DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DETERMINATION OF AMBIENT AIR QUALITY BY USING A GAUSSIAN DISPERSION MODEL IN ÇANAKKALE, TURKEY

by

Gizem TUNA

June, 2015
İZMİR

DETERMINATION OF AMBIENT AIR QUALITY BY USING A GAUSSIAN DISPERSION MODEL IN ÇANAKKALE, TURKEY

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Gizem TUNA

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"DETERMINATION OF AMBIENT AIR QUALITY BY USING A GAUSSIAN DISPERSION MODEL IN ÇANAKKALE, TURKEY"** completed by **GİZEM TUNA** under supervision of **PROF.DR. TOLGA ELBİR** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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DETERMINATION OF AMBIENT AIR QUALITY BY USING A GAUSSIAN DISPERSION MODEL IN ÇANAKKALE, TURKEY

ABSTRACT

An emission inventory of primary air pollutants based on anthropogenic sources was prepared for Çanakkale within an area of 170 km to125 km, which is located in northeast part of Turkey. The city is located in Marmara Region and is included in Marmara Clean Air Center to improve air quality in the city. The emission sources were in the city broadly classified as industrial, vehicular and marine traffic and residential heating emission in systematically. The emissions and air quality levels of four primary air pollutants, namely sulfur dioxide, particulate matter, carbon monoxide and nitrogen oxides were estimated. Data on activity levels of the major industries, fuel consumptions and passing numbers in vehicles and ships, natural gas and coal consumption statistics for residential heating activities were obtained and evaluated with the related emission factor from literature according to the source for calculation of the emissions for 2013. This emission data was used to determine air quality levels by using a Gaussian dispersion model (AERMOD). Finally, for the model validation comparison of the model results with measurement data obtained from 4 different stations was carried out in this study. While industry is most polluting sector for nitrogen oxide and sulfur dioxide, most polluting sectors for carbon monoxide and particulate matter are road traffic and residential heating, respectively. Industrial plants using lignite and imported coal for energy production and some districts using lignite for residential heating are main sulfur dioxide emissions in the city. Additionally, comparisons of daily average and predicted and monitored concentrations show that overall accuracy of the predictions was relatively high. The overall accuracies of concentration predictions (d) were about the value of 61 percentages for sulfur dioxide and particulate matter and the value of 67 percentages for nitrogen dioxide.

Keywords: Emission inventory, anthropogenic sources, AERMOD, model validation, Çanakkale.

BİR GAUSSIAN DAĞILIM MODELİ YARDIMIYLA ÇANAKKALE'DE DIŞ ORTAM HAVA KALİTESİ SEVİYELERİNİN BELİRLENMESİ

ÖZ

Türkiye'nin kuzeydoğusunda yer alan Çanakkale ili için antropojenik kaynaklardan kaynaklanan temel kirleticiler için 170 km'ye 125 km'lik bir alanı kapsayan emisyon envanteri ve model çalışması gerçekleştirilmiştir. Çanakkale ili Marmara bölgesinde yer almaktadır ve hava kalitesinin iyileştirilmesi için Marmara Temiz Hava Merkezi'ne bağlanmıştır. Bölgedeki emisyon kaynakları endüstriyel, karayolları taşıt ve denizyolları gemi trafiği ve evsel ısınma şeklinde sınıflandırılmıştır. Emisyon hesaplamaları ve model çalışmaları 4 adet temel kirletici olan partikül madde, kükürt dioksit, azot oksitler ve karbon monoksit için ayrı ayrı gerçekleştirilmiştir. Bölgede yer alan büyük sanayi tesislerinin aktivite bilgileri, taşıtlar için yakıt tüketimi ve geçiş sayılarına dair bilgiler ve evsel ısınma için doğalgaz ve kömür tüketim istatistikleri temin edilmiş ve bu bilgiler kaynak türlerine göre literatürde yer alan ilgili emisyon faktörleri ile değerlendirilerek 2013 yılına ait emisyonlar hesaplanmıştır. Hesaplanan emisyon değerleri bir Gaussian dağılım modeli olan AERMOD ile değerlendirilerek bölgedeki hava kalitesi seviyeleri belirlenmiştir. Son olarak da, model validasyonu için model çalışması sonucu elde edilen hava kalitesi seviyeleri bölgede yer alan 4 adet hava kalitesi ölçüm istasyonu verileri ile kıyaslanmıştır. Sanayi sektörü azot oksit ve kükürt dioksit emisyonları açısından en baskın sektör iken; karbon monoksit ve partikül madde için en baskın sektörler sırasıyla trafik ve evsel ısınmadır. Yakıt olarak yerli ve ithal kömür kullanan sanayi tesisleri ve evsel ısınma amacıyla kömür kullanan ilçe merkezleri bölgedeki yüksek kükürt dioksit emisyonlarının başlıca sebepleridir. Ek olarak, günlük ortalama model ve ölçüm sonuçlarının karşılaştırılması sonucu model sonuçlarının doğruluğu nispeten yüksek değerlerde bulunmuştur. Modellenen konsantrasyonlarının doğruluğu sırasıyla partikül madde ve kükürt dioksit için yüzde 61, azot oksitler için yüzde 67'dir.

Anahtar kelimeler: Emisyon envanteri, antropojenik kaynaklar, AERMOD, model validasyonu, Çanakkale

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CHAPTER ONE
INTRODUCTION

1.1 Introduction

Because of the increase in energy use and population as well as the rapid development on industrialization, it has been unavoidable to experience air-pollution problems in many cities around the world. Particularly, developing countries are facing with rapid growth. However, in the lack of sufficient environmental policies, this growth occurs at a noticeable and often increasing economic and social cost. Poor air quality that acts a serious environmental threat was caused by more people, industrial plants, and motor vehicles in many cities. Aside from its serious local effects, urban air pollution has deep regional and global impacts. Urban emissions are major contributors to the problems of ozone layer depletion and ground level ozone, as well as global warming and climate change (Broto & Bulkeley, 2013; Dulal & Akbar, 2013; Elbir, Mangir, Kara, Simsir, Eren & Ozdemir, 2010; Meng, Graus, Worrell & Huang, 2014).

Mostly anthropogenic sources (industrial plants, motor vehicles and residential areas) release air pollutants into the atmosphere in a region. Air pollutants mainly consist of gases such as sulfur dioxide, nitrogen dioxide, carbon monoxide, ozone, hydrocarbons and atmospheric particles from different emission sources. Deterioration of air quality caused by different activity sectors effect human health and ecosystems (Mcdonald, 2012).

Monitoring and management air quality in the cities are the key parameters to deal with air pollution problems. An effective environmental planning and management process helps decision makers to formulate and implement realistic and effective control strategies and action plans to have better air quality. To develop a consistent air quality plan at urban level includes in combination of dispersion models and emission data from the local sources in order to understand contributions of pollution sources in a region. For that reason, air quality management is assumed as a resource management.

Air quality management consists of three main processes; (1) emission inventories including description of air pollutant sources and estimated emission quantities, (2) air quality modeling and (3) air quality monitoring. Air quality monitoring is principal activity involved in air quality assessment and management, while air quality modeling is simultaneously used as a practical tool to determine spatial distribution of air quality levels in a region (Borge, Lumbreras, Perez, la Paz, Vedrenne, de Andres & Rodriguez, 2014; Elbir, 2003; Elbir & Muezzinoglu, 2004; Fu, Wang, Zhao, Xing, Cheng, Liu & Hao, 2013; Ozkurt, Sari, Akalin & Hilmioglu, 2013; Sari & Bayram, 2014; Tuna & Elbir, 2012).

At urban scale, developing a set of reliable tools for air quality modeling is often a very challenging task, because urban environments are particularly complex. The environments are characterized by the presence of several pollutants emitted from multiple sources. But, dispersion modeling offers a solution with the help of estimating the impact of point, line, area sources to surface air quality. When the accurate emission source characteristics, land use, terrain, meteorological data are given, dispersion models could determine total atmospheric concentrations in the modeling domain (Gibson, Sundu & Satish, 2013).

In recent decades, several air pollutant emission inventories have been established and air quality modeling studies have been carried out in Turkey (Alyuz & Alp, 2014; Elbir, Muezzinoglu & Bayram, 2000; Elbir & Muezzinoglu, 2004; Ozden, Dogeroglu &Kara, 2008; Kara, Mangır, Bayram & Elbir, 2014). Although emission inventory studies have been carried out in big metropolitan areas of Turkey, detailed emission inventories and modeling studies are still missing in other important regions such as Çanakkale. Çanakkale is a coastal city located in Marmara region and high PM_{10} and SO_2 concentrations were observed in some air quality stations in the city during winter months. Specifically, Çan, the biggest district of Çanakkale, has a large coal reservoir in the region. Therefore, use of lignite in residential areas for heating purposes is high causing high PM_{10} and SO_2 concentrations in winter (Ministry of Environment and Urbanization, 2013). Additionally, Ministry of Environment and

Urbanization in Turkey have started developing an air quality management system at regional scale and Marmara region was chosen as the first region to develop this system. Thus, Marmara Clean Air Center was established to evaluate air quality levels in Marmara region. Therefore, new air quality stations located at the most polluted districts were established to observe air quality levels in Çanakkale region.

The main objective of this study was to determine the contribution of anthropogenic emissions on the ambient air quality by using a dispersion model in Çanakkale region which is an important coastal region situated in northwestern part of Turkey. Emission inventory of four primary air pollutants (SO_2, NO_x, CO and PM_{10}) based on all anthropogenic sources (industry, residential heating, maritime and road transportation) of the city was prepared. An air quality modeling study was also carried out by using USEPA's AERMOD dispersion model. Moreover, a comparison of model predictions with the observations from four urban air quality networks was also carried out.

This thesis consists of five chapters. An overview and objectives of the study are presented in Chapter 1. Chapter 2 reviews the concepts and previous studies related to this work. Experimental work is summarized in Chapter 3. Results and discussions are presented in Chapter 4. Chapter 5 includes the conclusions and recommendations drawn from this study.

CHAPTER TWO
LITERATURE REVIEW

2.1 Literature Review

2.1.1 Emission Inventories

Air pollution arises from a variety of diverse sources operating over different temporal scales and spatial areas. In response to this, legislative processes are attempting to tackle air pollution through the process of air quality management (AQM). The focus of the AQM process is action at the local level, primarily by local government, within a framework of national actions.

The major tools of AQM are emission inventory, modeling and monitoring to review and assess air quality, and to assist policy makers in developing abatement strategies to reduce emissions coming from different pollutant sources and to form air quality management strategies in regional or global scale. An accurate emission inventory could provide fundamental information for exploring air pollution formation mechanism and also guide decision-making with respect to air pollution control strategy. Additionally, emission inventory is the most important input data for different type of air quality models that can be used evaluate air quality, so accuracy of emission inventory could impact accuracy of modeling result.

An emission inventory is a set of information on sources and emissions of air pollutants in a specified area. General approach designed in three stages; identification of pollutant sources, investigation of activity data and emission factor, calculation of emissions. The optimal methodology to set up an emission inventory would imply the direct quantification, with the help of direct measurements of all emissions from different type of sources in the specified area during the determined time scale. However this approach cannot be used practically, because inventories generally concern huge territories and some type of emissions (e.g. agricultural activities) due to their own nature are hardly quantifiable by means of measurements and data from source specific emission tests and or continuous emission

measurements are not always available. This analytic approach is fundamental tool only for a few types of sources, typically big industrial plants whose emissions are generally relevant and for this reason are checked by means of in-continuous monitoring system (Elbir & Muezzinoglu, 2004).

The spatial and temporal characteristics of emission inventory are also important for environmental decision makers to develop effective air pollution management strategies. An elaborate emission inventory with high resolution is the main information for understanding and solving complex air pollution problems in a region.

Several studies have developed emission inventories of single or multiple air pollutants from single or multiple pollutant sources at global scale (Bradley, Stedman & Bishop, 1999; Butler et al., 2008; Olivier, Bouwman, Van der Hoek, & Berdowski, 1998; Olivier, Bloos, Berdowski, Visschedijk & Bouwman, 1999). Butler et al. (2008) carried out a different study than the others. The reason that makes this study different from the other ones, the authors examined the representation of emissions from megacities in three global anthropogenic emission inventories and compared them to each other. Despite the many common sources of data between the inventories, and the similarities in their construction methodologies, there are some very large differences between the emissions for individual cities, even when the total global emissions are very similar and they have found that the geographical distribution of the emissions within countries plays a large role in explaining the differences between the inventories than differences in the country total emissions.

In the literature, some studies supporting Butler et al. (2008) shows that regional and local air quality may also strongly depend on emissions at these scales (Wang, Fu, Lin, Zhou, & Chen, 2009; Zheng et al., 2009). Thus, the fine scale emissions inventories are very useful for air pollution prediction. Because, the spatial and temporal resolution of the global inventories is normally low, and therefore does not capture the specific characteristic of each region. Hence, emission inventories at

provincial or local level are available in the literature (Alyuz & Alp, 2014; Elbir, 2004; Elbir & Muezzinoglu, 2004; Kara et al., 2014; Markakis et al., 2012; Ozden et al., 2008; Qiu et al., 2014; Waked, Afif & Seigneur, 2012; Wang et al., 2009; Zarate, Belalcazar, Clappier, Manzi, & Van den Bergh, 2007; Zheng et al., 2009; Zhou et al., 2014).

Having regard to direct measurement constraint of pollutant sources, estimating emissions with the help of emission factors are usually preferred method in the literature (Aleksandropoulou, Torseth, & Lazaridis, 2011; Coelho et al., 2014; Dincer & Elbir, 2007; Fu et al., 2013; Kara et al., 2014; Khatami, Ponche, Jabry & Mirabel, 1998; Sivacoumar, Bhanarkar, Goyal, Gadkari & Aggarwal, 2001; Qui et al., 2014; Sarı & Bayram, 2014; Waked & Afif, 2012; Wang, Chen, Huang & Fu, 2008).

This method is based on a linear relation between source activity and the emission, following a relation that can be generally outlined as follows:

$$E_i = A \times FE_i \tag{2.1}$$

where;
E_i = emission of pollutant
A = activity indicator (e.g. produced amount, fuel consumption, etc.)
FE_i = emission factor for the pollutant

The development of information for an emission inventory can be carried out in two methods. One method is the top-down methodology and the other is bottom-up methodology. In the case of a top-down approach generalized factors such as total fuel use, total population, total housing units, and total manufacturing are used as indicators of emissions. These emissions are spatially disaggregated at different levels, such as the provincial and municipal levels with statistical indicators (population, roads, land-use). Emission factors are developed that predict emissions per unit energy use or person. The top down approach is best used for emissions that impact global or very large regional scale problems because of reducing amount of

input parameters. In the literature for mid-sized and large cities, top-down approach is used to prepare emission inventory (Brioude et al., 2011; Saide, Zah, Osses & de Eicker, 2009; Tuia et al., 2007). Tuia et al. (2007) used this method for estimation of traffic emission in Chilean Gran Concepcion urban area. They use a model based on a top-down approach and estimate annual global hot emission from vehicles. Then, emissions distributed in space with a disaggregation approach and using GIS techniques.

On the other hand, in a bottom-up approach, the region of interest is divided into sectors of interest. Specific information is developed for each sector based on the specific industries, housing units, and vehicles that operate within that sector. This information is then used to estimate the emissions that will occur in each sector. A bottom-up approach requires considerably greater effort than the top-down approach, but it can provide more reliable and detailed data. In the literature, bottom up approach is generally used for preparing emission inventory at national or local scale to obtain more detailed data for air quality models (Aleksandropoulou et al., 2011; Alonso et al., 2010; De Vlleger, Panis, Styns & Torfs 2008; Elbir & Muezzinoglu, 2004; Fu et al., 2013; Kara et al., 2014; Pastorello, Caserini, Galante, Dilara & Galletti, 2011; Qui et al., 2014; Sabit, 2012; Wang et al., 2009; Yau et al., 2012; Zhang &Chan, 2014; Zhu, Kuhns, Gillies, & Gertler, 2014; Zhang et al., 2014). For preparing more accurate vehicle emission emission inventory, Wang et al. (2009) used bottom-up approach for the Beijing urban area in 2005 due to some limitations of top-down approach. The same emission factors for each vehicle fleet under average speed, or emissions allocated using the spatial surrogates from a larger geographic scale, may not reflect the real vehicle emission conditions at local scales. Therefore, more detailed information on the spatial distribution of roadway types, vehicle activity, and speeds along those roads were collected and evaluated with emission factors to provide better estimate of distributions of pollutants in the city.

Additionally, in the literature some studies compared bottom-up and top-down approaches in order to determine applicability of these methodologies (Cook, Touma, Beidler & Strum, 2006; de Elcker, Zah, Trivino & Hurni, 2008;

Timmermans et al., 2013; van der Gon et al., 2012; Zarate et al., 2012). Cook et al. (2006) compared top–down and bottom–up approaches for developing emission inventories originating from vehicles for modeling in Philadelphia for the year 1999. They found that results of bottom up approach which relies on combining motor vehicle emission factors and vehicle activity data from a travel demand model provided better estimates of levels and spatial distribution of on-road motor vehicle emissions than a top–down approach. However, it cannot be automatically assumed that a bottom-up inventory is better than a top down inventory. Another study which compared two different methods brought a different perspective (Zarate et al., 2012). They supported that air quality management for a longer period of time in order to draw final conclusions, the possibility to better couple both bottom-up and top-down techniques in order to optimize the evaluation of reduction scenarios. Therefore, some studies are present in the literature used combination of two methods for estimation the emission in the region (Coelho et al., 2014; Kesarkar, Dalvi, Kaginalkar & Ojha, 2007; Markakis et al., 2012; Miola & Ciuffo, 2011; Zheng et al., 2009). Zheng et al. (2009) used bottom up approach for point sources and top down approach for area sources and the other categories. Another study, Coelho et al. (2014) found that with the combination of the top-down and bottom-up approaches to emission estimation several improvements in the air quality results can be achieved, mainly for PM_{10}, CO and O_3 originating from road traffic emissions.

The second step of preparing emission inventory is selection of emission factor. It is another key parameter for emission inventory after selection of approach. Collected activity data should be evaluated with appropriate emission factors in order to calculate the total emissions for specific sources. Emission factors may be appropriate to use in a number of situations such as making source-specific emission estimates for regional inventories. Selection of emission factors has to take into consideration the fuel types, types of pollutants in compliance with technology in use in each sector, production range and availability of pollution control devices.

Generally, European CORINAIR database, U.S. Environmental Protection Agency (U.S. EPA) emission factors catalogue and Intergovernmental Panel on

climate Change Guidelines (IPCC) are the most widely-used emission factor database in the literature (Aleksandropoulou et al., 2011; Aste, Adhikari, Compostella & Del Pero, 2013; Elbir, 2004; Elbir & Muezzinoglu, 2004; Kara et al., 2014;; Miola & Ciuffo; 2011; Ozden et al., 2008; Sari & Bayram, 2014; Waked & Afif, 2012). However, some studies are available in the literature used detailed and specific emission factors realizing own measurement campaign on site (Brandt et al., 2011; Fu et al., 2013; Karademir, 2006; Tung, Tong, Hung, & Anh, 2011). Karademir (2006) evaluated the potential air pollution by using the emission factors determined based on the flue gas measurements conducted at over 100 industrial plants in Kocaeli which is most industrialized area of Turkey. Several studies using earlier studies are present which is carried out in the same region as reference for emission factors (Fu et al., 2013; Kesgin & Vardar, 2001).

National emission factors should be used more in local emission inventories to real estimation of emissions. But, it is not available in Turkey and the other developing countries. Therefore, European emission factors had to be adopted and used in calculations. In this study, European Environment Agency [EEA] (2007) and EEA (2009) database were used for traffic and residential heating emissions and EEA (2013) was used for industrial emissions.

In order to carry out an inventory it is important to use terms that are able to characterize all activities which are relevant for the evaluation of atmospheric emissions. Characterizing and predicting local air quality and regional effects resulting from emissions in a large city requires a detailed survey of emission sources. For example, information about the vehicle fleet, traffic patterns, and street configuration must be considered for mobile sources. National inventories require a broader approach for emissions estimation, as they encompass sources with larger geographic scales, including air and maritime transport and the national energy grid.

An emission inventory is characterized by three different types of emissions which are point, area and linear sources. Industrial facilities are generally characterized as point source and emissions of this type of source could be obtained

by measurements. Emissions from source distributed on the territory (domestic heating, agricultural source, etc.) are considered as area source. For this type of source, direct measurement is not feasible. Therefore, it is necessary to estimate them from statistical data and specific emission factors. Line sources are generally transportation activities such as road and maritime transport.

Previous emission inventories were generally prepared for anthropogenic sources. Some of them studied with multiple anthropogenic sources (Borge et al., 2014; Elbir et al, 2000; Elbir & Muezzinoglu, 2004; Fu et al., 2013; Kara et al., 2014; Ozden et al. 2008; Qui et al., 2014; Sivacoumar et al., 2001), while several of them studied with single anthropogenic sources such as industrial activities (Alp & Alyuz, 2010; Karademir, 2006), transportation sector (generally roads and maritime activies) (Bellasio, Bianconi, Corda, & Cucca, 2007; Dincer & Elbir, 2007; Ho & Clappier, 2011; Kesgin&Vardar, 2001; Miola & Ciuffo, 2011; Schrooten, 2008; Tuna &Elbir, 2013; Tung et al., 2011; Yau et al., 2012) and residential heating (Aste et al., 2013; Brandt et al., 2011; Pastorello et al., 2011; Sabit, 2012; Sari & Bayram, 2014).

In the literature, differences are found between the contributions of various sectors to the total emissions in the cities (Aleksandropoulou et al., 2011; Elbir & Muezzinoglu, 2004; Fu et al., 2013; Kara et al., 2014; Khatami et al., 1998; Qui et al., 2014; Sivacoumar et al., 2001; Zheng et al., 2009). Kara et al. (2014) found that industry was the most polluting sector with regard to SO_2 emissions, contributing about 83% of the total emissions in İstanbul for the year 2007, while residential heating was the most polluting sector for PM_{10} emissions with the contribution of 51%. Besides, traffic is most polluting sector for NO_x and CO emissions. Another study carried out for İzmir for the year 2000 (Elbir & Muezzinoglu, 2004) had similar results compared to Kara et al. (2014). Industry is the major contributor for SO_2, and PM_{10}, because it was dominated by residential heating and traffic that is the most polluting sector for NO_x. Zheng et al. (2009) also found that 91.4% of the SO_2 emissions were coming from power plant and industrial sources in China for the year 2006. Additionally, they found that industrial activities were also major contributor to total PM_{10} emissions with the contribution of 97.7% and %87 of the NO_x

emissions coming from power plants and mobile sources. On the other hand, another study in the literature showed different results in terms of source contributions (Qui et al., 2014) which was carried out for Central Plain Urban Agglomeration of China (CPUA) for the year 2010 and they found that major contributor of total NO_x emissions was power plants in the region. Because all of the power plant in the region had accomplished the installation FGD (flue-gas desulfurization) in CPUA region by the end of 2010 to abate the SO_2 discharge. Indeed, anthropogenic emissions resulting from human activities depend on factors such as industrial development, population and urbanization status of the region.

Final step should be determination of uncertainty of emission inventory. The accuracy level of an emission inventory is determined by uncertainties associated to the input parameters, activity data and emission factors. Uncertainty should be discussed in these emission inventories and assessed in a qualitative way since the accuracy of emission inventory affects the accuracy of model results. There are some studies in the literature discussing uncertainties in a emission inventory (Brioude et al., 2011; Fu et al., 2013; Pastorello et al., 2011; Qui et al., 2014; Zheng et al., 2009).

2.1.2 Air Quality Modeling

Emission inventories are not sufficient for the assessment of pollution in a region. An emission inventory should be assessed with air quality models to determine air quality levels in a region. Air quality modeling has the potential to provide reliable information about air quality level in a region and is increasingly becoming an essential component of all urban air quality management programs. The dispersion of a pollutant is completely governed by the local meteorological parameters and therefore this information is a necessary input for air quality dispersion modeling. Air quality dispersion models incorporating parameterization for PBL, turbulence, dispersion in the convective boundary layer and terrain interactions of pollutant plume are optimum for the estimation of spatial dispersion of pollutants (Kesaker et al., 2007).

Because, air quality modeling applications are integral part of air quality management with emission inventories to provide better understanding about air quality in a region, emission inventory studies in the literature were supported by air quality models to predict air quality levels (Elbir, 2002; Elbir, 2004; Huertas, Huertas, Cervantes, & Diaz, 2014; Holmes &Morawska, 2006; Karademir, 2006; Kesarkar et al., 2007; Kumar et al., 2006; Ma et al., 2013; O'Shaughnessy & Altmaier, 2011; Ozkurt et al., 2013; Rood, 2014; Sari & Bayram, 2014; Seangkiatiyuth Surapipith, Tantrakarnapa, & Lothongkum 2011; Sivacoumar et al., 2001; Tartakovsky, Broday, & Stern, 2013; Tuna & Elbir, 2013; Zou et al., 2010).

Generally, three different air quality models are used in the literature. These are ISCST3, AERMOD, CALPUFF. The CALPUFF modeling system is a non-steady-state Lagrangian puff model that simulates pollutant transport, transformation, and deposition in a three-dimensional spatially and temporally variable wind field (Rood, 2014). On the contrary, AERMOD is a steady-state Gaussian plume model useful for the computation of pollutant for three different types of pollutant source (point, area, volume) (U.S. EPA, 2004a). It was intended as a replacement of the Industrial Source Complex Version 3 (ISC3) model. Currently, AERMOD is the EPA's preferred model for regulatory compliance demonstration for criteria pollutants in the near field.

Elbir (2003), Elbir (2004), Elbir et al. (2010), Ozkurt et al. (2013) and Sari & Bayram (2014) used CALPUFF model in their studies. Elbir (2002), Karademir (2006), Sivacoumar et al. (2001) and Tuna & Elbir (2013) used ISCST3 model to predict air quality levels in different regions for different sources types. But, AERMOD is a fairly recent and promising model for estimating concentrations of air pollutants and Gibson et al. (2013), Kahraman, Tuna & Elbir (2014), Huertas et al. (2014), Seangkiatiyuth et al. (2011), and Zou et al. (2010) used AERMOD modeling system to predict air pollutant concentrations for different regions.

But, the effectiveness of these models used in the literature at different time scales should be verified. Zou et al. (2010) predicted 1-h, 3-h, 8-h, daily, monthly, and

annual concentrations of SO_2 by AERMOD in Texas and compare these results with observed air quality data. Predicted long-term concentrations (8-h, daily, monthly, and annual intervals) match their observed concentrations much better than 1-h and 3-h concentrations. Tartakovsky et al. (2013) and Rood (2014) carried out evaluation of some commonly used dispersion models to quantify their predictive capacity and performance. These studies showed that despite several limitations and assumptions in Gaussian dispersion models, these models are comparatively more accurate and consistent with the random nature of turbulence in the atmosphere and are best suited for pollutant dispersion. For example, Tartakovsky et al. (2013) found that for the complex terrain scenarios studied and under the severe uncertainties, AERMOD performed better than CALPUFF using accurate digital elevation model (DEM) data.

Additionally, to evaluate the performance of the model, comparison of model results with measured data should be carried out in a model study. The use of statistical performance measures is recommended. The statistical performance measures include measures of difference such as bias, variance of difference, mean square error and gross variability of the difference, and measures of correlation such as time, space, and time and space combined (Kumar et al., 2006).

In the literature, statistical evaluation of model results is a common issue for different modeling studies (Elbir, 2003; Gibson et al., 2013; Kesarkar et al., 2007; Kumar et al., 2006; Ma et al., 2013; Rood, 2014; Seangkiatiyuth et al., 2011; Sivacoumar et al., 2001; Tartakovsky et al., 2013; Zou et al., 2010). All of these studies used air quality monitoring stations to model for comparison except the studies of Ma et al. (2013) and Seangkiatiyuth et al. (2011). Seangkiatiyuth et al. (2011) compared predicted NO_2 with the data obtained during a 7 day continuous measurement campaign at 12 receptors in Bangkok. Ma et al. (2013) used results of different study carried out in the same region for comparison of the model results. Additionally, some studies in the literature carried out with detailed comparison (Kumar et al., 2006; Rood, 2014; Tartakovsky et al., 2013). They both compare two or three different modelling system each other and compare their results with measurements.

Çanakkale is an important city of Turkey in terms of air quality levels. Especially, in winter season high PM_{10} and SO_2 concentrations were observed in the city. However, none of this study mentioned above provides detailed information about the emissions of Çanakkale which is the coastal city located in northeastern part of Tukey. Some studies in the literature were carried out in Çanakkale for one or two pollutant sources and small scale studies (Deniz & Durmusoğlu, 2008; Kesgin & Vardar, 2001; Mentese & Yarımtepe, 2002; Ozkurt et al., 2013; Uysal, 2002). Çanakkale has Çanakkale Strait which has both transit and domestic traffic. Therefore, two different studies about estimation of maritime transport emissions of Çanakkale carried out in the literature (Deniz & Durmusoglu, 2008; Kesgin & Vardar, 2001). Another type of studies carried out for this region are using measurement data to evaluate air quality in the region (Mentese & Can Yarımtepe, 2012; Uysal, 2002). Air pollution levels in terms of SO_2 and particulate matter were studied in Çanakkale town centre and the results were evaluted in Uysal (2002). During the winter period the highest SO_2 and PM_{10} levels observed in the region for the year 1991-2001. Mentese & Can Yarımtepe (2012) found same results as Uysal (2002) for the year 2008-2011. When concentrations of PM_{10} and SO_2 observed during last two decades in Çanakkale city were compared to set values, it can be seen that levels of those pollutants were high especially in the winter. A detailed study was carried out for Çan and Bayramiç Region in Çanakkale for evaluation of the impact of SO_2 and NO_2 emissions on the ambient air-quality for 2007-2008 (Ozkurt et al., 2013). In this study, air pollution sources are categorized as point, area, and line sources. Point sources refer to representative huge energy and fuel consumption industrial facilities, such as power plants, central heating boilers, and large manufacturers which emit the majority of pollutants. Area sources account for emissions from small industrial complex scattered heating boilers, and residential activities. An emission inventory was prepared and CALPUFF modeling system was used for prediction of air quality level.

However, no study is available for Çanakkale at local scale evaluating all pollutant sources in the region. This study reports the modeling activities carried out

in Çanakkale highlighting the atmospheric emission inventory development and preparation as an illustrative example of the AERMOD modeling system. The emissions from major pollutants coming from all anthropogenic sources in the city were estimated, spatial distribution of air quality levels were plotted by ArcGIS 10.1 and predicted air quality data was compared with observed data which was obtained from 4 different air quality monitoring stations in Çanakkale region.

CHAPTER THREE
MATERIALS AND METHODS

Study area, source type and characteristic, emission calculation, air quality modeling and statistical analysis are explained in the following sections.

3.1 Study Area

Çanakkale is the second city (after İstanbul) which has lands in both Asia and Europe on Gallipoli Peninsula on the northwest coast of Turkey and on Biga Gallipoli, the prolongation of Anatolia. It has a 9,737 km^2 area and it was located between 25° 40'- 27° 30' East longitudes and 39° 27' - 40° 45' North latitudes (Municipility of Çanakkale, 2014a). A large part of the province enters in south Marmara, but a small area which located on the shores of the Gulf of Edremit enters the Aegean Region. Çanakkale is the fifth largest city of south Marmara in terms of population after Bursa, İnegöl, Balıkesir and Bandırma. Çanakkale has 12 districts as Ayvacık, Bayramiç, Biga, Bozcaada, Eceabat, Ezine, Gelibolu, Gökçeada, Lapseki, Yenice, Çan and the central district. It also has 34 municipalities, 564 villages and 101 neighborhoods. It is surrounded by Edirne, Tekirdağ and Balıkesir. Moreover, Çanakkale also includes Gökçeada which is the biggest island of Turkey in Aegean Sea and also Bozcaada are in its boundry. Location of the study area is illustrated in Figure 3.1.

Çanakkale has generally rough view covering with mountains and valleys. The highest mountain in the region is Kaz Mountain with 1767 m and the other high mountains located around Kaz Mountain. Koru Mountain which is an extension of Tekir Mountain on the Gallipoli Peninsula Mountain is 726 m high. The city is surrounded by sea and forests (Ministry of Environment and Urbanization, 2014).

The length of Çanakkale's coastal line is 671 km. The province of Çanakkale is located at the most western extremity of Anatolia and the city of Çanakkale is on the narrowest point of Dardanelles. The Çanakkale Strait or Dardanelles is a 68 km- long natural waterway connecting the Aegean Sea with the Marmara Sea. The narrowest

point of Dardanelles is Kilitbahir and Çimenlik fortresses, where it is 1250 m wide. The average depth of Strait is 45-50 m. The Çanakkale Strait separates two continents, Europe and Asia, and therefore it has an enormous geographical and strategic importance (Municipility of Çanakkale, 2014b).

The maritime traffic in the Çanakkale Straits includes the ships, which are in use in domestic transport and the transit passing with various aims. The average number of transit ships passing through the Çanakkale Strait was about 122 per day and 3,718 per month for the year of 2014. (Ministry of Transport, Maritime Affairs and Communication, 2014)**.** There is almost no difference by months in terms of passing numbers of the ships as shown in Figure 3.2. Çanakkale Strait also has domestic transportation which is especially dense in working hours of days. In addition to the transit passing, the total number of domestic passenger ships is 232 in daily (GESTAŞ, 2014). Average number of cruising was 994 per month. Number of monthly average cruising varies from 23 to 2,383 according to the domestic routes as shown in Figure 3.3.

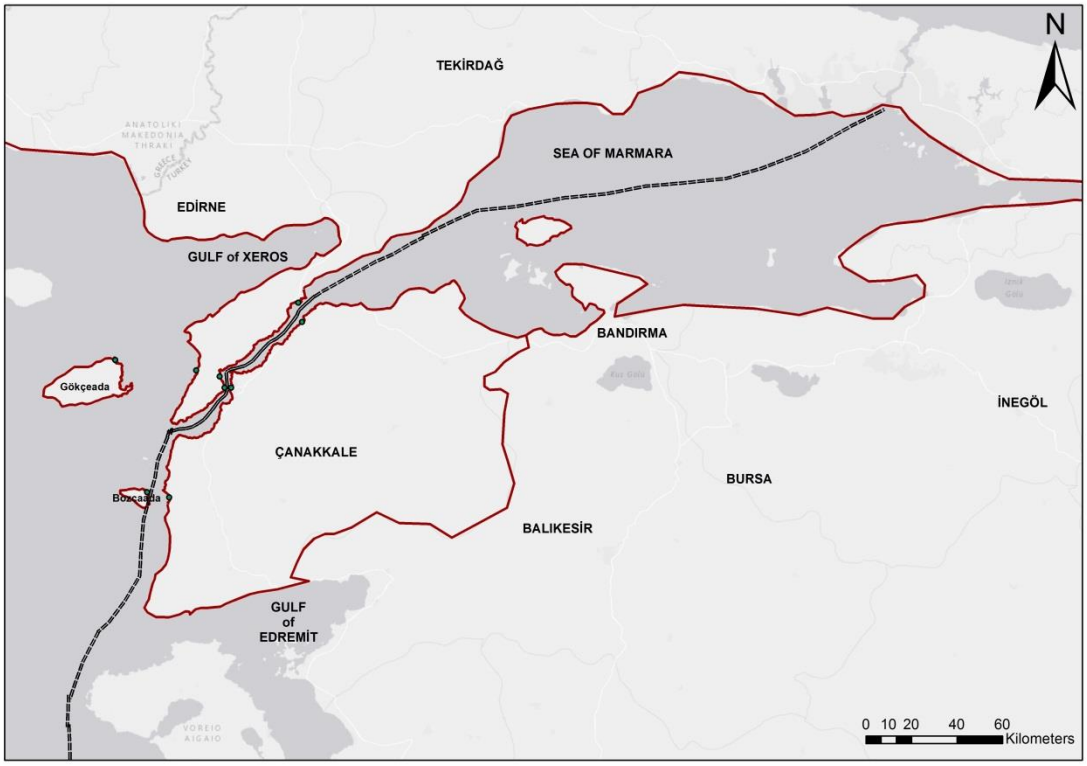

Figure 3.1 Location of study area

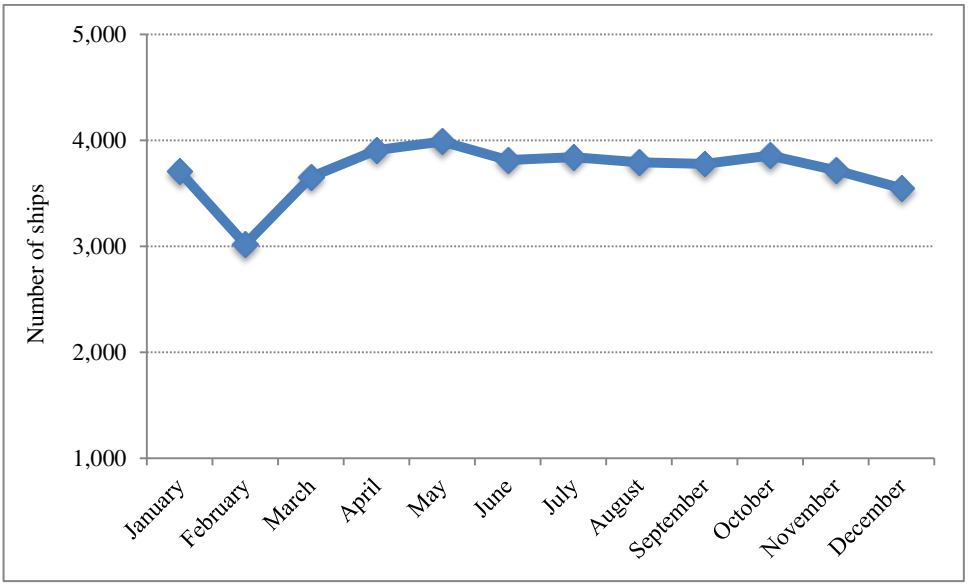

Figure 3.2 Monthly variation of number of ships passing through Çanakkale Strait

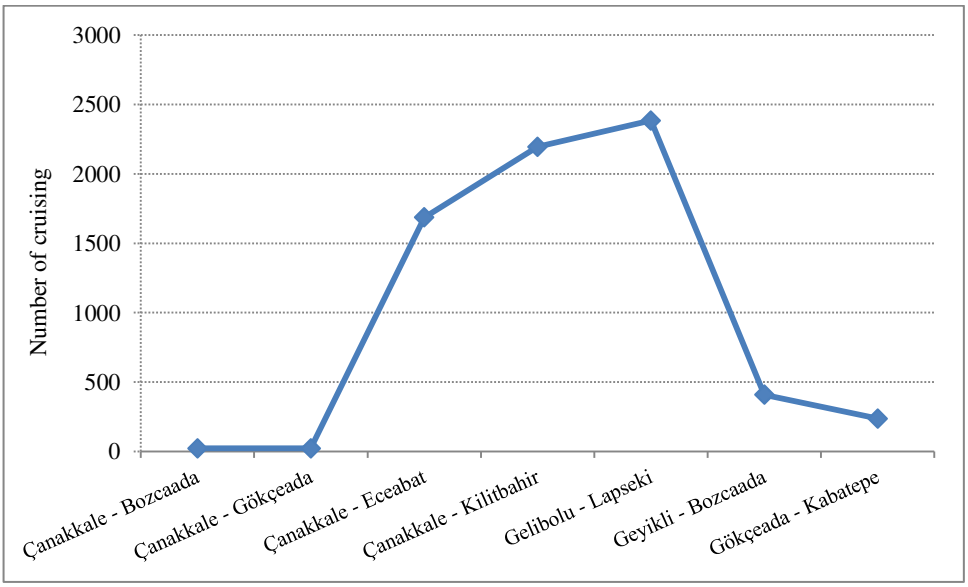

Figure 3.3 Distribution of number of monthly average cruising by domestic routes

Çanakkale is affected by Mediterranean and the Black Sea climate, but it is mostly prone to the Mediterranean climate. While the Mediterranean climate is dominant in Edremit Bay, central part of the city and Gallipoli peninsula are affected by cold winds coming from over Balkans. The climate during the tourism season is mild and the sea temperature reaches at maximum degrees during July and August. Minimum hourly average temperature observed in January with -3.7 °C and maximum temperature observed in July with +35.2 °C for 2013. The annual average of

temperature is 16.1 °C (General Directory of Meteorology [GDM], 2014). It is more rainy in fall and less in spring. In the central regions, altitude increases in Çanakkale. Therefore, temperature differences compared to the coastal areas increase over the central region (Municipility of Çanakkale, 2014a).

There are only a few days in Çanakkale without wind. The average number of windy days per years is 260 (Municipility of Çanakkale, 2014b). The strongest winds are seen in winter and autumn. The northeaster wind is most prevalent wind, blowing from the northeast. However, southerly winds also occasionally affect the city from time to time. When the wind blows sufficiently from the east, it helps to clear the air and makes city cool in the summer (Municipility of Çanakkale, 2014b). Wind rose for 2013 is illustrated Figure 3.4.

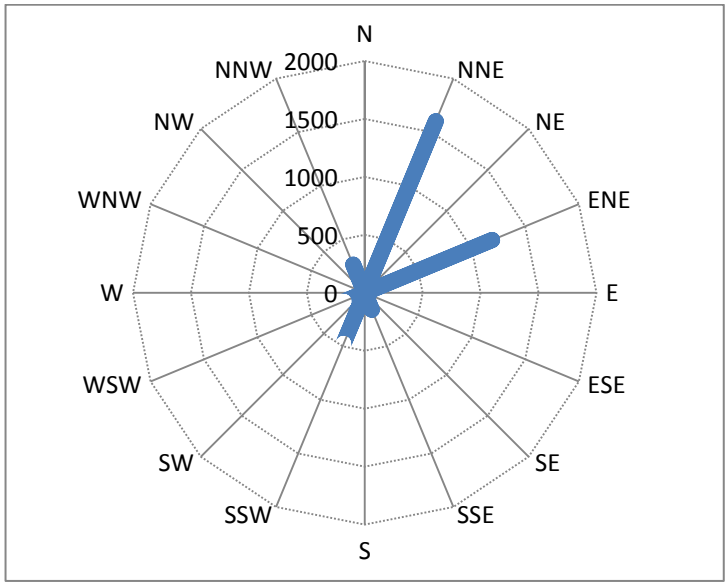

Figure 3.4 Wind rose for 2013

The population of Çanakkale is 502,328 for the year of 2013 (Turkish Statistical Institute [TSI], 2014a). The population density was 51 people per square kilometer. Population growth rate is 17.3 per thousand and this rate is more than Turkey's average growth rate. Fifty-eight percent of the total population is the urban population with 288,770 people and the town population is 43% of the total population with 213,558 people. As of the year 2013, 116,078 people live in the

center of the central district (TSI, 2014a). Population growth in Çanakkale is illustrated in Figure 3.5.

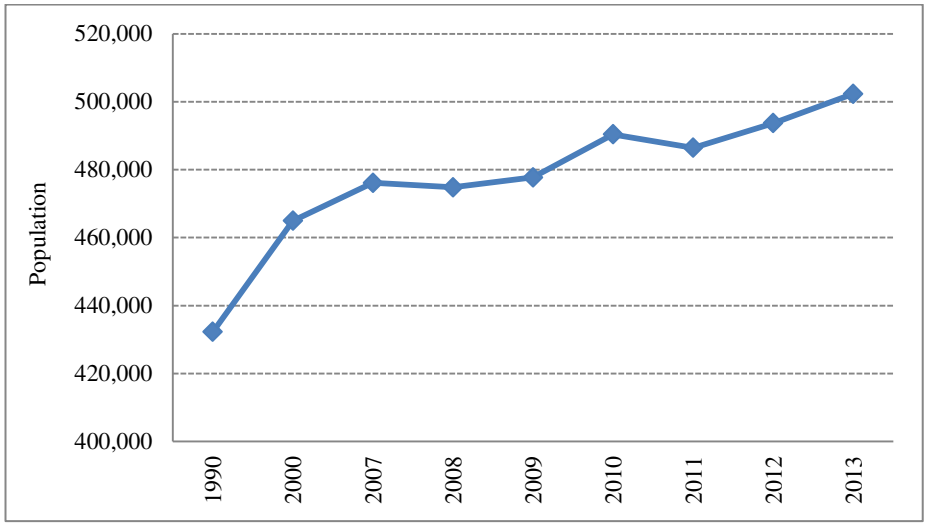

Figure 3.5 Population growth in Çanakkale (1990-2013)

Central district is the biggest district of Çanakkale with 149,881 population. In terms of population density, Biga, Çan and Gelibolu are the most crowded districts after the center district, respectively. Bozcaada is the smallest one. Population of province/district centers, towns/villages is given in Table 3.1. Distribution of the population in terms of the districts is illustrated in Figure 3.6.

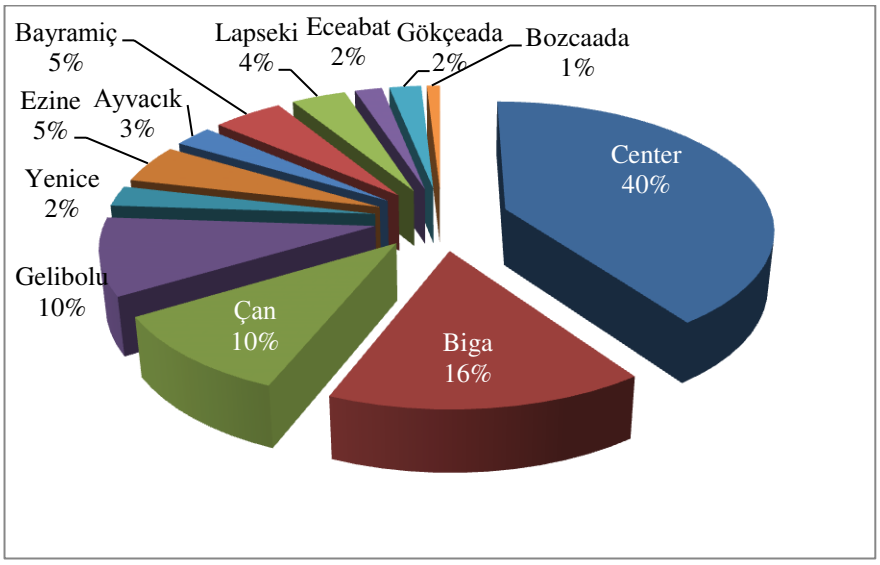

Figure 3.6 Distribution of population in terms of the districts

Table 3.1 Population of province/district centers, towns/villages by provinces and districts

	Population		
Province and districts	**Total**	**Province and district center**	**Town and villages**
Center	149,881	116,078	33,803
Biga	85,225	45,969	39,256
Çan	50,126	29,725	20,401
Gelibolu	43,345	27,927	15,418
Yenice	34,777	7,423	27,054
Ezine	32,165	14,002	18,163
Ayvacık	30,735	7,758	22,977
Bayramiç	30,117	14,188	15,929
Lapseki	25,661	11,062	14,599
Eceabat	9,123	5,541	3,582
Gökçeada	8,830	6,454	2,376
Bozcaada	2,643	2,643	-
Çanakkale	**502,328**	**288,770**	**213,558**

Source: TSI, 2014a.

The most abundant industrial sector across the city is food sector consists of the dairy and olive oil mills. Immediately after olive oil production, the city's major industrial products are the iron-steel plant, ceramic, glazed ceramic tile, cement, frozen and dried food, dairy products, zinc and lead ores and energy production plants (Governor of Çanakkale, 2014a). Energy production in the province is provided by the seven wind power plants and Çan Thermal Power Plant (Governor of Çanakkale, 2014a). Additionally, as well as small and large livestock, developing beekeeping and poultry are the main sources of income in the city (Governor of Çanakkale, 2014a).

A food industry in the city center, an iron-steel plant and two energy production plants in Biga, two ceramic plants, a power plant and Çan lignite plant in Çan, a cement plant in Ezine, a dairy plant in Bayramiç are prominent industries in Çanakkale. According to the annual report of the İstanbul Chamber of Industry about "Turkey's 500 Largest Industrial Plants", Çanakkale has 4 plants in 2013. These are a iron-steel plant (7), a cement plant (61), an energy production plant (112), a ceramic plant (117), respectively. Çanakkale also has two different organized industrial zone in the center and Biga districts. Total number of workplaces in these industrial zones consisting of mainly food industries are 48 (Governor of Çanakkale, 2014b).

3.2 Air Quality in Çanakkale

Air pollution one of the important environmental problems in the city because of growing population, increased maritime traffic, some sizeable economic activities such as significant industries that are emitting high quantities of air pollutants, domestic heating and traffic (Ministry of Environment and Urbanization, 2014). Air pollution in the city is mainly observed during the winter months. Considering all these rapidly growing air pollution sources in the city, Çanakkale is included in Marmara Clean Air Center.

In 2008, Marmara Clean Air Center that was founded in order to prevent or reduce air pollution impacts on the environment and human health. Additionally, it aims to collect information about air quality and inform the public by means of alert thresholds by the Ministry of Environment and Urbanization. Aim of the center is to provide more inhalable air in 11 different city (İstanbul, Edirne, Kırklareli, Tekirdağ, Kocaeli, Sakarya, Bilecik, Yalova, Bursa, Balıkesir, Çanakkale) located in Marmara Region. Together with this center, two new monitoring stations were establish in Çanakkale which has already two monitoring stations (Ministry of Environment and Urbanization, 2013). At these stations; SO_2, PM, NO_x, O_3, CO and meteorological parameters are measured (Ministry of Environment and Urbanization, 2013).

These stations are located in Çan, Lapseki, Biga and central districts. Air quality monitoring station in the city center has been located with the purpose of monitoring continuous SO_2 and PM_{10} levels. It was established by Ministry of Environment and Forestry in 2004. Air quality monitoring station located in Çan and Lapseki - Çardak were established in 2012 by the Directorate of Marmara Clean Air Center and since March of 2013 measurements have begun to be used. In addition, Lapseki - Çardak station which was established to determine air pollution originating from maritime traffic is rural station. Monitoring of PM_{10}, $PM_{2.5}$, SO_2, NO, NO_2, NO_x and O_3 is carried out at Çan station. At Lapseki station except PM_{10} all other parameters as the Çan station are monitored. Another station was established to determine the

contribution of integrated production plant and shipyard located in Biga to air quality of the by İÇDAS. Firstly, it was operated by İÇDAŞ, but it was transferred to Ministry of Environment and Urbanization in 2010. PM_{10}, $PM_{2.5}$, SO_2, NO, NO_2, NO_x, O_3 are monitored in Biga station. In the city, there is no station which is not connected to National Air Quality Monitoring Network (Ministry of Environment and Urbanization, 2014). Locations of the monitoring stations are illustrated in Figure 3.7 and Figure 3.8 shows the pictures of the station in Çanakkale.

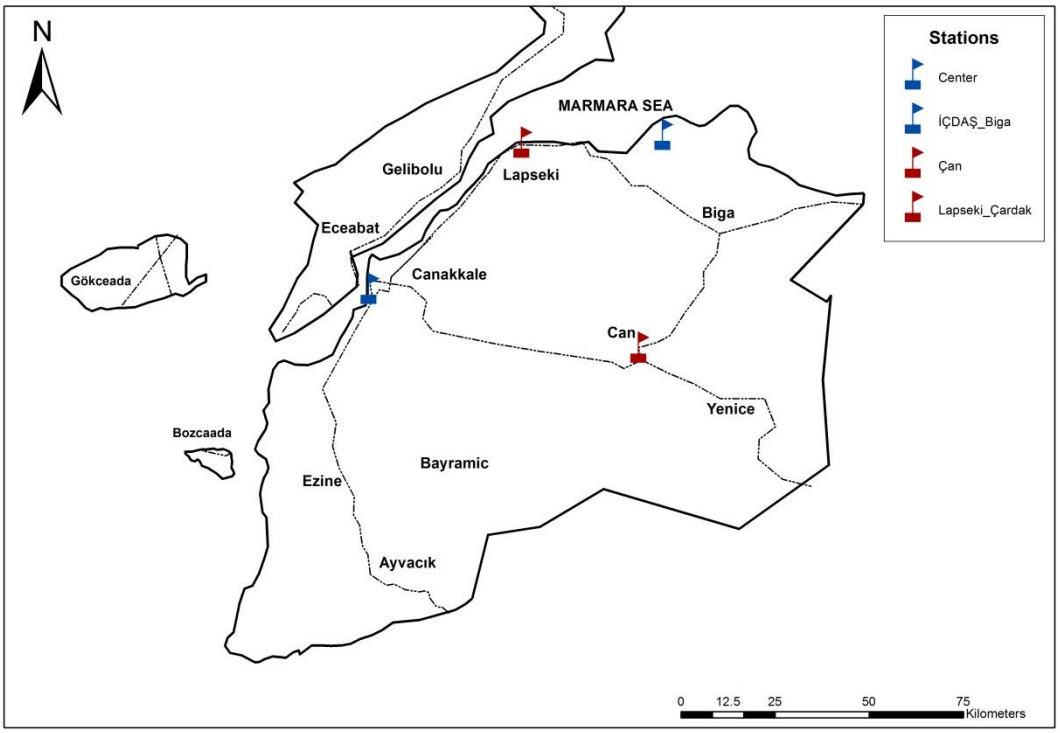

Figure 3.7 Location of air quality monitoring stations in Çanakkale

Figure 3.8 Pictures of ambient air quality monitoring stations in Çanakkale

Table 3.2 shows the monthly and annual average concentrations were measured in Çanakkale station in period of 2008-2013. It was recorded that the peak levels of air pollutants (SO_2 and PM_{10}) measured during the winter months (November-March) in the central district of Çanakkale from 2008 to 2013. But, in 2013 the decrease in SO_2 and PM_{10} concentrations are observed inversely proportional to the rate of increase in natural gas subscriptions.

Table 3.2 Monthly and annual average concentrations in Çanakkale station

		January	Ferbuary	March	April	May	June	July	August	September	October	November	December	Annual average
2008	**SO_2**	22		10	7	12	7	5	4	4	7	30	60	15.3
	PM_{10}	163	90	84	116	46	55	48			40	56	61	75.9
2009	**SO_2**	49	49	33	20	7	4	5	4	4	5	36	22	19.8
	PM_{10}	68	63	67	57	40	44	50	46	39	42	67	52	52.9
2010	**SO_2**	78	46	33	23	10	4	6	4	6	8	26	38	23.5
	PM_{10}	61	75	49	25	23	13	15	22	13	13	25	20	29.5
2011	**SO_2**	55	113	89	29	12	8	15	12	6	14	35	69	38.1
	PM_{10}	30	30	24	19	19	18	15	24	18	14	25	24	21.7
2012	**SO_2**	89	80	99	28	11	12	6	7	19	5	12	11	31.6
	PM_{10}	21	28	23	18	14	18	28	17	18	16	15	19	19.6
2013	**SO_2**	6	27	28	23	10	6	7	6	6	7	18	21	13.8
	PM_{10}	17	18	20	18	25	15	17	19	10	15	16	22	17.7

The maximum, minimum and annual average concentrations monitored at 4 ambient air quality stations during the year 2013 for SO_2 and PM_{10} are given in Table 3.3. The highest annual average concentrations for SO_2 and PM_{10} recorded were 162.5 $\mu g/m^3$ and 80.2 $\mu g/m^3$ respectively at Çan station. It was recorded that the daily limit value for SO_2 and PM_{10} in 3 monitoring stations during the year 2013 were not exceeded. But, limit value of 300 $\mu g/m^3$ for PM_{10} and 200 $\mu g/m^3$ for SO_2 were exceeded 1 day and 63 days at Çan station.

According to the results, PM_{10} and SO_2 concentrations measured in Çan station were higher than the other stations especially in winter season. The reason could be that using domestic lignite coal in order to residential heating in the Çan district. Additionally, a lignite mining plant, a thermal power plant and two different ceramic plants are located in Çan. But, in summer high concentration levels for SO_2 and PM_{10} were not observed in this station despite of the major industrial plants in the district. Therefore, the air quality levels exceeded the limit values are thought to be mainly caused by residential heating activities in this region.

Table 3.3 The maximum, minimum and annual average concentrations monitored at 4 ambient air quality stations

		Minimum concentration	Maximum concentration	Annual Average concentration	Number of exceeding
Çanakkale	**SO_2**	1.0	262	13.5	**-**
	PM_{10}	1.0	197	18	**-**
Çan	**SO_2**	2.0	1009.4	162.5	63
	PM_{10}	10.6	300.7	80.2	1
Lapseki	**SO_2**	1.8	27.7	7.4	**-**
	PM_{10}	-	-	-	**-**
Biga	**SO_2**	1.0	275.0	5.5	**-**
	PM_{10}	1.0	570.0	31.0	**-**

3.3 Pollutant Sources and their Characteristics

In a systematic way, emission sources were categorized into three types as point, line and area sources in this study. Point sources refer to production energy and fuel consumption industrial facilities, such as power plants and large manufacture plants which emit the majority of pollutants. Area sources account for residential heating emissions and line sources account for both vehicular (highways and major streets) and maritime traffic (transit and domestic traffic).

3.3.1 Point Sources

In the study area 6 major industrial facilities were identified contributing to air pollution and included in the emission inventory. Of these 3 are located in Çan district (two ceramic plants and a thermal power plant) and two thermal power plants are located in Biga and a cement plant is located in Ezine. Many industrial facilities containing small capacity plants and commercial areas are also located in two industrial zones named as Çanakkale and Biga OIZs in the region. But, in this study these plants mostly consisting of food industry are not taken into account due to their low or no emissions. On the other hands, a public power and cogeneration plant with 320 MWe capacity, two different power plant belonging to İÇDAŞ and two different ceramic plants (Çanakkale Ceramic and Etili Ceramic), a cement plant (Akçansa)

could be taken into consideration as the major industrial pollutant sources in the city. Fuel type and fuel consumption data belonging to industrial plants evaluated in this study was shown in Table 3.4.

Table 3.4 Fuel type and fuel consumption data about major industrial plants

Industrial plant	**Fuel type**	**Fuel consumption**
Çan Power Plant	Local lignite coal	1,236,675 t/yr
Akçansa Cement plant	Lignite coal + imported coal + petrocoke + fuel oil	481,611 t/yr
İÇDAŞ Bekirli Power Plant	Imported coal	1,671,691 t/yr
İÇDAŞ Değirmencik Power Plant	Imported coal	1,129,017 t/yr
Çanakkale Ceramic Plant	Natural gas	101,679,738 Nm^3/yr
Etili Ceramic Plant	Natural gas	4,397,969 Nm^3/yr

3.3.2 Line Sources

The key parameters for determination of emissions from highways were the vehicle numbers per day and average speeds, types of vehicles. Data about the average vehicle numbers per day and average speeds were obtained from General Directory of Highways (GDH) for the year of 2013. Data from a recent study conducted by İstanbul Metropolitan Municipality in collaboration with Dokuz Eylül University in 2009 and the another study was carried out in İzmir was used to determine of rate of vehicle types in terms of fuel types as gasoline, diesel, LPG and also rates of age distribution of the vehicles (Elbir, Bayram, Seyfioğlu, Altıok & Dumanoğlu, 2008; Elbir et al., 2009). Vehicles were classified as passenger car, light duty vehicles (small bus & pickup) and heavy duty vehicles (bus & truck) in this study.

Emissions calculated based on highways and also the contribution of major streets in Gökçeada and Bozcaada were also included. Highways are divided into zones. Therefore, the number of vehicles was calculated by taking the weighted average in terms of length of zone. The width of roads in Çanakkale considering the standards

of road width were chosen as 6 m for roads in Gökçeada and Bozcaada, 7 m for default highways, 14 m for divided roads in this study. According to the GDH, Çanakkale is located in 14th Regional Directorate. Locations of roads in the study area were given in Figure 3.9 and information about highways in Çanakkale was given in Table 3.5.

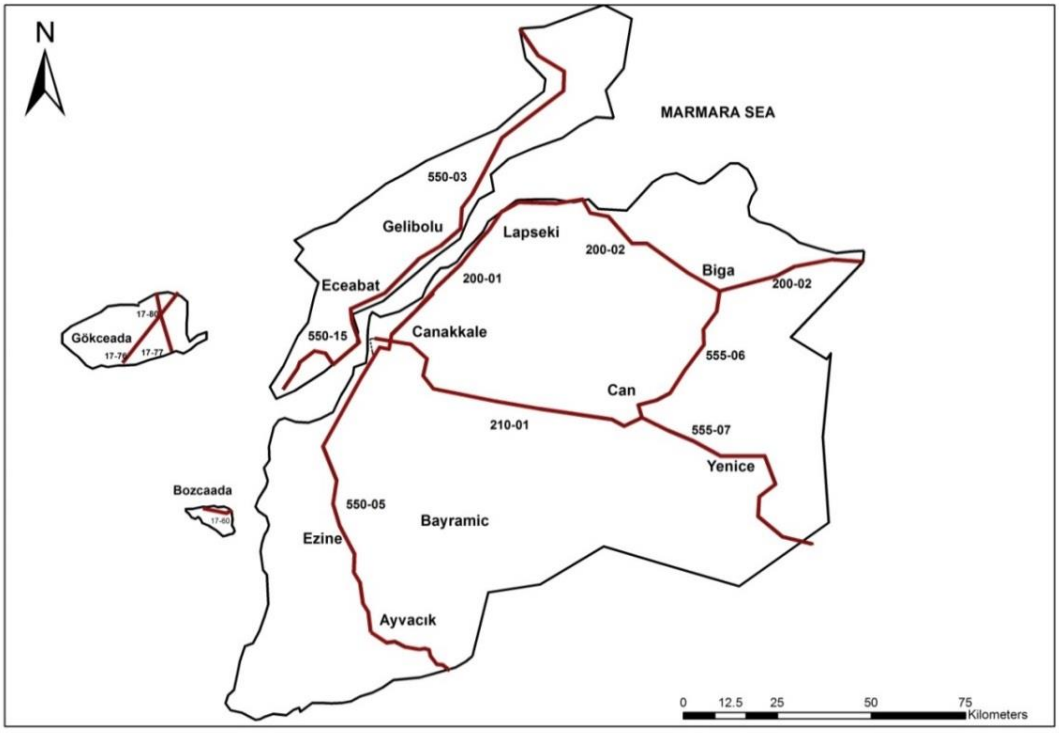

Figure 3.9. Location of highways in Çanakkale

Table 3.5 Summary information about highways in the study area

Codes of roads	**Lenght (km)**	**Width (m)**	**Passenger car (vehicle/day)**	**Light duty vehicle (vehicle/day)**	**Heavy duty vehicle (vehicle/day)**
550-05	84	14	5,839	861	2,268
200-01	35	14	5,264	1,080	890
200-02	83	14	3,663	891	827
210-01	63	7	1,658	245	193
555-06	37	14	3,325	624	559
555-07	65	7	1,689	1,104	290
550-15	35	7	1,896	215	208

Table 3.5 Summary information about highways in the study area (continue)

Codes of roads	**Lenght (km)**	**Width (m)**	**Passenger car (vehicle/day)**	**Light duty vehicle (vehicle/day)**	**Heavy duty vehicle (vehicle/day)**
550-03	85	7	3,947	684	556
17-76	10	6	853	67	32
17-77	29	6	377	42	17
17-80	4	6	2,566	238	74
17-60	7	6	480	15	21

Source: GDH, 2013.

Maritime traffic on Çanakkale Strait is another line source in the study area. The total daily number of cruising of domestic passenger ships is 194 in Çanakkale strait (GESTAŞ, 2014). The domestic transportation crossed over the straight on 7 different routes as were illustrated in Figure 3.10. In these routes, 10 ferries, 1 sea bus and 1 Ro-ro ship are under way. While sea bus is under way on Çanakkale–Gökçeada line, Ro-ro ship works on Kabatepe – Gökçeada line. The most intense route is Lapseki – Gelibolu with the number of 74 cruises per day. Data on the number of cruise, length of route, cruising time and fuel consumption of each ship was obtained from GESTAŞ (GESTAŞ, 2014). The collected data was summarized in Table 3.6. Additionally, the fuel consumption of passenger ships were calculated as hourly, daily and yearly basis.

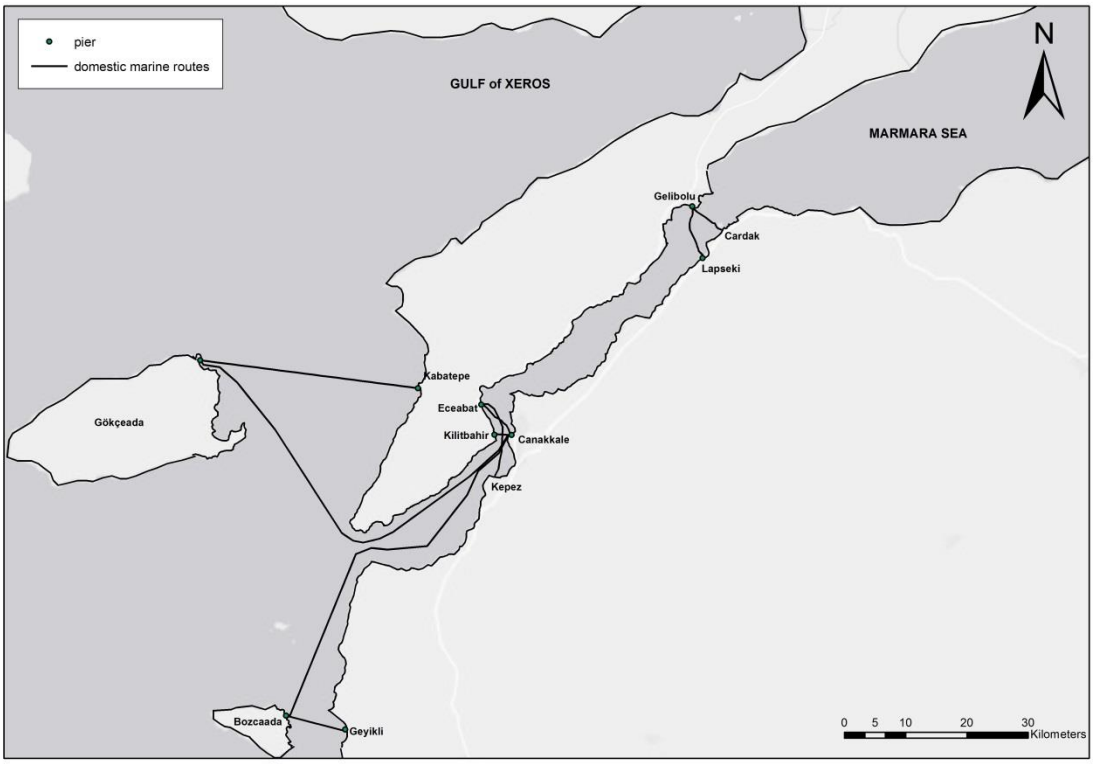

Figure 3.10 Domestic maritime routes in Çanakkale Strait

Table 3.6 Summary information about domestic transportation on Çanakkale Strait

Name of the routes	**Route Lenght (m)**	**Cruising time (minute)**	**Number of cruising per day**	**Fuel consumption (liter/cruising)**	**Fuel consumption (tons/month)**
Lapseki - Gelibolu	6.3	20	74	160	311.9
Çanakkale - Kilitbahir	1.5	7	62	23	43.5
Çanakkale - Eceabat	5.0	15	44	135	193.5
Kabatepe - Gökçeada	46.3	75	6	594	120.2
Geyikli - Bozcaada	7.4	30	6	160	55.6
Çanakkale - Gökçeada	53.7	65	1	800	15.6
Çanakkale - Bozcaada	46.3	55	1	800	15.6

The number of ships passing through the Çanakkale strait was recorded as 44,613 in 2013. Types of ships and the annual number of cruise on the Çanakkale strait for 2013 were obtained from Ministry of Transport, Maritime Affairs and Communication (Ministry of Transport, Maritime Affairs and Communication, 2014). Average speeds of ships according to the type of vessels range from

16 to 40 km/h. In order to determine annual fuel consumption of the vessels, EMEP/CORINAIR (EEA, 2009) database was used and fuel consumption factors according to the vessel types obtained. The type and number of transit ships and fuel consumption factors used in calculations are given in Table 3.7.

Table 3.7 Summary information about transit passing ship on Çanakkale Strait

Type of ships	**Number of cruising per year**	**Fuel consumption factor (tons/day)**	**Fuel Consumption (tons/year)**
GGC (General Cargo)	18,992	21.3	46,857
BBU (Bulk Carrier)	7,442	33.8	29,136
TTA (Crude Oil Tanker)	5,653	32.8	20,045
UCC (Container Ship)	4,653	32.8	12,374
TCH (Chemical Tankers)	2,307	32.8	8,180
URC (Vehicle Carrier)	1,849	32.8	6,556
LPG (Liquid Petroleum Gas Carrier)	1,038	32.8	3,451
MPR (Passenger)	806	70.2	4,588
MLV (Livestock Carrier)	529	32.8	1,563
OTH (Other)	375	26.4	1,147
XTG (Tugs)	319	14.4	677
GRF(Refrigerated Ships)	278	32.8	739
MVC (Motor Vessel Carrier)	165	32.8	627
NAV (Navigation)	107	32.8	407
RRE (Research Ship)	23	32.8	87
OFY (Ferry)	21	80.4	137
FFS (Fishing)	20	5.5	12
CHS (Cargo Ship)	19	32.3	71
OSY (Supply Ship)	9	32.8	27
DDR (Dredger)	8	32.8	47
Total	**44,613**	-	**136,728**

3.3.3 Area Sources

Emissions from sources of residential heating and traffic on major streets that were too small and difficult to be surveyed individually, were considered collectively as area sources. Thus, residential heating and traffic on major streets were evaluated as area sources in this emission inventory. The fuel use pattern in the city is consisted of local and imported coal as well as natural gas for residential heating in winter period (November–April). For the calculation of residential heating emissions, the collected data included mainly number of inhabitants, number of residences, type of fuels (coal and natural gas) used and fuel consumption statistics by the districts. Since, no data was available on spatial distribution of coal consumption by districts, total consumption were obtained from Çanakkale Directorate of Environment and Urbanization for the year of 2013 (Çanakkale Directorate of Environment and Urbanization, 2014) and distributed to districts in terms of population density. Population data was used from the population statistics provided by Turkish Statistical Institute (TSI) in 2013 and shown in Table 3.8. Total coal consumption per residence in the city is 1.6 tons/season. The percentage of domestic coal consumption is 70, while the percentage of imported coal consumption is 30 in the city.

Table 3.8 Population data in terms of the districts

Province and districts	**Total**	**Province and district center**	**Town and villages**
Center	149,881	116,078	33,803
Biga	85,225	45,969	39,256
Çan	50,126	29,725	20,401
Gelibolu	43,345	27,927	15,418
Yenice	34,777	7,423	27,054
Ezine	32,165	14,002	18,163
Ayvacık	30,735	7,758	22,977
Bayramiç	30,117	14,188	15,929
Lapseki	25,661	11,062	14,599
Eceabat	9,123	5,541	3,582
Gökçeada	8,830	6,454	2,376
Bozcaada	2,643	2,643	-
Çanakkale	**502,328**	**288,770**	**213,558**

Source: TSI, 2014

The highest contribution to total coal consumption in the city is from Gelibolu district because the residences in this region could not use natural gas due to lack of infrastructure system. Total coal consumption in Gelibolu district is 16,130 tons/season while the city center has 503 tons fuel usage per season because natural gas is widely used with the rate of 99%. For the year of 2013, district based seasonal fuel consumptions are given in Figure 3.11.

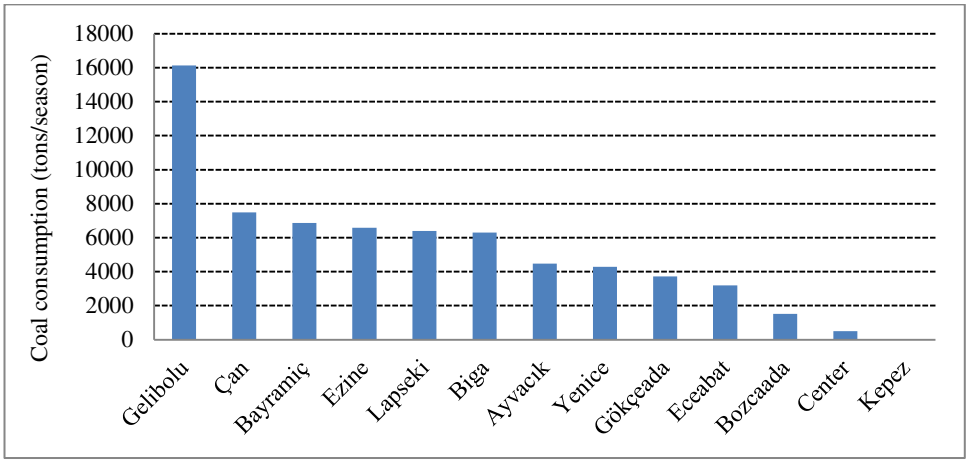

Figure 3.11 Seasonal coal consumptions of the districts (tons/season)

While all districts use coal for residential heating, only five districts of Çanakkale (Center, Çan, Biga, Bayramiç, and Ezine) use natural gas. Total natural gas consumption is approximately 50,198,586 m^3 in the winter season for five districts. Monthly natural gas consumption data for five districts were collected directly from the main natural gas distribution company (AKSA) in Çanakkale (AKSA, 2014). Distribution of natural gas consumption in terms of the districts is illustrated in Figure 3.12.

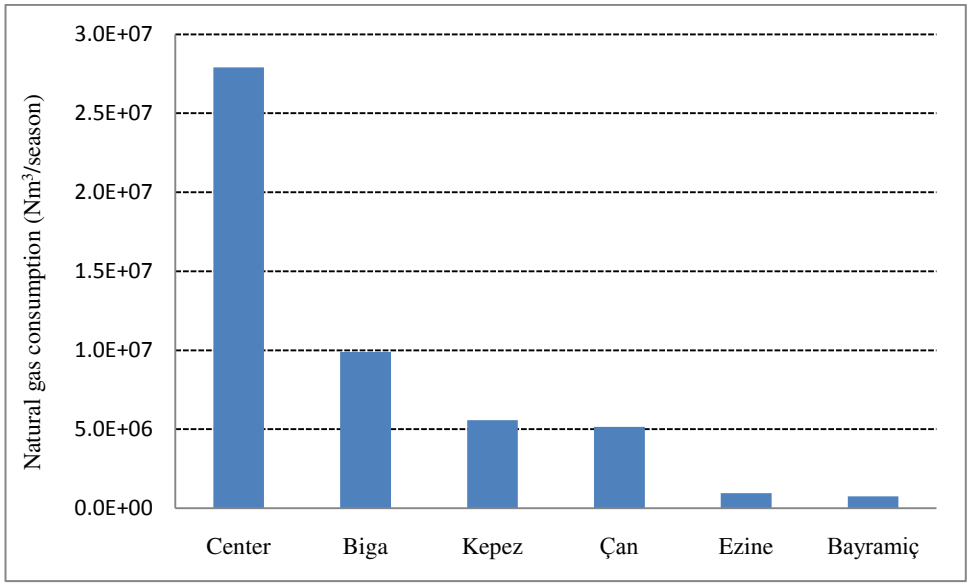

Figure 3.12 Natural gas consumption of the districts

Traffic on major streets in the city is also assumed as area source in the study. Number of registered vehicles categorized as motorcycle, passenger car, light duty and heavy duty vehicles in Çanakkale were provided from TSI for the year 2013 (TSI, 2014b). This data was spatially distributed in the region in terms of population of the districts. Vehicle numbers of urban area in Çanakkale are given in Table 3.9 and distribution of the vehicle types in the study area are also given in Figure 3.12.

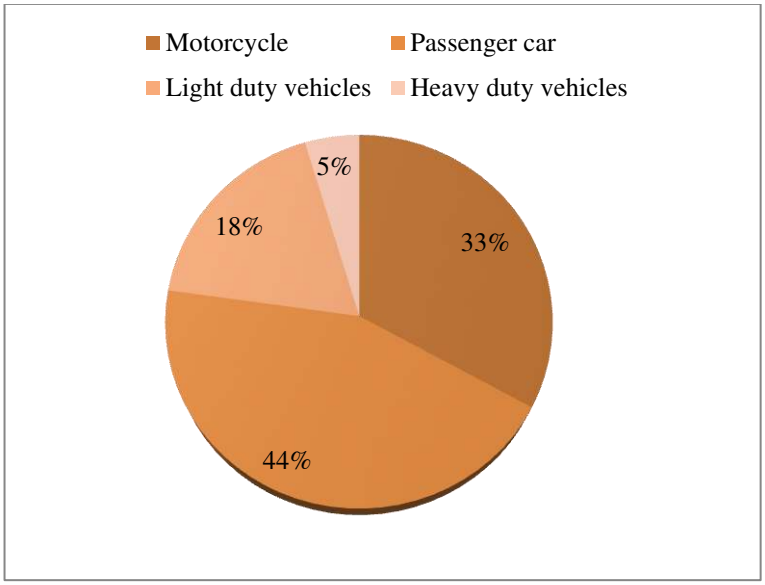

Figure 3.13 Distribution of the vehicle types in the city

Table 3.9 Vehicle numbers in the districts

	Vehicle numbers			
Districts	**Motorcycle**	**Passenger car**	**Light duty vehicles**	**Heavy duty vehicles**
Center	18,359	24,647	10,091	2,601
Kepez	2,488	3,340	1,368	352
Ayvacık	1,227	1,647	674	174
Bayramiç	2,244	3,013	1,233	318
Biga	7,270	9,761	3,996	1,030
Bozcaada	418	561	230	59
Çan	4,701	6,312	2,584	666
Eceabat	876	1,177	482	124
Ezine	2,215	2,973	1,217	314
Gelibolu	4,417	5,930	2,428	626
Gökçeada	1,021	1,370	561	145
Lapseki	1,750	2,349	962	248
Yenice	1,174	1,576	645	166
TOTAL	**48,160**	**64,656**	**26,471**	**6,823**

3.4 Calculation of Emissions

Collected activity data for all pollutant source categories was evaluated with the appropriate emission factors selected from the literature. Selection of emission factors take into account the fuel types, vehicle specifications (vehicle types, motor types, vehicle ages, , etc.), types of pollutants in accordance with technology in use in each sector, production range and availability of pollution control devices. In this study, the emission factors were taken from EMEP/CORINAIR Emission Inventory Guidebook (EEA, 2007; EEA, 2009; EEA, 2013). As national conditions for each emission sector were more or less differing from working conditions in Europe for which the emission factors were derived, more Turkish emission factors should have been used in this work. But, as these were not available, European emission factors had to be adopted and used.

For industrial plants EEA (2013) database was used for emission calculations. Emission factors were provided for 4 different fuel types (domestic and imported coal, natural gas and fuel oil) and converted by using heating value and sulfur content. These factors are shown in Table 3.13.

Table 3.10 Emission factors for industrial plants

	Original factor (g/GJ)				**Final factor (kg/ton-Nm^3)**			
	SO_2	**NO_2**	**PM_{10}**	**CO**	**SO_2**	**NO_2**	**PM_{10}**	**CO**
Natural gas	0.28	89.0	0.89	39.0	$9.70x10^{-6}$	$3.07x10^{-3}$	$3.07x10^{-5}$	$1.35x10^{-3}$
Imported coal	2016	247	7.9	8.7	53.98	6.61	0.21	0.23
Domestic coal	1680	60	6.9	13	33.74	1.20	0.14	0.26
Fuel oil	495	142	25.2	15.1	20.30	5.82	1.03	0.62

Emission factors according to the different fuel types and engine technology were determined in European countries for different types of sea vessels. Emission factors were selected from EEA (2007) for ferry traffic in Çanakkale Strait and these emission factors were assessed by the amount of fuel consumed per 1 meter and converted emission factors were obtained type of g pollutant per m route. The emission factors for transit ships were selected from EEA (2009). These factors are shown in Table 3.12.

Table 3.11 Emission factors for ferries and transit ships

Type of ship	**Emission factors**	**SO_2**	**PM_{10}**	**NO_x**	**CO**
Domestic	g/kg fuel	10.4	4.48	42.5	10.9
	g pollutant/ m road	0.076563	0.032941	0.3125	0.080147
Transit	kg/ton fuel	20×S%*	1.1	57	7.4

**S: 0.5 % for distilled fuel*

For highway traffic, emission factors were selected from EEA (2007) database. Emission factors depend on vehicle type, engine technology, fuel type and speed of vehicles, but usage of emission factors mostly depend on vehicle speed and provided as in the form of equations. In this study, equations depended on speed of vehicles were used for each pollutant type and vehicle category. For example; emission factor for the cars having EURO 4 technology using gasoline is given below;

$$EF = (0.136 - 0.000891 \times V) / (1 - 0.0141 + 0.0000499 \times V^2) \quad (3.1)$$

where;

EF: emission factor for CO (g/km)

V: speed of vehicle (km/h)

The units of original emission factors for natural gas, imported coal and domestic coal were converted into kg/tons or kg/m^3 by using their sulfur contents and heating values shown in Table 3.10. Converted final emission factors are shown in Table 3.11.

Table 3.12 Original emission factors for residential heating, g/GJ

	Original Factors (g/GJ)				**Heating value**	**Sulfur content**
Pollutant	**SO_2**	**NO_2**	**PM_{10}**	**CO**	**(kcal/kg, kcal/m^3)**	**(%)**
Natural Gas	0.5	70	0.5	30	8250	-
Imported Coal	540	110	404	4600	6400	0.9
Domestic Coal	1200	110	404	4600	4800	2

Table 3.13 Converted final emission factors for residential heating

	Final Factors			
Pollutant	**SO_2**	**NO_x**	**PM_{10}**	**CO**
Natural Gas (g/Nm^3)	0.0173	2.41626	0.01726	1.03554
Imported Coal (kg/ton)	14.5	2.9	10.8	123.2
Domestic Coal (kg/ton)	24.1	2.2	8.1	92.4

3.5 Air Quality Modeling

Air quality dispersion modeling is used to estimate the concentrations of pollutants at ground level at particular distances from emission sources. It has been recognized as a promising approach for predicting spatial and temporal variations of pollutants in the atmosphere and the behaviors of these pollutants through mathematical algorithms that take into account atmospheric dispersion. Chemical and physical processes are also studied in an attempt to approximate concentrations of pollutants.

While different types of dispersion models have been used over the world the most widely used technique relies on Gaussian models for estimating the impact of non-reactive pollutants. Gaussian refers to the statistical concept in which a group of arranged values follows a bell-shaped curve distribution. This type of arrangement is typically known as a normal distribution. In the case of air pollutants, the assumption of a Gaussian (normal) distribution is that when the contaminant plume is released at a point source. Most of the pollutants will be found in the middle of the plume. Under the Gaussian modeling approach the highest concentration of pollutants is assumed to be at the center of the plume and decreasing exponentially to near zero at the edges of the plume. The assumption that a stack plume disperses in a Gaussian manner also involves other assumptions such as steady state conditions (Cora & Hung. 2003).

Plumes are cloud-like masses of pollutants traveling through the air under the influence of diffusion and convective mechanisms. Plumes disperse in both horizontal and vertical directions. Plume rise and effective stack height are important parameters for calculating the dispersion of pollutants in the atmosphere. Plume rise and effective stack height are illustrated in Figure 3.13.

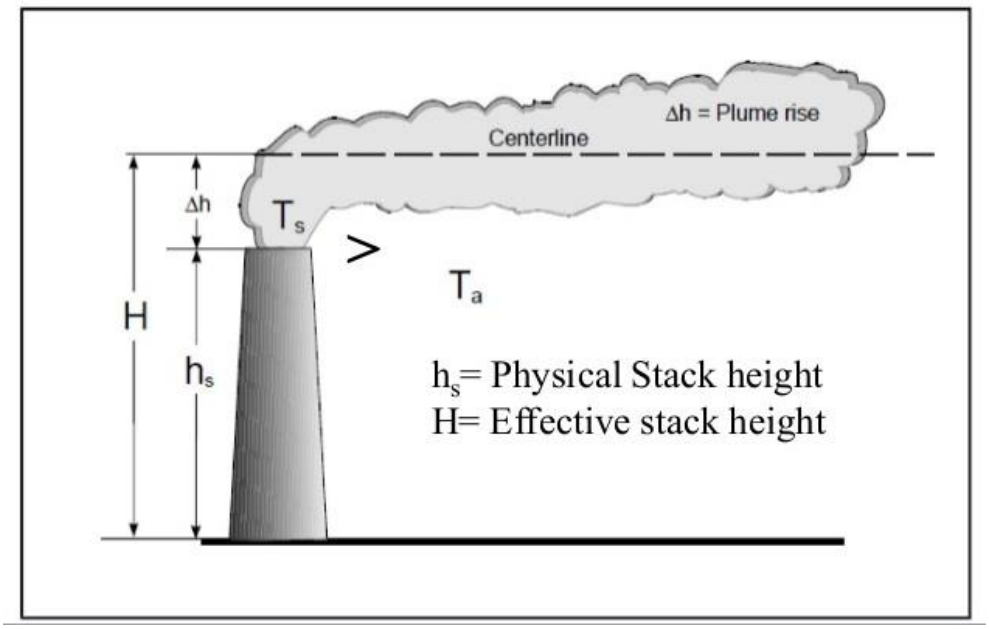

Figure 3.14 Plume rise and effective stack height

Default options of AERMOD include the use of stack-tip downwash and a routine for processing averages when calm winds or missing meteorological data occur. The model also includes non-default options for suppressing the use of stack-tip downwash and to disable the date checking for non-sequential meteorological data files.

Several source groups may be specified in a single run with the source contributions combined for each group. Source emission rates can be treated as constant throughout the modeling period or may be varied by month, season, hour-of-day or other optional periods of variation. These variable emission rate factors may be specified for a single source or for a group of sources.

AERMOD aims dispersion from a variety of polluting sources (e.g. point, area, and volume sources) using a number of model configurations. Additionally, line sources may also be modeled as a string of volume sources or as elongated area sources. Model configurations include different sets of urban or rural dispersion coefficients as well as simple and complex topography. The model has the capacity to employ hourly sequential preprocessed meteorological data to estimate concentrations of pollutants at receptor locations at different time scales ranging from 1 hour to 12 months. Variety of applications made it popular among the modeling community (U.S.EPA, 2004a).

One of the basic inputs to AERMOD is the run stream setup file which contains the selected modeling options as well as source location and parameter data, receptor locations, meteorological data file specifications and output options. Another type of basic type of input data needed to run the model is the meteorological data. AERMOD requires two types of meteorological data files that are provided by the AERMET meteorological preprocessor program. One file consists of surface scalar parameters and the other file consists of vertical profiles of meteorological data. For applications involving elevated terrain effects the receptor and terrain data will need to be processed by AERMAP. After the needed meteorological and terrain input files

are provided AERMOD can work (U.S.EPA. 2004a). The data flow in AERMOD modeling was illustrated in Figure 3.14.

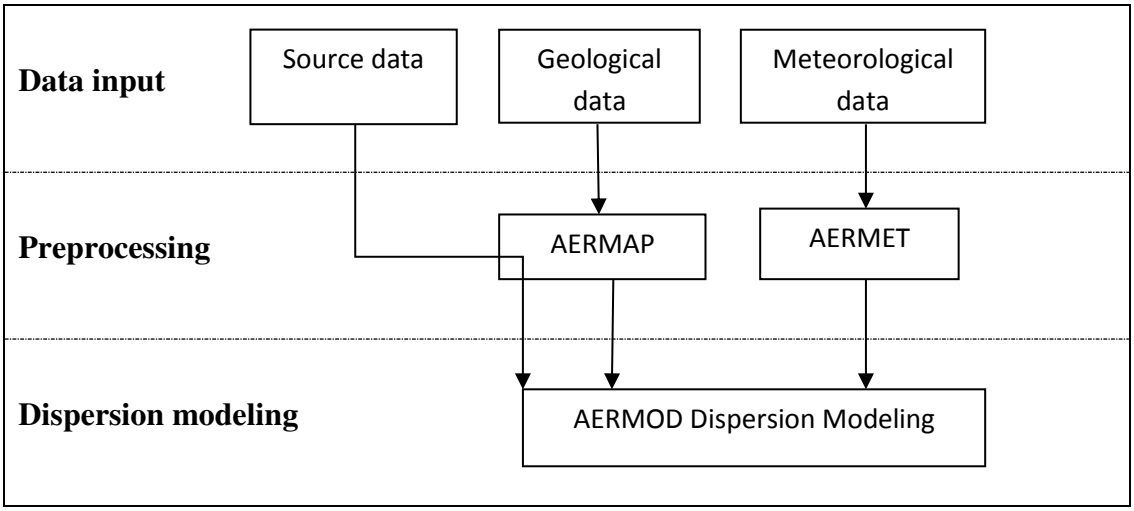

Figure 3.15 Data flow scheme in the AERMOD modeling

3.5.1 AERMET

AERMET is a meteorological preprocessor for organizing available meteorological data into a format suitable for use by the AERMOD air quality dispersion model. National Weather Service (NWS) hourly surface observations, NWS twice-daily upper air soundings and data from an on site-specific meteorological measurement program can be processed in AERMET.

There are three stages to processing the data. The first stage extracts meteorological data from archive data files and processes the data through various quality assessment checks. The second stage merges all data available for 24-hour periods (NWS and site-specific data) and stores these data together in a single file. The third stage reads the merged meteorological data and estimates the necessary boundary layer parameters for use by AERMOD.

To run the AERMET preprocessor the surface meteorological data were received from the meteorological station located in the center district of Çanakkale. The station number is 17112. The upper meteorological data from radiosonde soundings

were received from Göztepe station in İstanbul that is the nearest upper air station to Çanakkale. Therefore, radiosonde data obtained for the year of 2013 and the station number is 17062.

3.5.2 AERMAP

A preprocessor program, AERMAP, has been developed to process this terrain data in conjunction with a layout of receptors and sources to be used in AERMOD control files.

The terrain data for the AERMAP were extracted from the SRTM3 (Shuttle Radar Topography Mission) files. SRTM is a DEM with sample spacing of 3 arc–seconds (~ 90 m) using the Latitude/Longitude projection. Each file corresponds to one degree of latitude and longitude. The largest local domain (100 x 100 km) could require up to nine files. The names of the files; e.g. *N23W075.hgt* contain the latitude (North or South) and longitude (West or East) corresponding to the lower left corner of the grid system. SRTM is an international project spearheaded by the National Geospatial–Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA). The resolution of this data set is 10 times higher than GTOPO30.

In this study, study area is 170 km × 125 km to cover the Çanakkale region. The grid system with 1 km resolution was used for model domain. For the modeling of different sectors, sources were represented by different types. In this study, industrial plants were represented as point source, residential heating sector was represented as polygons and traffic sector was represented as line sources. 7 point sources for industrial sources, 1 area sources for area source, 70 polygons for residential areas and 339 area sources for traffic sector in this study area were determined and Figure 3.15 demonstrates these sources and domain of model study and summary of meteorological, geological and source characteristics for input to the AERMOD modeling system is shown in Table 3.14.

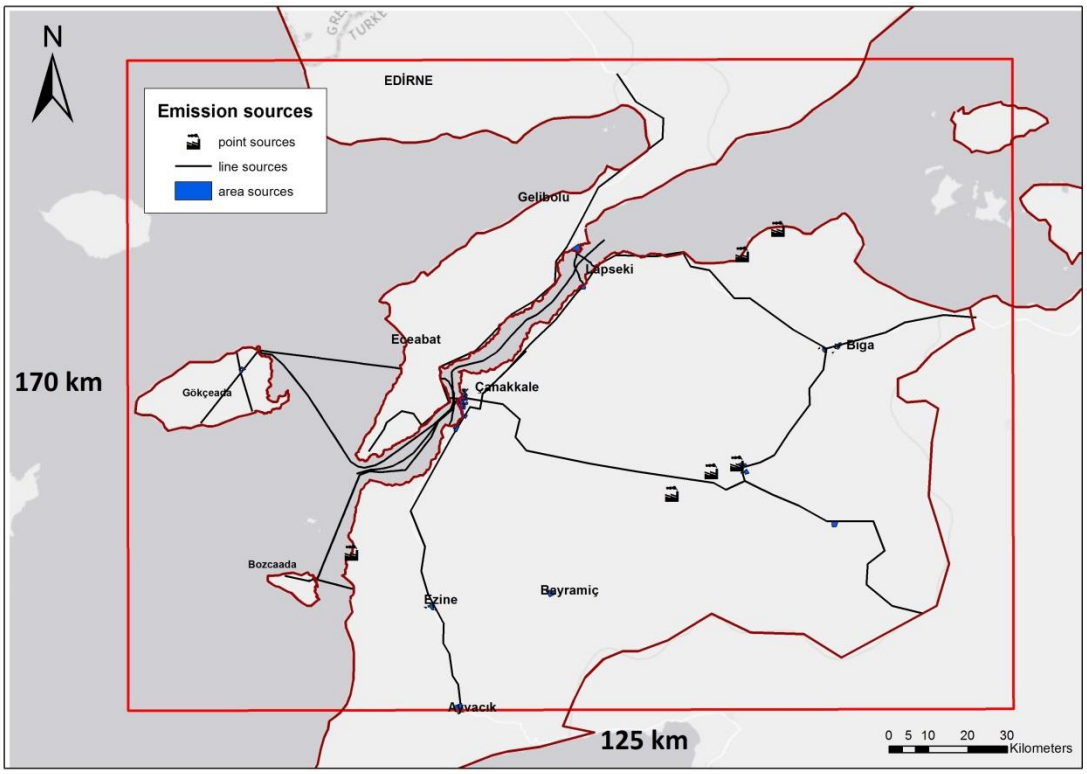

Figure 3.16 Location of emission sources and model domain

Table 3.14 Summary of meteorological, geological and source characteristics for input to the AERMOD modeling system

	Type	Observation	Source
AERMET	Surface Meteorological Data (hourly observations)	Wind speed, wind direction, temperature, cloud cover, ceiling cloud height, surface pressure, humidity and precipitation	Meteorological station in the center district, Çanakkale Station number: 17112
AERMET	Upper air meteorological data (hourly observations)	Wind speed, wind direction, temperature and pressure	12-hourly radiosonde data recorded from Göztepe station, İstanbul Station number: 17062
AERMAP	Geological data	Terrain elevations	SRTM3 data files (U.S. Geological Survey [USGS], 2014). Terrain elevation are in 1000 m horizontal resolution on 170 km × 125 km grid

Table 3.14 Summary of meteorological, geological and source characteristics for input to the AERMOD modeling system (continue)

	Type	Observation	Source
AERMOD	Source characteristic	Point source, area sources. Area poly source	7 point sources (industry), 1 area source (industry), 70 area sources (residential heating) and 339 area sources (traffic)

3.5 Statistical Analysis

The performance of AERMOD was evaluated by using the measured air quality dataset obtained from 4 different monitoring stations in Çanakkale. Therefore, statistical analysis was carried out which includes the calculation of root of mean square error (RMSE) and its components; the systematic RMSE ($RMSE_S$) and the unsystematic RMSE ($RMSE_U$), correlation coefficient, regression coefficients and index of agreement in this study.

The index of agreement (d) determines the degree to which magnitudes and signs of the observed value about mean observed value are related to the predicted deviation about mean predicted value and allows for sensitivity toward difference in observed and predicted values as well as proportionality changes. Three main statistical parameters calculated in this study are defined as follows: The index of agreement;

$$d = 1 - \frac{\sum_{i=1}^{N}(P_i - O_i)^2}{\sum_{i=1}^{N}(|P_i - O| + |O_i - O|)^2} \tag{3.2}$$

where N is the number of data, P_i is the model prediction, O_i is the observed concentration and O is the mean value of the observed data.

The correlation coefficient;

$$r = \frac{\sum_{i=1}^{N}(O_i - O)(P_i - P)}{\sigma_o \, \sigma_p} \tag{3.3}$$

where σ_o and σ_p are the standart deviations of observations and predictions. The root mean square error (RMSE) has two components; systematic and unsystematic. The systematic component of RMSE is;

$$RMSE_s = \left(\frac{1}{N} \sum_{i=1}^{N} \left(\hat{P}_i - O_i \right)^2 \right)^{1/2} \tag{3.4}$$

where $\hat{P}_i$ is predicted as the least squares linear regression of P_i and O_i with slope b and intercept a, respectively.

The unsystematic component of RMSE is

$$RMSE_u = \left(\frac{1}{N} \sum_{i=1}^{N} \left(\hat{P}_i - P_i \right)^2 \right)^{1/2} \tag{3.5}$$

The index of agreement (d) varies from 0.0 (theoretical minimum) to 1.0 (perfect agreement between the observed and predicted values). The value of d should be close to 1 and total RMSE should be close to 0 for a good prediction.

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Emission Inventory

Emissions from industries, road and maritime traffic and domestic heating activities were determined by the collected activity data along with respective emission factors for each sector and five main pollutants (SO_2, NO_x, PM_{10} and CO) for 2013 in Çanakkale. The total emissions of SO_2, NO_x, PM_{10} and CO were calculated as 8,990 tons/yr, 33,215 tons/yr, 1,057 tons/yr and 23,352 tons/yr, respectively. While industry is most polluting sector for NO_x and SO_2, most polluting sectors for CO and PM_{10} are road traffic and residential heating, respectively. Although emissions of particulate matter originating from industrial sector are low compared to other sectors, it should be noted that calculation of emission was carried out according to assumption of pollutant emitted from stacks under controlled conditions. Additionally, in the region there are some sand and gravel processing plants but, these activities could not be included in this study because of lack of data. Only Çan mining plant which is the largest mining plant in the region was included in the study with the approximate emission value to represent mining sector in the region. In winter season, PM_{10} and CO emissions are mainly arising from residential heating sector because all districts in the city used coal in this period (November-April). Although SO_2 and NO_x emissions from residential heating were not low enough to be underestimated, they are mainly coming from industrial activities in the city. Due to their dense population and high fuel consumption some districts in the city have high residential heating emissions. Besides the residential heating, the highest contribution to CO emissions is coming from road traffic. Distribution of total emissions according to the pollutant sectors is given Table 4.1 and illustrated in Figure 4.1.

Table 4.1 The estimated sectoral emissions in the study area, tons/yr

Pollutant Sector	**PM_{10}**	**SO_2**	**CO**	**NO_X**
Industry	79	5,928	1,227	22,590
Residential Heating	604	1,430	6,917	285
Road traffic	183	172	14,098	2,169
Maritime traffic	191	1,460	1,110	8,171
Total	**1,057**	**8,990**	**23,352**	**33,215**

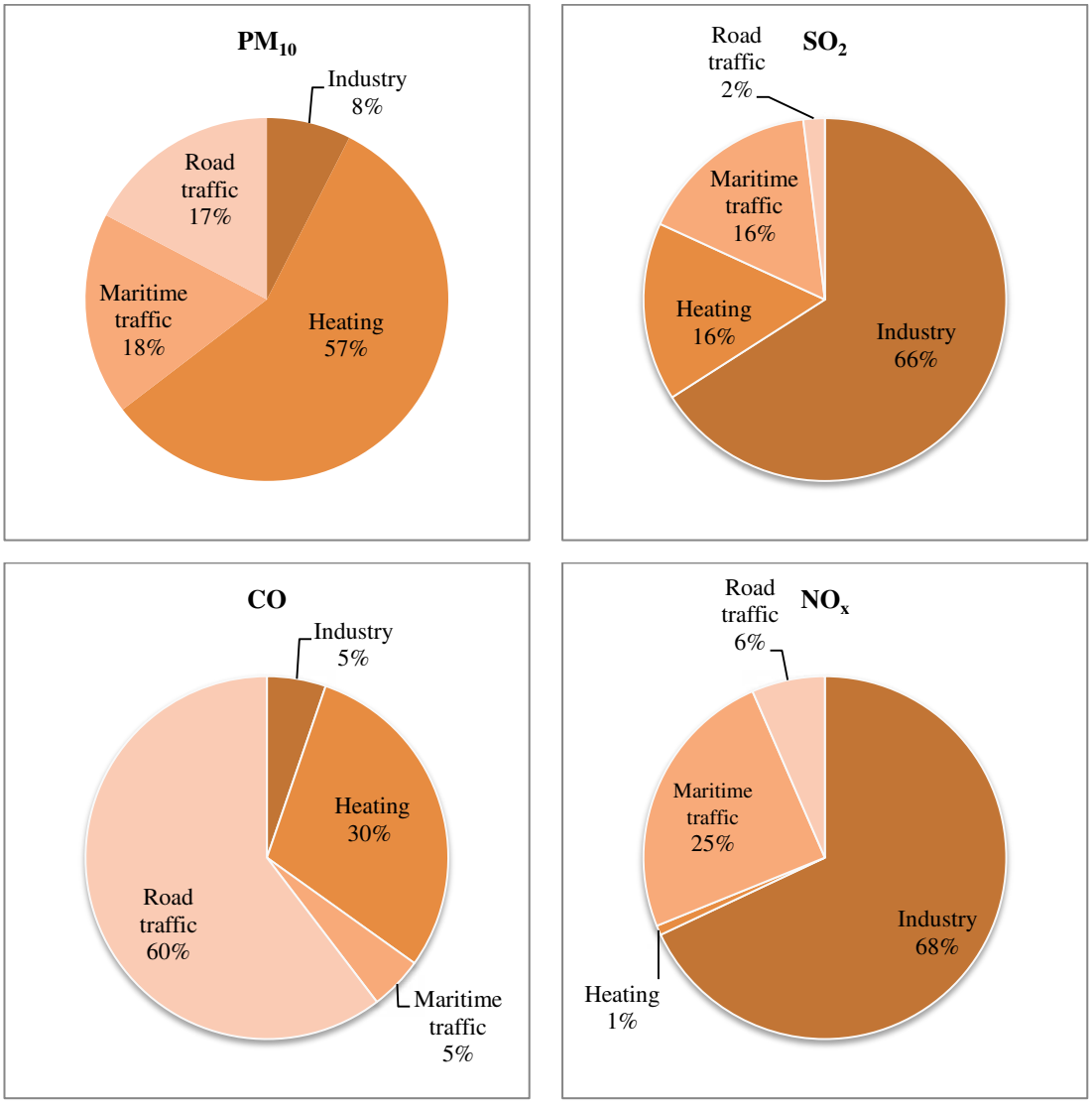

Figure 4.1 Contributions of pollutant sectors to total emissions

Information about industrial activities in the region was mainly obtained from provincial environmental status report for Çanakkale in 2013 (Çanakkale Directorate

of Environment and Urbanization, 2014). Three different fuel types (natural gas, lignite and imported coal) are used in industrial plants in Çanakkale. Ceramic plants located in the study area use natural gas as fuel while the others use mainly lignite. Calculated emissions originating from major industrial activities in the region are 79 tons/yr for PM_{10}, 5,928 tons/yr for SO_2, 1,227 tons/yr for CO and 22,590 tons/yr for NO_x. Emissions from industrial activities were given in Table 4.2 as plant basis.

Table 4.2 Emissions from industrial plants, tons/yr

Industrial plants	**Emissions (t/yr)**			
	PM_{10}	**SO_2**	**CO**	**NO_X**
Thermal Power Plant in Çan	1.7	2,473	323	1,490
Ceramic plant in Çan	3.1	1.0	137	312
Thermal power plant in Biga	3.5	2,006	389	11,057
Thermal power plant in Biga	2.4	1,355	263	7,467
Ceramic plant in Çan	0.1	0.04	5.9	13.5
Cement plant	68	93	109	2,250
TOTAL	**79**	**5,928**	**1,227**	**22,590**

While cement factory is most polluting plant to PM_{10} emissions with the contribution of 86%, SO_2 emissions are mainly coming from thermal power plants in the region. Contribution of all thermal plants to total SO_2 emissions is 98%. While a thermal power plant located in Çan is most polluting power plant contributing to 42%, a thermal power plant located in Biga is less polluting power plant contributing to 23%. Addition to SO_2 emissions, for CO emissions thermal power plants are also most polluting plants contributing to 80% of total industrial emissions. NO_x emissions are dominated by a thermal power plant located in Biga. Contribution of industrial plants to total emissions is illustrated in Figure 4.2.

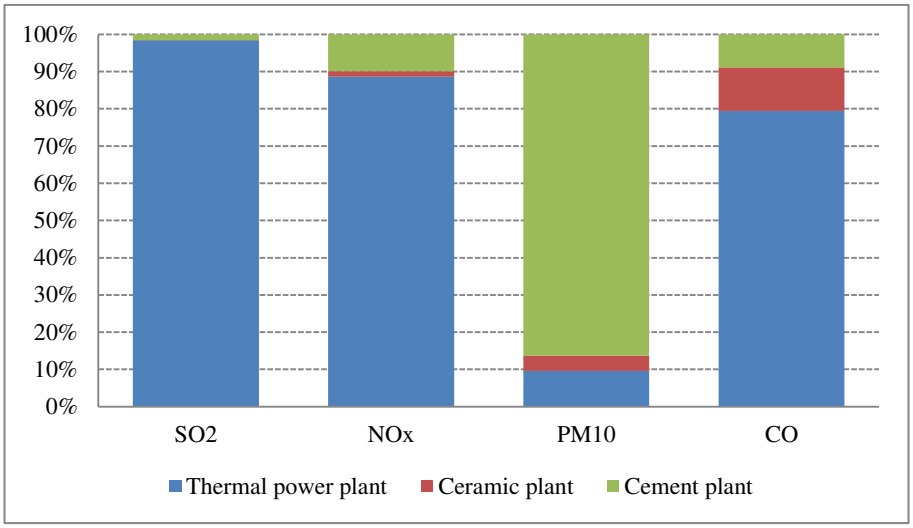

Figure 4.2 Contribution of industrial plants to total emissions from industry

Although natural gas was available in the city, coal is mainly used for residential heating. Therefore, PM_{10} emissions are mainly coming from residential heating sector due to use high amounts of coal. In the region, the amount of coal used in winter in residential areas was 67.5 thousand tons/season, the amount of natural gas used in winter for only five districts was approximately 50 million Nm^3/season for 2013. Emissions originating from total natural gas and coal consumption were 1,430 tons/season for SO_2, 285 tons/season for NO_x, 604 tons/season for PM_{10} and 6,917 tons/season for CO in the region. Additionally, it should be noted that all of the emissions from domestic activities were assumed to be emitted during the winter period (November - April). According to the results, while Gelibolu which has high coal consumption is the most polluting district for SO_2, PM_{10} and CO emissions, central district which mainly uses natural gas is most polluting sector for NO_x. Considering contribution of residential heating to total emissions, Gelibolu is followed by Çan, Bayramiç, Lapseki and Biga. Considering contribution to SO_2, PM_{10} and CO, Kepez is less polluting district due to less population density and high natural gas consumption. Distribution of residential heating emissions in terms of districts was given in Table 4.3.

Table 4.3 Distribution of residential heating emissions in terms of districts

Center of districts	SO_2 (tons/season)	NO_x (tons/season)	PM_{10} (tons/season)	CO (tons/season)
Center	11.1	68.6	5.0	80.0
Kepez	0.6	13.5	0.3	8.1
Ayvacık	94.9	10.9	40.0	455.8
Bayramiç	145.2	18.5	61.3	698.2
Biga	133.6	39.2	56.4	651.0
Bozcaada	32.3	3.7	13.6	155.3
Çan	158.6	30.6	67.0	766.6
Eceabat	67.8	7.8	28.6	325.5
Ezine	139.5	18.3	58.8	670.8
Gelibolu	341.6	39.2	144.1	1,640.7
Gökçeada	78.9	9.1	33.3	379.2
Lapseki	135.3	15.5	57.1	649.9
Yenice	90.8	10.4	38.3	436.1
TOTAL	**1,430**	**285.3**	**603.8**	**6,917**

Total emissions from road traffic consisting of highways which connect center district to other settlements and major streets located in the city are 14,098 tons/yr for CO, 172 tons/yr for SO_2, 2,169 tons/yr for NO_x and 183 tons/yr for PM_{10}. Emissions from road traffic are given in Table 4.4.

Table 4.4 Emissions from road traffic, tons/yr

	CO	NO_X	PM_{10}	SO_2
Highways	1,658	1,013	30	136
Major streets	12,440	1,156	153	36
TOTAL	**14,098**	**2,169**	**183**	**172**

Considering the contributions of highways and major streets to motor vehicle emissions were examined, highways are responsible for 79% of SO_2 emissions, 47% of NO_x emissions, 16% of PM_{10} and 12% of CO emissions from motor vehicles, while major streets are responsible for 21% of SO_2 emissions, 53% of NO_x emissions, 84% of PM_{10} emissions and 88% of CO emissions from motor vehicles in the city. Twelve highways located in the city were included in this study. Çanakkale-İzmir road with the most intense vehicular traffic is major contributor to emissions from highways. Forty percent of PM_{10} emissions, 33% of SO_2 emissions, 31% of NO_x emissions and 29% of CO emissions are originating from only Çanakkale-İzmir

highway. Another two major contributor highways were Lapseki-Biga and Eceabat-Gelibolu, as a descending order. Roads located in Gökçeada and Bozcaada are less contributing roads due to the less intense traffic. Contribution of the individual highways is shown in Figure 4.3.

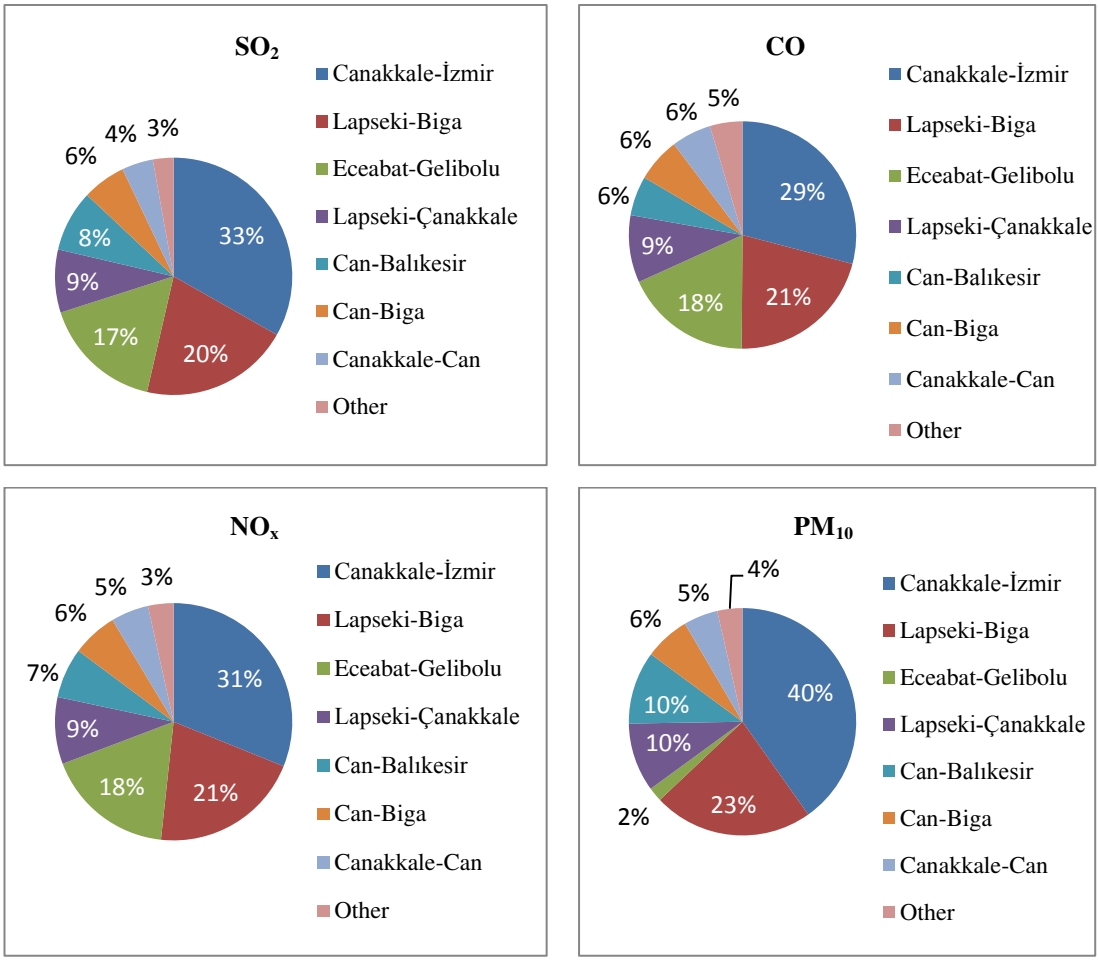

Figure 4.3 Contribution of the individual highway to emissions from highways

The city center, Biga, Can and Gelibolu had the highest contributions to emissions from major streets. Roads located in the city center were the major contributors for all pollutants with the ratio of 37%. Heavy-duty vehicles were the most polluting vehicle category contributing to about 74% of total emissions originating from major streets, while light-duty vehicles were the less polluting vehicle category contributing to about 4% of total emissions. Contribution of the vehicle types to traffic emissions is illustrated in Figure 4.4.

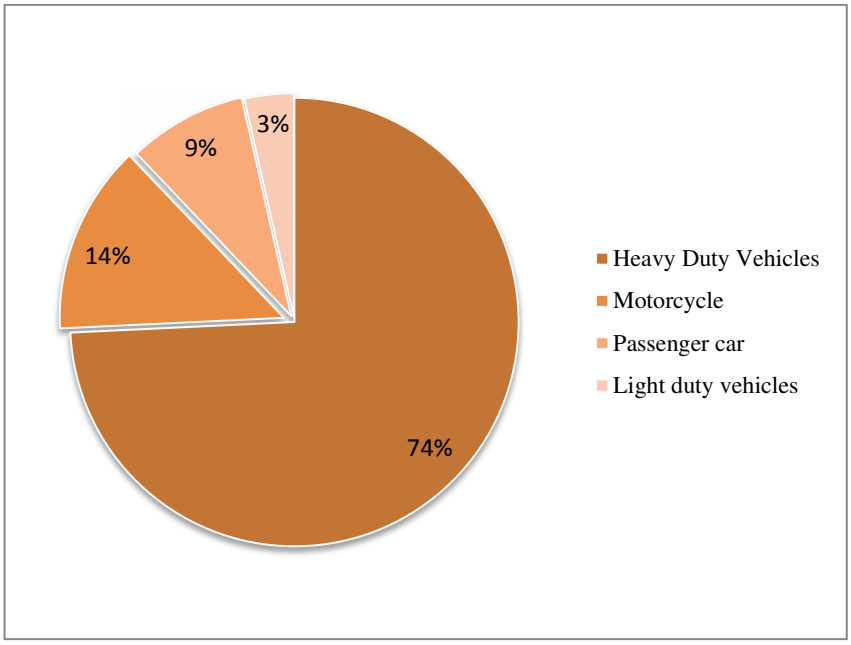

Figure 4.4 Contribution of the vehicle types of emission from major streets

In addition, vehicles using gasoline, diesel and LPG contributed to total emissions from major streets with the percentage of 85, 14.2 and 0.8, respectively.

Maritime traffic consisting of domestic transport and transit passing ship also exist in addition to the road traffic in the region. Emissions from transit passing ship were calculated as 7,785 tons/tr for NO_x, 1,018 tons/yr for CO, 1,366 tons/yr for SO_2 and 150 tons/yr for PM_{10}. When compared to emissions from domestic transport to emissions from transit passing ships in Çanakkale, transit passing ships are dominant part of maritime traffic sector for all pollutant type. Because large vessels cause high emissions with large engine capacity. In the literature, a study which was carried out for Turkish Strait and especially included transit passing ships and domestic transport showed similar results (Kesgin&Vardar, 2001). They found that the transit passing ships cause more than half of the amount of total ship emission on Bosphorus. But, contributions of transit passing ships to total maritime traffic emissions less than Dardanelles. Because Dardanelles is longer than Bosphorus and it causes more cruising time and more emission. Additionally, domestic transportation on Bosphorus is more than Dardanelles. The calculated emissions for Çanakkale Strait are given in Table 4.5 for 2013. Contribution of transit passing ships to total

maritime emissions are 93% for SO_2, 95% for NO_X, 79% for PM_{10} and 91% for CO emissions.

Table 4.5 Calculated maritime emissions on the Çanakkale Strait, tons/yr

	NO_x	**CO**	**SO_2**	**PM_{10}**
Domestic transportation (t/yr)	395	102	96	41
Transit passing ship (t/yr)	7,794	1,012	1,367	150
Total (t/yr)	8,189	1,114	1,463	191
Percentage for transit passing ships (%)	95	91	93	79

The most contributor ship types to transit passing emissions were general cargo with 18,992 passing number per year, bulk carrier with 7,442 passing number per year and crude oil tanker with 5,653 passing number per year, respectively. Contribution of general cargo, bulk carrier and crude oil tanker was found with the percentage of 34, 21 and 15, respectively. The other transit passing ships were contributed 30% totally to total emissions from transit passing ships.

Calculated emissions from domestic transportation were 386 tons/year for NO_x, 99 tons/year for CO, 94 tons/year for SO_2 and 41 tons/year for PM_{10}. Çanakkale-Lapseki line was the most pollutant domestic line contributing to about 38.8% for PM_{10}, 38.4% for SO_2, 38.2% for NO_x and 37.9% for CO. Because Çanakkale-Lapseki line is the densest line with 74 passing number per day. Çanakkale-Gökçeada line and Çanakkale-Bozcaada line had the minimum contribution to emissions from domestic transport.

Considering all emissions from traffic sector, total emissions were calculated as 10,340 tons/yr for NO_x, 15,207 tons/yr for CO, 1,632 tons/yr for SO_2 and 374 tons/yr for PM_{10}. The transit passing ship which major contributor of total traffic emissions contributing 40% of PM_{10}, 84% of SO_2 and 75% of NO_x of traffic emissions in Çanakkale, while major streets in the city contributing 82% of CO emissions from traffic emissions. Contribution of all individual traffic sectors to total traffic emissions is illustrated in Figure 4.5.

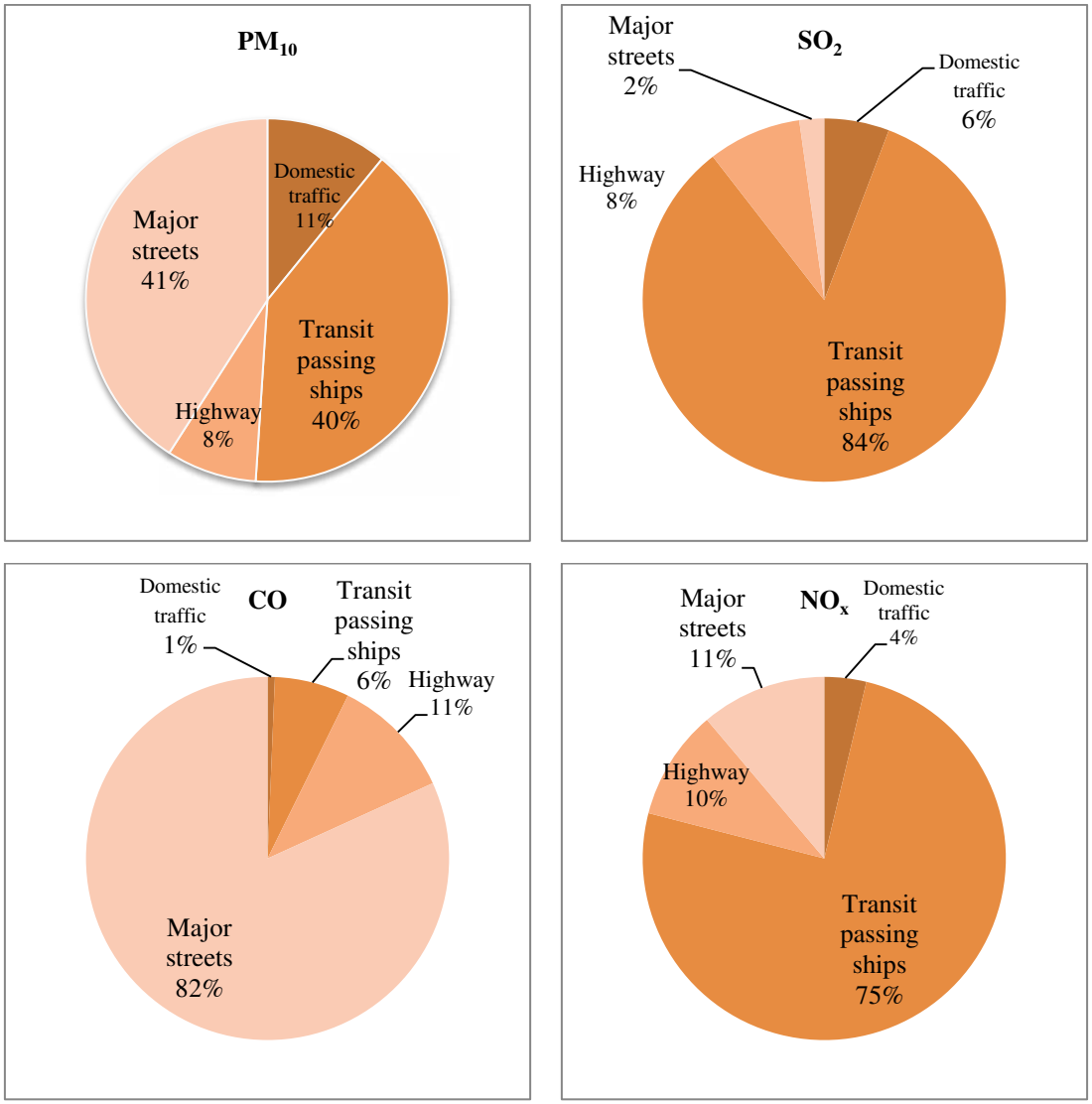

Figure 4.5 Contribution of individual traffic sector to emissions from traffic

4.2 Air Quality Modeling

Air quality levels in the atmosphere caused by emissions coming from industry, residential heating and traffic sector were determined in this study. The predicted concentrations due to industrial, domestic, traffic and total emissions were separately plotted in the form of maps for four pollutants (PM_{10}, SO_2, NO_x and CO). Additionally, location and date of maximum annual and hourly concentrations were highlighted. Contributions of all pollutant sources to air quality of region according to the pollutant types were examined separately. Finally, estimated air quality levels

were assessed with the limit values in Air Quality Assessment and Management Legislation in this study.

The maximum average annual and hourly concentrations due to the industrial plants and locations of them are given in Table 4.6.

Table 4.6 The maximum average annual and hourly concentrations and locations due to the industrial plants

Pollutant	**Maximum annual average concentration ($\mu g/m^3$)**	**Location (X,Y)**	**Maximum hourly average concentration ($\mu g/m^3$)**	**Location (X,Y)**
SO_2	11	428000, 4415000	185	492000, 4437000
PM_{10}	8	428000, 4415000	335	501000, 4430000
NO_x	254	428000, 4415000	4,246	428000, 4415000
CO	13	428000, 4415000	250	503000, 4432000

While maximum average annual concentrations observed in same location for all pollutant types, maximum hourly concentrations were observed in different locations. Maximum hourly SO_2 concentration (185 $\mu g/m^3$) occurs at the coordinates of (492000, 4437000) in the grid system. This coordinate is located in the region which is northeast of thermal Power Plant and ceramic plants in Çan and this concentration was observed in a day when the wind is blowing southeast direction. In this location there is no settlement. When the other high hourly concentrations are evaluated, the highest concentrations are observed in northeast of the cement plant located in coastal part of Ezine. These high concentrations are observed in different time scales but generally they are observed in the days when the wind is blowing from the south direction with high speeds. Maximum annual average concentration was observed around the cement plant. In addition to the cement plant, high annual average concentrations were observed around thermal power plant and ceramic plants located in Çan.

Maximum PM_{10} concentrations were observed around lignite mine located in Çan. These maximum concentrations were generally observed in the days when the wind

is blowing east-north-east direction. High concentrations were mainly observed around lignite mine and the cement plant. Higher concentrations were observed in the days when wind is blowing south and southeast with high wind speed (>2.5 m/s). However, the maximum hourly NO_x concentration was 254 µg/m^3, the second concentration decreases to 80 µg/m^3 level. Higher CO concentrations are mainly observed in northeast of thermal power plant in Çan. Spatial distributions of annual average concentrations for four pollutant types due to the industrial plant emissions are given in Figure 4.6- Figure 4.9.

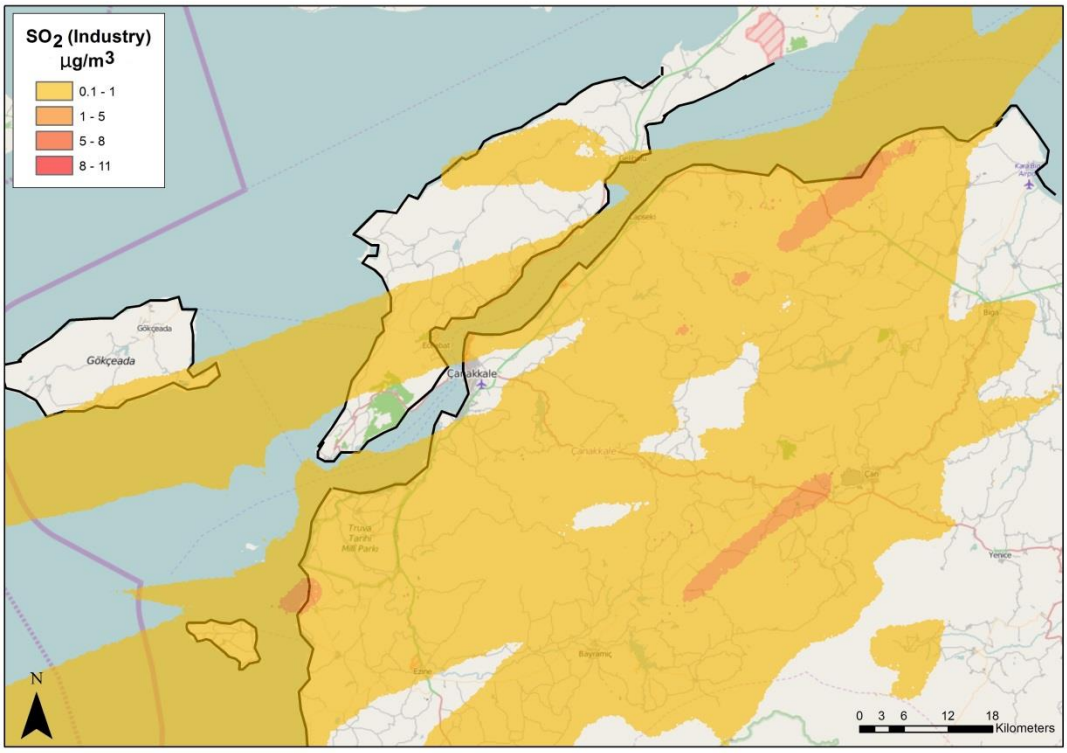

Figure 4.6 Spatial distribution of annual average SO_2 concentrations due to the industrial plants

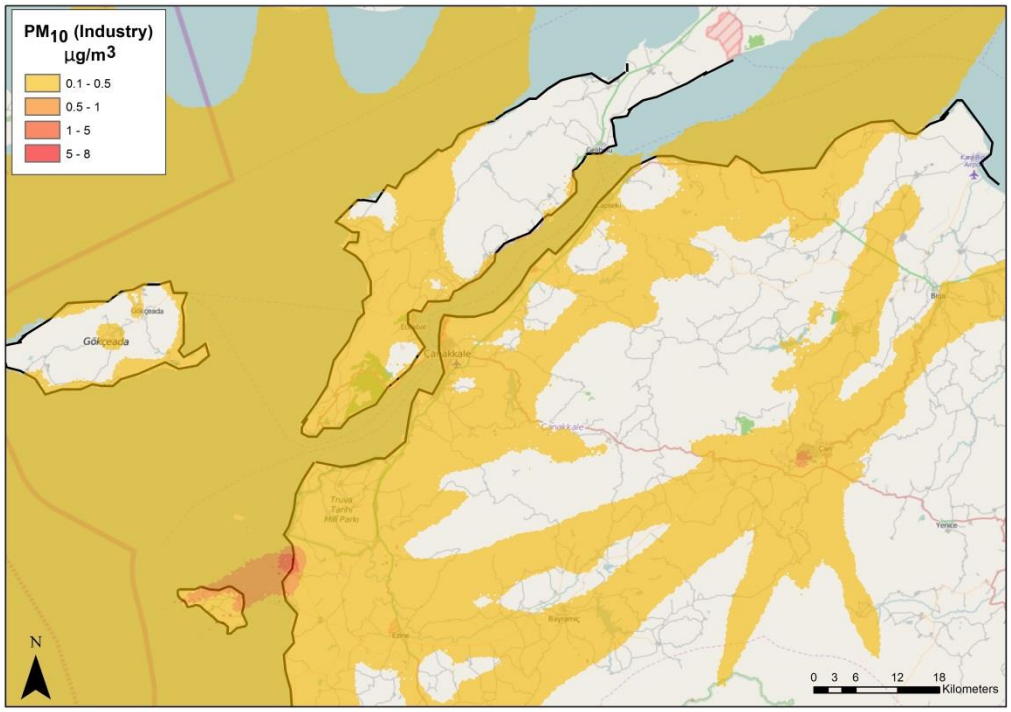

Figure 4.7 Spatial distribution of annual average PM_{10} concentrations due to the industrial plants

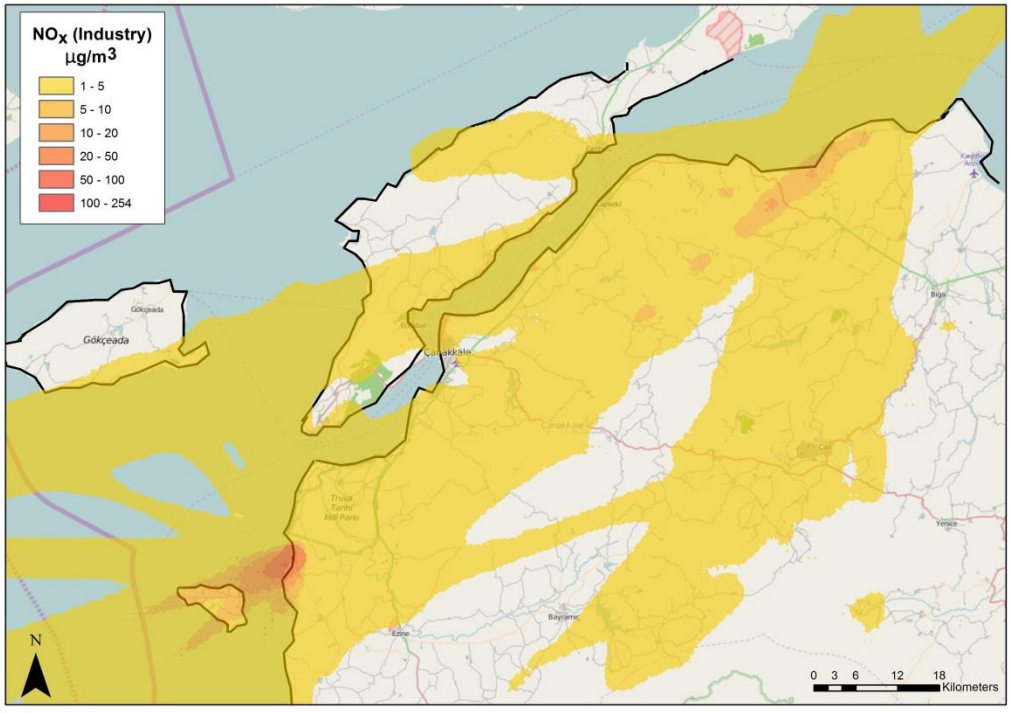

Figure 4.8 Spatial distribution of annual average NO_x concentrations due to the industrial plants

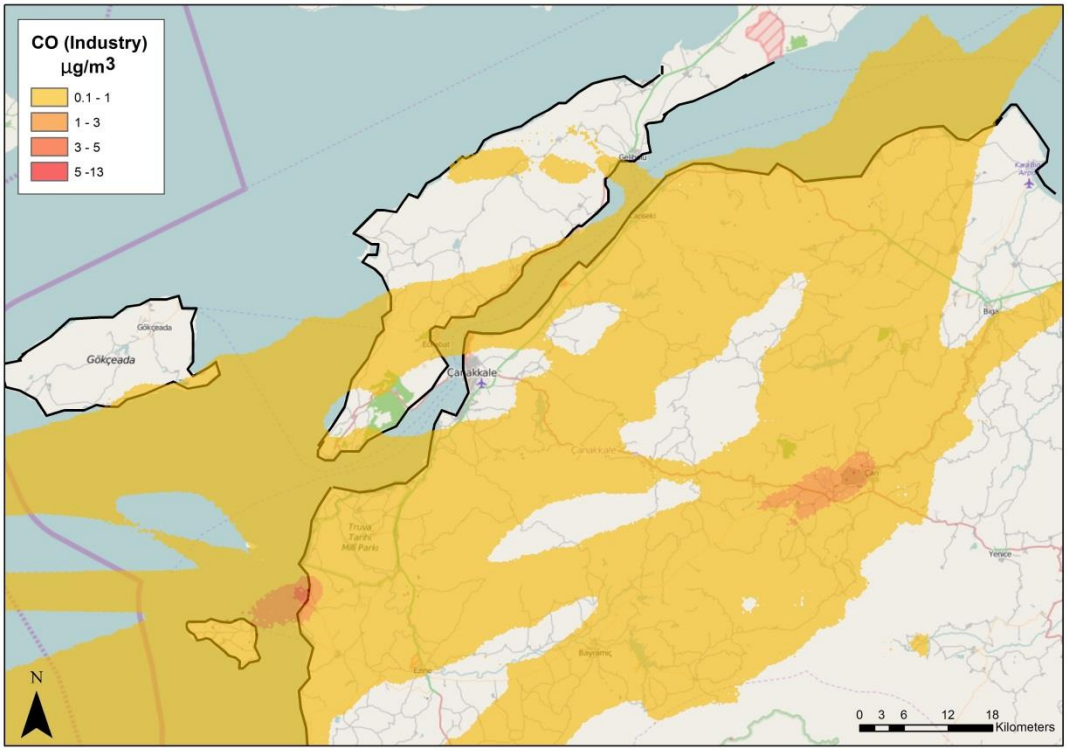

Figure 4.9 Spatial distribution of annual average CO concentrations due to the industrial plants

Another important pollutant source is residential heating in the study area. The maximum average annual and hourly concentrations due to the residential heating and locations of them are given in Table 4.7.

Table 4.7 The maximum average annual and hourly concentrations and locations due to the residential heating

Pollutant	**Maximum annual average concentration ($\mu g/m^3$)**	**Location (X,Y)**	**Maximum hourly average concentration ($\mu g/m^3$)**	**Location (X,Y)**
SO_2	39	472000, 4473000	1,363	471000, 4473000
PM_{10}	16	472000, 4473000	575	471000, 4473000
NO_x	6	449000, 4444000	182	448000, 4438000
CO	186	472000, 4473000	6,551	471000, 4473000

The results show that the most pollutant area is Gelibolu for SO_2, PM_{10} and CO. High annual and hourly concentrations were observed in same location in Gelibolu district except for NO_x. Because Gelibolu had the highest coal consumption

(16,130 tons/season) compared to other districts in the city and it has also dense population. In addition to Gelibolu, high concentrations were observed around the central district. These high concentrations around central district generally observed in some days of January when wind was blowing east and southeast direction. It is supposed that Çan, Bayramiç and Biga located east and southeast part of central district could cause high concentration in the central district. The maximum average annual NO_x concentration was observed at the coordinates of (449000, 4473000) in the grid system and the maximum hourly NO_x concentration was observed at the coordinates of (448000, 4438000) in the grid system. Both coordinates are located in central district. Because central district use mainly use natural gas for residential heating. Natural gas consumption was in central district was approximately 30 million tons/season. Sixty percent of natural gas consumed overall natural gas consumption in the city center. Maps illustrated spatial distribution of annual average concentrations (Figure 4.10 - Figure 4.13) show that high air quality levels for SO_2, PM_{10} and NO_x were concentrated in particularly Gelibolu and the other districts (Çan, Bayramiç, Biga, etc.) used mainly coal for residential heating. For NO_x high air quality levels were concentrated in particularly the districts used natural gas for residential heating.

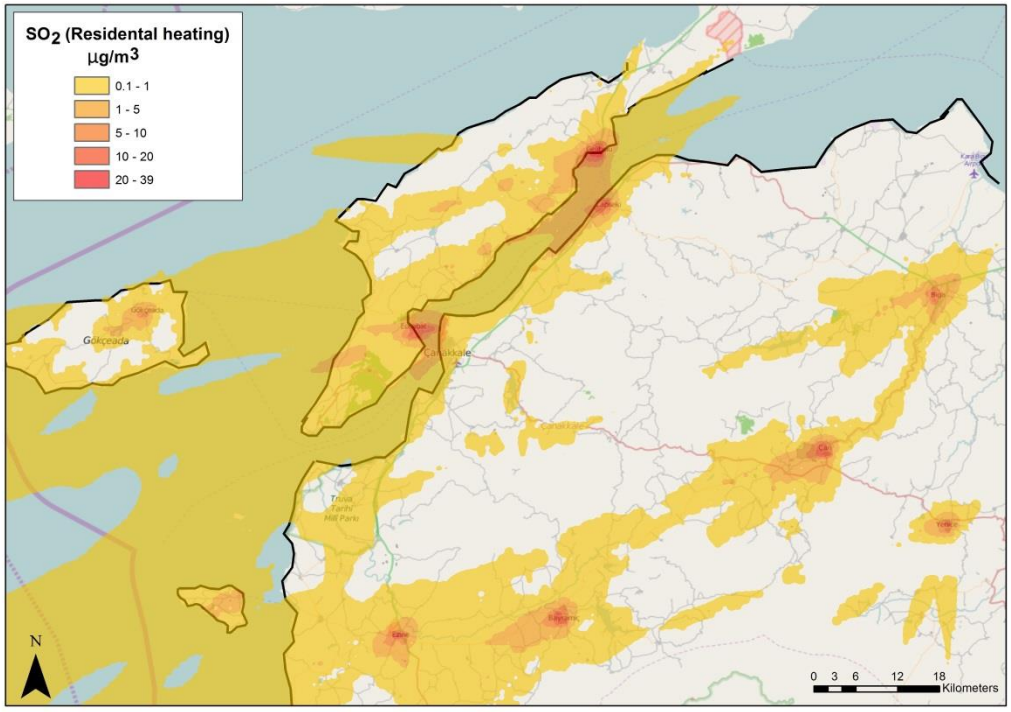

Figure 4.10 Spatial distribution of annual average SO_2 concentrations due to the residential heating

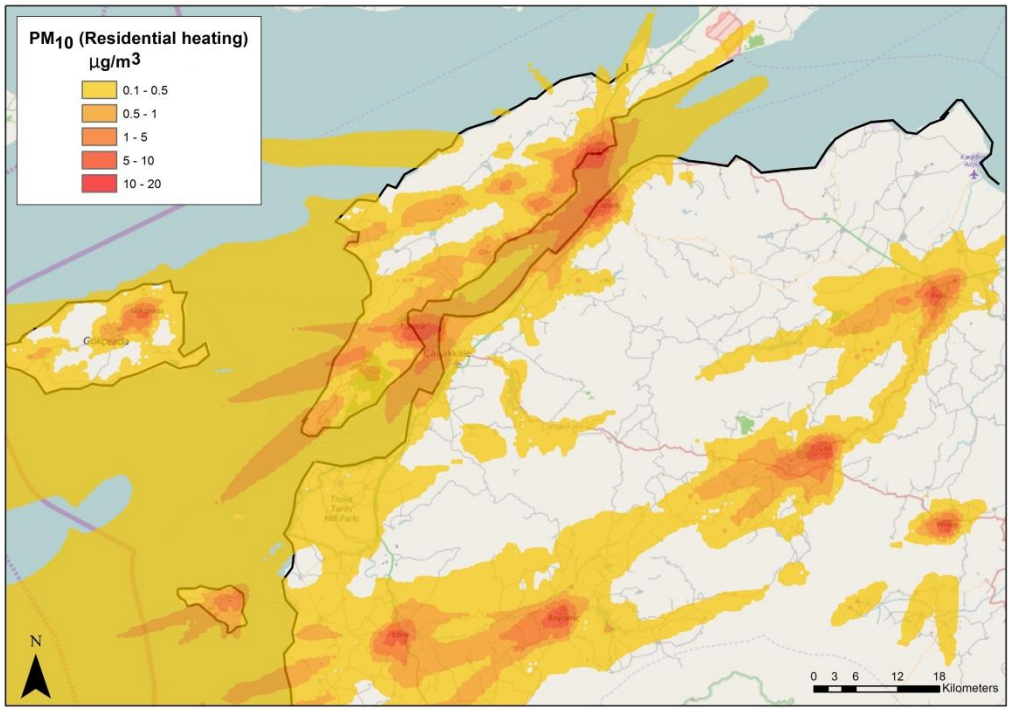

Figure 4.11 Spatial distribution of annual average PM_{10} concentrations due to the residential heating

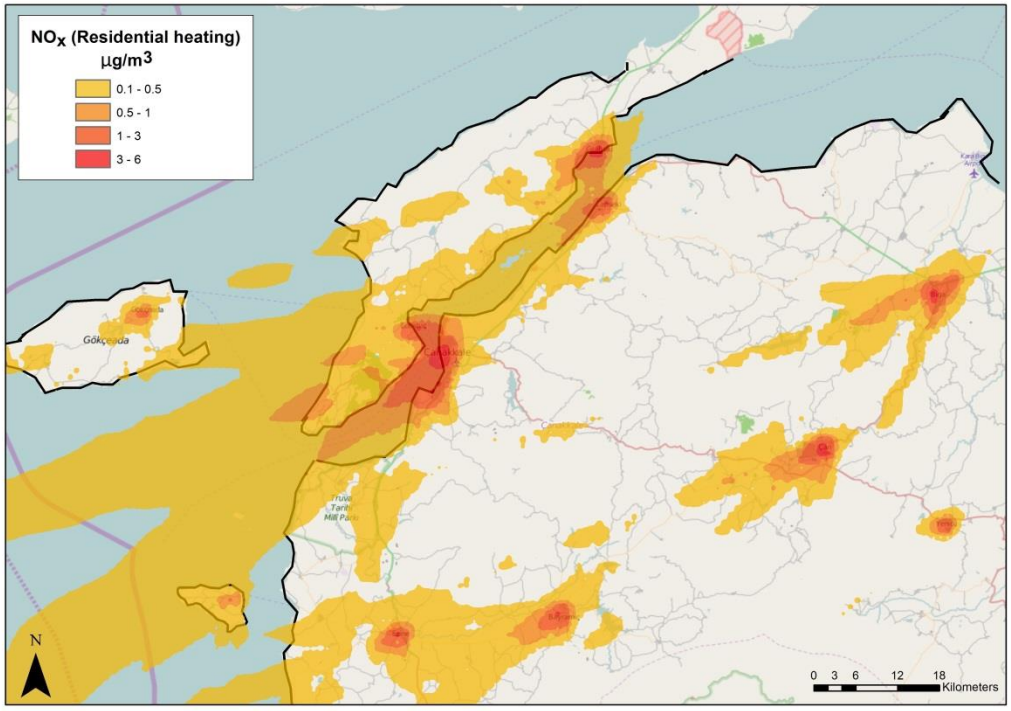

Figure 4.12 Spatial distribution of annual average NO_x concentrations due to the residential heating

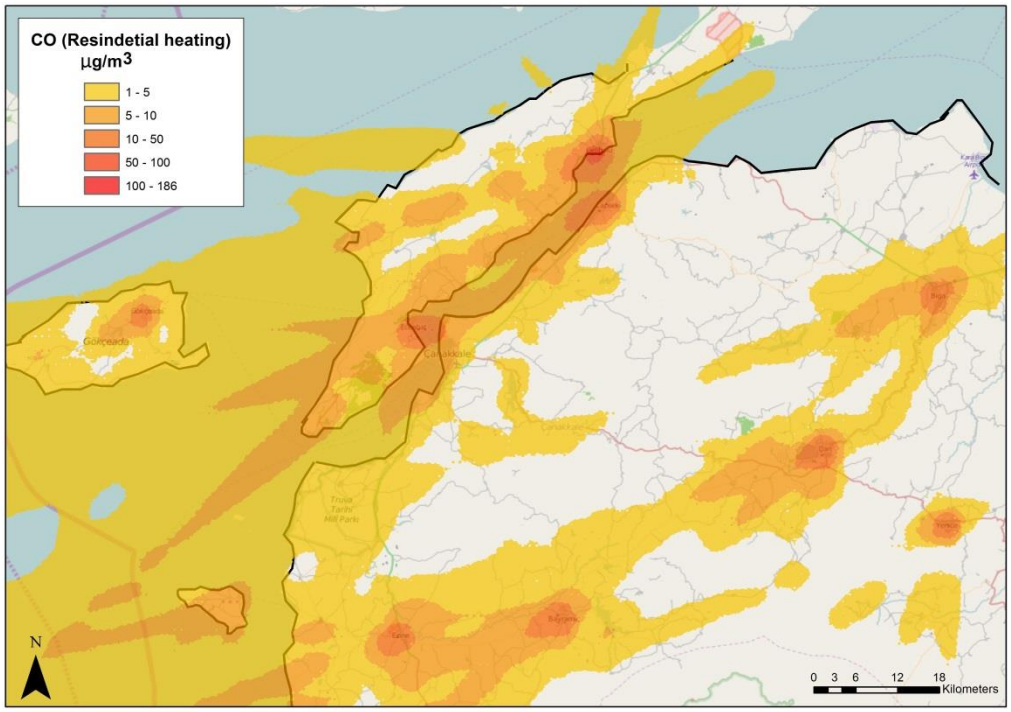

Figure 4.13 Spatial distribution of annual average CO concentrations due to the residential heating

The maximum average annual and hourly concentrations due to the major roads in the city and locations of them are given in Table 4.8.

Table 4.8 The maximum average annual and hourly concentrations and locations due to the major streets

Pollutant	**Maximum annual average concentration ($\mu g/m^3$)**	**Location (X,Y)**	**Maximum hourly average concentration ($\mu g/m^3$)**	**Location (X,Y)**
SO_2	2	450000, 4446000	68	449000, 4444000
PM_{10}	8	450000, 4446000	292	449000, 4444000
NO_x	60	450000, 4446000	2,159	449000, 4444000
CO	643	450000, 4446000	23,157	449000, 4444000

High concentrations were observed in central district and Biga which have dense population and vehicle traffic. For all pollutant types the maximum hourly concentrations were observed in same location located in central district and observed mainly in the days of January when wind is blowing east-north-east

direction with low wind speed (<1 m/s). According to the results, another high concentrations were generally observed in winter period when wind speed was low (<1).

The maximum average annual and hourly concentrations due to the highways and locations of them are given in Table 4.9.

Table 4.9 The maximum average annual and hourly concentrations and locations due to the highways

Pollutant	**Maximum annual average concentration ($\mu g/m^3$)**	**Location (X,Y)**	**Maximum hourly average concentration ($\mu g/m^3$)**	**Location (X,Y)**
SO_2	6	464000, 4456000	85	464000, 4456000
PM_{10}	1.4	464000, 4456000	22	464000, 4456000
NO_x	94	464000, 4464000	1,609	464000, 4464000
CO	171	464000, 4464000	2,931	464000, 4464000

The maximum hourly concentration was observed at coordinate of (464000, 4456000) in the grid system. This coordinate located in Çanakkale - Lapseki road which has the densest vehicle traffic. This concentration was observed in a day when wind is blowing northeast direction with low wind speed. While, locations of the high concentrations were different for SO_2, for another pollutant types (PM_{10}, NO_x, CO) locations of the high concentrations were generally same. When maximum annual average concentrations were examined, concentrations were generally observed around Çanakkale - Lapseki highway, but the other highways also contribute to annual concentrations. Total air quality levels due to the road traffic in the city are illustrated in Figure 4.14 - 4.4.17. When spatial distribution of the annual average concentrations was evaluated, mostly high concentrations were observed around Çanakkale – İzmir highway. Additionally, it is said that except NO_x, major streets in the city is dominant traffic sector for SO_2, PM_{10} and especially CO.

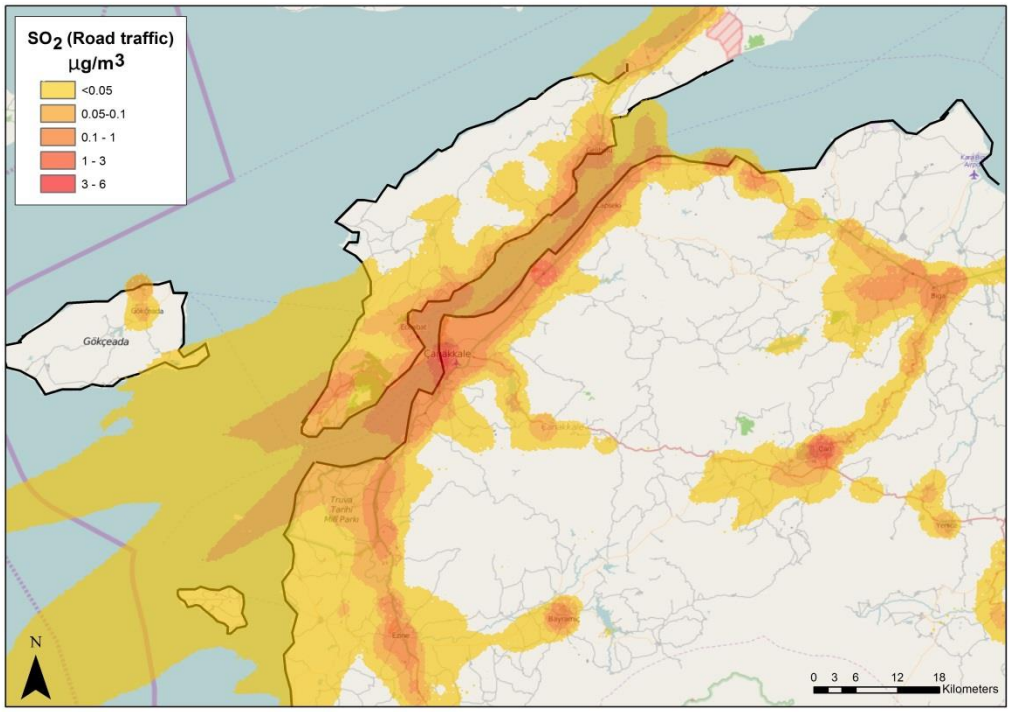

Figure 4.14 Spatial distribution of annual average SO_2 concentrations due to the road traffic

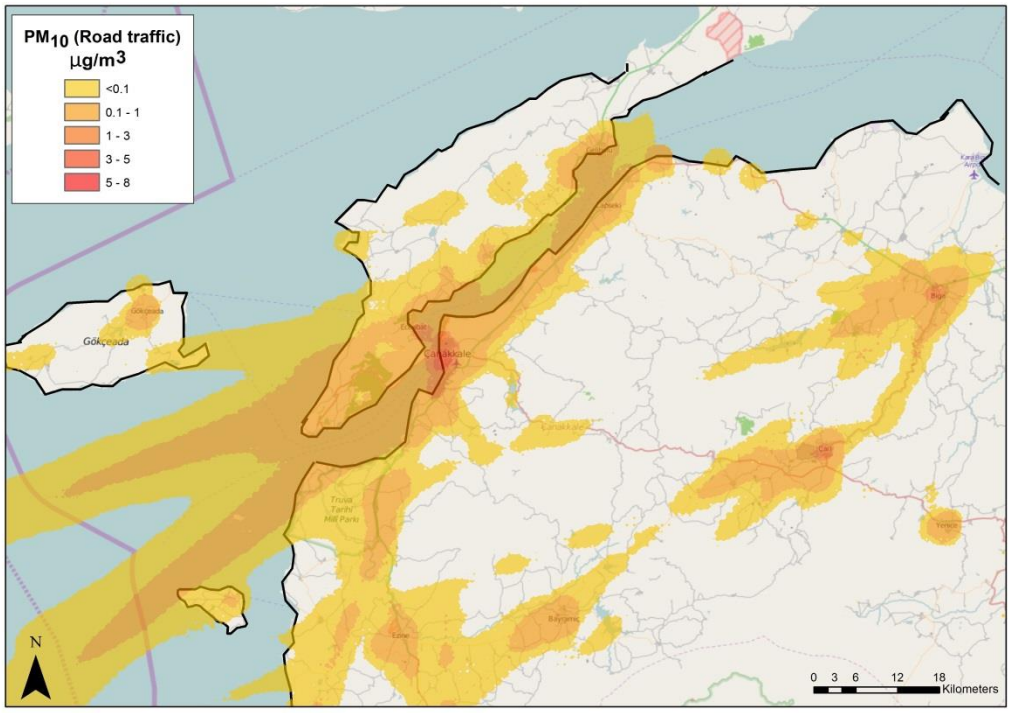

Figure 4.15 Spatial distribution of annual average PM_{10} concentrations due to the road traffic

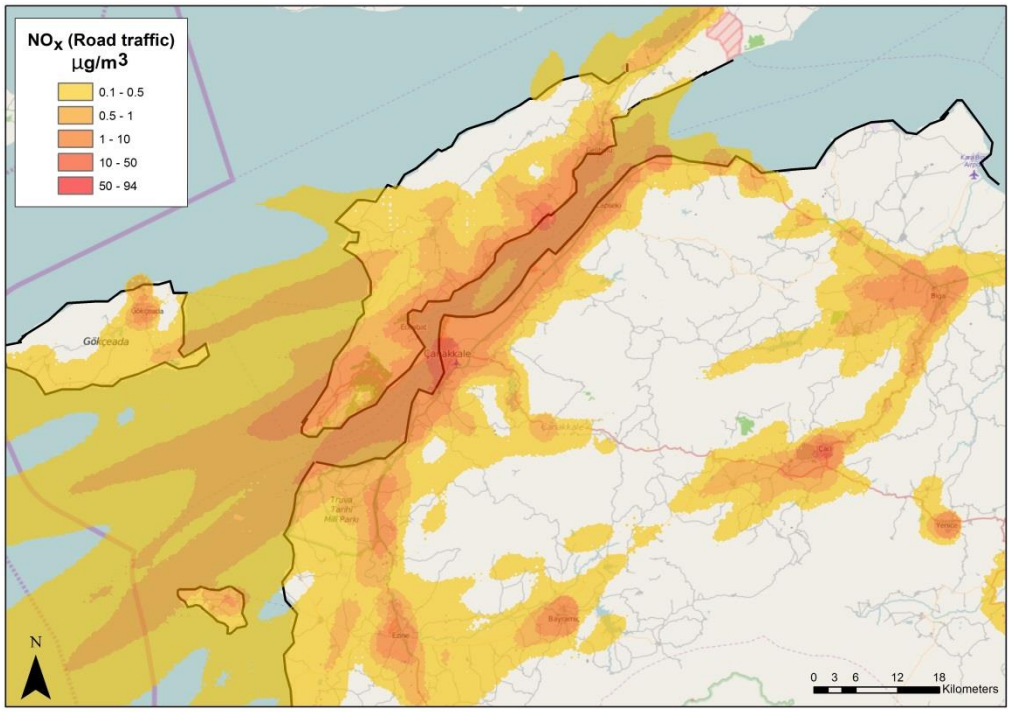

Figure 4.16 Spatial distribution of annual average NO_X concentrations due to the road traffic

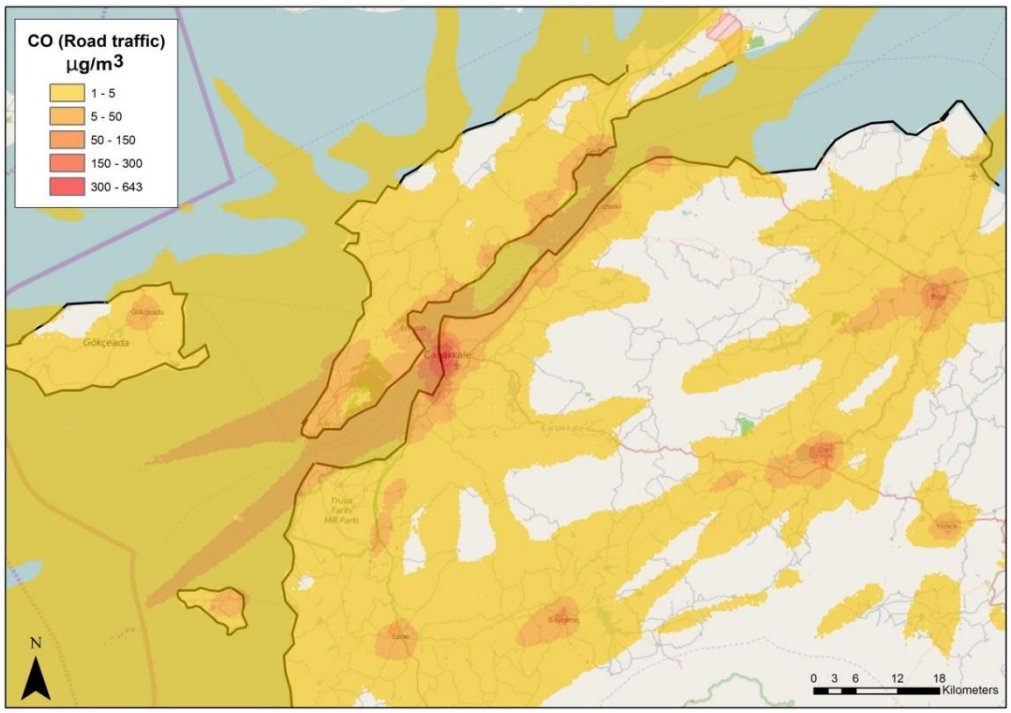

Figure 4.17 Spatial distribution of annual average CO concentrations due to the road traffic

The maximum average annual and hourly concentrations due to the transit passing ships and locations of them are given in Table 4.10.

Table 4.10 The maximum average annual and hourly concentrations and locations due to the transit passing ships

Pollutant	**Maximum annual average concentration ($\mu g/m^3$)**	**Location (X,Y)**	**Maximum hourly average concentration ($\mu g/m^3$)**	**Location (X,Y)**
SO_2	8	434000, 4430000	308	423000, 4427000
PM_{10}	0.8	434000, 4430000	35	473000, 4467000
NO_x	44	435000, 4431000	1,671	445000, 4439000
CO	6	434000, 4430000	235	473000, 4467000

The maximum hourly and annual concentrations were observed along the strait line and it was seen that they affected coastal areas depending on wind speed and direction. The maximum concentrations were generally observed in the days on March with low wind speed. With the impact of low wind speed concentrations are not spread. Therefore, the maximum concentrations were observed on strait line.

In this study, air quality levels were predicted for domestic transport which are another part of maritime traffic and were given in Table 4.11.

Table 4.11 The maximum average annual and hourly concentrations and locations due to the domestic transport

Pollutant	**Maximum annual average concentration ($\mu g/m^3$)**	**Location (X,Y)**	**Maximum hourly average concentration ($\mu g/m^3$)**	**Location (X,Y)**
SO_2	2	448000, 4444000	264	421000, 4406000
PM_{10}	0.8	448000, 4444000	114	421000, 4406000
NO_x	8	448000, 4444000	1,080	421000, 4406000
CO	2	448000, 4444000	277	421000, 4406000

The maximum hourly concentration for all pollutant types were observed around Çanakkale-Bozcaada route and coastal part of Bozcaada and this location is same for all pollutant types. Although Çanakkale-Bozcaada route has least dense traffic, this route is very long and large vessels with high fuel consumption work on this route. In terms of annual results, high concentrations were mainly observed Çanakkale-

Kilitbahir and Çanakkale-Gökçeada routes. High concentrations were observed in coastal part of Kilitbahir. Spatial distributions of maximum annual average concentrations were illustrated in Figure 4.18 - 4.21 for air quality levels for maritime traffic concentrations.

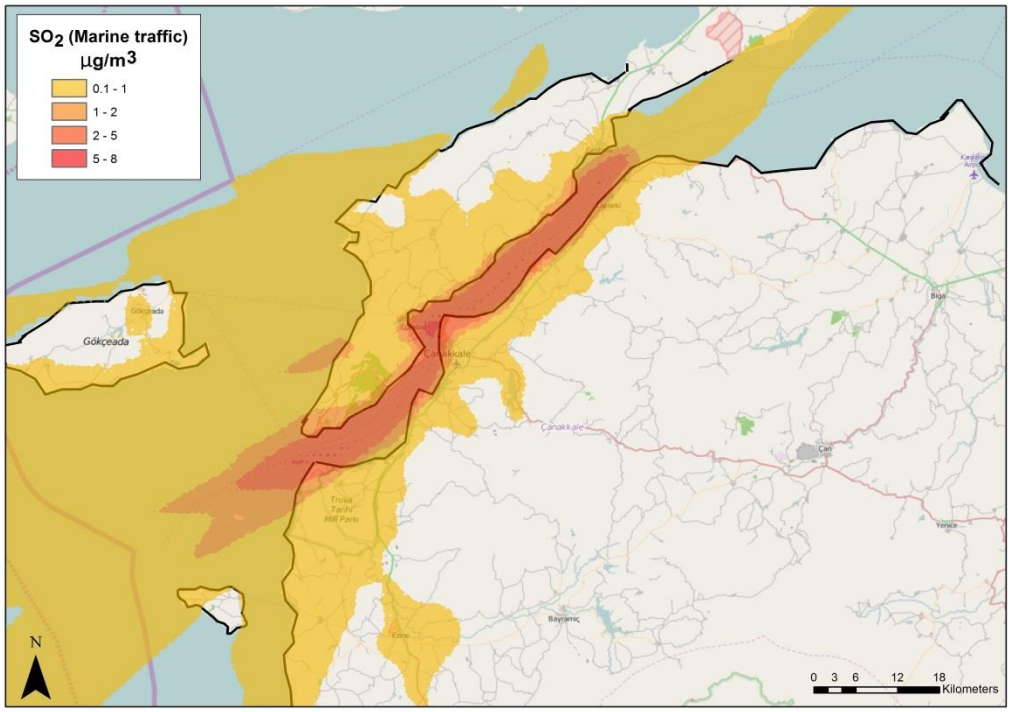

Figure 4.18 Spatial distribution of annual average SO_2 concentrations due to the maritime traffic

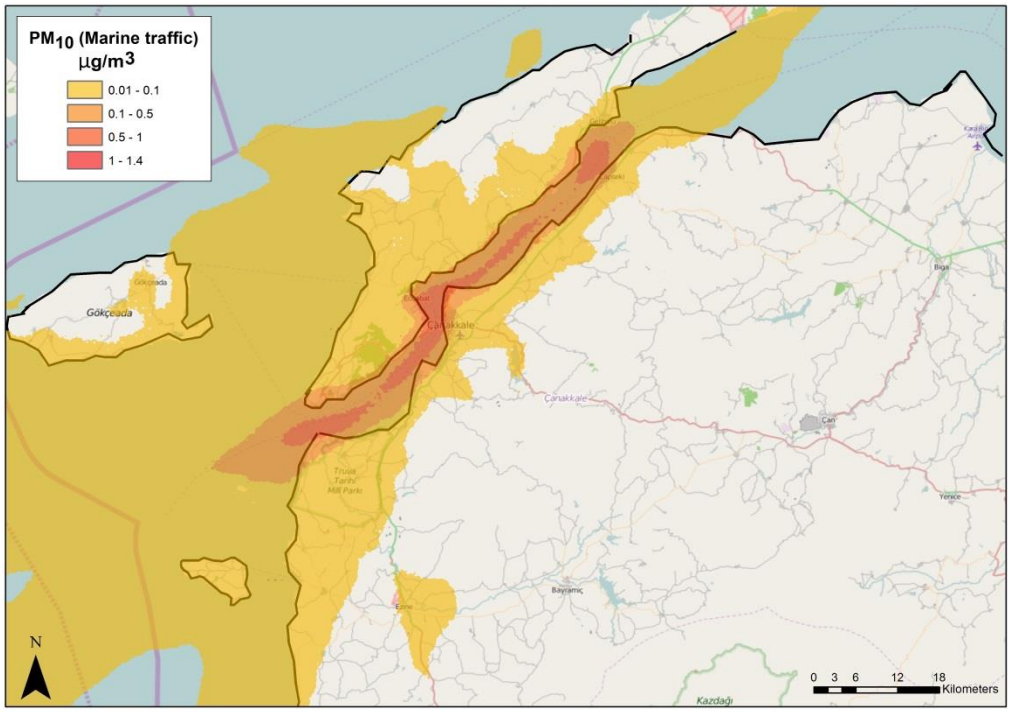

Figure 4.19 Spatial distribution of annual average PM_{10} concentrations due to the maritime traffic

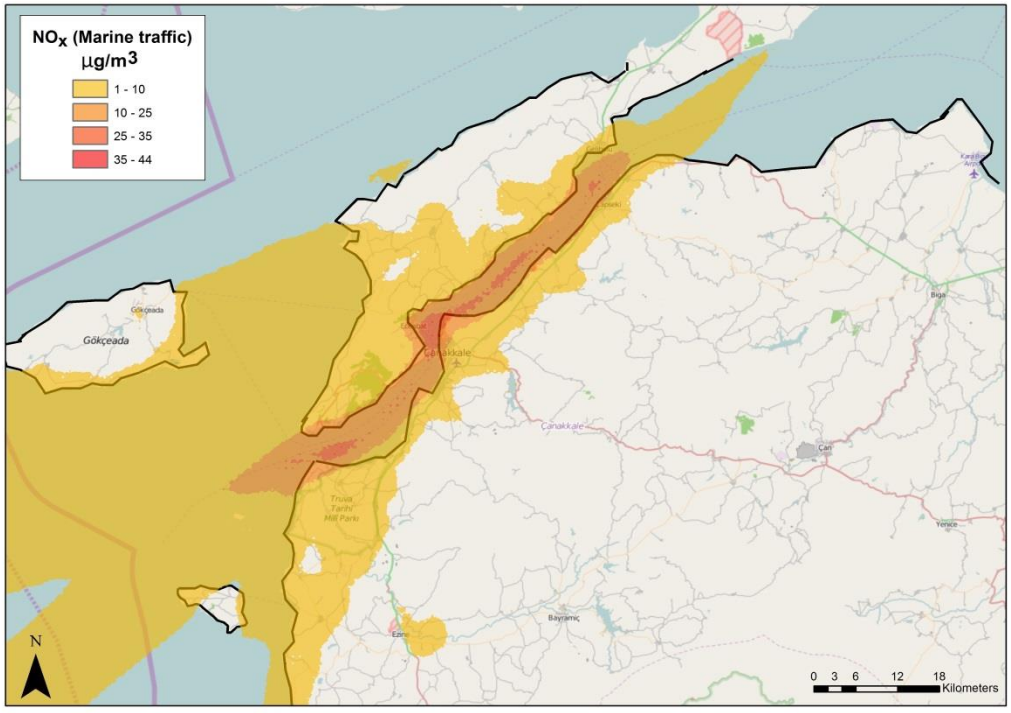

Figure 4.20 Spatial distribution of annual average NO_x concentrations due to the maritime traffic

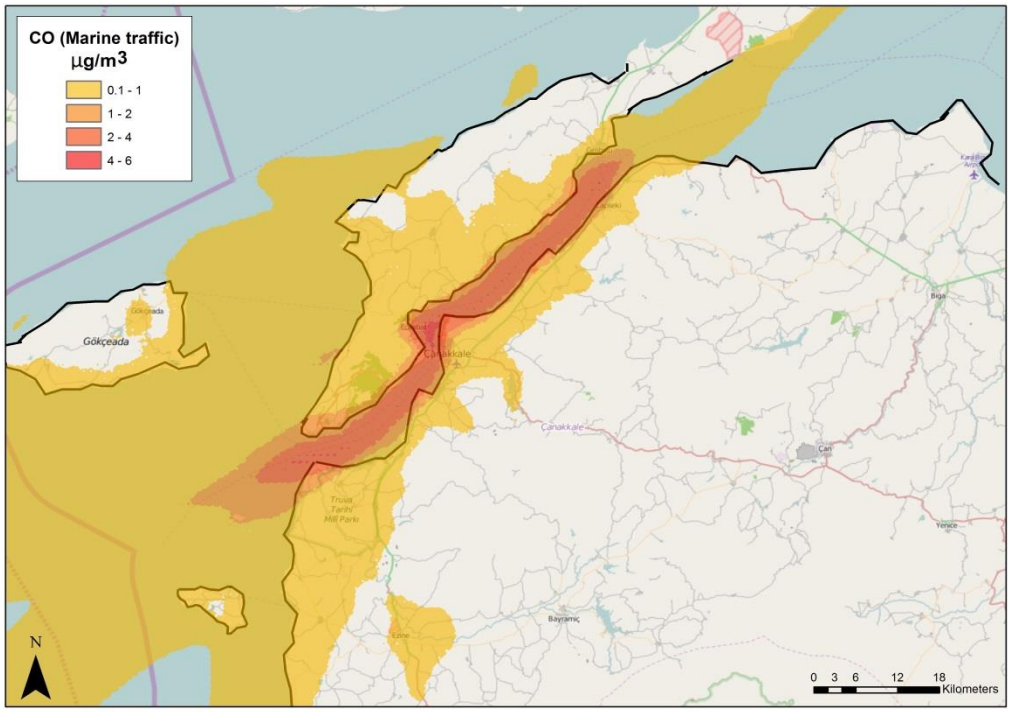

Figure 4.21 Spatial distribution of annual average CO concentrations due to the maritime traffic

Additionally, according to the results, it is said that except PM_{10} transit passing ships in the city is dominant maritime traffic sector for SO_2, NO_x and especially CO.

When all pollutant sources were examined together, the maximum annual average concentrations were estimated as 40 µg/m^3 for SO_2, 20 µg/m^3 for PM_{10}, 256 µg/m^3 for NO_x and 649 µg/m^3 for CO. According to the Air Quality Assessment and Management Legislation limit value for SO_2 was exceeded due to the residential activities in the region. Ninety-five percent of the maximum annual average concentration is coming from residential heating, and the other part (5%) is coming from other anthropogenic sources. Although natural gas has been available in the city until 2006, lignite is used for residential heating almost in all districts. Only five districts use natural gas and except central district, ratio of natural gas consumption in these districts is under 30%.

For the maximum annual average of PM_{10} concentration, limit value (40 µg/m^3) was not exceeded. Because the most populated district use natural gas for residential

heating with the ratio of 90% and major industrial plants such as thermal power plants located Biga and Çan use control technologies in the city. But, it should be noted that annual average limit value for PM_{10} was not exceed, time to time daily concentration of PM_{10} could be exceeded according to the model results. Eighty-three percent of the maximum annual average concentration is coming from residential heating, fifteen of it is coming from urban traffic and other part (2%) is coming from maritime traffic and industrial activities.

NO_x limit values (40 $\mu g/m^3$) are exceeded as the same SO_2. Particularly, industrial sector causes the high annual average concentrations and maritime and road traffic also cause the high annual average concentrations in the region. Ninety-nine percent of NO_x concentration is coming from industrial sector, other part (1%) is coming from other anthropogenic sources. This result shows that the most polluting sector for NO_x is industrial activities because it is assumed that there is no control technology in the industrial plants in this study due to the lack of available data about them.

In terms of the maximum annual average CO concentration, limit value in the Air Quality Assessment and Management Legislation was not exceeded. According to the evaluation of contribution to the maximum annual average concentration the most polluting sector is road traffic contributing to 99%. Residential heating contribute to the maximum annual average concentration of CO with the ratio of 1% and it could be said that there is almost no contribution from other sources. Figures 4.22-4.25 show that air quality levels of major pollutants carried out in this study due to the all sources in the city.

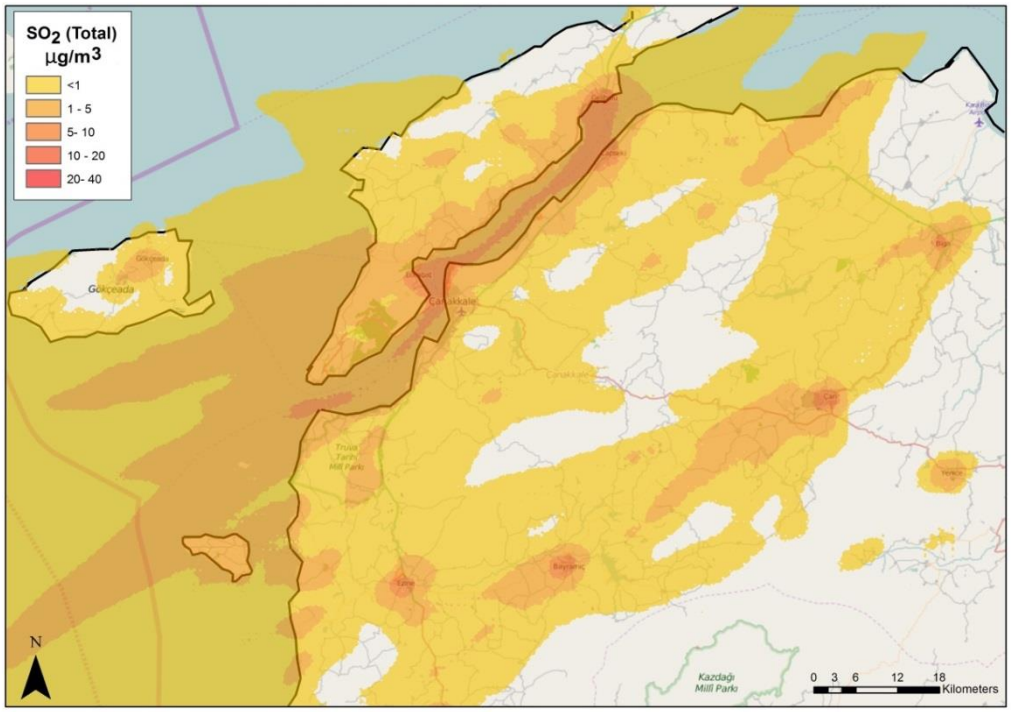

Figure 4.22 Spatial distribution of annual average SO_2 concentrations due to the all sources

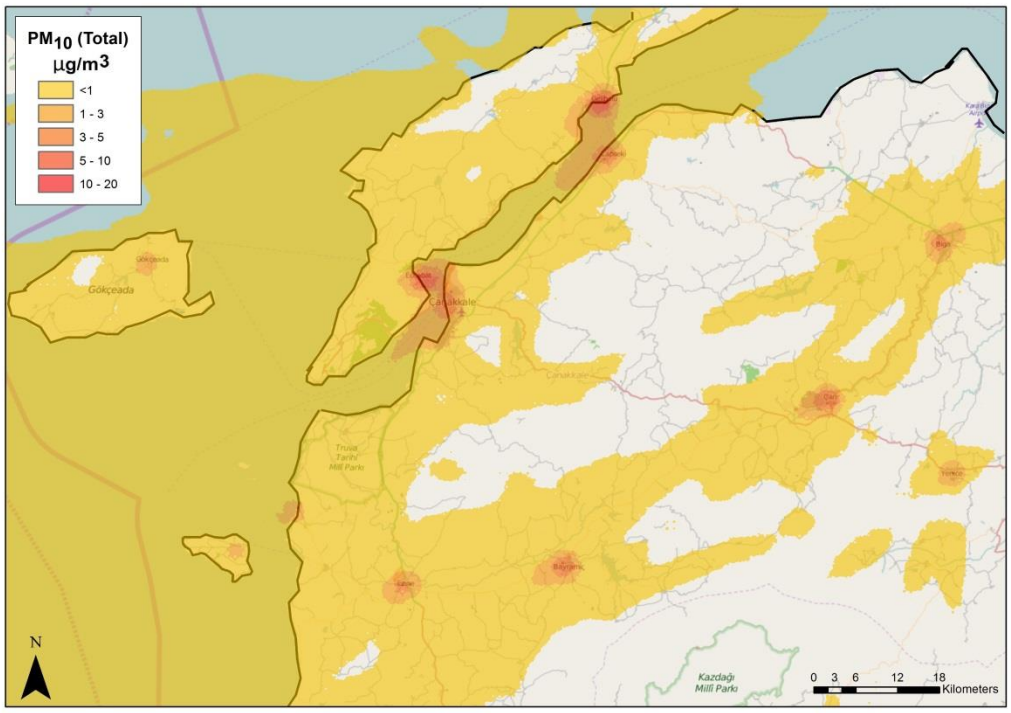

Figure 4.23 Spatial distribution of annual average PM_{10} concentrations due to the all sources

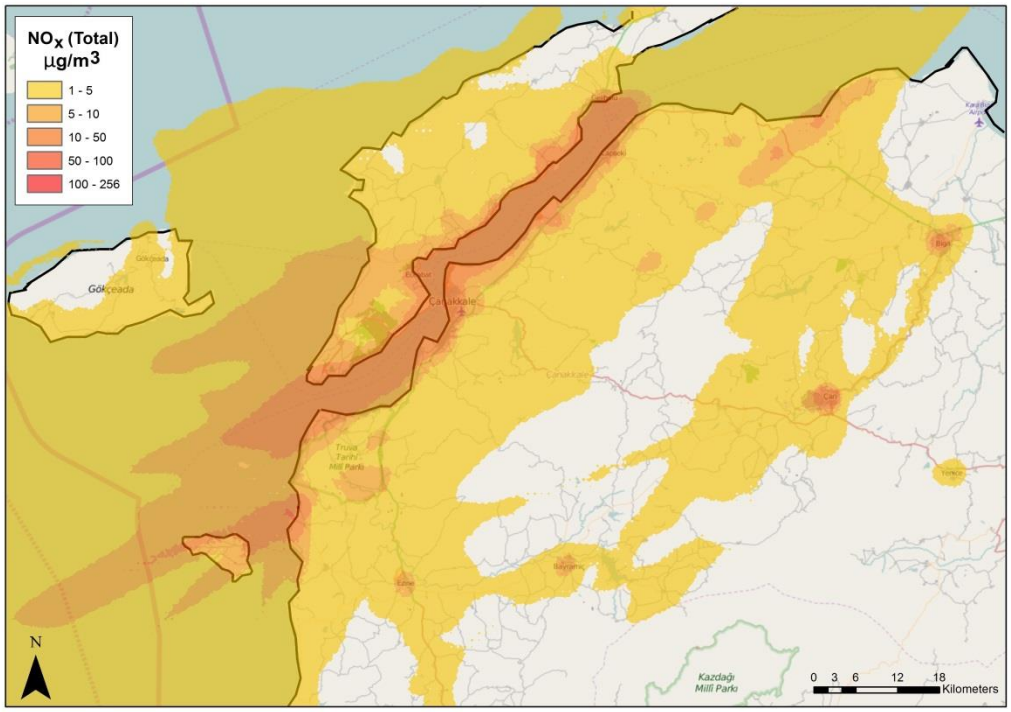

Figure 4.24 Spatial distribution of annual average NO_x concentrations due to the all sources

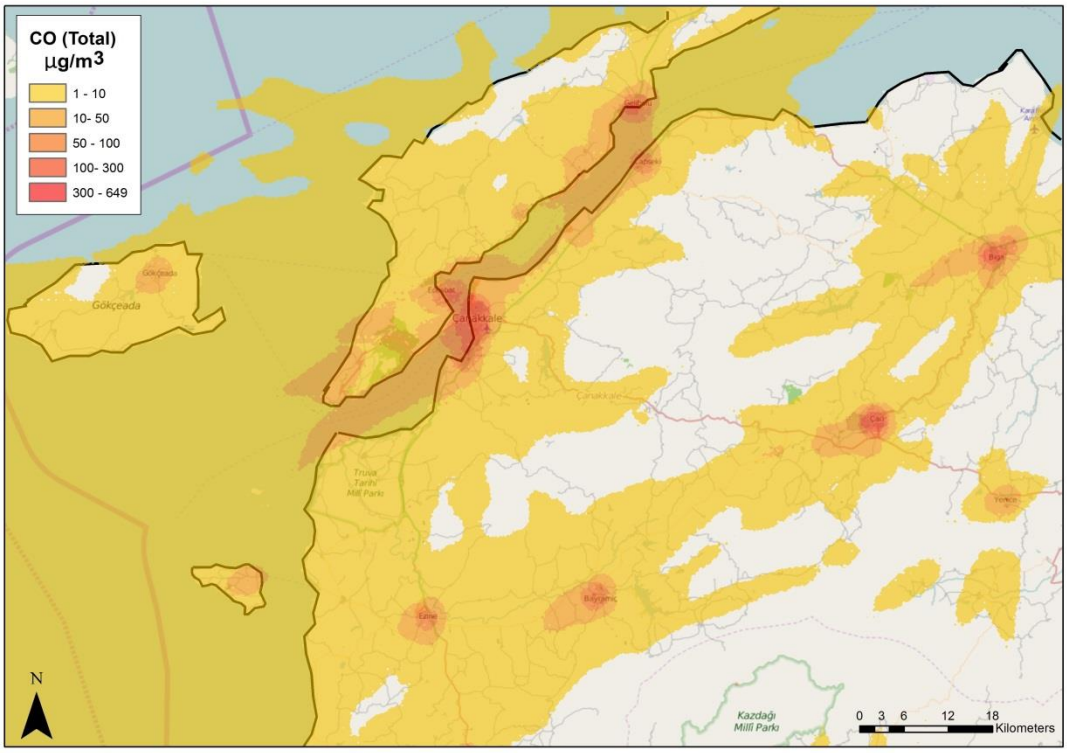

Figure 4.25 Spatial distribution of annual average CO concentrations due to the all sources

4.3 Statistical Analysis for Model Evaluations

The level of representativeness of the model predictions was determined by comparing them with observed air quality data. In this study, data from four different monitoring stations was evaluated with model results. SO_2 and PM_{10} were measured in the stations located in the central district and Biga. In addition to SO_2 and PM_{10}, NO_x was measured in only Lapseki and Çan stations.

Mainly two methods were used for statistical analysis: Root Mean Square Error (RMSE) and an index of agreement (d). The index of agreement determines the degree to which magnitudes and signs of the observed value about mean observed value are related to the predicted deviation the value of d should be close to 1 and total RMSE should be close to 0 for good prediction.

In addition to these two methods, a few more conventional statistical methods (i.e. determination of standard deviation, minimum, maximum, mean) were also used for model performance evaluation. Average predicted and monitored daily concentrations for the all stations were used to conduct the statistical analysis. The simple comparison of average predicted and monitored concentrations is shown for 4 stations and all pollutant types in Figures 4.26-4.34.

Comparisons of average and predicted and monitored concentrations show that overall accuracy of the predictions was relatively high. The overall accuracies of NO_x, SO_2 and PM_{10} concentration predictions (d) were about 61% for SO_2 and PM_{10} and 67% for NO_x. When each monitoring station was evaluated separately, accuracy of the prediction at Çan station for NO_x is better than Lapseki station with a value of 68%. For PM_{10} accuracy of the prediction at Biga station is better than the center and Çan stations with the value of 66%. For SO_2 accuracy of the prediction at Lapseki station is better than the other three stations with the value of 0.69. It should be noted that the uncertainty of the predictions might arise from two different sources: the emission calculations and dispersion modeling. But also, the uncertainty of air quality measurements at the stations as well as inappropriate geographical

locations of the stations might be important factors for not getting a higher correlation between the predictions and observations.

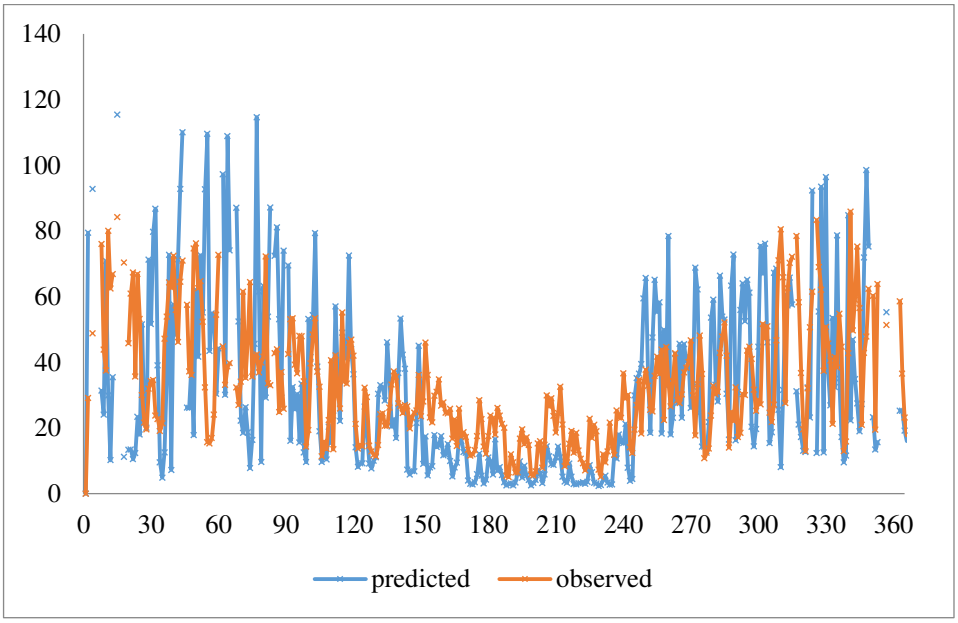

Figure 4.26. Comparison of predicted and measured NO_x concentrations for Çan station

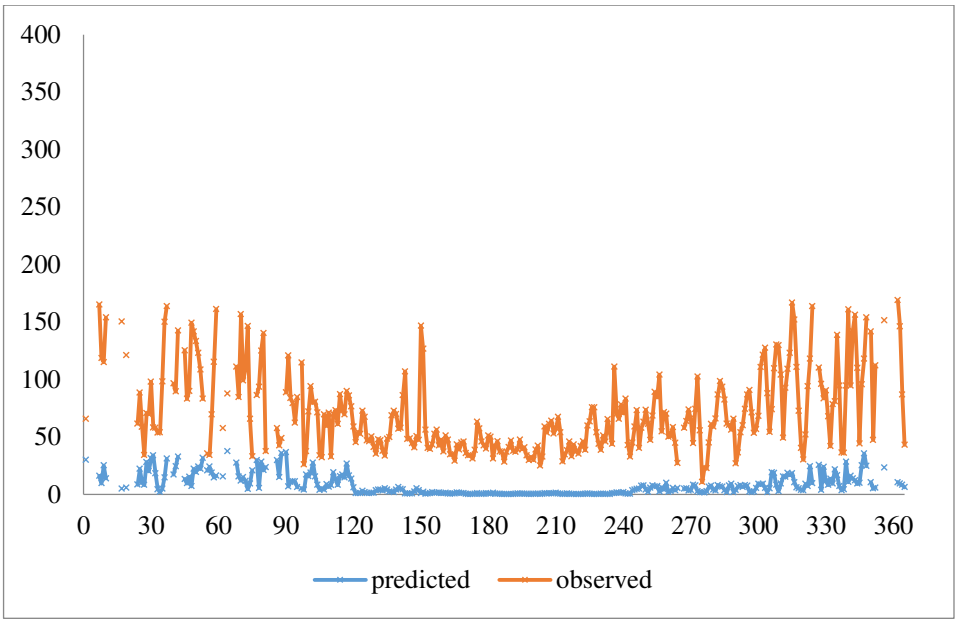

Figure 4.27 Comparison of predicted and measured PM_{10} concentrations for Çan station

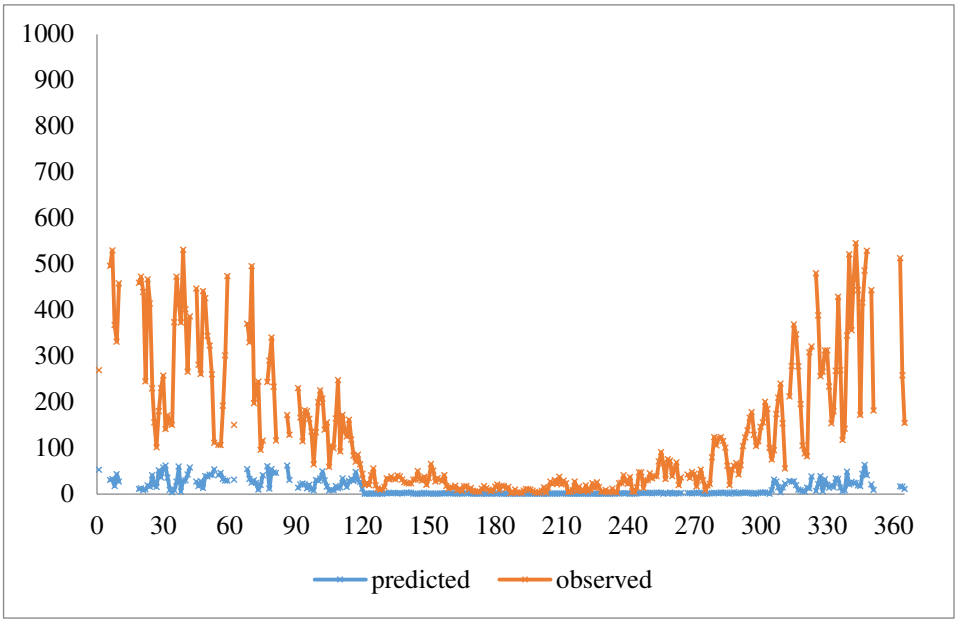

Figure 4.28 Comparison of predicted and measured SO_2 concentrations for Çan station

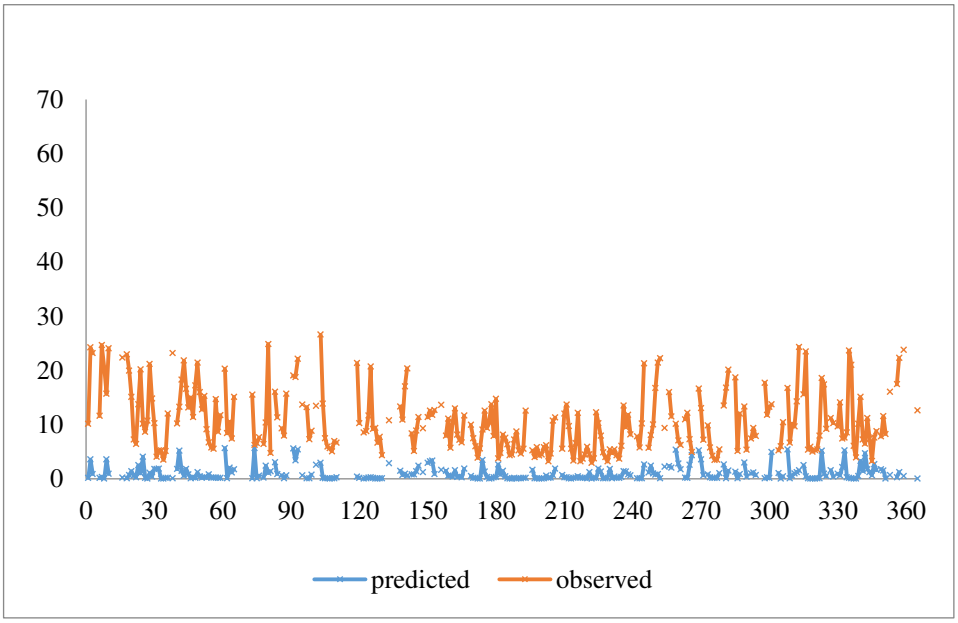

Figure 4.29 Comparison of predicted and measured NO_x concentrations for Lapseki station

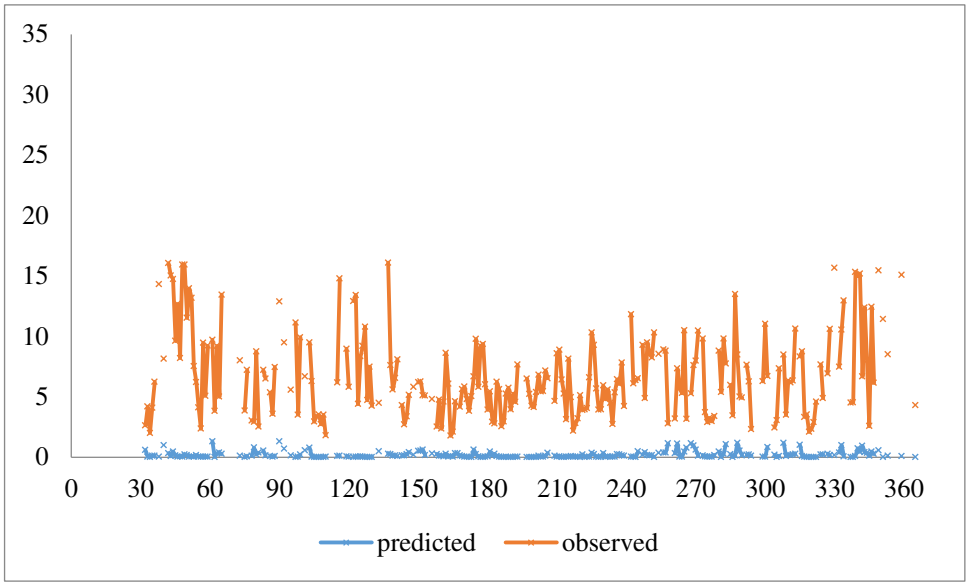

Figure 4.30 Comparison of predicted and measured SO_2 concentrations for Lapseki station

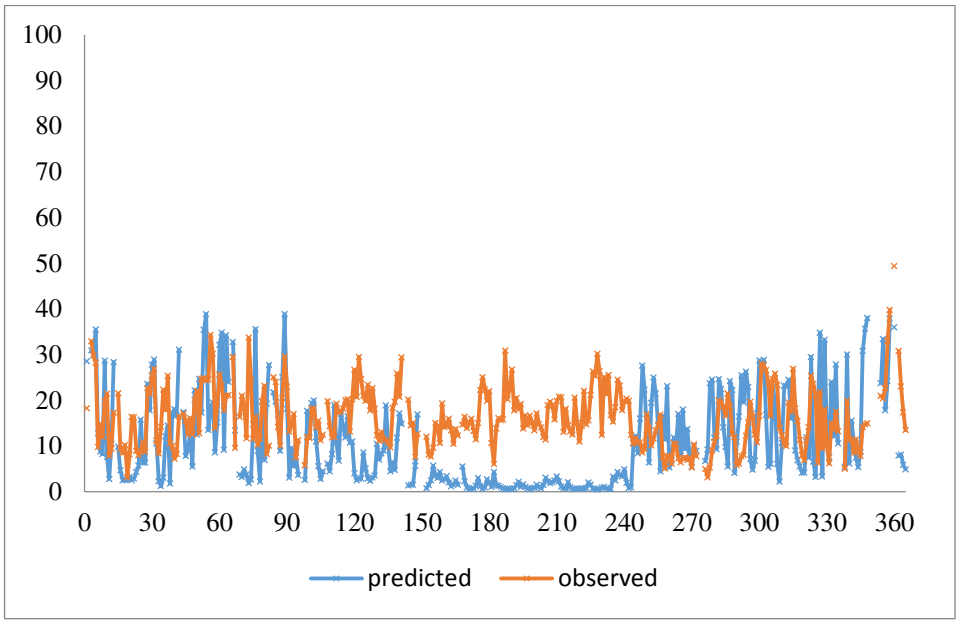

Figure 4.31 Comparison of predicted and measured PM_{10} concentrations for Çanakkale station

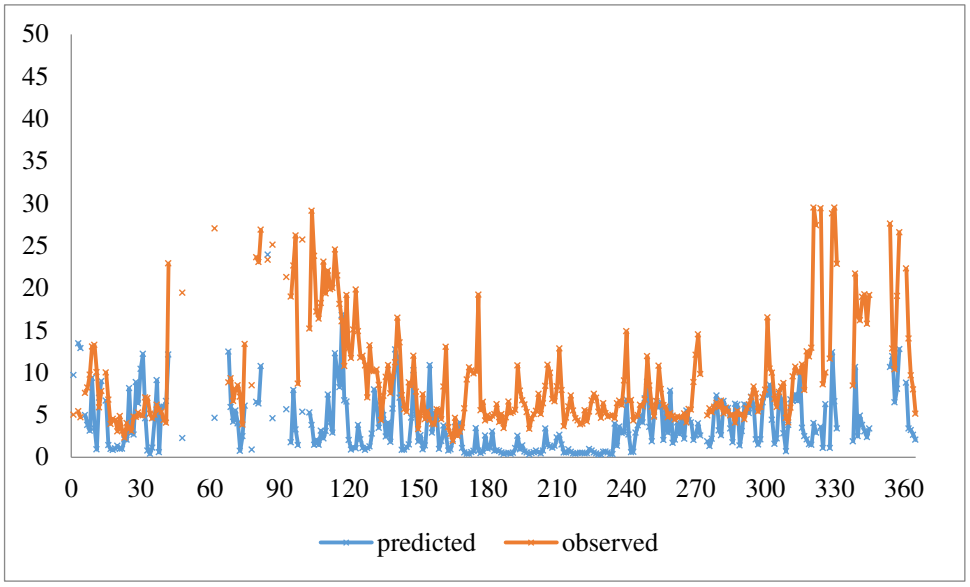

Figure 4.32 Comparison of predicted and measured SO_2 concentrations for Çanakkale station

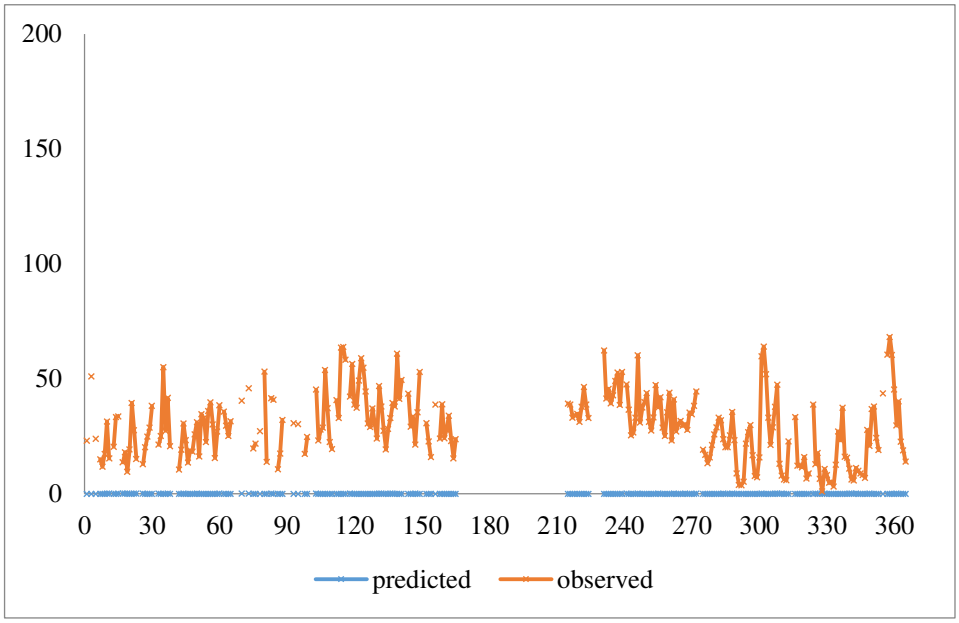

Figure 4.33 Comparison of predicted and measured PM_{10} concentrations for Biga station

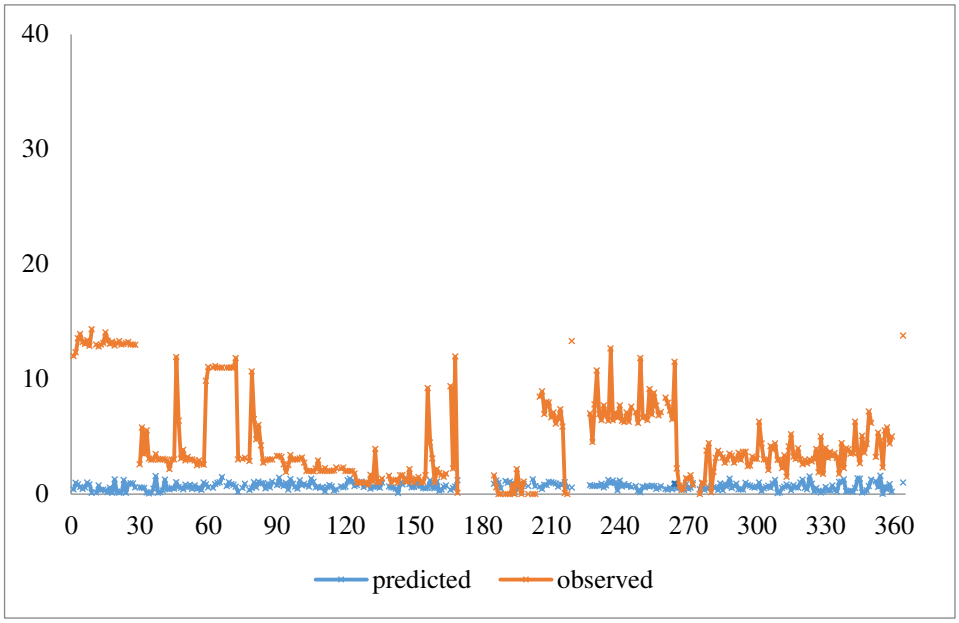

Figure 4.34 Comparison of predicted and measured SO_2 concentrations for Biga station

In this study, industrial plants except for 6 major plants were not included in calculations. Therefore, especially in Çanakkale station accuracy of prediction for PM_{10} was higher in winter season. The reason of low correlation between predicted SO_2 and PM_{10} concentrations in Biga station might be uncertainties in emission inventory.. Because a steel plant located in Biga was not included in calculations and the results indicate that this plant is a major emission source in Biga. In Çan region open landfill sites belonging to ceramic plants in the region were not taken into consideration. These are major fugitive dust sources. Therefore, it could be a reason of underestimated concentrations of PM_{10} in the region. At lignite mine located in Çan, burning of lignite which can be regarded as fugitive SO_2 emission in wet season was not taken into consideration, therefore, it could be a reason of low predicted SO_2 concentration in Çan station. According to a published report (Ministry of Environment and Urbanization, 2014), the thermal power plant located in Çan does not always effectively use the desulphurization unit. It could be another reason of high observed SO_2 concentrations in the region. Additionally, residential heating from town and villages of the districts were not included into the emission inventory due to lack of data. This situation affects all the results of winter period predictions

in this study. And also, assumptions in calculations of emissions from major streets did not exactly cover the all streets in the city.

Table 4.12 Statistical analysis of model results for SO_2

	Stations			
Parameters	**Çan**	**Lapseki**	**Biga**	**Çanakkale**
Number of valid observation	319	250	317	304
Predicted mean (P) ($\mu g/m^3$)	11.8	0.2	0.7	3.8
Observed mean (O) ($\mu g/m^3$)	130.5	6.8	4.7	9.4
Minimum predicted ($\mu g/m^3$)	0.16	0.003	0.01	0.29
Minimum observed ($\mu g/m^3$)	1.96	1.77	0	1.91
Maximum predicted ($\mu g/m^3$)	62.9	1.3	1.6	23.9
Maximum observed ($\mu g/m^3$)	545.7	16.1	14.3	29.5
Predicted deviation	15.8	0.3	0.3	3.4
Observed deviation	143.9	3.4	3.8	6.3
Systematic RMSE	112.3	5	4.3	6.4
Unsystematic RMSE	143.4	7.5	4.6	6.2
Total RMSE	179.1	7.4	5.6	8.2
Index of agreement (d)	**0.54**	**0.69**	**0.55**	**0.67**

Table 4.13 Statistical analysis of model results for PM_{10}

	Stations		
Parameters	**Çan**	**Biga**	**Çanakkale**
Number of valid observation	318	260	347
Predicted mean (P) ($\mu g/m^3$)	7.85	0.006	10.6
Observed mean (O) ($\mu g/m^3$)	70.7	29.3	16.2
Minimum predicted ($\mu g/m^3$)	0.19	0.0002	0.5
Minimum observed ($\mu g/m^3$)	10.6	1	3.1
Maximum predicted ($\mu g/m^3$)	37.6	0.03	38.8
Maximum observed ($\mu g/m^3$)	168.9	68.2	49.3
Predicted deviation	8.7	0.007	9.9
Observed deviation	34.9	14.2	6.7
Systematic RMSE	37.4	22.8	8.2
Unsystematic RMSE	66.9	33.8	11.3
Total RMSE	70.4	32.6	11.9
Index of agreement (d)	**0.56**	**0.66**	**0.61**

Table 4.14 Statistical analysis of model results for NO_x

	Stations	
Parameters	**Çan**	**Lapseki**
Number of valid observation	340	277
Predicted mean (P) ($\mu g/m^3$)	31.3	1.01
Observed mean (O) ($\mu g/m^3$)	33.3	10.7
Minimum predicted ($\mu g/m^3$)	2.3	0.01
Minimum observed ($\mu g/m^3$)	5.1	2.93
Maximum predicted ($\mu g/m^3$)	115.3	5.7
Maximum observed ($\mu g/m^3$)	85.8	26.6
Predicted deviation	26.3	1.3
Observed deviation	18	5.6
Systematic RMSE	19.8	8.1
Unsystematic RMSE	19.9	10.9
Total RMSE	24.9	11
Index of agreement (d)	**0.68**	**0.66**

CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion and Recommendations

A local emission inventory was prepared for an area of 170 km × 125 km at metropolitan area of Çanakkale in order to determine the air pollutant emissions from major pollutants sources. In the inventory, the emission sources were industrial, vehicular and maritime traffic and residential heating activities. Four major pollutants consisting of PM_{10}, SO_2, NO_x and CO and emitted through these sources were identified. The contributions different sources such as natural, biogenic sources and industrial process except major plants located in the city were not included in calculations of emissions. For all pollution sources model studies carried out separately and also totally to predict the air quality levels coming from all sources and determine the contributions of all sources to local air quality. To model validation, daily air quality levels from all sources were compared to 4 different monitoring stations located in the city.

The results of emission inventory show that SO_2 and NO_x emissions were coming from mainly industrial sector. Sixty-six percent of total SO_2 emissions and 68% of total NO_x emissions were coming from industrial plants. Residential heating was the most polluting sector contributing to about 57% of PM_{10} emission while road traffic is the most polluting sector for CO emissions with ratio of 60% in the study area. Mean reason of high PM_{10} emissions in the study area was usage of lignite for residential heating and three power plant were the mean reason of high SO_2 emissions in the city.

According to the Air Quality Assessment and Management Legislation limit value for SO_2 was exceeded due to the residential activities in the region. 95% of the maximum annual average concentration is coming from residential heating, and the other part (5%) is coming from other anthropogenic sources. Rate of natural gas usage in the city should be more common to obtain decrease in SO_2 levels.

NO_x limit values (40 $\mu g/m^3$) are exceeded as the same SO_2. Industrial sector mainly causes the high annual average concentrations and maritime and road traffic also cause the high annual average concentrations in the region. When contribution of the all sources to the maximum annual average concentration, 99% of NO_x concentration is coming from industrial sector, other part (1%) is coming from other anthropogenic sources. Due to the lack of data on NO_x removal obtained data of industrial plants, high concentrations were estimated the results of model study. It could be suggested that after obtaining detailed information on industrial plants, more accurate emission calculation could be carried out for this sector especially for NO_x emissions in the future studies which will be carried out for Çanakkale.

Additionally, only major industrial plants were included in this study. Despite of the all efforts, information about industrial plants could not be obtained from related institutions. It is important to be included other industrial plants in emission inventory. Because many mining plants and food industries exist in the city. Addition of new industrial plants into emission inventory will probably increase the amount of emission from industrial sector.

According to the statistical analysis of the model results, correlation between observed and predicted data was not high. The main reason of low accuracy is that industrial sector information about several industries in the region could not be obtained from the related institutions. Addition to this, town and villages were not included in emission calculations of residential heating due to lack of data.

This study provides the first emission inventory and modeling results including all anthropogenic emission sources in Çanakkale. With the modeling study, contribution of all pollutant sources to air quality of the city was determined. Additionally, comparison of air quality modelling results with ambient concentration measurements also provided useful information regarding uncertainties in the emission inventory.

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