETRA, LCPC, LRPC) and represents an improvement on the oldest one defined in the "Guidede Bruit" of 1980 that takes into account the meteorological conditions and the long distance (d >250m) prevision, as suggested in the ISO 9613 (Quartieri et al., 2009). According to French calculation method, noise emission depends on; vehicle type, speed, traffic flow type, longitudinal profile and road surface characteristics. Traffic flow type is a supplementary parameter to speed, which related with acceleration, deceleration, engine load, and pulsated or continuous traffic motion. Four categories are defined for traffic flow type: fluid continuous flow, pulsed continuous flow, pulsed accelerated flow and pulsed decelerated flow. There are three longitudinal profiles taken into account in calculating the sound emission of the highway slope, which are; horizontal carriageway, an ascending carriageway and a descending carriageway. Road surface characteristics are identified as porous surface; smooth asphalt (concrete or mastic); cement concrete and corrugated asphalt; smooth texture paving stones and rough texture paving stones in standard (NMPB, 1996). The emission changes are stored in all locations due to the changes in traffic volume, road surface, traffic speed etc. Each of the emission definitions is valid from the coordinate of origin to the end of the data string or to the place where a new definition is present. Light and heavy vehicle numbers for day time, evening time and night time are given in Table 2.2 for all time periods on an hourly basis. Other characteristics of selected road sections are shown in Table 2.10. Road surface was identified as smooth asphalt and traffic flow was selected as fluid continuous flow in all roads in the study area. The slope of the carriageway is calculated by software taking into account the digital ground model.

**Table 2.10.** Noise Modeling Inputs

| Road Name | Length (km) | Width (m) | Annual average daily traffic | Road Surface | Heavy Vehicle Velocity (km/h) | Light Vehicle Velocity (km/h) |
|---|---|---|---|---|---|---|
| Sehit Refik Cesur | 2.5 | 17.0 | 11,428 | Asphalt | 40 | 40 |
| Kahramanmaras | 2.8 | 7.5 | 11,672 | Asphalt | 50 | 50 |
| Hasan Saka | 0.4 | 17.0 | 6,864 | Asphalt | 40 | 50 |
| Yavuz Selim | 8.5 | 17.0 | 20,340 | Asphalt | 50 | 50 |
| Gazipasa | 0.3 | 7.5 | 19,264 | Asphalt | 50 | 50 |
| Cumhuriyet | 0.3 | 7.5 | 15,460 | Asphalt | 50 | 50 |
| Senol Gunes | 4.6 | 17.0 | 27,336 | Asphalt | 50 | 50 |
| Taksim | 3.4 | 17.0 | 21,896 | Asphalt | 50 | 50 |
| Sahil Yolu | 6.5 | 17.0 | 18,744 | Asphalt | 50 | 70 |
| Inonu | 3.4 | 7.5 | 14,444 | Asphalt | 50 | 70 |
| 010-21 6th section | 11.8 | 17.0 | 45,440 | Asphalt | 50 | 70 |
| 010-22 1st section | 8.6 | 17.0 | 54,372 | Asphalt | 50 | 70 |

### 2.3.2 Noise model meteorological data

In the NMPB calculation method, the input parameters that define the weather conditions are expressed as "p". This parameter represents the percentage of favorable to homogenous conditions, the average air temperature, and the relative humidity. The "p" parameter for a given area is calculated from the average of many years of meteorological observations. If enough data cannot be handled, this parameter is accepted as 50% for daytime, 75% for evening time and 100% for nighttime (WG-AEN, 2007). The effect of other meteorological conditions is taken into account by the meteorological correction factor "Cmet". For large distances between the sound source and the observer, this factor is expressed as:

$$Cmet = C_0 = 10\log(P_f + (1 - P_f) \times 10 - 0.1\Delta L) \qquad (2.5)$$

$P_f$: the frequency of circumstance of complimentary conditions,

$\Delta L$: Difference in sound level between positive and negative conditions. If no data is available, $\Delta L$ = 12 dB is assumed (NMPB, 1996).

Since the appropriate dataset for SoundPLAN is not available to represent the meteorological conditions in the study area, Cmet factors were used in the calculations.

### 2.3.3 Terrain data of noise model

Input data for the simulation of noise levels in the study region include geodatabase. Digital ground models (DGM), and building layers consist of geodatasets. Geometry of the building, usage aim of the building (residential, school, hospital or auxiliary building), number of flats and inhabitants per building are required information for preparing a building layer. In this study, digital maps which include building and elevation information were obtained from google earth, city map and "Shuttle Radar Topographic Mission (SRTM) 90 m Digital Elevation Data". In order to calculate inhabitants per building, the population of districts in study area was distributed to buildings according to area of them.

## 2.4 Validation Methods of Models

### 2.4.1 Validation methods of $NO_x$ dispersion model

The Index of Agreement (IOA) is a performance measurement method developed by an alternative to the correlation coefficient (r) and the coefficient of determination ($r^2$). IOA evaluates how the magnitudes of the observed values are related to the variances from the predicted values. The model is a standard measure of the fraction of the prediction error and ranges from "0.0" to "1.0". "0.0" indicates that there is no match between observations and predicted values while "1.0" shows that there is a perfect compatibility between observed and predicted values (Ozkurt et al., 2013; Willmott, 1984). In May 2011, IOA formula was rearranged as shown in the equation 2.6, limited to "-1.0" and "1.0" (accepting coefficient "c" as 2). When;

IOA = 0.5; the sum of the error-magnitudes is one half of the sum of the perfect model deviation and observed-deviation magnitudes.

IOA = 0.0; the sum of the magnitudes of the errors and the sum of the perfect model-deviation and observed-deviation magnitudes are equivalent.

IOA = − 0.5; the sum of the error-magnitudes is twice the sum of the perfect model-deviation and observed-deviation magnitudes.

IOA near "− 1.0" can mean that the model-estimated deviations about mean observed value are poor estimates of the observed deviations; but, they also can mean that there is

little observed variability. When IOA is approached to the lower limit, comments should be made cautiously (Willmott et al., 2012).

$$IOA = \begin{cases} 1 - \dfrac{\sum_{i=1}^{n}|P_i - O_i|}{c\sum_{i=1}^{n}|O_i - \bar{O}|}, \text{when } \sum_{i=1}^{n}|P_i - O_i| \le c\sum_{i=1}^{n}|O_i - \bar{O}| \\ \dfrac{c\sum_{i=1}^{n}|O_i - \bar{O}|}{\sum_{i=1}^{n}|P_i - O_i|} - 1, \text{when } \sum_{i=1}^{n}|P_i - O_i| > c\sum_{i=1}^{n}|O_i - \bar{O}| \end{cases} \quad (2.6)$$

The factor of two (FAC2) is defined as the percentage of prediction within a factor of 2 of the observed values and these should be within the following range (Abril et al., 2016):

$$\mathbf{FAC2 = 0.5 \le \frac{P}{O} \le 2.0} \quad (2.7)$$

The normalized mean square error (NMSE) is a standardized measure of the overall error from the comparisons between observed and predicted values. An exact data item would be of zero error. Smaller than 1.5 values of NMSE indicate a better performance and this is represented by (Abril et al., 2016):

$$\mathbf{NMSE} = \frac{\overline{(O-P)^2}}{\bar{O}*\bar{P}} \quad (2.8)$$

### 2.4.2 Validation methods of noise model

Because noise maps are made mostly on calculation that includes estimated parameters, the maps have certain uncertainty. The noise maps need to be verified with measurements performed in certain positions (Mioduszewski et al., 2011). Environmental background must be distinctly accounted for describing the road traffic noise to be expected at the measurement points. The position of the microphone must be anechoic and the power supply must be continuous (Sari et al., 2014).

Measurements were carried out by personnel of TÜBİTAK MAM Environment and Cleaner Production Institute's Air Pollution Control Laboratory in accordance with TS ISO 1996-2 "Acoustic - Definition, Measurement and Evaluation of Environmental Noise - Part 2: Determination of Environmental Noise Levels". Measurements were carried out in open air at 4 meters height from the ground level, according to END. Before starting the measurements, all instruments were calibrated using an acoustic

calibrator with a 94 dB (A) calibration value at 1 kHz. The system includes a loudspeaker producing acoustic pressure, a reference microphone for monitoring the generated level, pressure and temperature sensors for measuring atmospheric conditions, and a microprocessor controlling the operation of the calibrator. Each sound level meter was set up to assess the traffic noise at the A-weighted continuous sound pressure level in the study area (Sari et al., 2014).

According to the WG-AEN, published by the Working Group of the European commission in 2002/49 numbered 2007, the difference between the model and the measured values could be 1 dB within the 300 m validation distance, 3 dB within 600 m and 10 dB at distances of 2000-3000 m (WG-AEN, 2007). In the final report of the project "HARMONOISE-Harmonized Accurate and Reliable Methods for the Assessment and Management of Environmental Noise" completed for the noise level assessment and management purposes stated in the END, the standard deviation of the noise values calculated for the receptor points in urban areas is about 5 dB(A) (Vos et al., 2005). According to the United States Department of Transportation report, the results of road noise modeling are expected to be acceptable at an accuracy of ± 3 dB(A) (USDT, 2010).

# 3 RESULTS and DISCUSSION

## 3.1 Results of Emission Inventories Sourced from Road Traffic in the City Center of Trabzon

### 3.1.1 Air pollutants emission inventory

Air pollutants originating from road traffic are one of the most important factors influencing the air quality in the Trabzon city along with emissions from domestic heating and industry (MoEU, 2016). Road traffic sourced CO, NMVOC, $NO_x$, $PM_{10}$, $PM_{2.5}$ and $SO_2$ emissions were calculated by using the hourly vehicle counts for every time slices of a day (day, evening, night and daily average), the type of the registered vehicles, and the emission factors. Calculated emissions are shown in Table 3.1-3.4. Because of the intensity of daytime traffic with respect to evening time and nighttime, the maximum emission values can be observed in this slice of a day in the study area. Even though evening time period (4 hours) is shorter than daytime period (12 hours), hourly emission values in evening time are close to the daytime hourly emission values since light vehicle counts in evening time is almost equal to daytime vehicle counts as shown in Table 2.2.

**Table 3.1.** Hourly average daytime (07:00-19:00) road traffic sourced emissions (g/h) in Trabzon city center

| | Day (07:00-19:00) | | | | | |
|---|---|---|---|---|---|---|
| **Road Name** | **CO** | **NMVOC** | **$NO_x$** | **$PM_{10}$** | **$PM_{2.5}$** | **$SO_2$** |
| Sehit Refik Cesur | 3,956 | 706 | 1,703 | 87 | 22 | 0.21 |
| Kahramanmaras | 4,944 | 894 | 3,114 | 165 | 41 | 0.362 |
| Hasan Saka | 508 | 91 | 223 | 11 | 3 | 0.03 |
| Yavuz Selim | 31,904 | 5,657 | 10,755 | 530 | 133 | 1.34 |
| Gazipasa | 899 | 161 | 433 | 22 | 6 | 0.05 |
| Cumhuriyet | 704 | 128 | 462 | 25 | 6 | 0.05 |
| Senol Gunes | 21,449 | 3,841 | 10,403 | 537 | 134 | 1.23 |
| Taksim | 11,043 | 1,978 | 5,340 | 276 | 69 | 0.63 |
| Sahil Yolu | 16,895 | 3,057 | 10,798 | 571 | 143 | 1.24 |
| Inonu | 7,539 | 1,354 | 3,983 | 207 | 52 | 0.47 |
| 010-21 6th section | 107,908 | 19,099 | 33,548 | 1,633 | 408 | 4.25 |
| 010-22 1st section | 93,049 | 16,486 | 30,383 | 1,491 | 373 | 3.81 |
| **TOTAL** | **300,799** | **53,451** | **111,146** | **5,556** | **1,389** | **13.68** |

**Table 3.2.** Hourly average evening time (19:00-23:00) road traffic sourced emissions (g/h) in Trabzon city center

| | Evening (19:00-23:00) | | | | | |
|---|---|---|---|---|---|---|
| **Road Name** | **CO** | **NMVOC** | **$NO_x$** | **$PM_{10}$** | **$PM_{2.5}$** | **$SO_2$** |
| Sehit Refik Cesur | 3,389 | 603 | 1,357 | 69 | 17 | 0.17 |
| Kahramanmaras | 4,252 | 768 | 2,560 | 135 | 34 | 0.30 |
| Hasan Saka | 402 | 71 | 151 | 8 | 2 | 0.02 |
| Yavuz Selim | 35,588 | 6,313 | 12,230 | 605 | 151 | 1.52 |
| Gazipasa | 902 | 160 | 339 | 17 | 4 | 0.04 |
| Cumhuriyet | 351 | 63 | 186 | 10 | 2 | 0.02 |
| Senol Gunes | 13,698 | 2,436 | 5,230 | 263 | 66 | 0.64 |
| Taksim | 12,287 | 2,195 | 5,509 | 282 | 71 | 0.66 |
| Sahil Yolu | 14,047 | 2,505 | 5,889 | 299 | 75 | 0.71 |
| Inonu | 6,064 | 1,086 | 2,904 | 150 | 37 | 0.35 |
| 010-21 6th section | 80,341 | 14,204 | 23,689 | 1,142 | 286 | 3.03 |
| 010-22 1st section | 73,509 | 12,963 | 18,906 | 888 | 222 | 2.48 |
| **TOTAL** | **244,831** | **43,366** | **78,951** | **3,866** | **967** | **9.93** |

**Table 3.3.** Hourly average nighttime (23:00-07:00) road traffic sourced emissions (g/h) in Trabzon city center

| | Night (23:00-07:00) | | | | | |
|---|---|---|---|---|---|---|
| **Road Name** | **CO** | **NMVOC** | **$NO_x$** | **$PM_{10}$** | **$PM_{2.5}$** | **$SO_2$** |
| Sehit Refik Cesur | 3,319 | 589 | 1,182 | 59 | 15 | 0.15 |
| Kahramanmaras | 782 | 141 | 455 | 24 | 6 | 0.05 |
| Hasan Saka | 74 | 13 | 23 | 1 | 0 | 0.01 |
| Yavuz Selim | 5,226 | 925 | 1,614 | 78 | 20 | 0.20 |
| Gazipasa | 344 | 61 | 117 | 6 | 1 | 0.01 |
| Cumhuriyet | 255 | 45 | 109 | 6 | 1 | 0.01 |
| Senol Gunes | 6,876 | 1,223 | 2,620 | 132 | 33 | 0.32 |
| Taksim | 4,512 | 800 | 1,544 | 76 | 19 | 0.20 |
| Sahil Yolu | 8,463 | 1,506 | 3,296 | 166 | 41 | 0.40 |
| Inonu | 2,943 | 523 | 1,109 | 56 | 14 | 0.14 |
| 010-21 6th section | 23,090 | 4,103 | 8,561 | 428 | 107 | 1.05 |
| 010-22 1st section | 20,467 | 3,622 | 6,362 | 310 | 77 | 0.84 |
| **TOTAL** | **76,348** | **13,552** | **26,993** | **1,341** | **335** | **3.35** |

**Table 3.4.** Hourly average road traffic sourced emissions (g/h) for 24 hours in Trabzon city center

| | Daily Average | | | | | |
|---|---|---|---|---|---|---|
| **Road Name** | **CO** | **NMVOC** | **$NO_x$** | **$PM_{10}$** | **$PM_{2.5}$** | **$SO_2$** |
| Sehit Refik Cesur | 3,649 | 650 | 1,472 | 74 | 19 | 0.18 |
| Kahramanmaras | 3,441 | 622 | 2,135 | 113 | 28 | 0.25 |
| Hasan Saka | 345 | 62 | 145 | 7 | 2 | 0.02 |
| Yavuz Selim | 23,625 | 4,189 | 7,954 | 392 | 98 | 1.00 |
| Gazipasa | 714 | 128 | 312 | 16 | 4 | 0.04 |
| Cumhuriyet | 496 | 89 | 299 | 16 | 4 | 0.03 |
| Senol Gunes | 15,299 | 2,734 | 6,947 | 356 | 89 | 0.83 |
| Taksim | 9,073 | 1,621 | 4,103 | 210 | 53 | 0.49 |
| Sahil Yolu | 13,610 | 2,448 | 7,479 | 391 | 98 | 0.87 |
| Inonu | 5,761 | 1,032 | 2,845 | 147 | 37 | 0.34 |
| 010-21 6th section | 75,041 | 13,284 | 23,576 | 1,150 | 287 | 2.98 |
| 010-22 1st section | 65,598 | 11,611 | 20,463 | 997 | 249 | 2.59 |
| **TOTAL** | **216,654** | **38,471** | **77,729** | **3,869** | **967** | **9.61** |

As shown in Figure 3.1, light vehicles are responsible for 93% of daily average CO emissions, 92% of NMVOC emissions, and 57% of $SO_2$ emissions while, 50% of daily average $NO_x$ emissions and 56% of $PM_{10}$ emissions are caused by heavy vehicles in Trabzon city center. According to vehicle count results, daily average light vehicles are 73% and heavy vehicles are 27% of the total. In Trabzon city center, almost 60% of the light vehicles consume LPG and gasoline with the proportion of 32% and 26% respectively. As seen from Table 2.9, gasoline and LPG fueled engines emit much more CO, NMVOC and $SO_2$ than diesel engines. If it is considered that almost all heavy vehicles have diesel-fueled engines (Table 2.3) and the percentage of heavy vehicle number is approximately one third of light vehicle number, $NO_x$ and $PM_{10}$ emissions from roads are mainly caused by heavy vehicles in Trabzon city center. Diesel engines produce high levels of PM and $NO_x$ emissions, while CO and HC emissions are less since in this type of engines, excess air coefficient is higher than that of gasoline engines (MoNE, 2011).

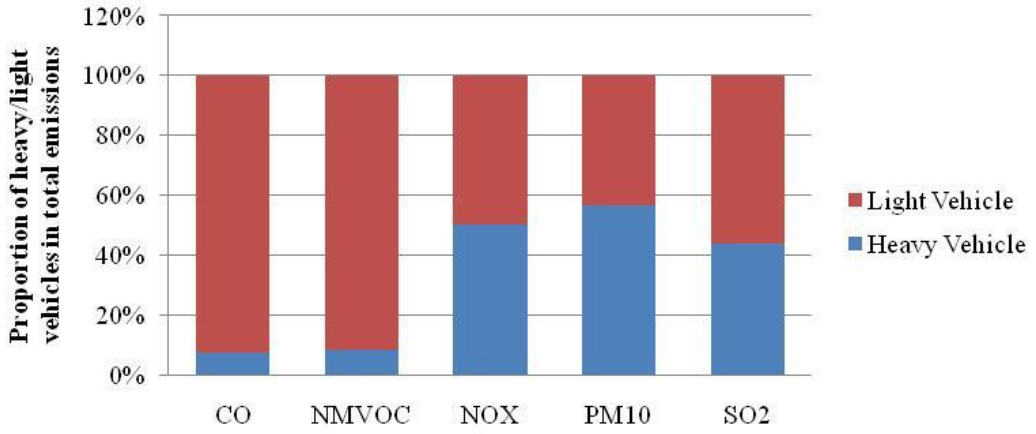


**Figure 3.1.** Effect of heavy/light vehicles proportion in total emissions

### 3.1.2 Noise emission inventory

Noise emission depends on traffic volume, slope and the surface material of road, traffic speed, proportion of the heavy and light vehicles, topography etc. Noise emissions sourced from roads in Trabzon were calculated by SoundPLAN with the help of the input parameters which are explained detailed in section 2.2 and results are presented in Table 3.5.

**Table 3.5.** Noise emission and heavy vehicle distribution in all road sections in city center of Trabzon

| | Day (07:00-19:00) | | Evening (19:00-23:00) | | Night (23:00-07:00) | | Daily Average (Den) | |
|---|---|---|---|---|---|---|---|---|
| **Road Name** | **Heavy Vehicle %** | **Noise Emission [dB(A)]*** | **Heavy Vehicle %** | **Noise Emission [dB(A)]*** | **Heavy Vehicle %** | **Noise Emission [dB(A)]*** | **Heavy Vehicle %** | **Noise Emission [dB(A)]*** |
| Sehit Refik Cesur | 30.75 | 87.09 | 27.66 | 85.92 | 22.76 | 84.96 | 27.97 | 91.78 |
| Kahramanmaras | 47.44 | 88.41 | 45.44 | 87.5 | 43.93 | 79.94 | 46.78 | 89.88 |
| Hasan Saka | 31.70 | 86.33 | 25.08 | 84.23 | 18.18 | 75.55 | 29.60 | 86.76 |
| Yavuz Selim | 20.52 | 88.34 | 21.31 | 88.95 | 17.03 | 79.81 | 20.47 | 90.31 |
| Gazipasa | 35.61 | 89.76 | 25.03 | 88.16 | 21.08 | 83.28 | 31.40 | 91.84 |
| Cumhuriyet | 49.27 | 90.5 | 39.86 | 86.25 | 30.63 | 83.56 | 45.49 | 91.87 |
| Senol Gunes | 35.91 | 91.72 | 25.66 | 88.22 | 25.58 | 85.22 | 33.04 | 93.43 |
| Taksim | 35.78 | 90.13 | 32.49 | 90.12 | 21.13 | 83.93 | 32.86 | 92.74 |
| Sahil Yolu | 48.08 | 90.44 | 29.61 | 87.27 | 26.49 | 84.62 | 41.40 | 92.55 |
| Inonu | 39.66 | 89.22 | 35.36 | 87.72 | 25.09 | 83.14 | 36.69 | 91.51 |
| 010-21 6th section | 17.29 | 91.6 | 15.21 | 89.95 | 24.43 | 86.08 | 17.70 | 94.14 |
| 010-22 1st section | 19.24 | 92.67 | 10.05 | 89.9 | 17.28 | 85.76 | 17.42 | 94.31 |

* This value represents total noise emission which is caused by both heavy and light vehicles in road sections

The annual average daily traffic counts are very close to each other in Yavuz Selim Boulevard (20,340) and Taksim Street (21,896) (Table 2.10). Although the speed of vehicles and road surface material is same in these streets, noise emission is higher in Taksim Street due to the higher heavy vehicle proportion. In Cumhuriyet Street and Sahil Yolu Streets annual average daily traffic values and heavy vehicle ratios are close to each other. However vehicle speeds are higher in Sahil Yolu Street (Heavy vehicles: 50/Light Vehicles: 70) than Cumhuriyet Street. As a result of vehicle speed differences, daily average noise levels were found higher in Sahil Yolu Street.

## 3.2 Model Validation

### 3.2.1 Validation of $NO_x$ dispersion modeling

There are four air quality monitoring stations of the Ministry of Environment and Urbanization in the city center of Trabzon. Coordinates and the geographical locations of the stations in the study area are given in Table 3.6 and Figure 3.2. The hourly emission measurements of the stations can be accessed instantly and retrospectively from the website of the MoEU.

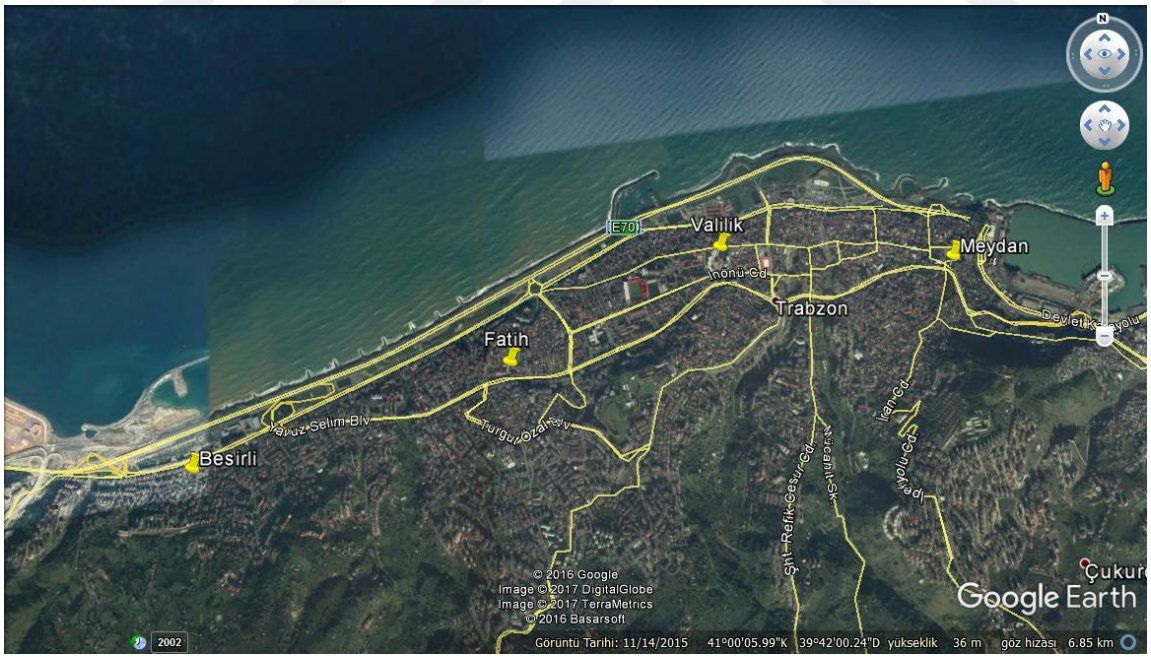


**Figure 3.2.** Air quality measurement stations in the city center of Trabzon (Google Earth, 2017)

**Table 3.6.** Coordinates of air quality monitoring stations in Trabzon city center

| Receivers | Name | Latitude | Longitude |
|---|---|---|---|
| 1 | Besirli | 40°59'36.98"N | 39°40'5.00"E |
| 2 | Fatih | 40°59'56.98"N | 39°41'38.98"E |
| 3 | Valilik | 41° 0'20.97"N | 39°42'43.96"E |
| 4 | Meydan | 41° 0'15.99"N | 39°43'53.98"E |

$NO_x$ emissions sourced from road traffic have been modeled with AERMOD by assigning receptor points to the coordinates of these stations. Day time, evening time, night time and daily mean $NO_x$ emission distributions were modeled separately. Then, predicted daily average emissions at these stations were compared with the daily average measurement values.

The most important sources of the air pollution that is experienced especially in the winter periods are emissions from domestic heating and the vehicles in Trabzon city center (MoEU, 2016). According to the circular issued under the air pollution control management actions by the Ministry of Environment and Forestry (Previous name of MoEU) in 2004, in order to reduce domestic heating sourced emissions, "domestic heating should not be applied on days when the outdoor temperature is over 15°C day and night" (MoEF, 2004). When the meteorological data of Trabzon in 2016 is examined, temperatures below 15°C can be observed in fall, winter and spring. However temperature does not fall below 15°C in June, July and August. Traffic related emissions are expected more representative in summer months due to the lack of domestic heating emission effects. For this reason, validation of the model was performed with predicted results and observed values in summer months in this study.

Calculated traffic related $NO_x$ concentrations and measured values at four stations are shown in Figure 3.3 - Figure 3.6. As it is seen from the figures, in Besirli and Fatih stations, there is a big difference between predicted and observed values of $NO_x$ emissions. The reasons of underestimations could be different pollutant sources (such as; power production and industrial activities that are explained in section 1.1.2), differences between model input and real meteorological variable values, and other measurement uncertainities in these stations.

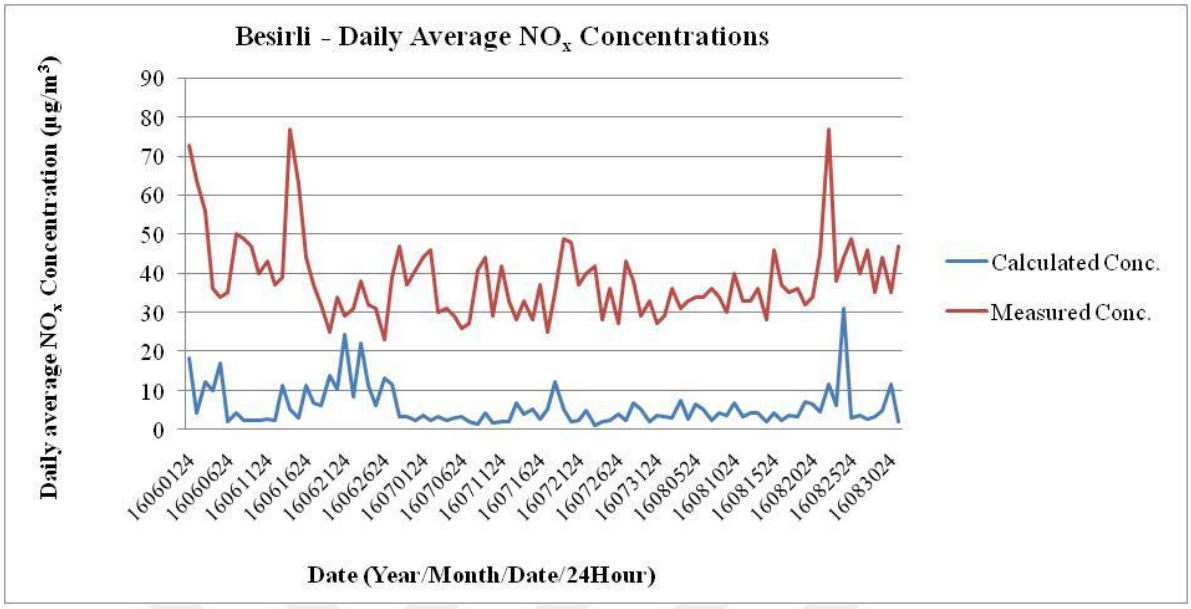


**Figure 3.3.** Calculated and measured daily average $NO_x$ concentrations in summer at Besirli station

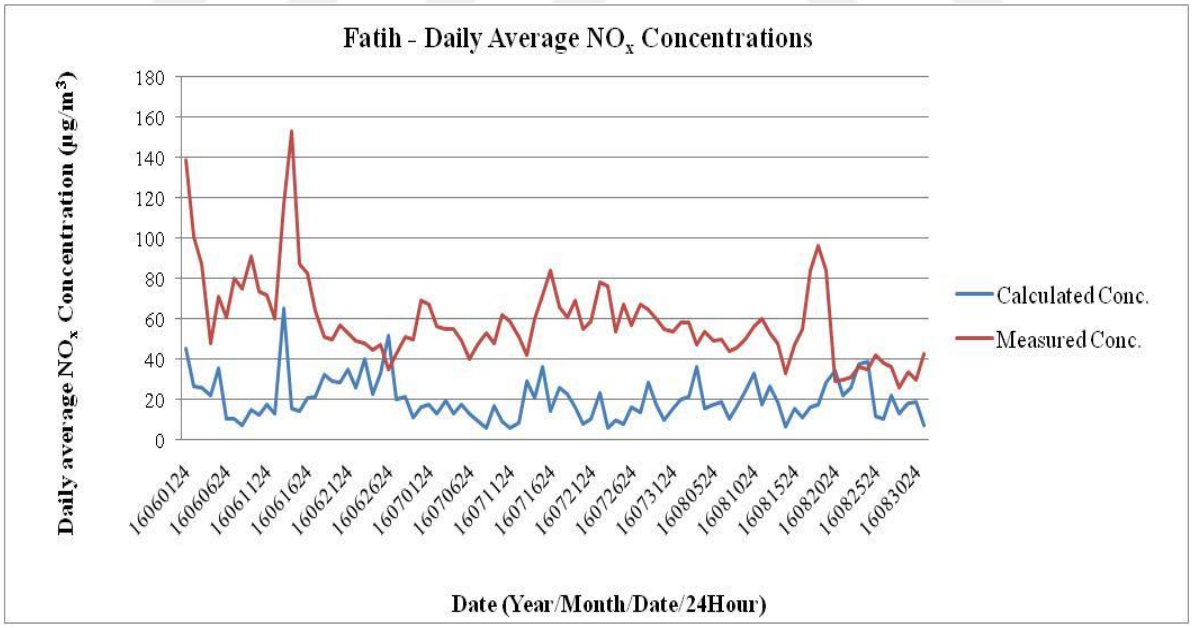


**Figure 3.4.** Calculated and measured daily average $NO_x$ concentrations in summer at Fatih station

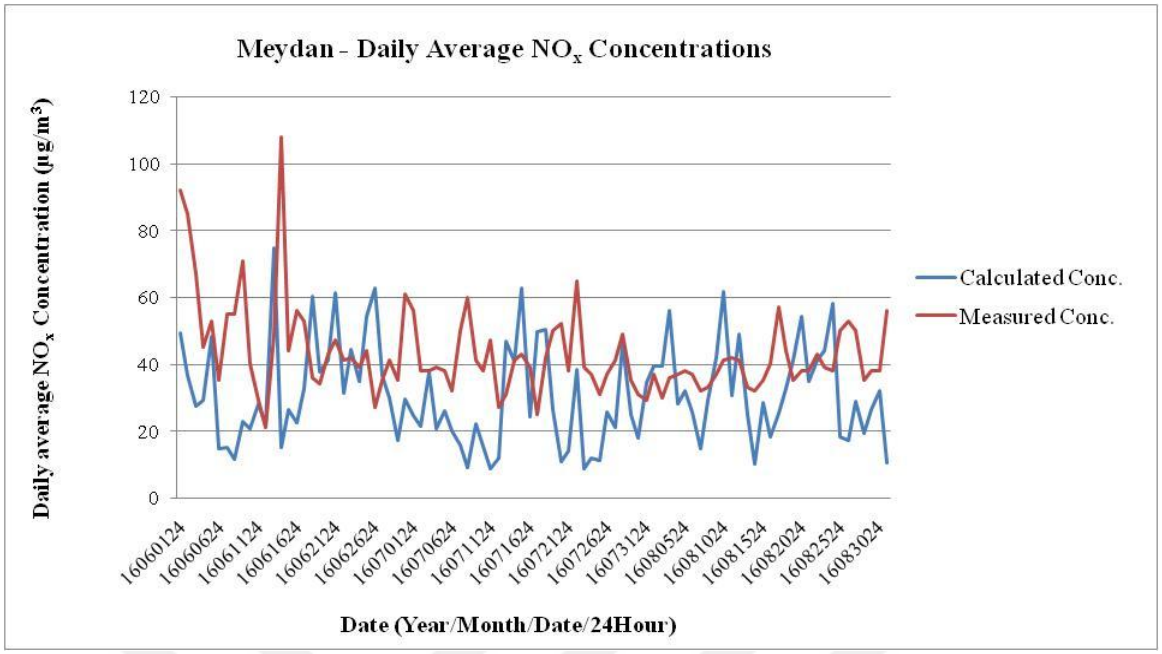


**Figure 3.5.** Calculated and measured daily average $NO_x$ concentrations in summer at Meydan station

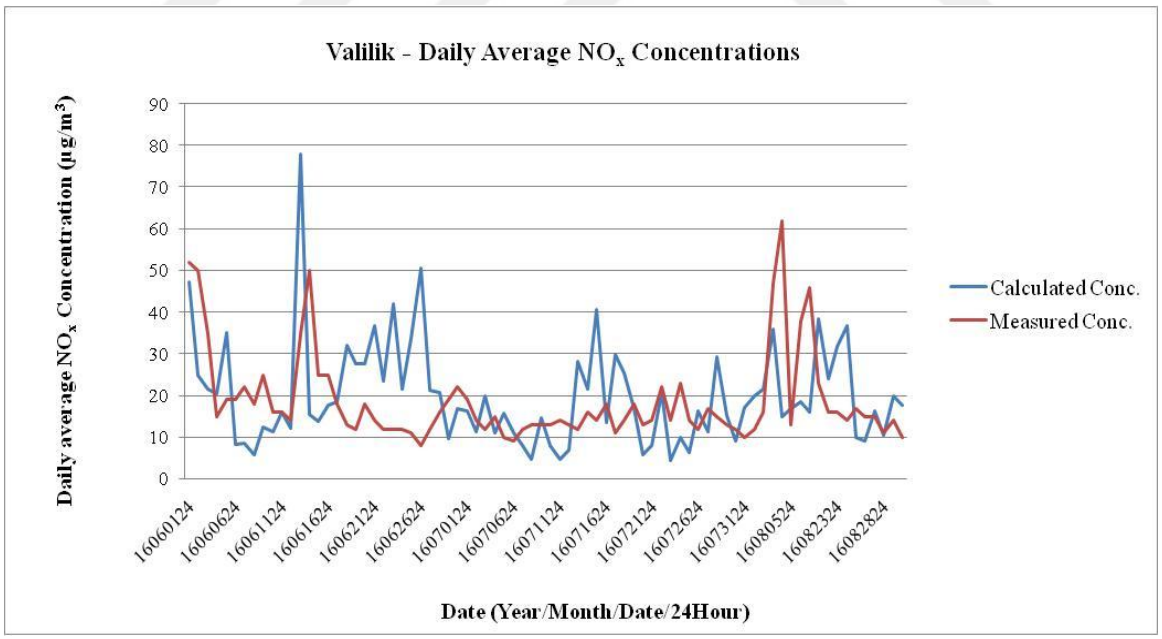


**Figure 3.6.** Calculated and measured daily average $NO_x$ concentrations in summer at Valilik station

Measured and calculated concentrations of $NO_x$ is very close to each other in Meydan and Valilik stations. Although model results and measurements do not match perfectly, there is a synchronisation between their fluctuations in all stations.

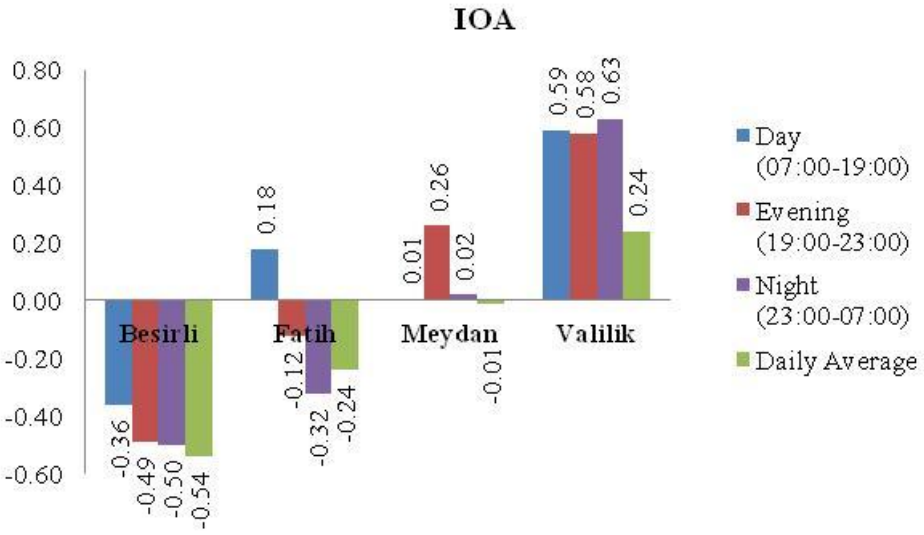


**Figure 3.7.** IOA results of calculated and measured $NO_x$ values for day, evening, night and daily average

Model was validated with three statistical methods: IOA, NMSE, and FAC2 that are explained in materials and methods section. Index of Agreement (IOA) values were calculated by using model results and measured values with the help of the Equation 2.6. IOA values change between "-1.0" and "1.0". If the value is zero, the sum of the magnitudes of the errors and the sum of the perfect model-deviation and observed-deviation magnitudes are equivalent. IOA values near "-1.0" means that the model-estimated deviations about mean observed value are poor estimates of the observed deviations. According to the results given in Figure 3.7, it can be seen that the model results are compatible with the measurements at Meydan and Valilik stations. But at Besirli and Fatih stations, this compliance is lower, IOA value is close to -1.0. Possible reason of this situation could be the dominance of other $NO_x$ sources in these stations. IOA value is better in the daytime period in the Fatih station as an exceptional case. In daytime, the high emission of $NO_x$ at Meydan and Valilik stations could be transported to the Fatih region by dominant wind which comes from the east.

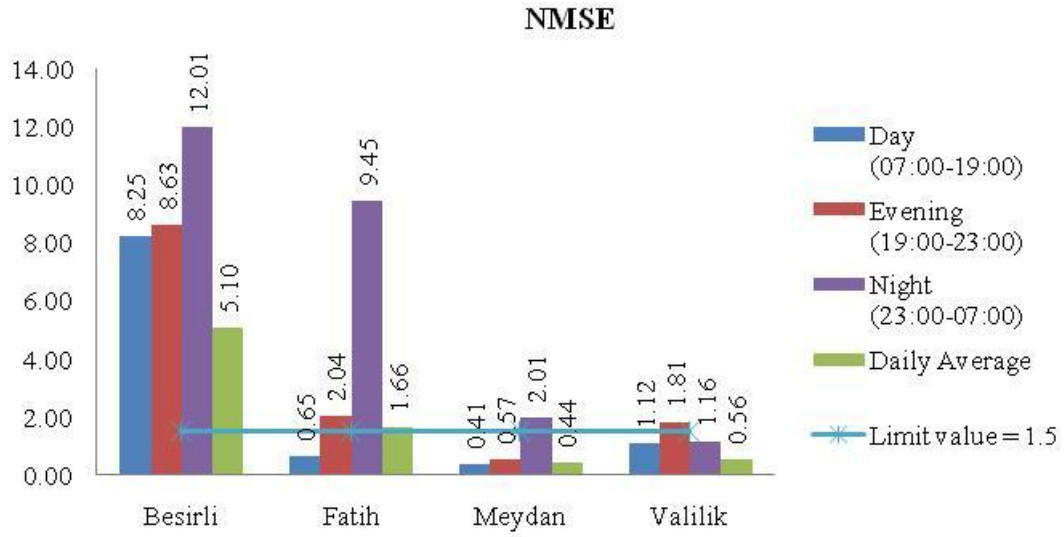


**Figure 3.8.** NMSE values for day, evening, night and daily average

Meydan and Valilik stations are located in areas where roads are concentrated, so road traffic emissions are expected to be high at these stations. These stations are also placed in front of the higher mountaneous regions with respect to Besirli and Fatih stations. Dispersion of traffic sourced $NO_x$ emissions more difficult in Meydan and Valilik stations because of the topographical structures, meteorological effects, and the inversion phenomenon. So, concentrations of $NO_x$ are high in these areas and as a result, compatibility of model results and measurements is higher in these regions.

NMSE is a different method that is used to measure the relevance between the observed and calculated values by using Equation 2.8. When the NMSE values is lower than 1.5 and approaches to zero, the model results can be accepted. As can be seen in the graph given in Figure 3.8, the calculated model results for Valilik station are consistent with the measurements except the evening hours. At the Meydan station, there are high compatibility between observed and predicted values except the nighttime period. The high NMSE values that are found for Besirli and Fatih stations prove that the model and measurement results are inconsistent.

FAC2 values were calculated by using model results and measurement values by using the formula given in Equation 2.7. When the FAC2 values close to “1.0”, the model results can be accepted. According to the results given in Figure 3.9, the model results are only compatible with the measurements at Meydan and Valilik stations.

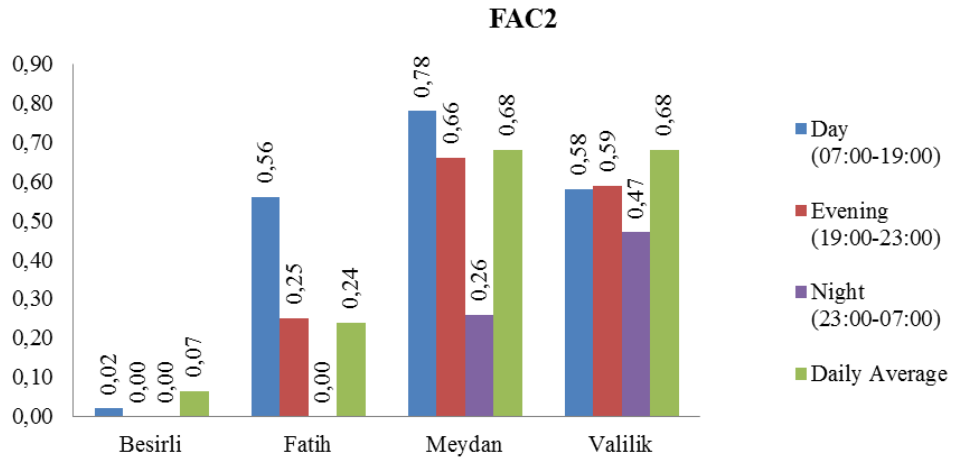


**Figure 3.9**. The factor of two (FAC2) values for day, evening, night and daily average

According to statistical evaluation results, model calculation values could only be validated with measurements at Meydan and Valilik stations. Because these stations are located in areas where roads are concentrated, it is expected that road traffic emissions are high and compatibility of the model with measurements is good. Nighttime values of FAC2 is lower in these two stations because traffic sourced $NO_x$ emissions are not dominant and other $NO_x$ sources are predominant in nighttime period. Although there are little uncertainties in statistical verification results, in general results show that the validation process of the model in the study area has been completed successfully. Validated grid-wise values of the model can be used to determine the distribution of $NO_x$ and identify critical locations in the study area.

### 3.2.2 Validation of traffic noise modeling

Eight control points were determined within the study area for the model validation of road traffic noises with 24 hours sound pressure level measurements. The model results are calculated taking into account the effect of road traffic for the identified receptor points. Because modeling represents one year, it is assumed that the model calculation results will show negligible variability throughout the year and so will be comparable with the measurement results. The coordinates of the measurement points, model results, and observed values are shown in Figure 3.10 and Table 3.7.

**Table 3.7.** Comparison of model results with noise measurements for $L_{den}$ value

| No | Name | Latitude | Longitude | Predicted $L_{den}$, dB(A) | Observed $L_{den}$, dB(A) | Difference dB(A) |
|---|---|---|---|---|---|---|
| 1 | Yalıncak Municipality Building | 40° 59.077'N | 39° 49.031'E | 80,6 | 83,6 | 3 |
| 2 | HalukUlusoy Football Facilities | 41° 00.561'N | 39° 42.999'E | 81,4 | 84,7 | 3,3 |
| 3 | Social Security Institution Provincial Directorate | 41° 00.197'N | 39° 43.028'E | 65,8 | 62,7 | -3,1 |
| 4 | Highways Social Facilities | 40° 59.703'N | 39° 46.597'E | 73,3 | 75,5 | 2,2 |
| 5 | Trabzon Metropolitan Municipality | 41° 22.130 'N | 39°42.589'E | 68,3 | 68,9 | 0,6 |
| 6 | Provincial Directorate of Environment and Urbanism | 40° 59.662'N | 39° 40.113'E | 69,5 | 72,3 | 2,8 |
| 7 | Trabzon Port Authority | 41° 00.440'N | 39° 44.232'E | 66,7 | 67,2 | 0,5 |
| 8 | Fatih High school | 40° 59.945'N | 39° 41.622'E | 69,6 | 72 | 2,4 |

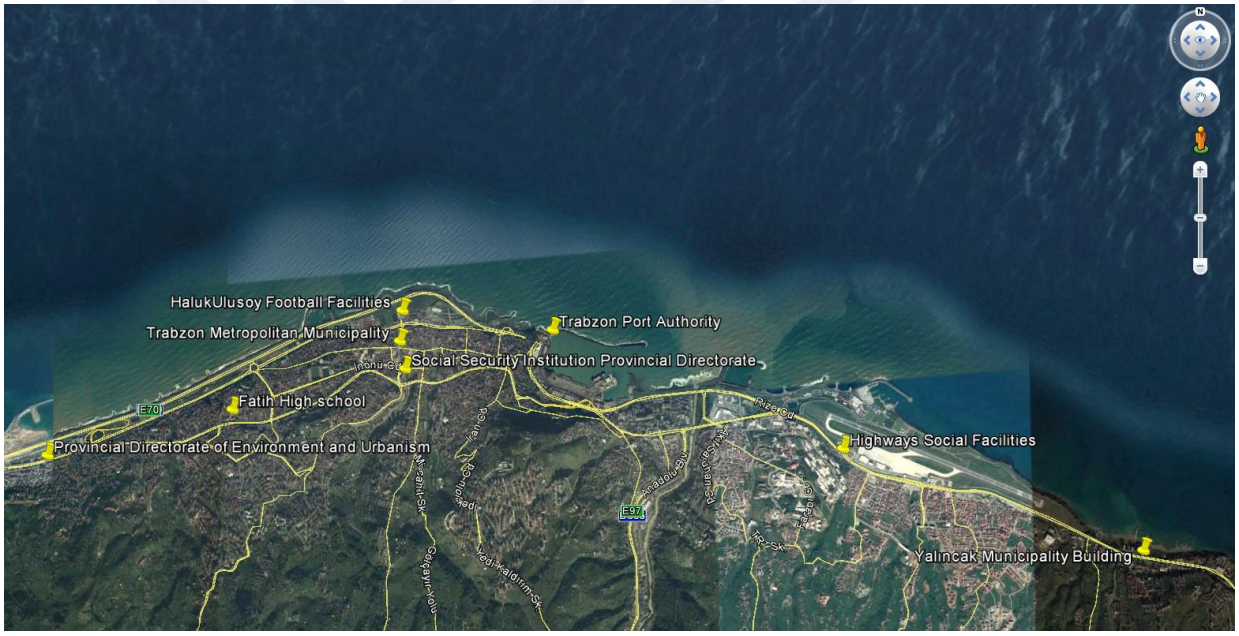


**Figure 3.10.** Locations of noise measurement points (Google Earth, 2017)

The verification points were selected such that, the dominant source is road traffic noises in the study area. But the background noise effect is inevitable which is emitted from other sources. When model and measurement results are compared, it can be considered that ± 3 dB(A) difference is acceptable for the validation of model. Possible reasons for the differences between measurement results and model outputs are the influence of various sources on the urban scale to the measurement results at the receptor point, the uncertainty due to the modeling software and method, the building

area, the ground geometry, and the emission input data (USDT, 2010). Calculated model results were compared with the measurements for all time periods. The differences between the predicted and observed values was found below 3 dB(A) in about 63% of identified measurement points. As a result, it can be said that the model outputs are in good and reliable intervals.

### 3.3 Traffic Sourced Noise and $NO_x$ Modeling Results in Trabzon

Buildings are classified as households, school and hospital according to their purpose of usage and defined in models. The number of buildings, type of building and number of residences that are exposed to specific noise levels and $NO_x$ concentrations can be obtained from model results. There are 252 schools, 78 hospitals and 95,900 households in the study area.

#### 3.3.1 Air quality modeling results

The distribution of air pollutants originating from road traffic is affected by factors such as physical, geographical differences, topographical, meteorological conditions, seasonal changes and traffic intensity. Considering these factors, the concentrations of road traffic sourced $NO_x$ at the receptor points were determined by AERMOD. $NO_x$ concentrations were calculated by using daily average $NO_x$ emissions, terrain, and meteorological data as input. Distribution maps of $NO_x$ emissions are shown in Appendix-Figure 1-3 which are prepared by the interpolation of maximum hourly, daily, and yearly values at receptor points. It was observed that the spread of pollutants in the maps was towards to the east because the daily dominant wind direction is east and south west according to one year meteorological data (Figure 2.7). In addition, sea-breeze flow is significantly influenced by buildings in residential areas and mountains that are extending parallel to the coast. The inner parts of the city are not affected by $NO_x$ pollution as in coastal regions.

Road traffic sourced $NO_x$ emissions were most heavily observed around the Yavuz Selim Boulevard, Kahramanmaras Street, Sahil Yolu Street and O10 highway which are located in highly populated residential and coastal areas. According to the model results, vicinity of Taksim Street, Sehit Refik Cesur Street and Senol Gunes Boulevard are less affected by road traffic sourced $NO_x$ emissions which are located in the more

inner parts of the city. However, when we look at the average $NO_x$ emissions, the emission values sourced from Kahramanmaras Street are half of the values of Taksim Street, and one-third of the values of Senol Gunes Boulevard (Table 3.4). These results show that topographical and meteorological effects and especially inversion phenomenon play a very important role in the dispersion of $NO_x$ emissions (Figure 3.11).

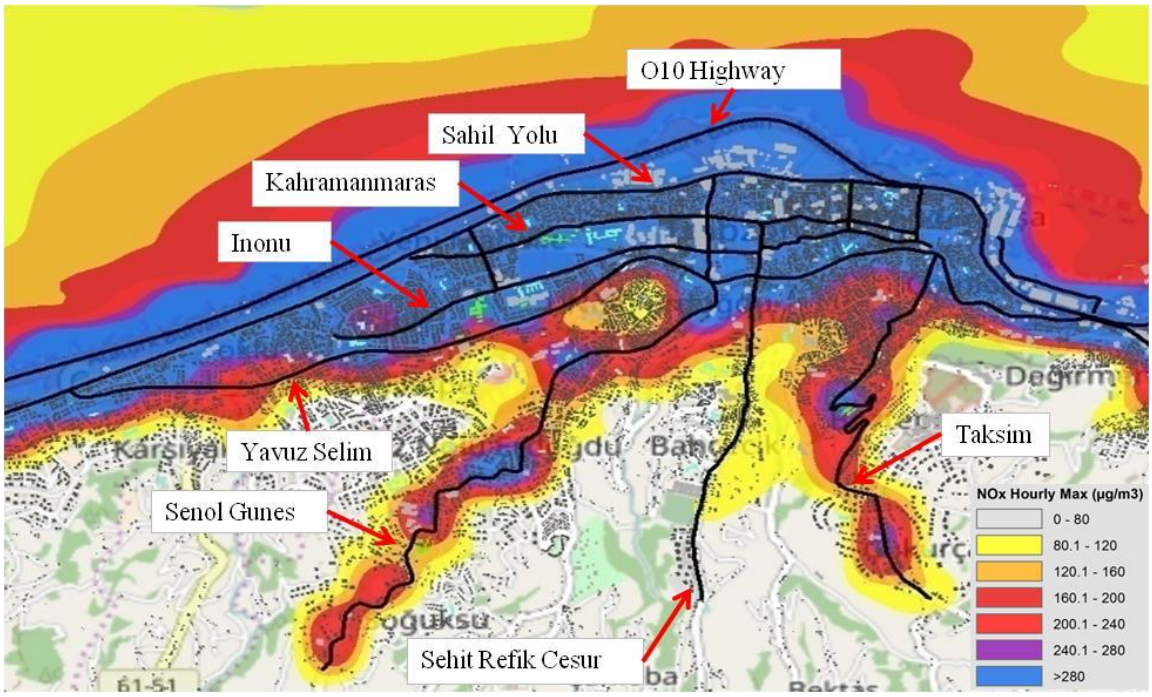


**Figure 3.11.** Topographical effect on the distribution of hourly maximum NOx emissions

According to the Air Quality Assessment and Management Regulation issued by the Ministry of Environment and Urbanization in Turkey, the 1-hour average $NO_x$ emissions at a receptor site cannot exceed 18 times the limit value in a year. It is targeted that the limit value of $NO_x$ emission for 2024 is 200 µg/m$^3$. The legal emission limit was 300 µg/m$^3$ in 2014 when the directive is published. This limit is planned to be reduced 10 µg/m$^3$ every year, to reach the goal of 2024 (MoEU, 2008). Since this study was conducted using meteorological data of the year 2016, the limit value is accepted as 280 µg/m$^3$. If the average hourly $NO_x$ emissions for each receptor exceed the limit value 19 times during a year, it is considered that there is a critical $NO_x$ exposure. In Appendix-Figure 4, the distribution map shows the areas where the limit values are exceeded. According to these results, the most critical and populated areas are highly

affected in a similar way from road traffic sourced $NO_x$ emissions which are placed around Yavuz Selim Boulevard, Kahramanmaras Street and Sahil Yolu Street. Results show that, 10% of total population, 29 schools, and 19 hospitals are exposed to traffic related $NO_x$ emissions above the threshold values during a year (Table 3.8).

**Table 3.8.** Traffic Related $NO_x$ exposure results

| **Hourly Limit $NO_x$ Value at Receivers During a Year (µg/m3)** | **Households** | **Population** | **School** | **Hospital** |
|---|---|---|---|---|
| < 280 | 67,032 | 237,851 | 190 | 54 |
| > 280 | 13,570 | 31,804 | 29 | 19 |

### 3.3.2 Noise modeling results

The effects of roads vary depending on the intensity and flow regime of the traffic at day time, evening time and night time. Exposure calculation studies were conducted separately for different time periods on road impacted areas. The study areas are considered to be "Areas where commercial buildings and noise sensitive uses are coexist in areas where households are concentrated" which is defined in the Annex VII-Table 1 of the "Environmental Noise Assessment and Management Regulation". Threshold values of noise exposure for the roads which are given in the same table are used for the evaluations in the domain of the roads (MoEU, 2010b).

END and "Environmental Noise Assessment and Management Regulation" require an estimation of the areas that are exposed to each of the following bands of $L_{den}$ values in dB(A) and 4 m above the ground: 55 dB(A)–59 dB(A), 60 dB(A)–64 dB(A), 65 dB(A)–69 dB(A),70 dB(A)–74 dB(A), >75 dB(A), for road traffic. The noise maps for $L_{den}$, $L_{day}$, $L_{evening}$ and $L_{night}$ that show the equivalent noise levels were created on the basis of the calculated noise level in grid points and given in Appendix-Figure 5-8, respectively. Results show that, road traffic sourced noise affects mainly vicinity of the roads. Meteorological and topographical features do not effect noise dispersion in these areas.

As a result of the evaluations, the number of houses, residences, schools and hospitals where the threshold values were exceeded in the study area were determined. The exposure results in the study area where the limit values are exceeded for night, day and evening time periods are given in Table 3.9. According to the results, in the city center

of Trabzon, 9% of the population is exposed to 58 dB(A) and higher noise levels during the nighttime period because of the road traffic. During evening time, 9% of population is exposed to 63 dB(A) and higher noise levels. 7% of the total population is exposed to 68 dB(A) and higher noise levels during daytime.

**Table 3.9.** Noise exposure results in Trabzon city center

| Threshold Values (dBA) | Households | Population | School | Hospital |
|---|---|---|---|---|
| **<68 ($L_{day}$)** | 6,100 | 21,700 | 19 | 16 |
| **<63 ($L_{evening}$)** | 8,400 | 29,400 | 32 | 24 |
| **<58 ($L_{night}$)** | 8,400 | 29,300 | 32 | 27 |

## 3.4 Examination of the Relationship between Air Pollution and Noise

### 3.4.1 Correlation between traffic related $NO_x$ and Noise

Correlation between concentration of traffic sourced $NO_x$ emissions and noise level at many receptors was determined in terms of Pearson's correlation coefficient in this study. Pearson's correlation coefficient is a statistical measure of the strength of a linear relationship between matched data. It is represented by "r" and positive "r" values indicate positive linear correlation while negative values indicate negative linear correlation. A value of "0" denotes no linear correlation. If the value is close to "1.0" or "–1.0", it is accepted that there is a strong linear correlation (Chowdhury et al., 2015).

In this study, the dispersion of emissions from road traffic in the city center of Trabzon was modeled separately for three time slices' and daily period. The maximum $NO_x$ concentrations at the receptor points were obtained. In the same way, the road traffic sourced noise distribution in the study area was modeled and the noise values at the designated receptor points were calculated for the three time slices and daily average of the day. Two separate distribution models were assembled in the geographic information system (GIS) software and intersection points were identified. 767 intersection points were found in noise and $NO_x$ dispersion model data sets. The Pearson correlation values at these points were found as 0.78, 0.75, 0.76 and 0.74 for daily average (den), daytime, evening time, and nighttime periods, respectively (Table 3.10).

The annual average $NO_2$ concentrations obtained from the monthly passive sampler measurements and the long-term average noise levels sourced from the traffic was analyzed. Correlation coefficient between $NO_2$ and noise ($L_{24}$ hours) was found to be 0.62 (Foraster et al., 2011). In another research, the correlation coefficient was reported as 0.46 between modeled values for both noise ($L_{24}$ hours) and 3 month mean $NO_2$ concentrations (Klaeboe et al., 2000). The relationship between measured $NO_x$ and noise values were researched in another study. The correlation coefficient was found as 0.64 (Davies et al., 2009).

**Table 3.10**. Correlation between the maximum noise level and the maximum concentration of $NO_x$ for intersected receptor points for different time slices of a day

| **Time Slices** | **Pearson Correlation Factor (r)** |
|---|---|
| Den (daily average) | 0.78 |
| Day (07:00 – 19:00) | 0.75 |
| Evening (19:00 – 23:00) | 0.76 |
| Night (23:00 – 07:00) | 0.74 |

The linear regression is used to examine the linear relationship between a dependent variable Y and an independent variable X. The initial determination of the probable relationship between two continuous variables should always be based on the distribution graph. Such a plot will show whether the relationship is linear or not. In the linear regression model, the regression curve is defined by the equation $Y = a + bX$ and is a straight line. In this line, parameter "a" represents intersection with "y" and parameter "b" represents slope. In a decreasing regression line, slope is negative ($b<0$), so there is a negative relationship between the two variables. A positive relationship between the two variables is represented by the increasing regression line ($b>0$) (Schneider et al., 2010). According to the results obtained there are positive relationships between traffic related $NO_x$ concentrations and noise values in all time slices of a day (Figure 3.12 - Figure 3.15).

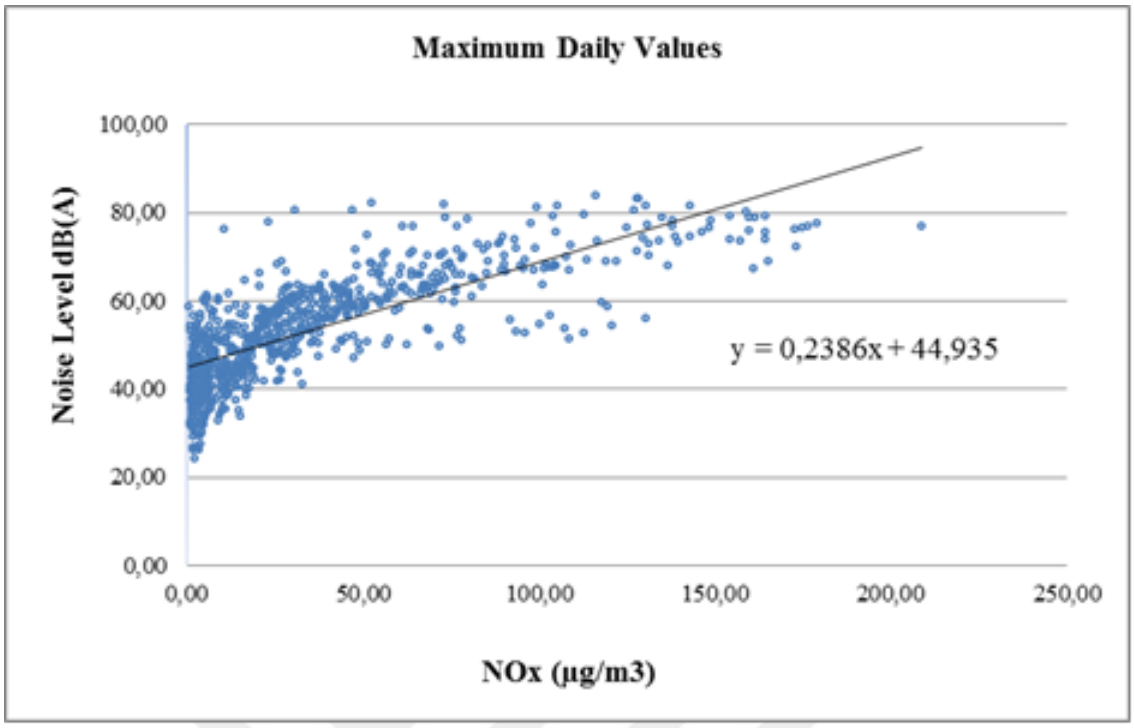


**Figure 3.12.** Linear regression line of maximum daily noise level and $NO_x$ concentrations in intersected receiver points.

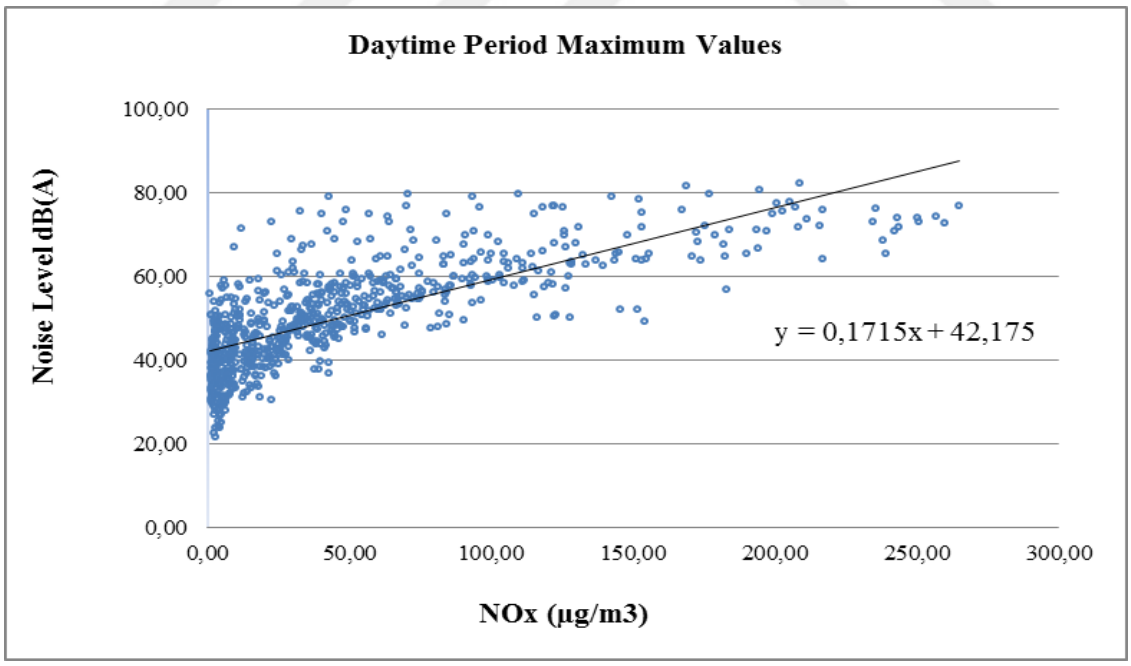


**Figure 3.13.** Linear regression line of maximum daytime (07:00-19:00) noise level and $NO_x$ concentrations in intersected receiver points.

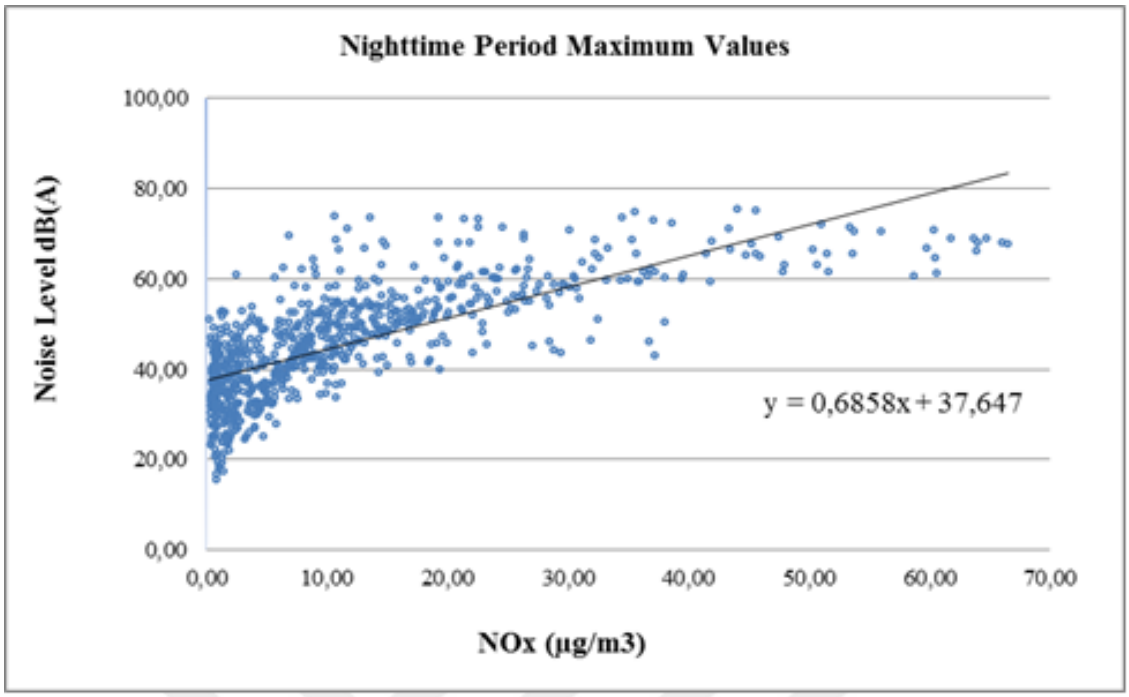


**Figure 3.14.** Linear regression line of maximum evening time (19:00-23:00) noise level and $NO_x$ concentrations in intersected receiver points

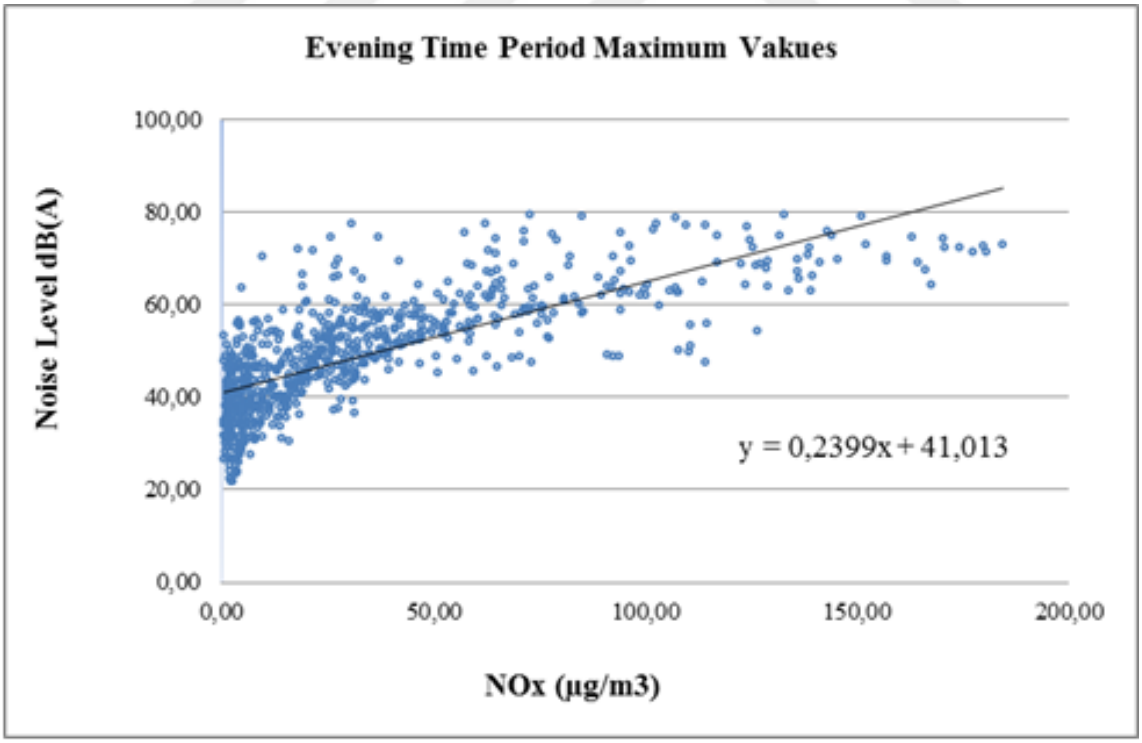


**Figure 3.15.** Linear regression line of maximum nighttime (23:00-07:00) noise level and $NO_x$ concentrations in intersected receiver points.

### 3.4.2 Combined exposure to traffic related Noise and $NO_x$

Motor vehicles are one of the primary sources of air and noise pollution, but the production mechanisms and modes of dispersion of emissions vary. While gaseous pollutants are generated directly from internal combustion engines, noise is emitted from the engine and tires via air displacement. Noise is transmitted by reflected and breakable pressure waves and rises by riding, but in free-field conditions, exposure to noise is reduced by the distance from the source and there is a short half-life (Davies et al., 2009; King et al., 2016). However, the air pollutants leaving the vehicles are dispersed exponentially as they move away from the sources (King et al., 2016). Atmospheric conditions (such as temperature, wind direction and intensity) that change as a result of local meteorological effects can have an effect on noise propagation, but their effects may be more important in the distribution of $NO_x$ concentrations (Davies et al., 2009).

It is clear that meteorological variables such as wind speed and wind direction affect the concentration distribution of air pollutants in the atmosphere, as seen in the above discussions and previous studies. The concentration of air pollutants varies depending on the recirculating vortexes in the downwind and upwind regions under certain meteorological conditions (King et al., 2016). However, meteorological variables have not direct effects on noise propagation as the traffic volume and road characteristics. It is difficult to interpret and observe the effect of traffic volume and road characteristics on the concentration of air pollutants (Chowdhury et al., 2015).

According to the calculations performed in the study area, 10% of Trabzon population, 29 schools and 19 hospitals were exposed more than 18 times per year to the hourly $NO_x$ concentrations higher than the limit value (280 $\mu g/m^3$). The population living in the buildings which are exposed to the traffic noise threshold values at any time slices (limit values are shown in Table 1.7) constitutes 21% of the total population. Moreover, there are 92 schools and 48 hospitals where noise limit values were exceeded. 6% of the total population of the Trabzon city center exposed to noise and $NO_x$ emissions above the limit values (Table 3.11).

**Table 3.11.** Combined exposure to traffic related Noise and $NO_x$

| | Households | Population | School | Hospital | % of Total Population |
|---|---|---|---|---|---|
| $NO_x$ Exposure (µg/m3) | 13,570 | 31,804 | 29 | 19 | 10.12% |
| Noise Exposure dB(A) | 17,845 | 65,956 | 92 | 48 | 20.99% |
| Noise and $NO_x$ Exposure | 6,617 | 19,157 | 29 | 19 | 6.10% |

Figure 3.16 shows the buildings which are exposed to noise and $NO_x$ emissions above legal limit values. It is observed that vicinity of the Sahil Yolu Street, Kahramanmaras Street, Inonu Street and eastern part of Yavuz Selim Boulevard are heavily affected by two environmental factors. It is seen that only the noise exposure is dominant and the air pollution is below the limit values in the sections which are placed in south of Yavuz Selim Boulevard. The altitude is starting to increase and getting higher at the southern regions of Yavuz Selim Boulevard. In coastal side of the city, inversion phenomenon and other meteorological conditions could be the reasons of the higher traffic sourced $NO_x$ concentrations. Noise propagation mechanism is not affected by meteorological and topographical conditions as $NO_x$ dispersion. As it seen from Figure 3.16, roadsides are highly affected by traffic noise in Trabzon city center.

As it was discussed in previous sections, the main sources of noise and $NO_x$ emissions could be heavy vehicles. High ratio of heavy vehicles could be the reasons of these two environmental factors' limit exceedance cases. As shown in Table 2.10, Kahramanmaras Street and Yavuz Selim Boulevard have the same vehicle speeds and their annual average daily traffics are 11,672 and 20,340 respectively. However, the percentage of heavy vehicles in Kahramanmaras Street is 47% while it is 20% in Yavuz Selim Boulevard. As seen from Figure 3.16, although the number of vehicles on Yavuz Selim Boulevard is doubled, road traffic sourced noise and $NO_x$ exposure is higher in the vicinity of Kahramanmaras Street.

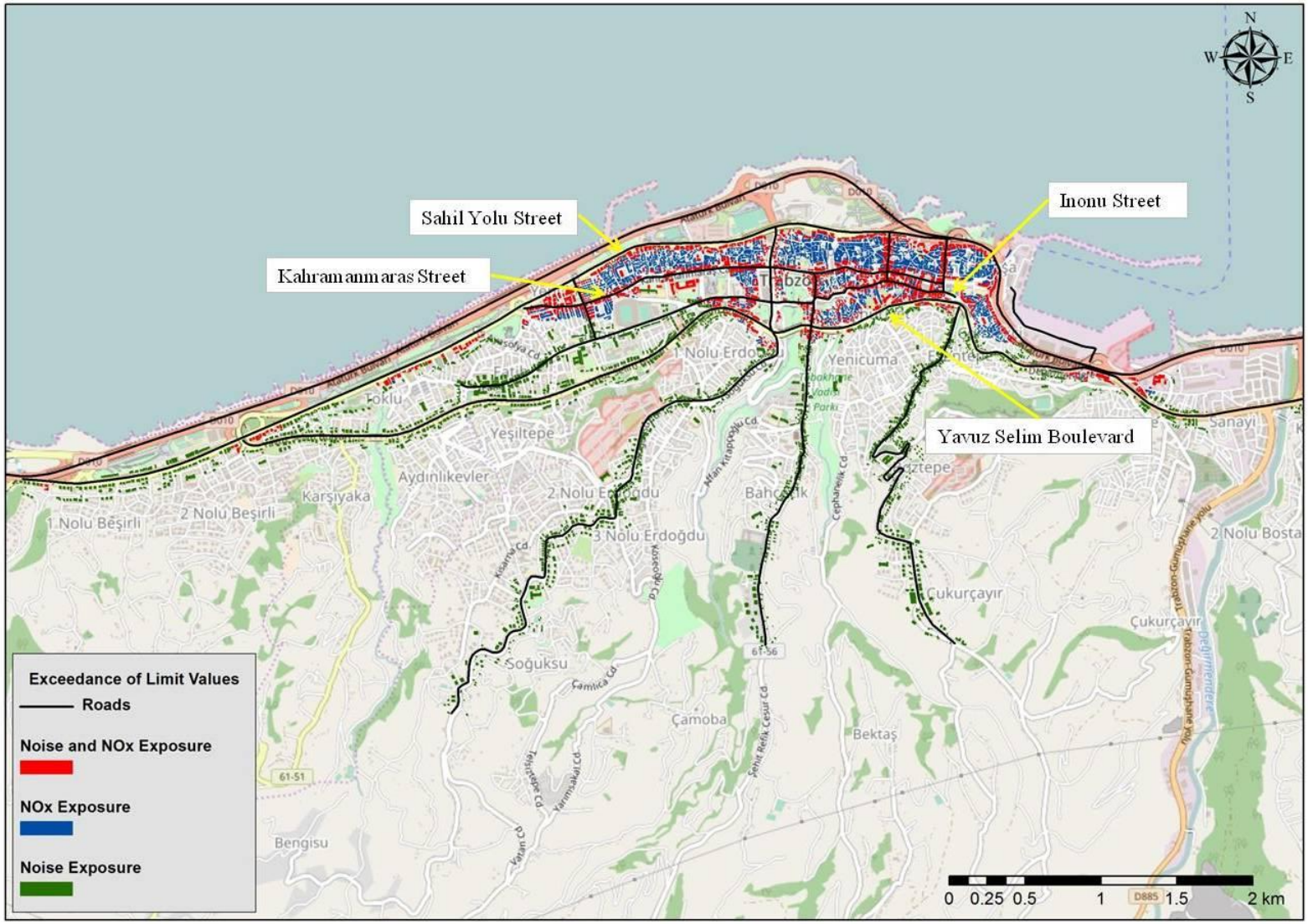


**Figure 3.16.** Traffic Noise and $NO_x$ Exposure in Trabzon city center

# 4 CONCLUSION

In the scope of this work, road traffic sourced noise and air pollutants' emission inventory were prepared, noise and $NO_x$ emission dispersions were modeled, model results were validated with on-site measurements in the city center of Trabzon. Correlation relationship between traffic sourced $NO_x$ and noise was evaluated. Moreover, the population affected by these two environmental factors in Trabzon city center has been determined.

Emissions of CO, NMVOC, $NO_x$, $PM_{10}$, $PM_{2.5}$ and $SO_2$ in the study area were calculated as 1898, 337, 681, 34, 8 and 0.084 tons/year respectively. Light vehicles are responsible from 93% of daily average CO emissions, 92% of NMVOC emissions and 57% of $SO_2$ emissions while, 50% of $NO_x$ emissions and 56% of $PM_{10}$ emissions caused by heavy vehicles. If it is considered that almost all heavy vehicles have diesel-fueled engines and the percentage of heavy vehicle number is approximately one third of light vehicle number, it can be concluded that the $NO_x$ and $PM_{10}$ emissions from roads are mainly caused by heavy vehicles in Trabzon city center.

Noise emission inventory shows that the main parameters of road traffic noise emissions could be; heavy vehicle proportion in total traffic load and vehicle speeds. Higher noise emission were calculated because of the higher heavy vehicle proportion in two streets which have same road surface material, similar representative vehicle speeds and very close annual average daily traffic counts. Although heavy vehicle ratio, road surface material, and annual average daily traffic values are same or close to each other, daily average noise levels are found higher in a street which has higher vehicle speeds.

$NO_x$ dispersion modeling results and site measurements were compared using summer months' concentrations due to the disturbing effects of domestic heating in other seasons. Although model results and measurements not match perfectly, there is a synchronisation between their fluctuations in all air quality monitoring stations. Performance of $NO_x$ dispersion modeling was evaluated by using Index of Agreement, Normalized Mean Square Error, and Factor of Two methods. According to all these statistical methods, model and measurement results are compatible especially in Meydan and Valilik stations which are located in front of the high mountainous region

where roads are concentrated. Due to topographical features and meteorological effects, pollutants could not disperse in the Meydan and Valilik area.

For road traffic noise model validation purpose, eight control points were determined within the study area. The differences between model results and the measurements for all time periods were found below 3 dB (A) in about 63% of the receptor points.

In addition, the flow of sea breeze is significantly affected by buildings and mountains running parallel to the shore. It is seen that the inner parts of the city are not affected as much as the coastal areas from $NO_x$ pollution. Topographical, meteorological effects and especially inversion phenomenon may be the main parameters on the dispersion of $NO_x$ emissions. According to results obtained, 10% of total population, 29 schools, and 19 hospitals are exposed to the traffic related $NO_x$ emissions above the threshold values during a year.

Road traffic noise modeling results show that, vicinity of the roads are heavily affected from road traffic noise. As a result of the evaluations, in the city center of Trabzon, 9% of the population and 27 hospitals are exposed to 58 dB(A) and higher noise levels during the nighttime period because of the road traffic. 7% of the total population, 19 schools, and 16 hospitals are exposed to 68 dB(A) and higher noise levels during daytime.

Correlation between concentration of traffic sourced $NO_x$ emissions and noise level at many receptors was determined in terms of Pearson's correlation coefficient. 767 intersection points were found in noise and $NO_x$ dispersion model data. The Pearson correlation coefficients at these points were 0.78, 0.75, 0.76, and 0.74 for daily average (daytime, evening time, and nighttime average), day time, evening time, and night time periods respectively. These values are higher than the results of previous studies within the literature.

Evaluation of the combined exposures to traffic related noise and $NO_x$ shows that in coastal side of the city, inversion phenomenon and other meteorological conditions could be the reasons for the higher traffic sourced $NO_x$ concentrations. Noise propagation mechanism is not affected by meteorological and topographical conditions as $NO_x$ dispersion. 10% of Trabzon city's population was exposed to $NO_x$ concentrations higher than the limit value and 21% of the total population living in the

buildings was exposed to traffic noise greater than the threshold values. It was determined that 6% of the total population, 29 schools, and 19 hospitals are exposed to noise levels and $NO_x$ concentrations above the limit values in the city center of Trabzon. Moreover, it was observed that high ratio of heavy vehicles could be the main reason for these limit exceedances.

In conclusion, this study shows that the population in the urbanized areas of Trabzon province was highly affected from noise and $NO_x$ emissions due to road traffic. It has been discussed that geographical structure of the city and meteorological effects are important parameters that affect the dispersion of them. It can be said that the correlation between road traffic sourced $NO_x$ emissions and noise is dependent on complex local factors and for this reason, local conditions must be considered for more accurate results. It has been observed that high heavy vehicle proportion in traffic causes higher exposures from traffic both for $NO_x$ and noise. The inversion phenomenon causes higher air pollutant concentrations at receptors in the coastal side of the city and urban areas. The road traffic sourced noise and air pollution problems can be encountered in urban areas when environmental factors (topographic and meteorological features) are not considered in city planning.

Road traffic emissions can be reduced by various transport planning strategies and policies such as; encouraging use of public transport and cycling, restricting heavy vehicle entrances into urban roads by creating alternative routes, establishing control mechanisms for the reduction of automobile and truck emissions, and replacing existing public transportation vehicles with hybrid or electric vehicles. These kinds of urban planning and management strategies can reduce traffic sourced noise and air pollution at the source. Findings in this study can be useful for future land use planning of Trabzon city to reduce the effects of traffic sourced noise and air pollution on public health. Moreover, in future works, separate and combined health effects of noise and $NO_x$ exposures can be examined with the guidance of these findings.

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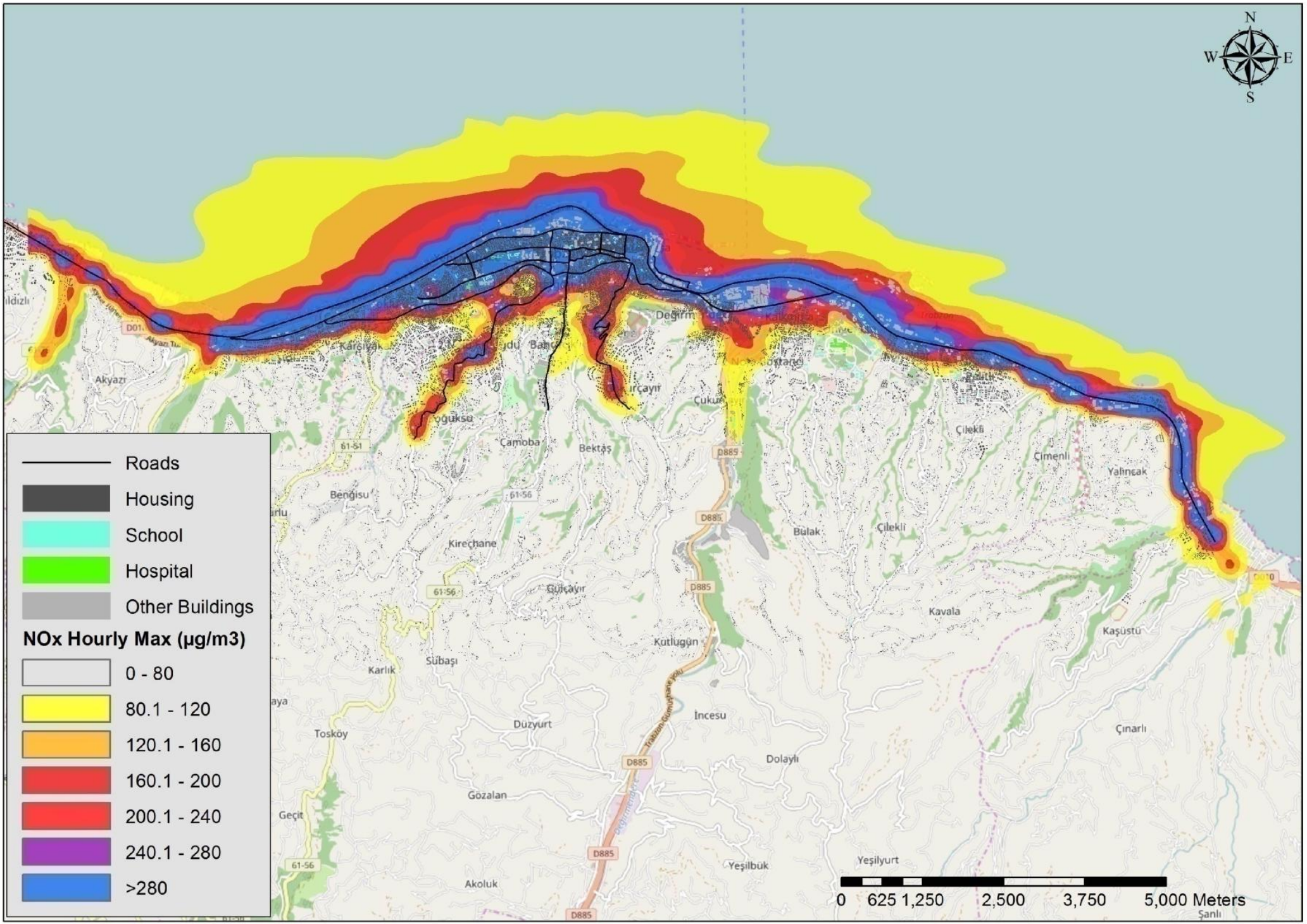
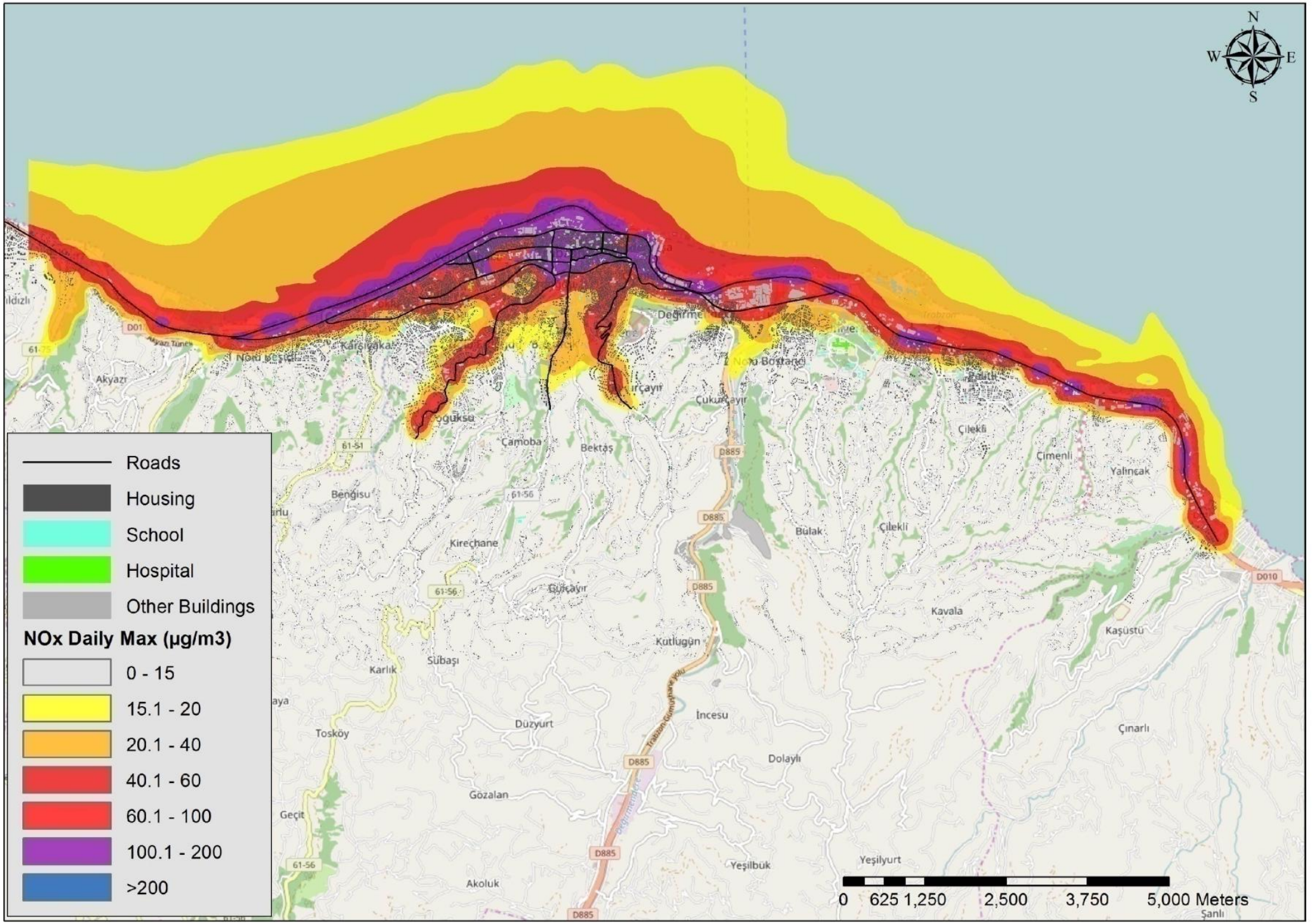
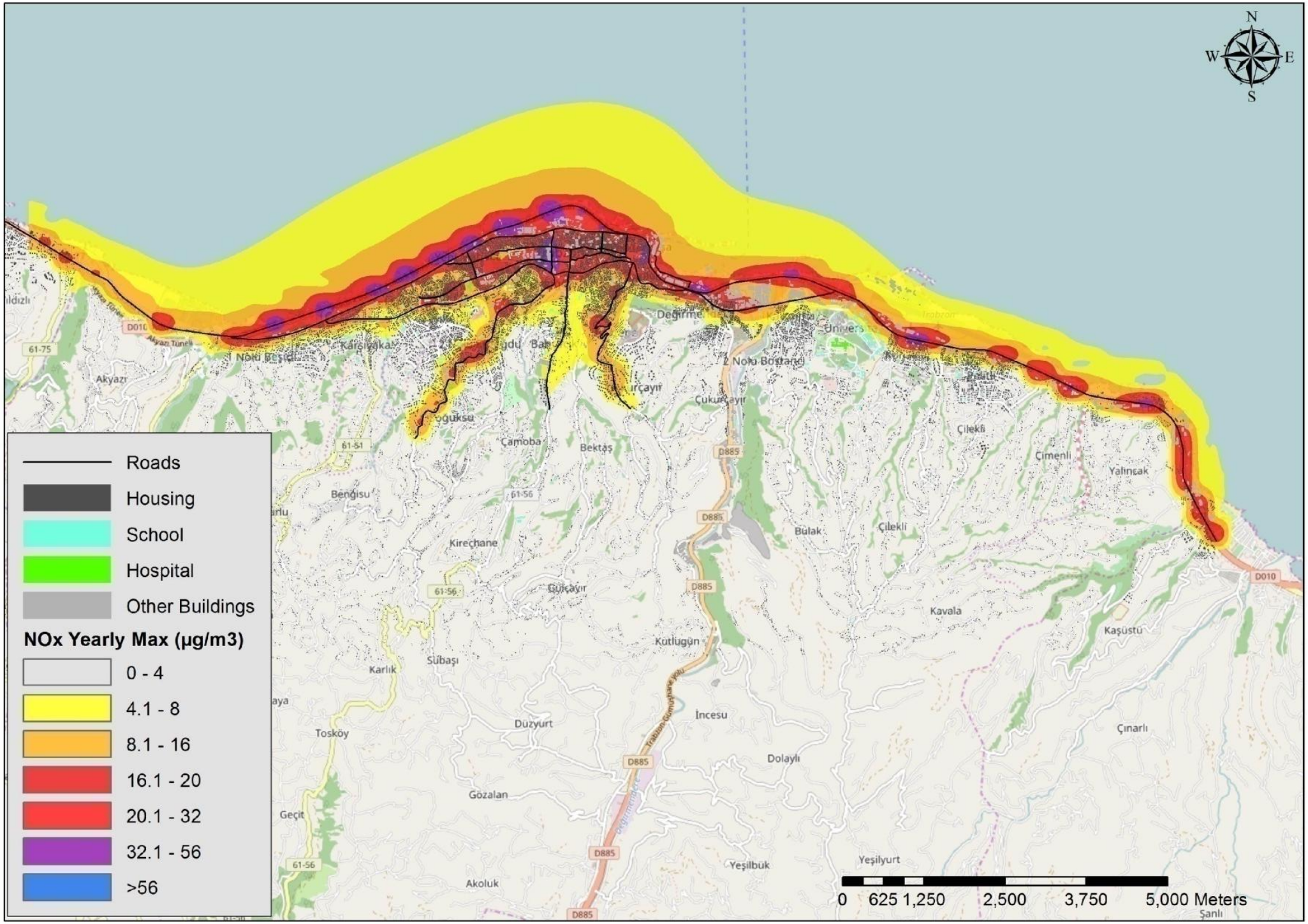
# APPENDIX



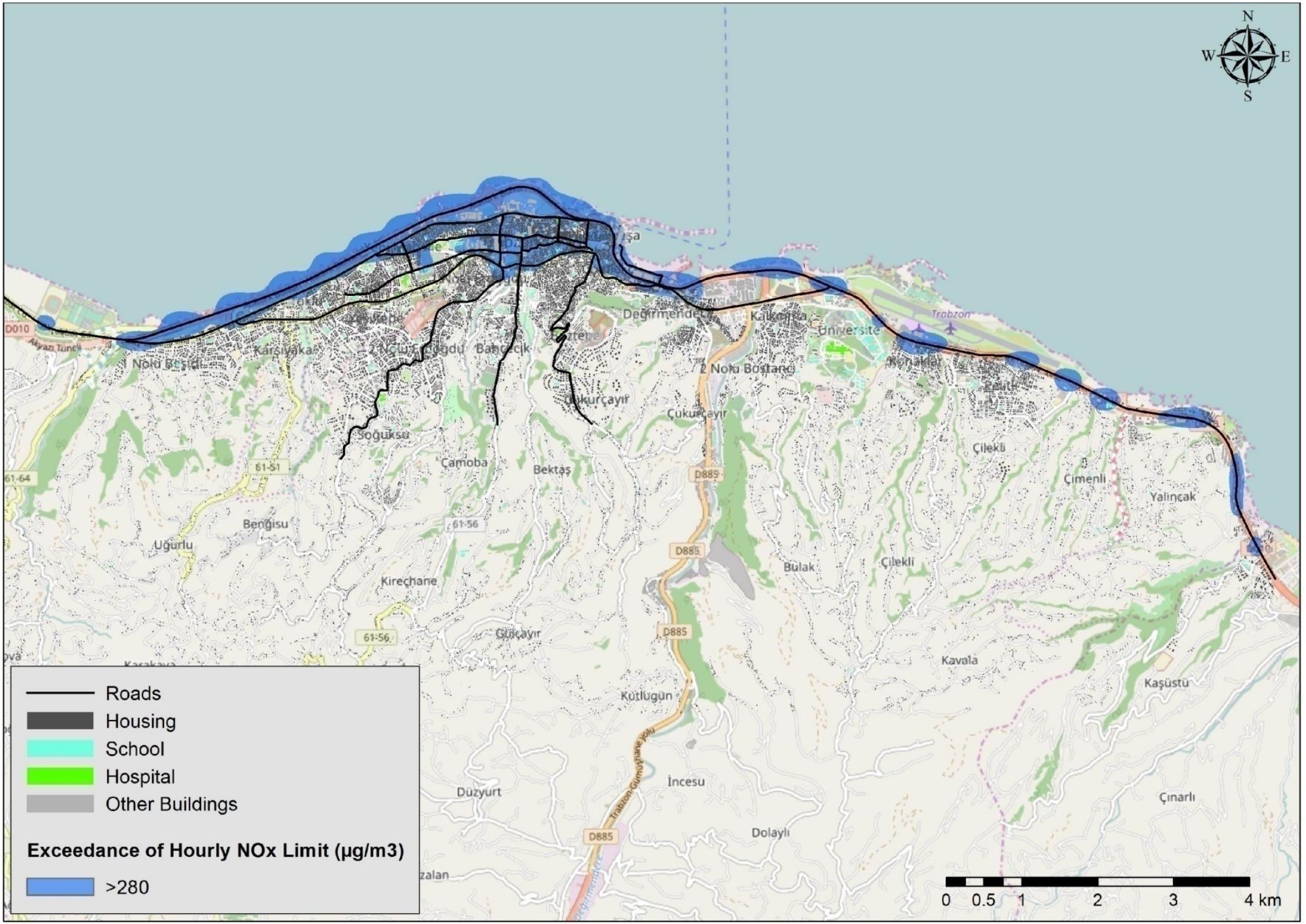

**Appendix-Figure 1.** Hourly maximum $NO_x$ concentrations caused by road traffic in the city center of Trabzon



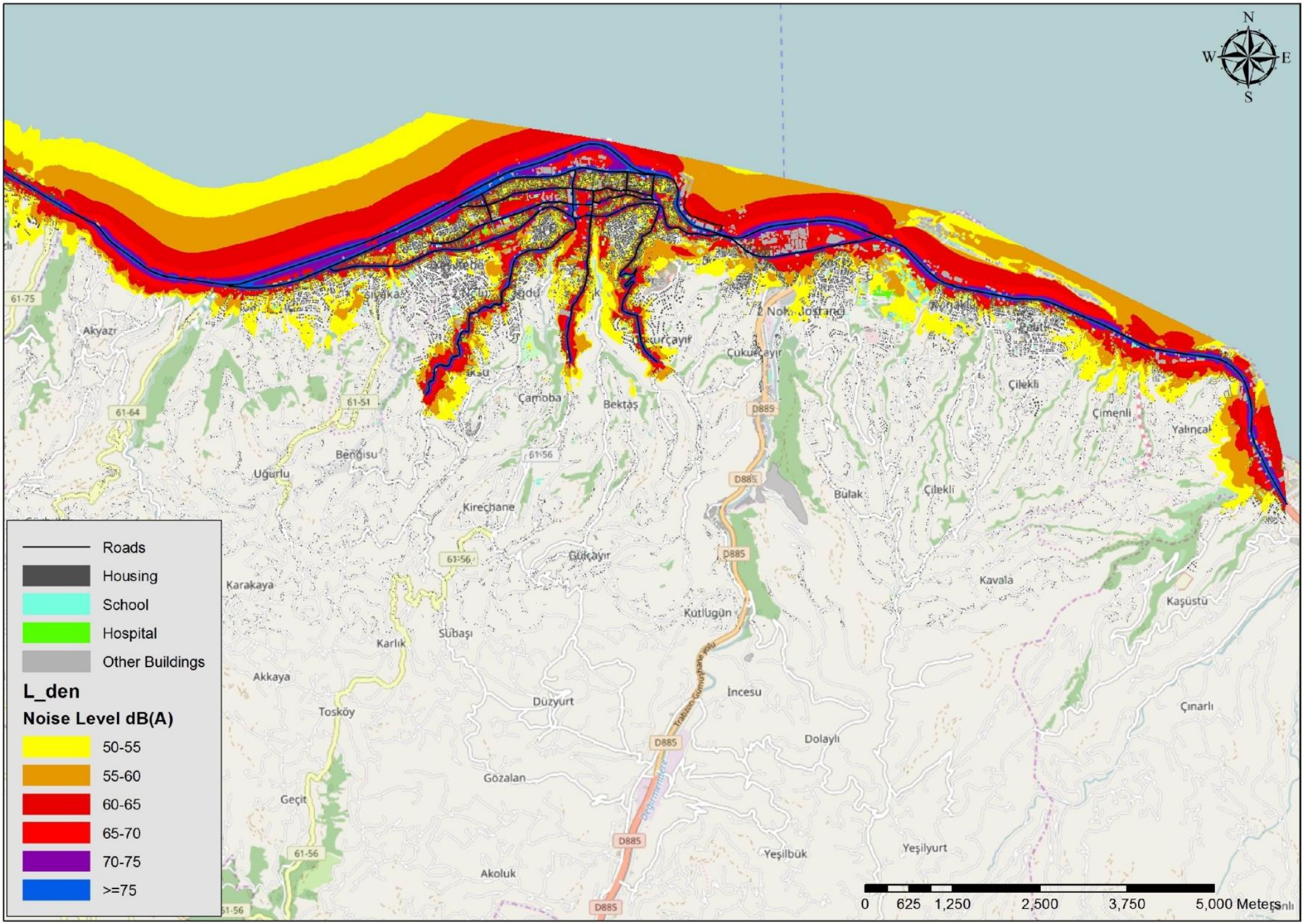

**Appendix-Figure 2.** Daily maximum $NO_x$ concentrations caused by road traffic in the city center of Trabzon



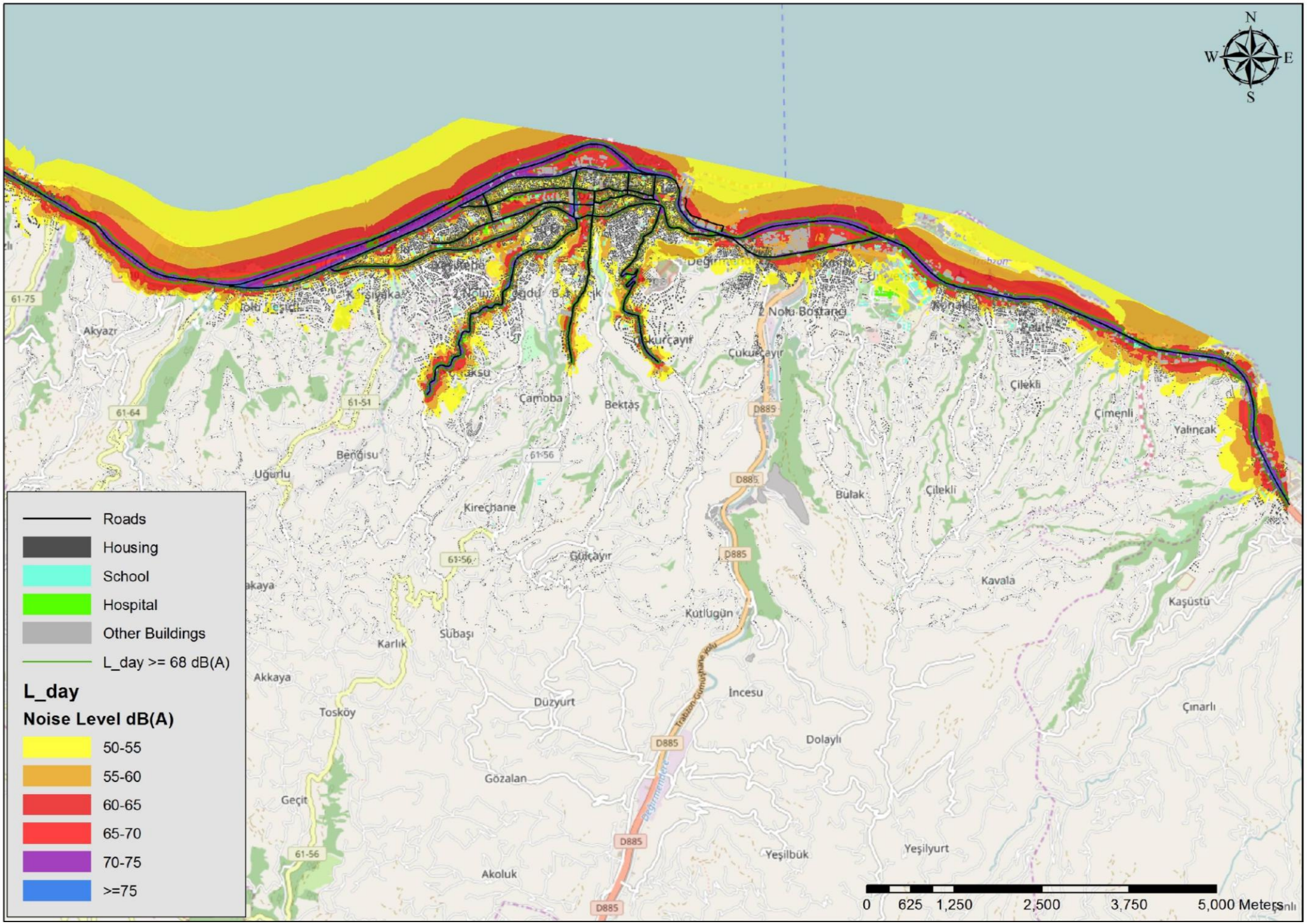

**Appendix-Figure 3.** Yearly maximum $NO_x$ concentrations caused by road traffic in the city center of Trabzon



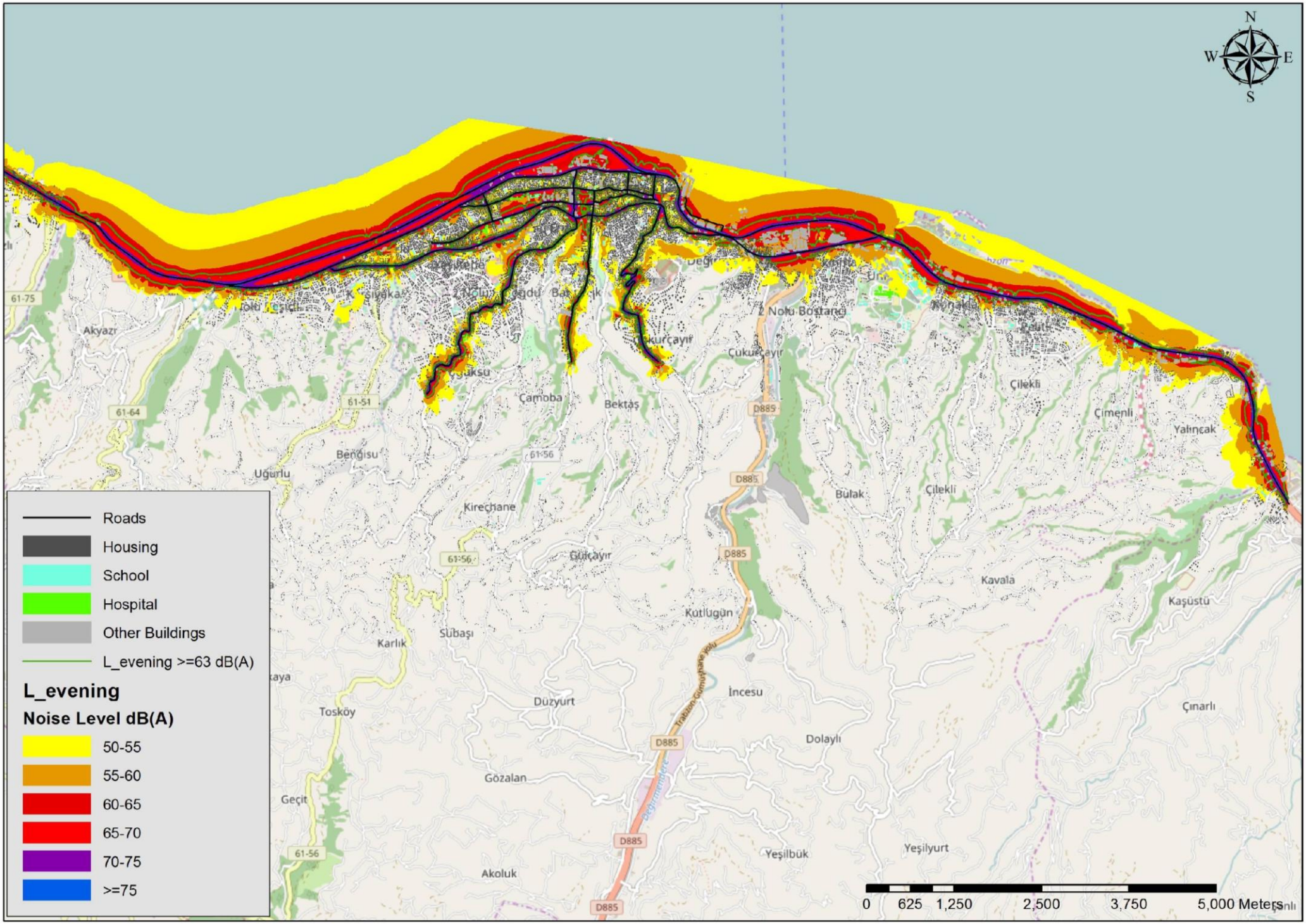

**Appendix-Figure 4.** Exceedance of $NO_x$ limit value during a year in the city center of Trabzon



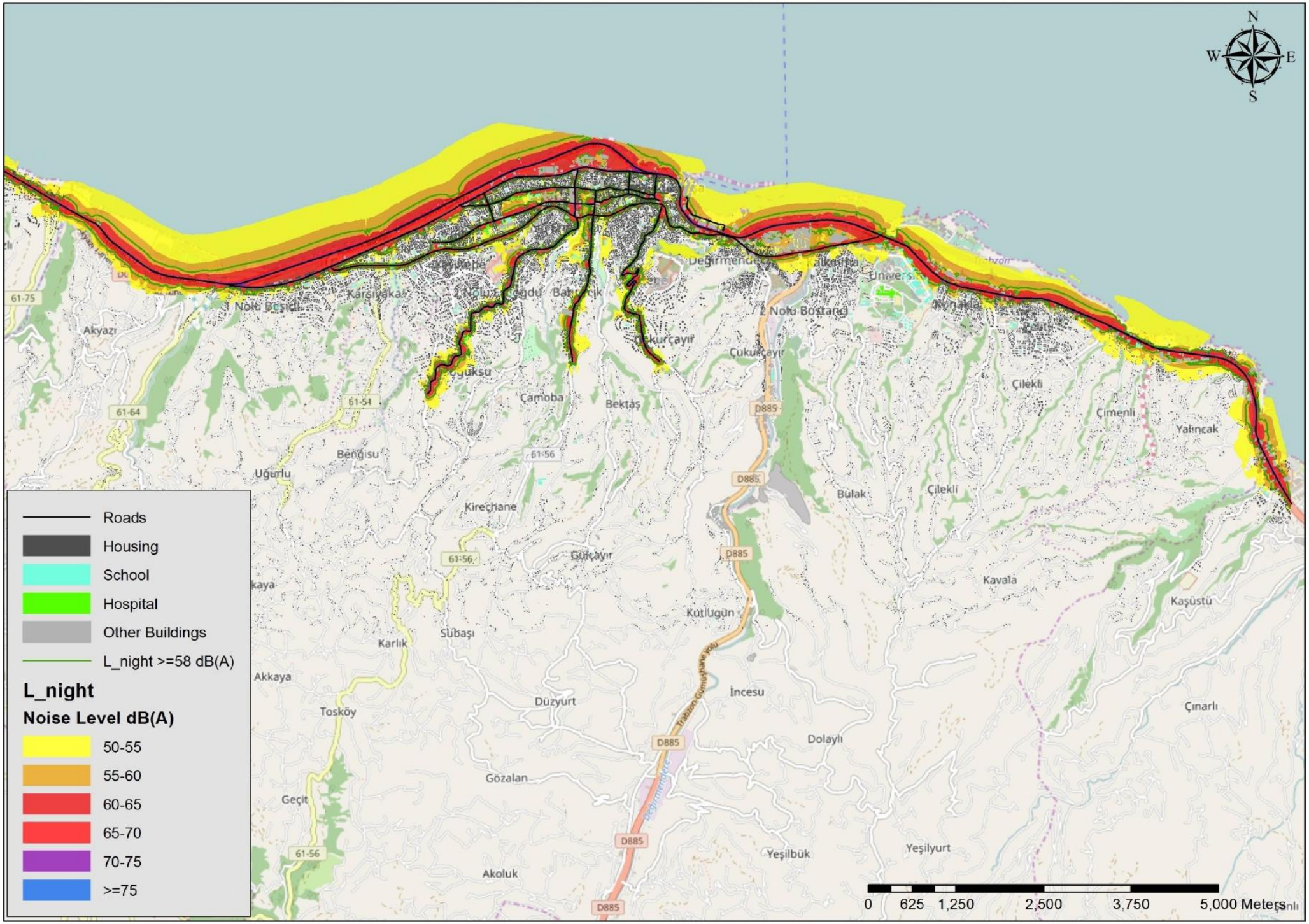

**Appendix-Figure 5.** Yearly average $L_{den}$ Noise levels caused by road traffic in Trabzon city center




**Appendix-Figure 6.** $L_{day}$ Noise levels caused by road traffic in Trabzon city center




**Appendix-Figure 7.** Yearly average $L_{evening}$ Noise levels caused by road traffic in Trabzon city center




**Appendix-Figure 8.** Yearly average $L_{night}$ Noise levels caused by road traffic in Trabzon city center

**CURRICULUM VITAE**


**Name, Surname** **:** Melike Neşe Tezel

**Date of Birth** **:** 26.09.1987

**E-mail** **:** nesetezel@yahoo.com


**Education**

| | |
|---|---|
| 2007 – 2010 | B.S. Chemical Engineering – Marmara University |
| 2004 – 2009 | B.S. Environmental Engineering – Marmara University |
| 2007 – 2012 | B.S. Business Administration – Anadolu University |
| 2001 – 2004 | Bursa Cumhuriyet High school, Bursa, Turkey |

**Employment**

| | |
|---|---|
| 2015 – | Researcher, TUBITAK Marmara Research Center, Environment and Cleaner Production Institute, Gebze, Kocaeli, Turkey |
| 2014 – 2015 | Technical Purchasing Manager, Pulcra Chemicals, Kocaeli, Turkey |
| 2012 – 2014 | Production Planning Engineer, Pulcra Chemicals, Kocaeli, Turkey |
| 2011 – 2012 | Project Engineer, Novel Arıtma Construction Industry and Trade Inc., İstanbul, Turkey |
| 2010 – 2010 | Sales Engineer, Argus Machinery Equipment Industry and Trade Inc., İstanbul, Turkey |

**Internships**

| | |
|---|---|
| 2010 – 2010 | Robert Bosch, Bursa, Turkey |
| 2010 – 2010 | DOSAB Domestic and Industrial Wastewater Treatment Plant, Bursa, Turkey |
| 2010 – 2010 | ISKI Omerli Water Treatment Plant, İstanbul, Turkey |

**Foreign Language**

- English

**Thesis**

- Principles of Electrochemical Design and an Application: Cathodic Protection, BSc. Thesis, Faculty of Engineering, Chemical Engineering Program, Marmara University, Istanbul, Turkey, 2010.
- Ozonation and Ozone/Hydrogen Peroxide Process Applications of Pasakoy Advanced Biological WWTP Effluent for Reuse Purposes, BSc. Thesis, Faculty of Engineering, Environmental Engineering Program, Marmara University, Istanbul, Turkey, 2009.

**Conference Papers:**

1. **Tezel M.N**, Erdol M, Sari D, Hamamci S.F, Ozkurt N, Correlation between $NO_x$ and Noise Pollution Originated from Road Traffic in Trabzon City, Turkey. 2nd International Conference on Civil and Environmental Engineering, Nevsehir 8-10 May 2017.
2. **Tezel M.N**, Erdol M, Sari D, Hamamci S.F, Ozkurt N, Comparison of Noise Hot Spots Calculation for Two Airports Located in Different Areas. International Scientific Conference on Applied Sciences, Antalya 27-30 September 2016.
3. Erdol M, **Tezel M.N**, Sari D, Hamamci S.F, Ozkurt N, Determination and Assessment of Noise Exposure Sourced from Road Traffic in Malatya, 3rd National Environment Congress, Marmaris, 24-28 September 2016.

**Trainings / Courses / Certificates**

1. Certificate of C2 Type Action Plans Preparation, Chamber of Physics Engineers, Ankara/Turkey, 21-24 January 2017.
2. Certificate of B1 Type Industrial Noise Report/Map Preparation, Chamber of Physics Engineers, Ankara/Turkey, 30 April – 04 May 2016.
3. Certificate Program of B2 Type Transportation Noise Report/Map Preparation, İstanbul Technical University Continuing Education Center, İstanbul/Turkey, 04-13 April 2016.

4. A2 Type Engineering Acoustic, Chamber of Physics Engineers, İstanbul/Turkey, 20-23 February 2016.
5. MS Office Access Training, TÜSSİDE, Kocaeli/Turkey, 27-29 January 2016 (24 hrs).
6. VDA6.3 Process Audit and Checklist for the Car Industry Internal Auditor, DQS, İstanbul/Turkey, 08-10 January 2015.
7. ISO 9001:2008 Quality Management System, ISO 14001:2004 Environment Management System Internal Auditor Training, DQS, İstanbul/Turkey, 02-03 April 2015.
8. SAP Controlling Module (CO) Training, ISIS, Kocaeli/Turkey, 22-24 October 2014.
9. SAP Production Planning Module (PP) Training, INNOCON, Kocaeli/Turkey, February – March 2013.

**Technical Skills**

- SoundPLAN v. 7.3 Noise map model.
- Aermod View v.7.4.0- Air pollution dispersion model.
- AutoCAD
- SAP
- Fortran
- Visual Basic
- Microsoft Office Programs