E. DÖLEK

COMPARISON OF ISCST3 AND AERMOD AIR DISPERSION MODELS: CASE STUDY OF CAYIRHAN THERMAL POWER PLANT

EMRE DÖLEK

DECEMBER 2007

METU 2007

COMPARISON OF ISCST3 AND AERMOD AIR DISPERSION MODELS: CASE STUDY OF CAYIRHAN THERMAL POWER PLANT

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

EMRE DÖLEK

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
DEPARTMENT OF ENVIRONMENTAL ENGINEERING

DECEMBER 2007

Approval of the thesis:

COMPARISON OF ISCST3 AND AERMOD AIR DISPERSION MODELS: CASE STUDY OF CAYIRHAN THERMAL POWER PLANT

submitted by **EMRE DÖLEK** in partial fulfillment of the requirements for the degree of **Master Science in Department of Environmental Engineering, Middle East Technical University** by,

Prof. Dr. Canan Özgen _______________
Dean, Graduate School of **Natural and Applied Sciences**

Prof. Dr. Göksel N. Demir _______________
Head of Department, **Environmental Engineering**

Prof. Dr. Aysel Atımtay _______________
Supervisor, **Dept. of Environmental Engineering, METU**

Examining Committee Members:

Prof. Dr. Gürdal Tuncel _______________
Dept. of Environmental Engineering, METU

Prof. Dr. Aysel Atımtay _______________
Dept. of Environmental Engineering, METU

Assoc. Prof. Dr. Ayşegül Aksoy _______________
Dept. of Environmental Engineering, METU

Assoc. Prof. Dr. İpek İmamoğlu _______________
Dept. of Environmental Engineering, METU

Dr. O. Cevdet Öztin _______________
Chemical Engineering Dept., METU

Date: 27.12.2007

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name :

Signature :

ABSTRACT

COMPARISON OF ISCST3 AND AERMOD
AIR DISPERSION MODELS:
CASE STUDY OF ÇAYIRHAN THERMAL POWER PLANT

Dölek, Emre
M.S., Department of Environmental Engineering
Supervisor: Prof. Dr. Aysel Atimtay

December 2007, 136 pages

In this study, emission inventory was prepared and pollutant dispersion studies were carried out for the area around Çayırhan Thermal Power Plant to determine the effects of the plant on the environment. Stack gas measurement results were used for the emissions from the power plant and emission factors were used for calculating the emissions from residential sources and coal stockpiles in the study region. Ground level concentrations of SO_2, NO_x and PM_{10} were estimated by using EPA approved dispersion models; namely ISCST3 and AERMOD.

The ground level concentrations predicted by two models were compared with the results of ambient air pollution measurements for November 2004. Predictions of both ISCST3 and AERMOD were underestimating the ground level SO_2 concentrations. However, AERMOD predictions are better than ISCST3 predictions. The results of both models had good correlation with the results of NO_x measurements. It has been shown that the contribution of the power plant to SO_2, NO_x and PM_{10} pollution in the area studied is minimal.

Keywords: Air Pollution, Emission Inventory, Air Quality Modeling, ISCST3 Model, AERMOD Model

ÖZ

ISCST3 VE AERMOD DAĞILIM MODELLERİNİN KARŞILAŞTIRILMASI: ÇAYIRHAN TERMİK SANTRALI ÖRNEK ÇALIŞMASI

Dölek, Emre
Yüksek Lisans, Çevre Mühendisliği Bölümü
Tez Yöneticisi: Prof. Dr. Aysel Atimtay

Aralık 2007, 136 sayfa

Bu çalışmada, Çayırhan Termik Santralinin çevresi üzerindeki etkilerini tayin etmek için termik santral ve etrafında bulunan kirletici kaynaklarının envanteri çıkarılmış ve bu kaynaklardan salınan kirleticilerin atmosferde dağılım çalışması yapılmıştır. Emisyon envanteri hazırlanırken, santralden kaynaklanan emisyonlar için baca gazı ölçüm sonuçları; yerleşim alanları ve kömür stok sahalarından kaynaklanan emisyonların hesabı için ise emisyon faktörleri kullanılmıştır. SO_2, NO_x ve PM_{10} kirleticilerinin yer seviyesi konsantrasyonları EPA tarafından onaylanan ISCST3 ve AERMOD dağılım modelleri kullanılarak hesaplanmıştır

Model sonuçları 2004 yılı Kasım ayında yapılan ortam havası kirlilik ölçüm sonuçları ile karşılaştırılmıştır. Her iki model kullanılarak elde edilen SO_2 konsantrasyonları ölçüm sonuçlarının altında bulunmuştur. Ancak, AERMOD ile bulunan sonuçlar, ISCST3 ile bulunan sonuçlardan daha iyidir. NO_x ölçüm sonuçları model sonuçları ile daha iyi bir korelasyon göstermiştir. Çalışma sonunda Çayırhan Termik Santralinin SO_2, NO_x and PM_{10} açısından çevresi üzerindeki etkilerinin çok az olduğu belirlenmiştir.

Anahtar Kelimeler: Hava Kirliliği, Emisyon Envanteri, Hava Kalitesi Modellemesi, ISCST3 Modeli, AERMOD Modeli

To My Family

ACKNOWLEDGMENTS

I would like to thank to my thesis advisor Prof. Dr. Aysel Atımtay for her patience and encouragement and her insights and suggestions that helped to shape my study. Her valuable feedback contributed greatly to this thesis.

I am grateful to Murat Aytekin, who is Environmental Coordinatar of Ciner Group. He advised me and helped me in various aspects of my research. His visionary thoughts and energetic working style have influenced me greatly on my career.

My deepest gratitude goes to my family for their unflagging love and support throughout my life; this thesis is simply impossible without Tacettin Dölek, Nilgün Dölek and also Emrah Dölek.

TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

LIST OF ABBREVIATIONS

AERMOD	American Meteorological Society/Environmental Protection Agency Regulatory Model
ASU	Arizona State University
DEM	Digital Elevation Model
EIA	Energy Information Administration
EPA	Environmental Protection Agency
ESP	Electrostatic Precipitator Units
FGD	Flue Gas Desulphurization Units
GJ	Giga Joule
GMT	Greenwich Mean Time
GWh	Gigawatt hour
HP	High Pressure
hPA	Hektopascal
IEO	International Energy Outlook
ISCLT3	Industrial Source Complex - Long Term Version 3
ISCST3	Industrial Source Complex - Short Term Version 3
LP	Low Pressure
MP	Medium Pressure
MW_e	Megawatt Electricity

OECD	Organization for Economic Co-operation and Development
PM	Particulate Matter
RMSE	Root Mean Square Error
SHW	State Hydraulic Works
SPO	State Planning Organization
TAQPR	Turkish Air Quality Protection Regulation
TCEQ	Texas Commission on Environmental Quality
TETC	Turkish Electricity Transmission Company
TSP	Total Suspended Particulates
U.S.A.	United States of America
VOCs	Volatile Organic Compounds
WCI	World Coal Institute

CHAPTER 1

INTRODUCTION

Energy is an indispensable fundamental input to modern life. People are entirely dependent on continuous supply of energy for most of the everyday activities. Our dependency on energy is increasing significantly every year. Therefore, energy became the primary factor of specifying governments' political, economical and social strategies. Countries are setting alliances and cooperation to ensure a safe supply of energy.

Energy can be supplied in two categories. The first category is the "primary energy" which is supplied from natural resources, such as coal, oil, natural gas, wood, wind, hydro power, and sunlight. The second category is the "secondary energy" which is in more useable forms than the primary energy, such as electricity and gasoline.

In order to meet this increasing demand on energy, government and private sector are investing huge amount of money in energy production. Especially, they are focusing on electricity generation. World electricity consumption is expected to double between the years 2003 and 2030 according to the projections of IEO2006. Non-OECD countries will account for 71 percent of this projected growth, and OECD countries account for the 29 percent. Today, more than 60% of the world electricity generation is being supplied by fossil fuels. In the near future, considerable change in this profile is not expected (EIA, www.eia.doe.gov). In Figure 1.1, projection of fuel shares of world electricity generation can be seen.

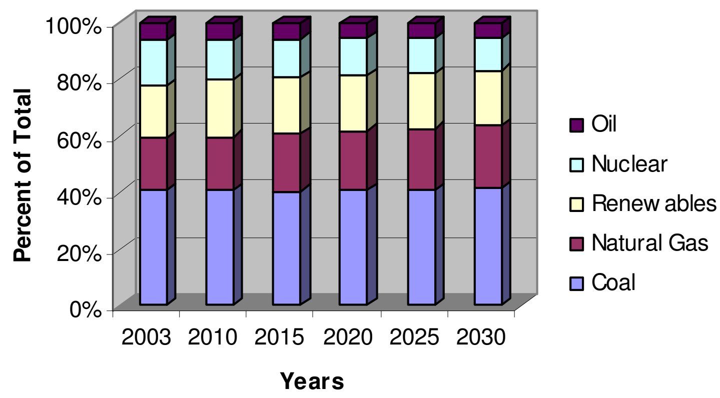


Figure 1.1 Shares of fuels used in world electricity generation 2003-2030 (EIA, www.eia.doe.gov)

In Turkey, primary energy production and electricity consumption have steadily increased since 1950's. While Turkey was producing electricity of around 800 GWh/year in 1950's, this amount has increased 190 times in 2005 to 151,000 GWh/year (SHW, www.dsi.gov.tr/hizmet/enerji.htm). Percent share of primary energy resources in electricity production in Turkey for year 2003 is given in Figure 1.2 (TETC, http://www.teias.gov.tr/istatistik/33.xls).

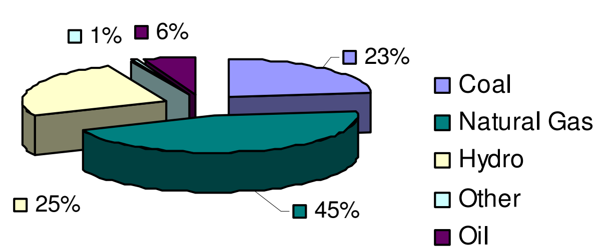


Figure 1.2 Shares of primary energy resources used in actual electricity production (TETC, http://www.teias.gov.tr/istatistik/33.xls)

Energy production and use can affect the environment in many ways, with every diverse impact from different fuel sources. Burning fossil fuels for electricity generation results in significant air pollution. Types and amount of the air pollutants emitted depend on the type of combustion process, on the fuel and on processing of combustion gases (Baumbach, 1996). Moreover, the electricity sector is the most important air pollution source among industrial sectors. Electricity generation produces a large amount of nitrogen oxides (NO_x), sulphur dioxide (SO_2), particulate matter (PM) emissions and other pollutants as seen in Figure 1.3 (Baumbach, 1996).

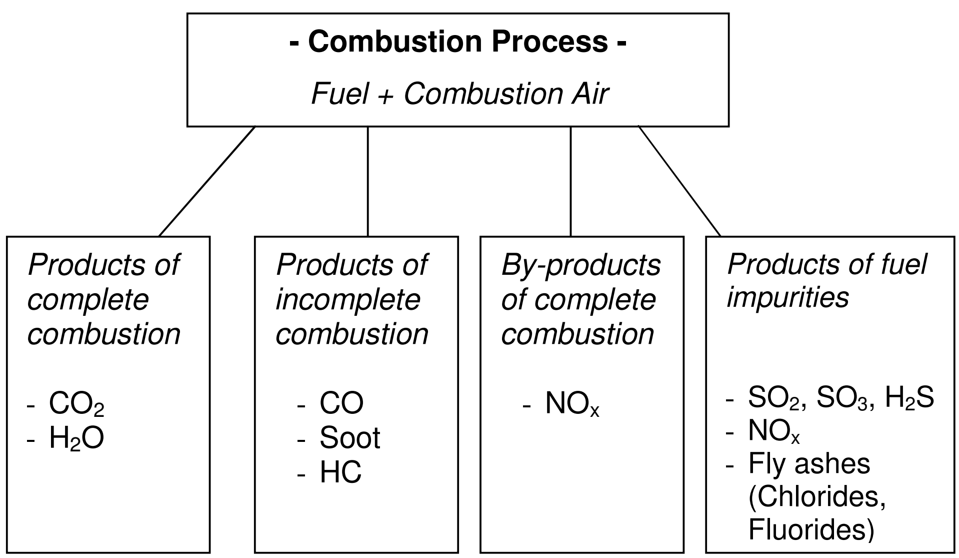


Figure 1.3 Air pollutants from combustion of fuels (Baumbach, 1996)

Air pollution and human induced climate change are the most pressing environmental problems arising from energy use. While situation vary significantly among individual countries, fuel combustion is the major sources of air pollution across OECD regions as indicated in Table 1.1.

Table 1.1 Contribution of energy use to air pollutants across OECD regions (OECD Environment Outlook, 2001)

Air Pollutant	**Transport**	**Electricity Production**	**Other Combustion Sources (industry and residential)**	**Other**
SO_x	4%	23%	71%	2%
NO_x	52%	28%	16%	4%
Particulates	17%	12%	26%	45%

In Turkey, the electricity production sector contributes 58% of the total SO_2 emissions. The industrial fuel combustion contributes 27%, and the industrial processes contribute 2.5% of the total SO_2 emissions. Because of the high sulphur content of diesel fuel, household heating with diesel fuels contributes 10% of the total SO_2 emissions and mobile sources contribute 2.5% of the total SO_2 emissions as seen in Figure 1.4. For nitrogen oxides, mobile sources contribute 32.5% of the NO_x total emissions, while the shares from other sources are: 20.1% from household heating; 22.1% from the power sector; 21.7% from industrial fuel combustion; 2.4% from industrial processes and 1.2% from agricultural sources as seen in Figure 1.5 (The European Environment State and Outlook, 2005).

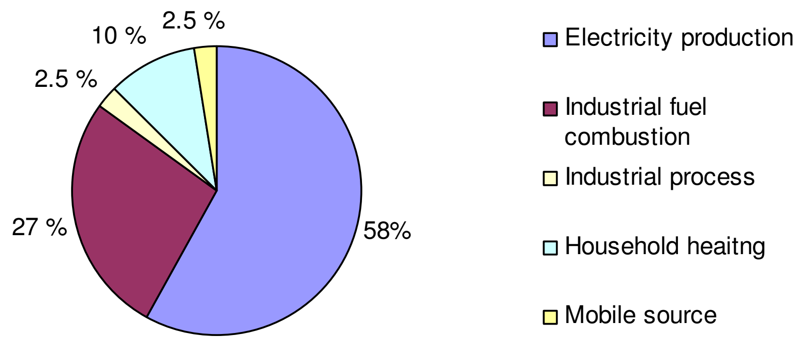


Figure 1.4 Contributions of SO_2 emission from various sources (The European Environment State and Outlook, 2005)

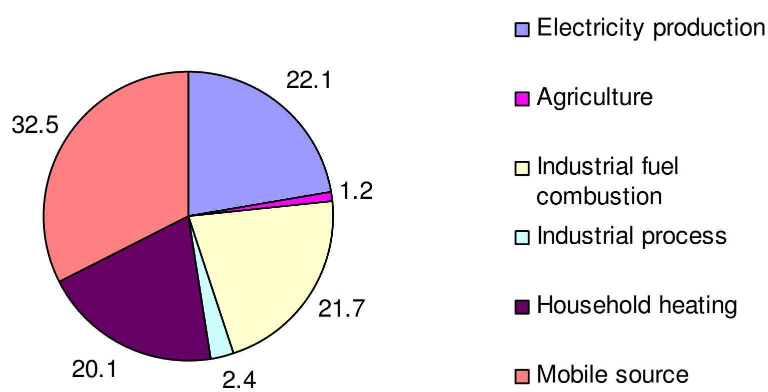


Figure 1.5 Contributions of NO_x emission from various sources (The European Environment State and Outlook, 2005)

1.1 Effects of Air Pollution

The harmful effects of air pollutants on human beings have been the major reason for efforts to understand and control their sources. The human body and other biological systems have a tremendous capacity to take in all types of chemicals and either utilize them to support some bodily function or eliminate them (Stern et al, 1994). The effects of nitrogen oxides, sulphur dioxide and particulate matter are explained below as they are the main air pollutants emitted from fuel combustion.

1.1.1 Nitrogen Oxides

Oxides of nitrogen (NOx) are formed during combustion process at high temperatures through oxidation of the nitrogen in the combustion air and through the combustion of the fuel-bound nitrogen (Baumbach, 1996).

Both NO_2 in its untransformed state, and the acid and nitrate transformation products of NO_2, can have adverse effects on human health or the environment. NO_2 itself can cause adverse effects on respiratory systems of humans and animals, and damage to vegetation. When dissolved by water vapor, the acids formed can have adverse effects on the respiratory systems of humans and animals. Nitric acid (HNO_3) can cause damage to vegetation, buildings and materials, and contribute to acidification of aquatic and terrestrial ecosystems (Environment Canada, http://www.ec.gc.ca). When NO_2 is transformed into nitrate particles that are subsequently deposited on aquatic and terrestrial ecosystems, acidification can result. When nitrate is combined with other compounds in the atmosphere, such as ammonia, it becomes an important contributor to the secondary formation of respirable particulate matter ($PM_{2.5}$). NO_2 is one of the two primary contributing pollutants, along with volatile organic compounds (VOCs), to the formation of ground-level ozone formation. Both ozone and $PM_{2.5}$ is known to have harmful effects on human health and the environment (Environment Canada, http://www.ec.gc.ca).

1.1.2 Sulphur Dioxide

If the sulphur contained in fuel is burned completely, sulphur dioxide is formed. SO_2 is a colorless gas with a pungent odor; it can be detected in the air from approximately 0.6-1 mg/Nm^3. During in complete combustion, e.g., when there is a lack of air, elementary sulphur (S) or hydrogen sulphide (H_2S) can be formed under reducing conditions from the sulphur compounds in the fuel depending on the temperature (Baumbach, 1996).

Both SO_2 in its untransformed state, and the acid and sulphate transformation products of SO_2, can have adverse effects on human health or the environment. SO_2 itself can cause adverse effects on respiratory systems of humans and animals, and damage to vegetation. When dissolved by water vapor to form acids it can again have adverse effects on the respiratory systems of humans and animals, and it can cause damage to vegetation, buildings and materials, and contribute to acidification of aquatic and terrestrial ecosystems. When transformed into sulphate particles that are subsequently deposited on aquatic and terrestrial ecosystems, acidification can result, and when sulphate is combined with other compounds in the atmosphere, such as ammonia, it becomes an important contributor to the secondary formation of respirable particulate matter ($PM_{2.5}$) (Environment Canada, http://www.ec.gc.ca).

1.1.3 Particulate Matter

Particulate matter (PM) consists of airborne particles in solid or liquid form. PM may be classified as primary or secondary, depending on the compounds and processes involved during its formation. Primary PM is emitted at the emissions source in particle form, for example, the stack of an electrical power plant. Ash is derived from non-combustible material introduced in the combustor along with the fuel itself. The ash produced in coal combustion, for example, arises from mineral inclusion in the coal as well as from heteroatoms, which are present in the coal molecules (Flagan and Senfeld, 1998).

Secondary PM formation results from a series of chemical and physical reactions involving different precursor gases, such as sulphur and nitrogen oxides, and ammonia reacting to form sulphate, nitrate and ammonium particulate matter (Environment Canada, http://www.ec.gc.ca).

Before atmospheric particles can cause adverse health effects, they must enter and be deposited in the human respiratory system. Particles can be described as inhalable, thoracic or respirable, based on their penetration and potential for deposition. Particles larger than 10 μm generally do not pass through the nasal hairs and defense mechanism of the upper respiratory system. Thoracic and respirable particles are significant public health concerns since they enter respiratory airways and are deposited in lung tissue (Godish, 2004).

1.2 Air Pollution Modeling

Air pollution modeling is a mathematical tool used to predict and simulate the distribution and the behavior of air pollutants emitted to the atmosphere. They are very useful especially for decision makers who are working on air pollution monitoring. Air pollution can not be measured in every point for particular area because it takes a lot of money and time. Therefore, by the help of air pollution models, one can for example determine the suitable points for making pollution measurements. The model results can be used for different purpose in decision making.

The purpose of mathematical models is to quantitatively combine the effects of source strength and meteorology to describe the resulting ambient air pollution concentration. Source strength is affected by a number of variables including the size of the source, variable emission rates, and the efficiency of air pollution control equipment employed. Meteorology is affected by wind speed and direction, atmospheric stability, inversion height, and terrain features. Ambient air pollution concentrations occurring downwind of a source consist of two components: pollution contributed directly by the source and the background pollution. Useful mathematical model must be able to account for all these parameters (Miller and Noll, 1976).

A model is a simplified picture of reality. It doesn't contain all the features of the real system but contains the features of interest for the management issue or scientific problem we wish to solve by its use. Models are widely used in science to make predictions and/or to solve problems, and are often used to identify the best solutions for the management of specific environmental problems (Ministry of Environment of New Zealand, 2004).

Dispersion models can take many forms. The simplest are provided in the form of graphs, tables or formula on paper. Today dispersion models more commonly take the form of computer programs, with user-friendly interfaces and online help facilities (Ministry of Environment of New Zealand, 2004).

Most modern air pollution models are computer programs that calculate the pollutant concentration downwind of a source using information on the:

- contaminant emission rate
- characteristics of the emission source
- local topography
- meteorology of the area
- ambient or background concentrations of pollutant (Ministry of Environment of New Zealand, 2004).

A generic overview of how this information is used in a computer-based air pollution model is shown in Figure 1.6.

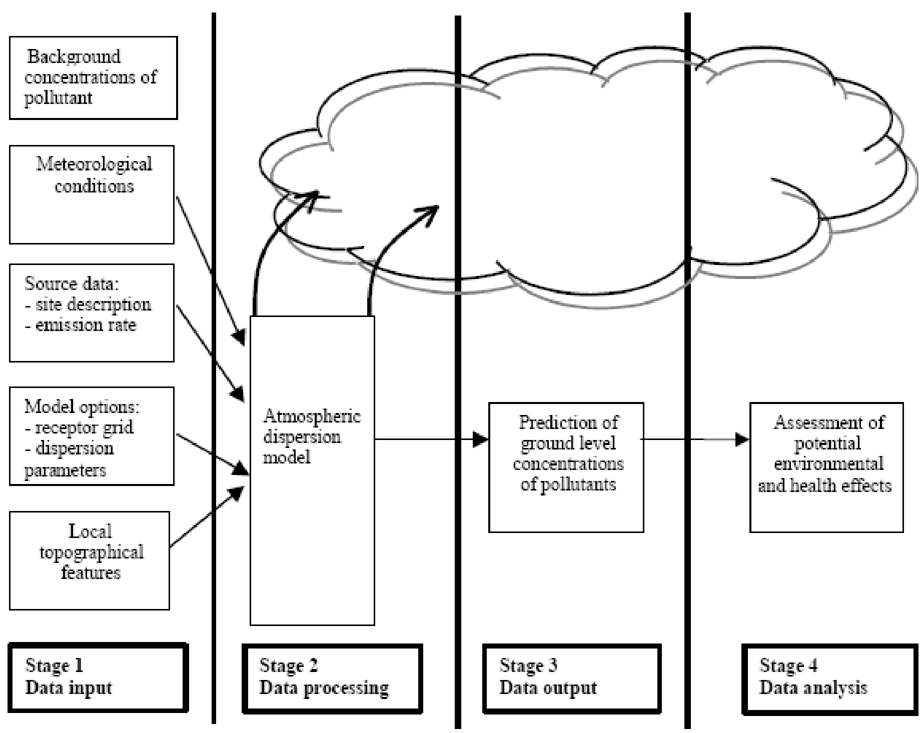


Figure 1.6 Overview of the air pollution modeling procedure (Ministry of Environment of New Zealand, 2004)

1.3 Objectives and Scope of the Study

The main objectives of the study are:

- To prepare an emission inventory for the Çayırhan region for SO_2, NO_x and PM
- To estimate ground level concentrations of pollutants by using two different dispersion models and to prepare ground level concentration maps,
- To evaluate performance of the models used by using the results of ambient air pollution measurements

In this study, emission inventory for Çayırhan region was prepared by using measurements of emissions from Çayırhan Thermal Power Plant and estimations of emissions from residential sources and coal stockpiles at the region. The pollution parameters were sulphur dioxide (SO_2), nitrogen oxides (NO_x) and particulate matter (PM). The emission data for the thermal power plant was obtained from Çayırhan Power Plant (Ciner Group, 2005). These pollutants were measured at the stack of the power plant continuously by analyzers. The emissions from villages and coal stockpiles were estimated by using CORINAIR emission factors and AP 42 emission factors.

The emission inventory was used as input data for air dispersion models; Industrial Source Complex Short Term Version 3 (ISCST3) and AERMOD. The results of these models were compared with the limit values of Turkish Air Quality Protection Regulation (TAQPR). Also, ground level concentration maps of SO_2, NO_x and PM were prepared according to results of each dispersion model for different averaging times.

The ground level concentration results of two dispersion models were not only compared with each other but also compared with the measurement results of the ambient air pollution concentrations. The ambient air concentrations of SO_2 and NO_x at 15 points around the Çayırhan Thermal Plants were measured in November, 2004 by an environmental consultant company hired by the power plant. By making use of these measurement results, model results were evaluated.

CHAPTER 2

ÇAYIRHAN THERMAL POWER PLANT AND PRODUCTION OF ELECTRICITY

2.1 Çayırhan Thermal Power Plant

Çayırhan Thermal Power Plant is located in the Central Anatolia and about 120 km northwest of Ankara. Çayırhan town is the nearest (3 km) residential district in the region to the thermal power plant. In general, the region has highland topographical properties. The minimum level is 478 m high above sea level and maximum level is 1800 m high above sea level. The location of the power plant and geographical characteristics of the area are shown in Figure 2.1. A general view of the power plant is seen in Figure 2.2.

Çayırhan Thermal Power Plant was founded in 1987 by the Turkish Electricity Generation and Transmission Authority. It was purchased by the Ciner Group in 2000 during privatization and became the first private thermal power plant in Turkey. The plant consists of 4 units with total capacity of 620 MW_e (See Table 2.1). It consumes 5 million tons of Çayırhan (Beypazarı) lignite coal having a total sulphur content of 3.4 % by weight and generates 4.3 billion kWh of electricity annually. It is the most efficiently working thermal power plant in Turkey. It uses the pulverized coal combustion technology. All four units equipped with Electrostatic Precipitators (ESP) and Flue Gas Desulphurization units.

The emission permit for the power plant was obtained in 07/07/2005 from the Ministry of Environment and Forestry according to regulations.

Table 2.1 Electricity production capacities of the units

UNITS	Start to Operate	Output Capacity
I. UNIT	1988	150 MW_e
II. UNIT	1988	150 MW_e
III. UNIT	2000	160 MW_e
IV. UNIT	2000	160 MW_e

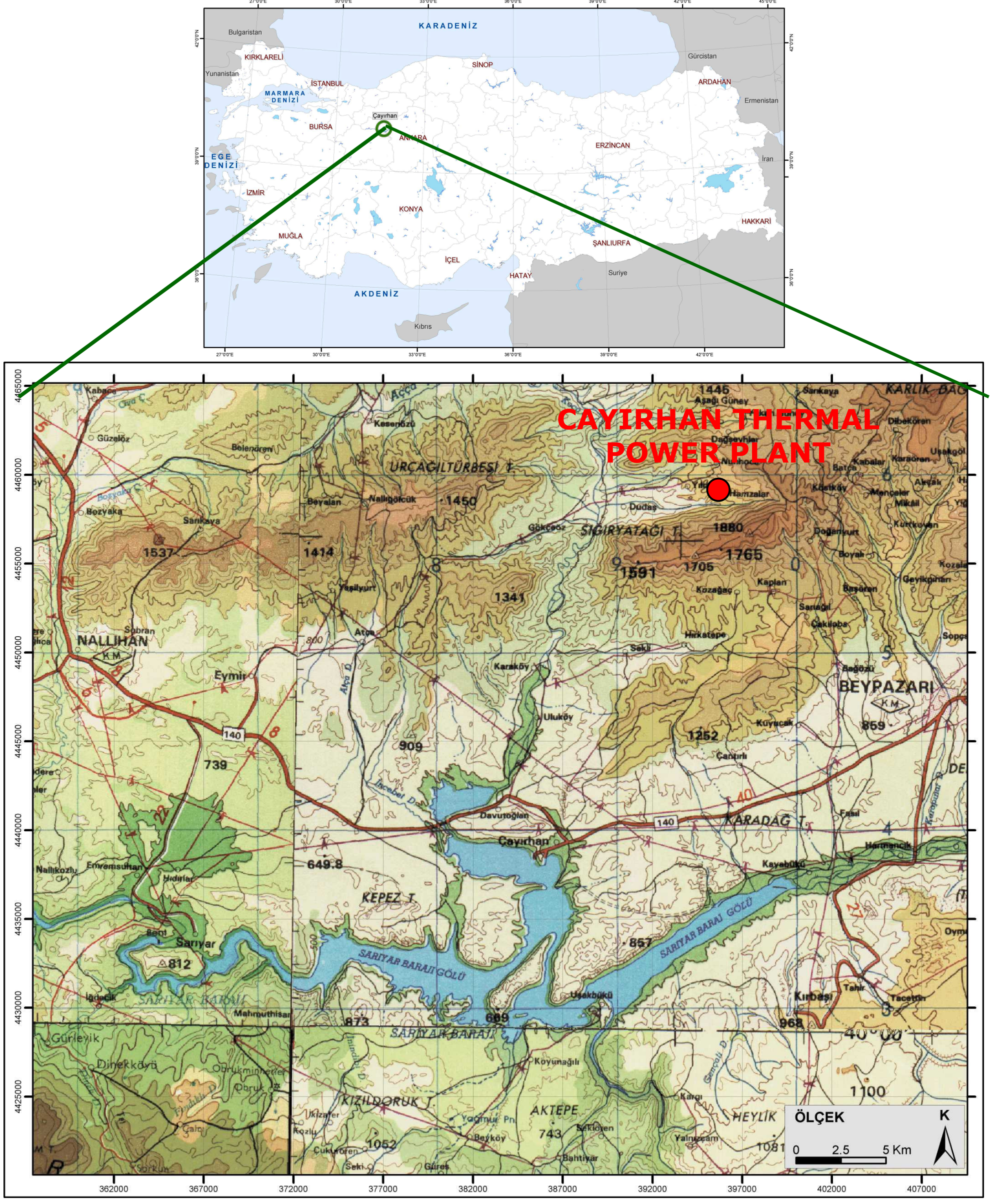


Figure 2.1 Location of the Çayırhan Thermal Power Plant

Figure 2.2 General view of the Çayırhan Thermal Power Plant

2.2 Electricity Production in Çayırhan Thermal Power Plant

The main process in a thermal power plant based on coal combustion is to convert chemical energy of coal to electrical energy. Chemical energy stored in the coal is first converted into thermal energy, then to mechanical energy and, finally, to electrical energy. Çayırhan Thermal Power Plant is a conventional plant where pulverized coal is combusted. In a conventional plant, pulverized coal is burnt in a boiler to produce steam. Produced steam is diverted to steam turbine in order to drive electrical generator. Figure 2.3 presents general flow sheet for generation of electricity from coal.

The electricity generation process in Çayırhan Thermal Power Plant consists of the following units:

- Coal Handling and Preparation
- Raw Water Preparation
- Steam Generation (Boiler)
- Steam Turbine and Generator
- Condenser and cooling System
- Flue Gas Treatment System

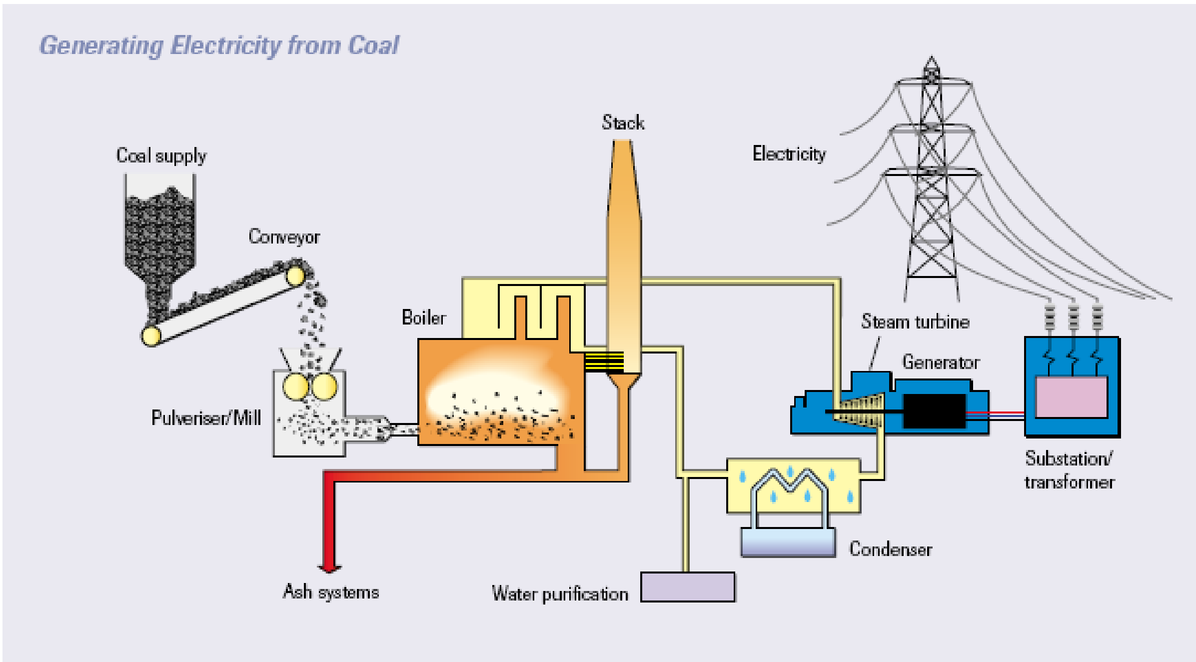


Figure 2.3 General process flow diagram for pulverized coal power plants (INTUSER, www. intuser.net)

2.2.1 Coal Handling and Preparation

Raw coal needs to be prepared properly for safe, economical and efficient use in a pulverizing coal combustion system. In all coal pulverizing systems, solid fuel is dried, ground, classified and then transported to the boilers.

The coal that is used at Çayırhan Thermal Power Plant is lignite coal and is supplied from Çayırhan Coal Mine Sites. Extracted coal from mine is fed into crushers in order to get appropriate particle size to ensure a rapid ignition and complete combustion of carbon for maximum efficiency, and to minimize ash and particulate deposits on heat-exchanger surfaces. Some of the coal is washed in coal washing unit before feeding into crushing equipment. Figure 2.4 shows the coal washing unit, and Figure 2.5 shows the washed coal after the coal washing units.

Figure 2.4 Coal washing unit

Figure 2.5 Washed coal from coal washing unit

Mined coal is of variable quality and contains substances such as clay, sand and carbonates. Coal washing is the cleaning process in which this mineral matter is removed from mined coal to produce a cleaner coal. The coal is also sized and blended to meet power plant specifications. Coal washing increases the heating value and the quality of the coal, by lowering the level of sulphur and mineral constituents.

The coal preparation process involves characterization, liberation, separation and disposition. Characterization identifies the composition of the different raw coal particles. Liberation involves crushing the mined coal and reducing it to very fine particles. Separation is the partitioning of the individual particles into their appropriate size groupings and separating the mineral matter particles from the coal. Finally the disposition stage involves the dewatering and storage of the cleaned coal and the disposal of the mineral matter.

Subsequently, washed and crushed coal is kept in coal stockpiles. These stockpiles are the source of fugitive dust especially in dry seasons. Figure 2.6 shows the coal stockpiles in the study area. In order to prevent fugitive dust formations watering is occasionally done by using ejectors. After stockpile, the next destination of the coal is boilers. All transportation of the coal is carried out on closed conveyor belts. These closed carrying equipments are essential for prevention of fugitive dust. Coal transportation systems and closed conveyor belts are seen in Figure 2.7 and Figure 2.8.

Figure 2.6 Coal stockpiles

Figure 2.7 Coal transportation systems in Çayırhan Thermal Power Plant

Figure 2.8 Closed conveyor belts

2.2.2 Water Preparation

The purity level of raw water is very important for thermal power plants in order to produce high pressure steam. The water used in Çayırhan Thermal Power Plant is pumped from the Sariyar Dam Lake which is 2 km away from the power plant. First the water is treated with chlorine. Then, it is pumped to four raw water ponds. The capacity of each pond is 5000 m^3.

Some portion of the water in raw water ponds is treated with lime ($Ca(OH)_2$) and ferric chloride ($FeCl_3$) to remove temporary hardness. Then, it is sent to the sand filters. After the sand filter unit, this water is used as drinking water, auxiliary cooling water and fireplug water.

The rest of the water is treated for steam production in the power plant. Pure water is used for steam production and it is recycled in closed system. As losses in recycling system occur, pure water has to be added to the recycling system when necessary. In order to use the raw water in the process to make steam, permanent hardness of the water has to be removed. Therefore, raw water is treated with resins and produced pure water is stored in pure water tanks. Moreover, chemicals like DEHA (Diethylhydroxylamine) are used in order to remove dissolved oxygen from the water because dissolved oxygen causes corrosion in the system.

2.2.3 Steam Generation (Boiler)

The boiler or steam generator is a combination of the economizer, evaporator, superheater and the reheater:

- <u>Economizer:</u> After the water/steam circuit, feed-water is heated in the economizer to a temperature of 10 ºC below the saturation point. The economizer is the first heat-exchanger of the boiler extracting heat from the low temperature flue-gas at the exit of the boiler.

- Evaporator: In the combustion chamber, the chemically bound energy of the fuel is released and this energy is transferred across the heat-exchanger walls to the water/steam circuit. The heat exchanger tubes are placed on the walls of the boiler. The heated water in the economizer is then evaporated in the evaporator at least to the saturation point for subcritical pressure water/steam conditions, or to superheated temperatures for supercritical conditions. Usually the evaporator tubes constitute the combustion chamber walls and are aligned in a vertical or a spiral arrangement. A few modern plants work with supercritical water/steam pressure, i.e. a pressure above the critical point in the water-steam diagram. At supercritical pressure the conversion occurs without a phase transition, so the evaporation energy is zero and only a peak in heat capacity represents the change in the continuous fluid.

- Superheater: The highest temperature region of the boiler is used to produce superheated steam. Superheated steam has a temperature significantly above the condensation temperature. Such temperatures are necessary to facilitate the high pressure drop in the steam turbine and thus avoid condensation during the expansion of steam in the high pressure steam turbine. The steam expansion is coupled with a pressure drop in the steam turbine and with an adiabatic decrease of the steam temperature. This results in generation of work in the turbine. Part of this expanded steam is bled off and used to heat the feed-water.

- Reheater: The bulk of the steam is reheated by the flue-gas in the reheater systems to extract further work and to achieve a higher efficiency in the subsequent medium-pressure steam turbine. To optimize the efficiency, supercritical plants often use a double reheat stage before steam is introduced into the low pressure steam turbine (European Commission, 2006).

2.2.4 Steam Turbine

In the steam turbine, the thermal energy of the steam is converted to mechanical work (i.e. turbine shaft rotation). This occurs between the steam inlet point of the turbine and the condenser, with the steam expansion being used as the driving force to generate work. During this adiabatic steam expansion, the temperature of the steam decreases in association with a pressure drop from about 300 to 0.03 bars for modern large combustion plants. Due to the large difference in pressure, steam expansion is normally done in three stages – the high pressure (HP), medium pressure (MP) and low pressure (LP) stages of steam turbines. In most cases, these steps allow the steam to be reheated in reheaters before re-entering the next pressure step in the steam turbine (European Commission, 2006).

2.2.5 Condenser

Finally, in the condenser located downstream of the low pressure section of the turbine, steam is condensed back to water (condensate). After expansion in the steam turbine, some condensation and kinetic energy remains in the steam which is not transferable to mechanical energy. Efficient condensation systems allow a reduction in the pressure of the steam turbine to well below atmospheric pressure (vacuum of down to 0.03 bars, depending on the cooling water temperature and the cooling water mass flow rate). This maximizes the extraction of mechanical energy due to the expansion of steam in the turbine (European Commission, 2006).

2.2.6 Cooling system

Cooling techniques are applied to remove the condensation energy from the steam, i.e. the thermodynamically unusable energy of the process. The operation of large combustion plants is governed by 'Carnot's principle'. The heat source, i.e. the boiler, provides the energy required for the water vaporisation. The cold source, i.e. the condenser, condenses the steam coming out of the low pressure turbine. The condenser and the cooling system are, therefore, the key parts of the facility. Regardless of the mode of cooling adopted, it is in fact one of the main interfaces between the combustion plant and the surrounding environment. The efficiency and the availability of a power plant depend, to a great extent, on the integrity and cleanness of the condenser and the cooling system (European Commission, 2006).

2.2.7 Flue Gas Treatment System

Considering environmental aspects, air pollution is one of the important issues for thermal power plants. Electricity generation produces a large amount of nitrogen oxides (NO_x), sulphur dioxide (SO_2), particulate matter (PM) emissions (Baumbach, 1996). At Çayırhan Thermal Power Plant, flue gas which is produced due to combustion process passes through the flue gas treatment system.

Flue gas treatment system consists of two main treatment technologies:

1. Electrostatic Precipitator Units (ESP)
2. Flue Gas Desulphurization Units (FGD)

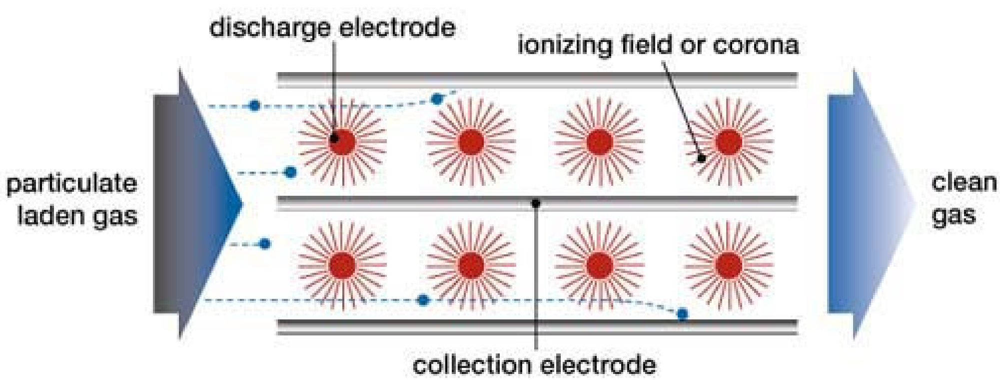
2.2.7.1 Electrostatic Precipitators Units

Most fuels contain some incombustible materials, which remain behind when the fuel is burned, called ash. The ash left behind by the combustion of coal contains mostly the oxides of silicon, calcium, and aluminum, with trace of other minerals. The basic strategy of control for particulate pollutants is to agglomerate them into larger particles that can easily be collected. This can be done by forcing the individual particles to contact each other or by contacting them with drops of water (De Nevers, 1995).

The characteristics and the amount of the fly ash depend on the fuel used, for example, on the mineral composition of the coal and the combustion type. The performance of the particulate control device is affected by changes in the resistivity and cohesiveness of the fly ash, which depends on the mineralogy of coal as fuel and the amount of unburned carbon content in the fly ash. The combustion type affects the particle size distribution in the fly ash and hence also affects particulate emissions. Fine particulate matter may also contain higher concentrations of heavy metal elements than coarser particles. This is because fine particles have a greater total surface area available for trace elements (heavy metals), such as mercury, to condense on (European Commission, 2006).

During the combustion of fossil fuels, the mineral matter (inorganic impurities) converts to ash and partly leaves the boiler as fly ash along with the flue-gas. Electrostatic precipitators are widely used particle collecting systems particularly where waste gas streams have large, steady volumetric flow rates. They are commonly used to remove fly ash from high S-coal-using power plants (Godish, 2004).

In the ESP, the discharge electrode (cathode) is changed with a high voltage (about 40 KV) and an ionizing field or “corona” is formed around these electrodes. The gas molecules around the electrodes are ionized. When the flue gas passes through the flue-gas, the charged ions collide with, and attach themselves to, fly ash particles suspended in the gas. The electric field forces the charged particles out of the gas stream toward the grounded plates (acting as anode) where they collect in a layer. The plates are periodically cleaned by a rapping system to release the layer into the ash hoppers as an agglomerated mass. In practice an ESP is divided into a number of discrete zones (European Commission, 2006). Conceptual flow diagram of an electrostatic precipitator is given in Figure 2.9 (ASU, www.eas.asu.edu).



Corona: An electrical discharge accompanied by ionization of surrounding atmosphere.

Figure 2.9 Conceptual flow diagram of an electrostatic precipitator (ASU, www.eas.asu.edu)

The cost of electrostatic precipitators includes costs due to electricity consumption, maintenance expenses (strongly depending on the boiler process and fuel properties) and the conveying of the precipitated ash, but generally they are cost-effective devices for reducing particle emissions. Operational costs are smaller than the corresponding costs of the other techniques, and the use of modern control systems reduce these expenses even more. These devices are competitive at power plants which have a wide range of power equipment and a variety of boiler processes (European Commission, 2006).

In Table 2.2, basic design parameters of the electrostatic precipitators which are used in Çayırhan Thermal Power Plant are given.

Table 2.2 Design parameters of electrostatic precipitators used in Çayırhan Thermal Power Plant

Parameter	**Value**
Number	4
Make	Waagner – Biro
Gas volume per body	455350 Nm^3/h
Flue gas velocity	1.3 m/s
Design temperature	190 ^0C
Flue gas inlet temperature	160 ^0C
Dust concentration at precipitator inlet	81 g/Nm^3
Dust concentration at precipitator outlet	$\leq$ 150 mg/Nm^3
Efficiency	99.9%

2.2.7.2 Flue Gas Desulphurization Units

The largest source of sulphur emission is from burning coal to generate electricity, e.g. about 65% of total U.S. SO_2 emissions in 1991 (De Nevers, 1995). Sulphur occurs naturally in fuels. In coal, it is bound as pyrite, FeS_2, mineral sulphates, elemental sulphur, and inorganic compounds and mercaptans. The most of the sulphur is oxidized to form SO_2. High sulphur coals typically contain 2 to 5% sulphur. Low sulphur coals have less than 1% sulphur (Schnelle and Brown, 2002).

Nowadays, various SO_2 control technologies are used to reduce SO_2 emissions to atmosphere. Some SO_2 technologies, e.g., coal beneficiation, coal gasification, and solvent refining, remove sulphur prior to combustion. Others, e.g., fluidized bed combustion, remove sulphur during combustion process; flue gas desulphurization systems remove it after combustion has been completed and before gases are emitted to atmosphere (Godish, 2004).

The flue-gas leaving the particulate control system usually passes through a heat-exchanger and enters the FGD absorber, in which SO_2 is removed by direct contact with an aqueous suspension of finely ground limestone whereas limestone should have more than 95% of $CaCO_3$. Fresh limestone slurry is continuously charged into the absorber. The scrubbed flue-gas passes through the mist eliminator and is emitted to the atmosphere from a stack or a cooling tower. Figure 2.10 presents the spray tower absorber which is the most commonly used in wet FGD systems throughout the world. The spray tower normally has three to four spray heads with a number of spray nozzles through which an aqueous suspension of finely ground limestone is atomized and sprayed with uniform distribution. The flue-gas introduced into the absorber is in close contact with freely moving droplets, usually in a countercurrent configuration with no gas flow restricting devices. Liquid mists carried over are captured by mist eliminators (European Commission, 2006).

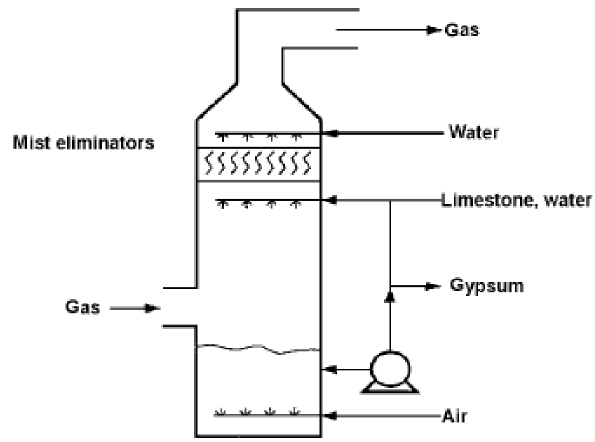


Figure 2.10 A spray tower absorber (European Commission, 2006)

Flue Gas Desulphurization (FGD) systems are widely used to control sulphur dioxide (SO_2) emissions from large coal-combustion power plants. Wet scrubbers, especially the limestone-gypsum processes, are the leading FGD technologies. They have about 80% of the market share and are used in large utility boilers. This is due to their high SO_2 removal efficiency and their high reliability. Limestone is used in most cases as the sorbent, as it is available in large amounts in many countries and is cheaper to process than other sorbents. By-products are either gypsum ($CaSO_4.2H_2O$) or a mixture of calcium sulphate/sulphite, depending on the oxidation mode. If the gypsum can be sold, total overall operating costs may be reduced (European Commission, 2006).

At Çayırhan Thermal Power Plant, conventional limestone wet scrubbing systems are used for removing SO_2 from stack gas. The stack of each unit has individual wet scrubbing systems. FGD systems had been installed in 1992 for Unit 1 and Unit 2. Unit 3 and Unit 4 had been constructed with their FGD systems and started to operate together. Figure 2.11 and Figure 2.12 show the FGD units and their stacks at Çayırhan Thermal Power Plant.

Figure 2.11 Stacks of the FGD systems at Çayırhan Thermal Power Plant

Figure 2.12 Stacks of the FGD systems at Çayırhan Thermal Power Plant

Limestone is transported from the limestone mine that is 7 km away from the power plant. Limestone is passed through pre-crushers to have maximum 6 cm particle size. Subsequently, mills are used for grinding the limestone and getting limestone powder. Limestone powder is delivered to limestone solution preparation unit. Prepared limestone solution is sprayed on flue gas by the help of scrubbers. The minimum efficiency of wet scrubbing system used at Çayırhan Thermal Power Plant is 95%. The reactions in the absorber are given below:

$SO_2 + H_2O \rightarrow H_2SO_3$

$CaCO_3 + 2H_2SO_3 \rightarrow Ca(HSO_3)_2 + CO_2 + H_2O$

$Ca(HSO3)_2 + O_2 + 2H_2O \rightarrow CaSO_4 \cdot 2H_2O + H_2SO_4$

The overall reaction between SO_2 and $CaCO_3$ is:

$CaCO_3 + SO_2 + 2\ H_2O + \frac{1}{2}\ O_2 \rightarrow CaSO_4.2\ H_2O + CO_2$

In Table 2.3, basic design parameters of the flue gas desulphurization units which are used in Çayırhan Thermal Power Plant are given.

Table 2.3 Design parameters of flue gas desulphurization units used in Çayırhan Thermal Power Plant

Parameter	**Value**
Number	4
Make	Bischoff
Overall height	100 m
Number of spray levels	8
Number of spray nozzles	22
Flow rate (max)	1,250,000 m^3/h
Internal gas velocity	3.5 m/s
Limestone consumption	22.5 t/h
Efficiency	min 95%

CHAPTER 3

REVIEW OF LITERATURE

Canpolat (1999) used a mathematical model (Industrial Source Complex Version 3) to predict ground level concentration of pollutants by using emission data of the cement plant. In order to determine the study area for air quality calculations, a 4 km x 4 km area was selected where the cement plant is at the center of the region. He mentioned that the location of the cement plant (pollution source) is very important according to pollution criteria and the area within 1000 m boundary of cement plant was mostly affected from the emissions.

For the İskenderun Region of Turkey, ISCT3 model was used to estimate the ground level concentration of PM, SO_2, NO_x and CO by Chaudhary (2003). The dimensions of the study area were 25 km x 50 km. Topographical data was included into the modeling calculations. The modeling result showed that the pollutant concentrations in urban areas like İskenderun, Dörtyol and Payas were mainly due domestic heating activities and urban traffic. However, Dörtyol and Payas have some impacts due to emissions from re-rolling steel mills and İsdemir. Also, he used statistical analyses in order to determine the model accuracy and he concluded that the model was 67% accurate in predicting the ground level concentrations of SO_2. The model under predicted the observed concentrations of $SO_{2.}$

Elbir (2002) prepared a local emission inventory in the city of İzmir, Turkey. The studied pollutants were total particulate matter (PM), sulfur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (VOC) and carbon monoxide (CO). Emissions of these pollutants were determined by estimation methods making use of suitable emission factors. In the second phase of his study, he used ISCST3 and

CALPUFF models to model dispersion of pollutants. According to his study, the statistical analyses showed that the overall accuracy of the SO_2 concentration predictions is 72% for the ISC model and 68% for the CALPUFF model.

In a study, Ghandour (2001) compared the prediction results of a decision making model (ISCST3) with the diffusion tubes network measurements. The study concluded that existing small villages can affect concentrations of NO_2 and SO_2 significantly. He mentioned that modeling result are not enough alone and a continuous verification of dispersion models with onsite measurements is essential for decision making.

Atli (2002) investigated the effects of Adana Cement Factory on air quality in the region. He focused on the ground level concentrations of PM_{10}, NO_x, CO and SO_2 on a 20 km x 20 km study area. The maximum PM_{10} concentration was predicted as 139.84µg/Nm^3 for 1 year averaging period. Maximum NO_x concentration was 55.96µg/Nm^3, maximum CO concentration was 243µg/Nm^3 and the predicted maximum concentration of SO_2 was 4.5µg/Nm^3.

The short-term and long-term versions of Industrial Source Complex Models (ISCST3 and ISCLT3) were evaluated for estimating long-term concentrations using sulphur dioxide data from emission inventory of Lucas County, Ohio, USA, for the year 1990. Inter comparison of the ISCST3 and ISCLT3 models indicated that these models yielded relatively good performance in their prediction of monthly and quarterly average concentrations, with relative fractional biases of 0.26 to 0.55 and normalized mean square error values that are about 0.12 to 0.44. Both the ISCST3 and ISCLT3 models predicted concentrations that were lower than the observed concentrations. The concentrations predicted by the ISCST3 model were closer to the observed concentrations when compared with the concentrations obtained using the ISCLT3 model. The study suggests that the ISCST3 model is better for estimating long-term concentrations of sulphur dioxide as compared to the ISCLT3 model (Kumar et al., 1999).

In their work Karppinen et al. (1997) compared the predictions of the ISC model with those measured in an urban area and a suburban area. Their results indicated that the model, although inherently adjusted for the urban setting, predicted the suburban concentrations with higher accuracy.

Al-Rashidi et al. (2005) described the use of mathematical modeling for investigation of the efficiency of existing monitoring sites for the impact of SO2 emissions from power stations in the state of Kuwait. The Industrial Source Complex Short Term (ISCST3) model was utilized to obtain the spatial and temporal variations of SO_2 over residential areas. Statistical comparison between the 50 highest daily measured and predicted SO_2 concentrations at six monitoring sites shows that the model is capable of generating results with accuracy of 60-94%.

Another study was conducted by Krishna et al. (2005). The emissions from 38 elevated point sources and 11 area sources had been used for computing the ground level concentrations of SO_2. The 8- and 24-h averaged model-predicted concentrations had been compared with corresponding observed concentrations at three receptors where ambient air quality is monitored during the study period. A total of 90 pairs of the predicted and observed concentrations had been used for model validation by computing different statistical errors and through Quantile–Quantile (Q–Q) plot. The results showed that the model-predicted concentrations were in good agreement with observed values and the model performance was found to be satisfactory.

Jamshedpur, the steel city of India situated in the eastern part of India is affected by increasing air pollution levels as a result of concentrated industrial activities. Sivacoumar et al. (2000) estimated the impact of NO_x due to various air pollution sources using ISCST Gaussian dispersion model at Jamshedpur. The contribution of NOx concentration from industrial, vehicular and domestic sources was found to be 53, 40 and 7%, respectively. Further statistical analysis was carried out to evaluate the model performance by comparing measured and predicted NOx concentrations. The model performance was found good with an accuracy of about 68%.

CHAPTER 4

MATERIALS AND METHODS

4.1. Emission Inventory

An emission inventory is a list of the amount of pollutants from all sources entering the atmosphere in a given period of the time. Emission inventories are very useful to control agencies as well as to planning and zoning agencies. They can point out the major sources whose control can lead to considerable reduction of pollution in the area. They can be used with appropriate mathematical models to determine the degree of overall control necessary to meet ambient air quality standards (Stern, 1994).

In this study the emission inventory in the Çayırhan area has been made. The emission inventory of the study area consists of 3 types of source.

1. Stacks of Çayırhan Thermal Power Plant
2. Residential Areas
3. Coal Stockpiles

4.1.1 Stacks of Çayırhan Thermal Power Plant

The physical and chemical characteristic of the fuel is one of the most important matters affecting the emission rates due to combustion. The properties of the coal used in Çayırhan Thermal Power Plant are given in Table 4.1.

Table 4.1 Analyses of coal used in Çayırhan Thermal Power Plant

Parameters	Units	Original Coal
Water	% (wt)	24.69
Ash	% (wt)	29.52
Volatile Matter	% (wt)	25.09
Fixed Carbon	% (wt)	20.70
Lower Heat Value	kcal/kg	2669
Higher Heat Value	kcal/kg	2945
Combustible Sulphur	% (wt)	2.49
Total Sulphur	% (wt)	3.40

There are 4 stacks installed in the power plant. Each stack has a continuous analyzer for measuring and recording emission rates and concentrations of air pollutants. Table 4.2 shows the emission rates measured by the analyzers and Table 4.3 shows properties of stacks and flue gas.

Table 4.2 Emission inventory of stacks of Çayırhan Thermal Power Plant

Paramet ers	Units	Sources				Total, kg/h
		Stack 1	Stack 2	Stack 3	Stack 4	
SO_2	g/s	31.11	42.78	39.17	10.00	443.016
NO_x	g/s	76.39	55.00	58.06	58.06	891.036
PM	g/s	8.78	5.17	8.45	7.86	108.936
SO_2	mg/Nm^3	301	614	399	120	
NO_x	mg/Nm^3	738	793	581	660	
PM	mg/Nm^3	85.48	29.19	63.49	90.96	

Table 4.3 Stack source data

Parameter	Units	Sources			
		Stack 1	Stack 2	Stack 4	Stack 4
Stack height	m	100	100	100	100
Diameter	m	4	4	4	4
Exit velocity	m/sec	19.1	18.6	14.3	14.1
Flue gas temperature	^{0}K	331	334	336	332

4.1.2 Residential Areas

There are 8 residential regions located at the study area. Çayırhan is the most crowded city with 8636 people and Çantırlı is the smallest village with 148 people. The population data of the last census (year 2000) was obtained from the State Institute of Statistics and the dwelling numbers were provided by local authorities. In Table 4.4, population and dwelling information are presented.

Table 4.4 Population and dwelling data for the study area according to census in 2000

Villages	Population	Dwellings
Çayırhan	8636	3292
Kayabükü	457	62
Sekli	365	210
Karaköy	309	221
Davutoğlan	273	80
Atça	210	84
Uluköy	184	76
Çantırlı	148	30

Local people use coal for domestic heating. The coal extracted at Çayırhan mine site has high sulphur content that is above the limits permitted and is not allowed to be used for domestic heating. Therefore, coal is obtained from Eskişehir Koyunağılı mine site for residential usage. The chemical and physical properties of this coal are presented in Table 4.5

Table 4.5 Chemical and physical properties of Eskişehir Koyunağılı coal

Parameters	Units	Original Coal
Water	% (wt)	27.46
Ash	% (wt)	13.01
Volatile Matter	% (wt)	28.58
Fixed Carbon	% (wt)	30.94
Lower Heating Value	kcal/kg	3908
Higher Heating Value	kcal/kg	4249
Combustible Sulphur	% (wt)	0.82
Total Sulphur	% (wt)	1.39

The contribution of emissions from small combustion installations to the total emissions varies and depends on pollutants type and given country. A very important role is played by the emissions from small residential installations which are typically responsible for more than a third of the total particulate matter emissions of stationary combustion but in some countries this sector may dominate, e.g., in Austria (in 1995) more than 70% of PM emissions from stationary combustion are thought to have originated from this source. Many countries using coal as a major part of domestic and commercial heating requirements have serious air pollution problems, one such example is Poland; the TSP (total suspended particulate) emissions from small combustion sources is 35% of the national total emissions (CORINAIR, 2005).

Furthermore the influence of those sources on the local air quality could be significant due to the low height of the flue gas releases, even where their share in total emissions is not dominant. This is particularly the case in the regions where solid fuels are predominately used in the residential sector (CORINAIR, 2005). The research on emission inventory for Ankara showed that 58.7% SO_2 emission was contributed from combustion for heating purpose (Atımtay et al, 1995).

An **emissions factor** is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant. Emission factors used in this study to estimate emissions from domestic heating sources are presented in Table 4.6. (CORINAIR, 2005).

Table 4.6 Emission factors used to estimate emission rates of residential sources around Çayırhan Thermal Power Plant (CORINAIR, 2005)

Fuel	**Emission Factors (g/GJ)**		
	NO_x	**SO_2**	**PM_{10}**
Coal	130	698	400

The calculation procedure for SO_2 emission factor for coals and heating oils is proposed as fallows (CORINAIR, 2005):

$$EF_{SO_{2,k}} = 2 \times \overline{Cs_k} \times (1-\overline{\alpha_{S,k}}) \times \frac{1}{H_k} \times 10^6$$

$EF_{SO_{2,k}}$ emission factor for SO_2 for fuel type k [g/GJ]

$\overline{Cs_k}$ average sulphur content of fuel type k (mass S/mass fuel [kg/kg])

H_k average lover heating value for fuel type k [MJ/kg]

$\overline{\alpha_{S,k}}$ average sulphur retention in ash

Sulphur retention in ash is the difference between the sulphur dioxide concentration calculated from the total sulphur content of fuel (c_{max}) and the sulphur dioxide concentration of the flue gas (c_{eff}) divided by the sulphur dioxide concentration calculated from the total sulphur content of the fuel.

$$\alpha_s = (c_{max} - c_{eff})/c_{max}$$

In the study region, 4000 kg coal is consumed per household during the winter season according to the information provided from local authorities. It was assumed that 500 kg coal/month is consumed per household in November and March when the monthly average temperatures are 7.5 ^{0}C and 7.1 ^{0}C, respectively, based on 30 years data. 1000 kg coal/month is consumed per household in December, January, and February when the monthly average temperatures are 2.9 ^{0}C, 1.1 ^{0}C, and 2.8 ^{0}C, respectively, based on 30 years data.

Table 4.7 presents monthly emission rates from each residential area during November and March. In order to calculate emission rates during December, January, and February, these emission rates were multiplied with 2 while using the dispersion models. A sample calculation for emission rates is given in Appendix A.

Table 4.7 Monthly emission rates from residential sources in November and March

Source	**SO_2**	**NO_x**	**PM_{10}**
Çayırhan ($g/s*m^2$)	1.33E-05	2.47E-06	7.60E-06
Sekli ($g/s*m^2$)	2.80E-06	5.21E-07	1.60E-06
Atça ($g/s*m^2$)	1.35E-06	2.52E-07	7.76E-07
Çantırlı ($g/s*m^2$)	1.93E-06	3.60E-07	1.11E-06
Karaköy ($g/s*m^2$)	4.93E-06	9.18E-07	2.82E-06
Uluköy ($g/s*m^2$)	2.67E-06	5.01E-07	1.54E-06
Kayabükü ($g/s*m^2$)	3.30E-06	6.15E-07	1.89E-06
Davutoğlan ($g/s*m^2$)	3.90E-06	7.26E-07	2.23E-06

4.1.3 Coal Stockpiles

There are 2 main coal stockpile located at the study area. One coal stock piles is located at mining site across the Çayırhan Thermal Power Plant and the other coal stockpile is located at the power plant site. PM_{10} emission occurs due to wind erosion and maintenance. PM_{10} emission rates of coal stockpiles were calculated with emission factors provided by the U.S. EPA (1995a).

For active coal stockpiles, emission factor is 1.8 x u (wind speed, m/sec). The unit of the emission factor for PM_{10} is kg/(hectare x hr). In this study, monthly average wind speeds were used in order to estimate particulate matter emission from coal stockpiles. Table 4.8 shows the PM_{10} emission factors calculated for each month in 2004.

Table 4.8 PM_{10} emission factors

Month	* Average Wind Speed, u (m/s)	Emission Factor = 1.8 x u (kg/hectare x hr)
January	1.4	2.52
February	1.0	1.80
March	1.1	1.98
April	1.5	2.70
May	1.4	2.52
June	1.6	2.88
July	1.3	2.34
August	1.6	2.88
September	1.2	2.16
October	0.8	1.44
November	0.7	1.26
December	0.7	1.26

* Obtained from 2004 wind data

4.2 Dispersion Modeling Studies

Contaminants discharged into the air are transported over long distances by large-scale air-flows and dispersed by small-scale air-flows or turbulence, which mix contaminants with clean air. This dispersion by the wind is a very complex process due to the presence of different-sized eddies in atmospheric flow. Even under ideal conditions in a laboratory the dynamics of turbulence and turbulent diffusion are some of the most difficult in fluid mechanics to model. There is no complete theory that describes the relationship between ambient concentrations of air pollutants and the causative meteorological factors and processes (Ministry of Environment of New Zealand, 2004).

An atmospheric dispersion model is a:

- Mathematical simulation of the physics and chemistry governing the transport, dispersion and transformation of pollutants in the atmosphere
- Means of estimating downwind air pollution concentrations for given information about the pollutant emissions and nature of the atmosphere processes (Ministry of Environment of New Zealand, 2004).

Atmospheric dispersion models use mathematical and numerical techniques to simulate the physical and chemical processes that affect air pollutants as they disperse and react in the atmosphere. The heart of the matter is to estimate the concentration of a pollutant at a particular receptor point by calculating from some basic information about the source of the pollutant and the meteorological conditions (Schnelle and Brown, 2002).

4.2.1 Dispersion Models Used in the Study

In this study, two dispersion models were used:

1. Industrial Source Complex Short Term Version 3 (ISCST3)
2. AERMOD (**A**merican Meteorological Society/**E**nvironmental Protection Agency **R**egulatory **MOD**el)

Industrial Source Complex Short Term Version 3 was developed by U.S. EPA (1995b). It is the most widely used model. It is a steady-state Gaussian plume model which is used with some modifications to model various kinds of sources, e.g., simple point source emissions from stacks, multiple vents, storage piles, conveyor belts, and the like. Therefore, the parameters such as meteorological conditions and emissions rate are kept constant through the calculations.

The ISCST3 model accepts hourly meteorological data records to define the conditions for plume rise, transport, diffusion, and deposition. The model estimates the concentration or deposition value for each source and receptor combination for each hour of input meteorology, and calculates user-selected short-term averages. For deposition values, either the dry deposition flux, the wet deposition flux, or the total deposition flux may be estimated. The total deposition flux is simply the sum of the dry and wet deposition fluxes at a particular receptor location. The user also has the option of selecting averages for the entire period of input meteorology (EPA, 1995b).

U.S EPA (2004a) recommended a new dispersion model AERMOD and this new model is replacing Industrial Source Complex Version 3 (Federal Register, 2005). AERMOD, also a steady-state plume model, improves estimates of dispersion in the planetary boundary layer by accounting for varying dispersion rates with height, refined turbulence based on current planetary boundary layer (PBL) theory and advanced treatment of mixing height, plume rise and complex terrain. AERMOD input and output, however, remain very similar to ISCST3. In this study, AERMOD PRIME, version of AERMOD with addition of an advanced plume rise and building downwash algorithm, was used as second dispersion model. The PRIME model features enhanced plume dispersion coefficients due to the turbulent wake and reduced plume rise caused by a combination of the descending streamlines in the lee of the building and the increased entrainment in the wake (Trinity, 1991).

The both models are regulatory models. It is not possible to modify or make changes in the algorithms of the models.

Relative to ISC3, AERMOD currently contains new or improved algorithms for: 1) dispersion in both the convective and stable boundary layers; 2) plume rise and buoyancy; 3) plume penetration into elevated inversions; 4) computation of vertical profiles of wind, turbulence, and temperature; 5) the urban boundary layer; and 6) the treatment of receptors on all types of terrain from the surface up to and above the plume height.

ISCST3 and AERMOD generate different results in the same circumstances. AERMOD use new or improved algorithms in its calculation compared to ISCST3. It takes more meteorological data into account, and analyzes the effect of factors such as the type of terrain and land use. ISCST3 contains several outdated concepts and practices, such as the simplified dispersion scheme based on the Pasquill-Gifford-Turner approach to characterize atmospheric turbulence using stability classes which was initially developed for rural low-level sources and does not always lead to reasonable predictions for all source types and locations. A key difference between the two models is the replacement of the Pasquill-Gifford-Turner system with the use of Planetary Boundary Layer (PBL) and similarity theory to determine dispersion coefficients. The Planetary Boundary Layer is the lowest portion of the atmosphere where the pollutants are emitted, transported, mixed and dispersed and a general term used to describe the turbulent air layer next to the earth's surface that is controlled primarily by surface heating and friction. The Planetary Boundary Layer typically ranges from a few hundred meters in depth at night to 1 - 2 kilometers during the day (TCEQ, 2003). AERMOD makes use of the surface characteristics such as albedo, bowen ratio, and surface roughness to generate more realistic estimates.

Table 4.9 provides a more extensive list of the comparison features between AERMOD and ISCST3 (U.S. EPA, 2003).

Table 4.9 The comparison features between AERMOD and ISCST3 (U.S. EPA, 2003)

Feature	ISCST3	AERMOD	Comments
Types of sources modeled	Point, area, and volume sources	Same as ISCST3	Models are comparable
Plume Rise	Uses Briggs equations with stack-top wind speed and vertical temperature gradient	In stable conditions, uses Briggs equations with winds and temperature gradient at stack top and half- way to final plume rise; in convective conditions, plume rise is superposed on the displacements by random convective velocities	AERMOD is better because in stable conditions it factors in wind and temperature changes above stack top, and in unstable conditions it accounts for convective updrafts and downdrafts
Meteorological Data Input	One level of data accepted	An arbitrarily large number of data levels can be accommodated	AERMOD can adapt multiple levels of data to various stack and plume heights

Table 4.9 (continued)

Feature	ISCST3	AERMOD	Comments
Profiling Meteorological Data	Only wind speed is profiled	AERMOD creates profiles of wind, temperature, and turbulence, using all available measurement levels	AERMOD is much improved over ISCST3 in this area
Plume Dispersion: General Treatment	Gaussian treatment in horizontal and vertical	Gaussian treatment in horizontal and in vertical for stable conditions; non-Gaussian probability density function in vertical for unstable conditions	AERMOD's unstable treatment of vertical dispersion is a more accurate portrayal of actual conditions
Characterization of Modeling Domain Surface Characteristics	Choice of rural or urban	Selection by direction and month of roughness length, albedo, and Bowen ratio, providing user flexibility to vary surface characteristics	AERMOD provides the user with considerably more options in the selection of the surface characteristics
Boundary Layer Parameters	Wind speed, mixing height, and stability class	Friction velocity, Monin-Obukhov length, convective velocity scale, mechanical and convective mixing height, sensible heat flux	AERMOD provides parameters required for use with up-to-date planetary boundary layer (PBL) parameterizations; ISCST3 does not
Terrain Depiction	Elevation at each receptor point	Controlling hill elevation and point elevation at each receptor, obtained from special terrain pre-processor (AERMAP) that uses digital elevation model (DEM) data	AERMOD's terrain pre-processor provides information for advanced critical dividing streamline height algorithms and uses digital data to obtain receptor elevations

Table 4.9 (continued)

Feature	**ISCST3**	**AERMOD**	**Comments**
Plume Interaction with Mixing Lid: convective conditions	If plume centerline is above lid, a zero ground-level concentration is assumed	Three plume components are considered: a “direct” plume that is advected to the ground in a downdraft, an “indirect” plume caught in an updraft that reaches the lid and eventually is brought to the ground, and a plume that penetrates the mixing lid and disperses more slowly in the stable layer aloft (and which can re-enter the mixed layer and disperse to the ground)	The AERMOD treatment avoids potential underpredictions suffered by ISCST3 due to its “all or nothing” treatment of the plume; AERMOD’s use of convective updrafts and downdrafts in a probability density function approach is a significant advancement over ISCST3
Plume Interaction with Mixing Lid: stable conditions	The mixing lid is ignored (assumed to be infinitely high)	A mechanically mixed layer near the ground is considered. Plume reflection from an elevated lid is considered.	AERMOD’s use of a mechanically mixed layer is an advancement over the very simplistic ISCST3 approach

4.2.2 Gaussian Plume Model

The Gaussian-plume formula is derived assuming ‘steady-state’ conditions. That is, the Gaussian-plume dispersion formula does not depend on time, although they do represent an ensemble time average. The meteorological conditions are assumed to remain constant during the dispersion from source to receptor, which is effectively instantaneous. Emissions and meteorological conditions can vary from hour to hour but the model calculations in each hour are independent of those in other hours. Due to this mathematical derivation, it is common to refer to Gaussian-plume models as steady-state dispersion models. Steady-state models calculate concentrations for each hour from an emission rate and meteorological conditions that are uniform across the modeling domain. Thus they simulate hourly-average concentrations (Ministry of Environment of New Zealand, 2004).

4.2.3 Model Options

4.2.3.1 Source Options

Unlimited point, flare, area, line, volume, and open pit (open pit in ISCST3 only) sources may be entered as a source into the model. Sources may be grouped so that concentrations are calculated from individual sources, specific groups of sources, or all sources combined. Results for an unlimited number of source groups can be generated in a single run. A source file can be easily edited to vary the scenario (Trinity, 1991).

4 stacks of Çayırhan Thermal Power Plant (point sources), 8 residential villages (area sources) and 2 coal stockpiles (area sources) were used as source parameters in this study. SO_2, NO_x and PM_{10} are the air pollutants investigated by this study.

Variations in the production can result in time dependent emission rates. Models use this variable emission rates based on the hour of day, month, and season. Stability category (ISCST3 only) and wind speed (AERMOD only) are also necessary for the model (Trinity, 1991).

Emission rate data should ideally be obtained from measurements undertaken at either on the site in question (for an existing site) or on a similar site (if available). Alternatively, emission rates may be calculated from manufacturer's specifications or directly by using the industrial process knowledge. When no appropriate measured emission rates are available, published emission factors can be useful. Published emission factors give the mass of pollutants discharged from the stack per mass of fuel consumed, or product produced. Emission factors are useful as a first estimate of emission rates for pollutants where collection of actual emission rate measurements is impractical or impossible (Ministry of Environment of New Zealand, 2004).

4.2.3.2 Receptor Options

Receptors are the people or objects negatively affected from the pollution. Receptor grids can be created automatically or manually using Cartesian or polar coordinates. Discrete and boundary receptors can also be defined. Concentrations can be calculated for all terrain elevations and for receptors above ground elevation (flagpole receptors). An unlimited number of receptor grids may be entered for each modeling run. An unlimited number of receptors can be modeled. The user has the ability to eliminate onsite and offsite receptors from the modeling analysis. The user can input elevated receptor heights in order to model the effects of terrain above (or below) stack base, and may also specify receptor elevations above ground level to model flagpole receptor (Trinity, 1991).

The study area in this work area was selected as 25 km x 30 km which was divided into grids having 500 m size. This receptor grid has 3000 receptor points and ground level concentrations are calculated at these receptor points by dispersion models. The coordinates of southwest corner of the receptor grid is X: 374000 and Y: 4430000. Both, ISCST3 and AERMOD require X, Y and Z values of the study area. For topographical input, N40E031.DEM file covering the study area was used. The resolution of the file is 90 meter. The visualization of the DEM file is given in Figure 4.1. The term DEM refers to Digital Elevation Model. Digital elevation model (DEM) data are arrays of regularly spaced elevation values referenced horizontally either to a Universal Transverse Mercator projection or to a geographic coordinate system. The grid cells are spaced at regular intervals along south to north profiles that are ordered from west to east. Shortly, digital elevation model is a digital file consisting of terrain elevations for ground positions at regularly spaced horizontal intervals (National Research Council, 2006).

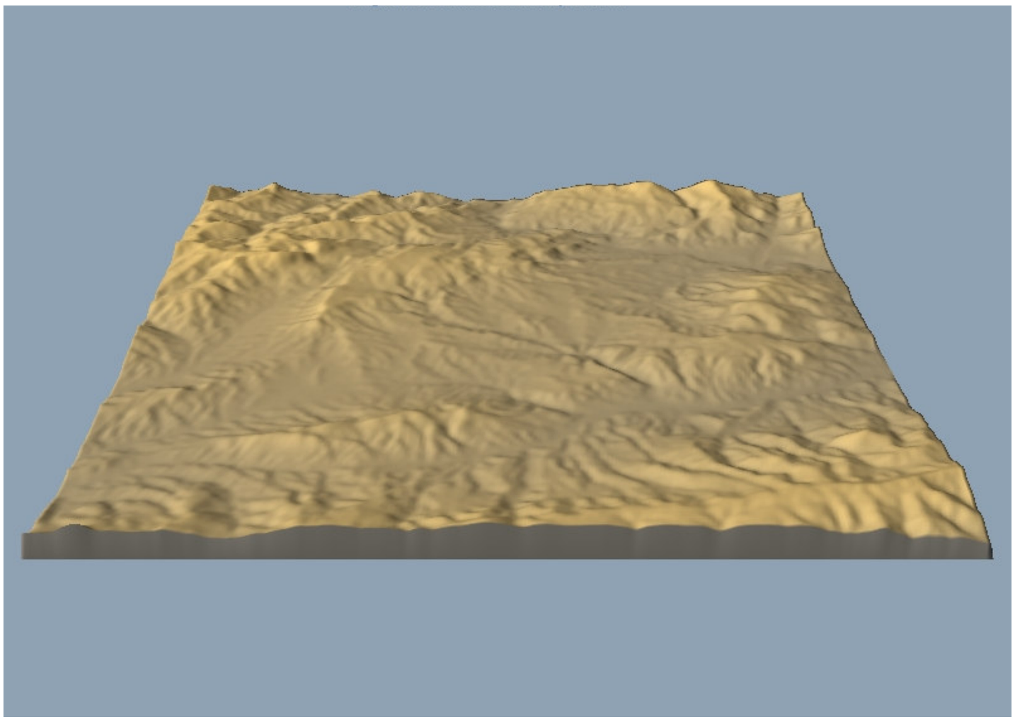


Figure 4.1 Visualization of the N40E031.DEM file

Besides this receptor grid system, 15 discrete receptors were located on the grid system. These discrete receptors were used for estimating pollution concentrations at locations where ambient air quality measurements were performed.

4.2.3.3 Meteorological Options

The ground-level concentrations resulting from a constant discharge of contaminants change according to the weather conditions at the time. Meteorology is fundamental for the dispersion of pollutants because it is the primary factor determining the diluting effect of the atmosphere. Therefore, it is important that meteorology is carefully considered when modeling. Ground-level concentrations of contaminants are primarily controlled by two meteorological elements: wind direction and wind speed (for transport), turbulence and mixing height of the lower boundary layer (for dispersion) (Ministry of Environment of New Zealand, 2004).

ISCST3 Meteorological Data

The ISCST3 model calculates concentrations from user-specified meteorological data. It accepts hourly meteorological data preprocessed by PCRAMMET, RAMMET or MPRM, as well as ASCII formats.

In this study, PCRAMMET (U.S. EPA, 1999) was used to prepare meteorological input data for ISCST3. The input data requirements for PCRAMMET depend on the dispersion model and the model options for which the data are being prepared. For concentration estimates for which the effect of settling and removal processes of dry and wet deposition are not required, the necessary data are:

- Wind direction,
- Wind speed,
- Dry bulb temperature,
- Opaque cloud cover,
- Cloud ceiling height,

- Morning mixing height, and
- Afternoon mixing height.

The mixing heights are based on upper air soundings at 1200 GMT and 0000 GMT, respectively.

The operations performed by PCRAMMET include:

- Calculate hourly values for atmospheric stability from meteorological surface observations;
- Interpolate twice daily mixing heights to hourly values;
- Optionally, calculate the parameters for dry and wet deposition processes; and
- Output data in an unformatted or ASCII format required by regulatory air quality dispersion models.

AERMOD Meteorological Data

AERMOD requires a preprocessor that organizes and processes meteorological data, and estimates the necessary boundary layer parameters for dispersion calculations in AERMOD. The meteorological preprocessor that serves this purpose is AERMET (U.S. EPA, 2004b).

AERMOD accepts hourly meteorological data, consisting of a "surface" file and a "profile" file that has been preprocessed by the AERMET preprocessor. AERMET includes three stages of preprocessing of the meteorological data. The first two stages extract, quality check, and merge the available meteorological data. The third stage requires input of certain surface characteristics (surface roughness, Bowen ratio, and albedo) that vary from site to site. The user needs to know whether the land use is water, deciduous forest, coniferous forest, swamp, cultivated land, grassland, urban, or desert shrubland (Trinity, 1991).

As a surface meteorological input data, Aben ERMET requires same hourly observations as PCRAMMET. However, AERMET needs Radiosonde observations (generally collected twice-daily, at 0000 Greenwich Mean Time (GMT) and 1200 GMT) of:

- Atmospheric pressure
- Height above ground level
- Temperature
- Wind direction
- Wind speed

An Overview of Meteorology of the Study Area

In Turkey, The State of Department of Meteorology operates two kinds of measurement stations: small meteorology stations and synoptic meteorological stations. Small meteorology stations are able to record only surface meteorological data. Synoptic meteorological stations are able to record radiosonde (upper air) meteorological data besides surface meteorological data.

The closest meteorology station to the study area is Beypazarı station which is a small meteorology station. Surface hourly observations were obtained from Beypazarı station. On the other hand, the closest synoptic meteorological station to the study area is Ankara station. Therefore, upper air data was obtained from Ankara station.

Moreover, long period meteorological data for the past 30 years (1975 - 2004) has been obtained from Beypazarı station and was examined in order to understand general characteristics of meteorology of the study area.

Monthly average values for the parameters like temperature, relative humidity, wind speed, local pressure, and precipitation obtained from the Beypazarı meteorological station are given in Table 4.10.

As it can be seen from the Table 4.10 the average temperature values varies between 1.1 ^{0}C measured for January and 24.8 ^{0}C measured for July. Based on the 30 year temperature data, highest temperature is 43 ^{0}C which was recorded in July 30th, 2000, and the lowest temperature was recorded in February 22nd, 1985 as -17.3 ^{0}C. The calculated annually average value of the measured ambient air temperature is 13 ^{0}C.

When the relative humidity values given in the Table 4.10 are reviewed, it can be seen that the monthly average values are between 49% (July) and 76% (December). The average annual relative humidity is 61% based on the given data.

Table 4.10 Monthly average values of meteorological parameters based on the 30 year data (1975-2004) obtained from Beypazarı meteorology station.

Month	Temperature (^{0}C)	Relative Humidity (%)	Wind Speed (m/s)	Local Pressure (hPA)	Precipitation (mm)
January	1.1	74	1.4	938.9	48.2
February	2.8	70	1.5	937.7	32.9
March	7.1	63	1.7	936.3	32.6
April	12.4	60	1.9	934.7	48.4
May	17.3	58	1.9	935.8	43.0
June	21.6	53	2.0	935.5	28.8
July	24.8	49	2.1	934.4	13.9
August	24.4	50	1.9	935.2	14.6
September	20.0	52	1.6	937.6	12.9
October	14.1	62	1.3	939.8	28.8
November	7.5	69	1.3	940.1	37.4
December	2.9	76	1.3	939.2	55.3
Annual	**13**	**61**	**1.7**	**937.1**	**Total=396.8**

The wind roses presented Figure 4.2 are plotted based on the data given in Table 4.10. As can be seen from the wind roses the prevailing wind directions are ENE and N based on the wind speed and number of wind blows, respectively.

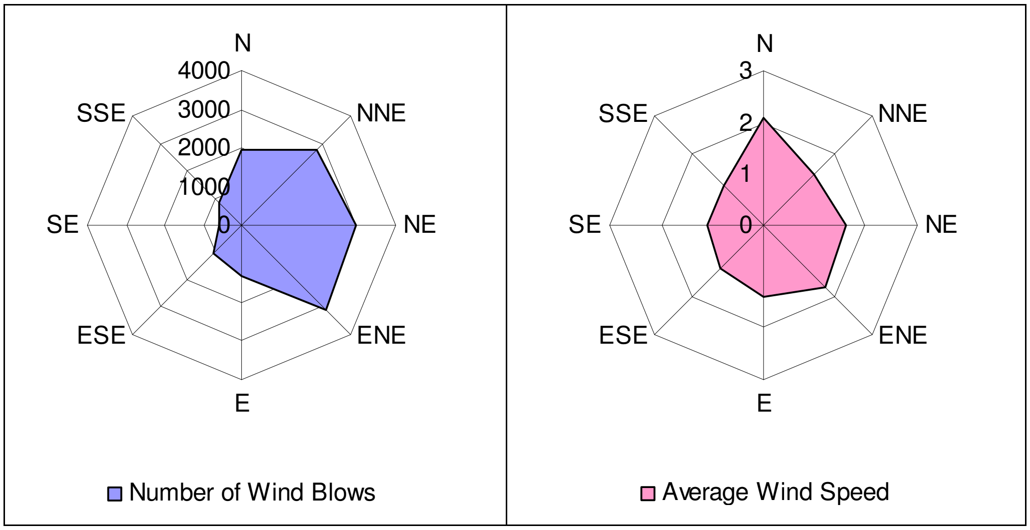


Figure 4.2 Wind roses for the study area for data period of 1975 - 2004

Meteorological Data of Year 2004

Air quality modeling study for the Çayırhan Thermal Power Plant was performed for the year 2004. Hourly surface meteorological data and upper air data for year 2004 were used in this study.

In order to understand the general meteorological characteristics in 2004, monthly average values for the parameters temperature, relative humidity, wind speed, and precipitation obtained from the Beypazarı meteorological station are given in Table 4.11.

As it can be seen from Table 4.11 the average temperature values varies between 1.2 ^{0}C measured for January and 25.7 ^{0}C measured for July. In 2004, highest temperature is 39 ^{0}C which was recorded in July 30th and August 1st, and the lowest temperature was recorded in February 15th as -14.3 ^{0}C. The calculated annual average value of the measured ambient air temperature is 13.3 ^{0}C.

The monthly average of relative humidity values ranges between 46% (July) and 78% (January). The average annual relative humidity is 59% based on the given data. It was seen in the study area that meteorological characteristics for the year 2004 was very similar to average long period (30 years) meteorological characteristic.

Table 4.11 Monthly average values of meteorological parameters based on annual meteorological data of 2004

Month	Temperature (^{0}C)	Relative Humidity (%)	Wind Speed (m/s)	Precipitation (mm)
January	1.2	78	1.4	48.2
February	2.3	68	1.0	32.9
March	7.8	57	1.1	32.6
April	12.7	54	1.5	48.4
May	17.1	54	1.4	43.0
June	21.4	54	1.6	28.8
July	25.7	46	1.3	13.9
August	24.0	52	1.6	14.6
September	20.9	52	1.2	12.9
October	15.5	60	0.8	28.8
November	7.8	66	0.7	37.4
December	2.7	70	0.7	55.3
Annual	**13.3**	**59**	**1.2**	**Total=321.9**

Annual wind rose were plotted in order to present prevailing wind speeds and wind directions in the study area during 2004. Figure 4.3 shows the wind rose for the period between 1 January 2004 and 31 December 2004. According to this figure, dominant wind directions are NE, S and NEN. Nearly 12% of the time wind blows from NE, about 11% of the time wind blows form S and 9% of the time wind blows from NEN. As can be seen from the wind roses the prevailing wind directions are ENE and N based on the wind speed and number of wind blows, respectively.

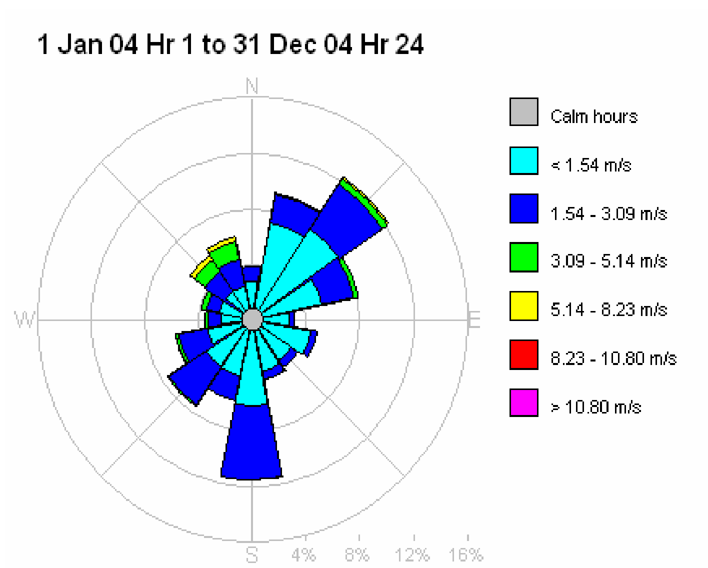


Figure 4.3 Annual wind rose in the study area for the year 2004

4.3 Turkish Air Quality Protection Regulation

The 1983 Environmental Law considers environmental issues in a broad way and establishes the principle of the “polluter pays”. The main instrument for air quality management in Turkey is the Turkish Air Quality Protection Control Regulation (TAQPR, 1986), which aims to protect human beings and the environment from the hazards of air pollutants.

TAQPR sets the limits for ambient air pollution concentrations. These limits are presented Table 4.12. Council Directive 1999/30/EC of 22 April 1999 is relating to limit values for sulphur dioxide, oxides of nitrogen and particulate matter in ambient air applying in European Union. Table 4.13 gives the limit values of Council Directive 1999/30/EC.

Table 4.12 Ambient air pollution limits according to TAQPR (TAQPR, 1986)

Pollutants	Unit	Short Term Limits**	Long Term Limits*
SO_2	$\mu g/Nm^3$	400	150
NO_2	$\mu g/Nm^3$	300	100
NO	$\mu g/Nm^3$	600	200
PM_{10}	$\mu g/Nm^3$	300	150

* Long Term Limit is the arithmetic mean of all measurements. Usually, a period of one year data is used computations.
** Short term limit is the maximum daily average value or is the value, which should not exceed statistically the 95% of all monitoring results when all monitoring values are sorted in descending order.

Table 4.13 Ambient air pollution limits according to Council Directive 1999/30/EC

Pollutants	Unit	Daily Limits*	Annual Limits*
SO_2	$\mu g/Nm^3$	125	-
NO_x	$\mu g/Nm^3$	-	40
PM_{10}	$\mu g/Nm^3$	50	40

* Limit values for the protection of human health

4.4 Ambient Air Quality Measurements and Model Performance Evaluation

Ambient air pollution measurement studies were conducted in November 2004 by an environmental consultant company hired by the Power Plant. SO_2 and NO_x were measured with passive tubes at 15 locations at the study area around the plant for a period of one month. Results of these measurements were reported to the Ministry of Environment and Forest in 2005 (ENVY, 2005). Sampling locations were selected to be in the main directions considering the power plant as a center. Also, diffusion tubes were located at each residential area to determine the pollutant concentrations at these villages. Figure 4.4 presents the locations of the diffusion tubes for measuring SO_2 and NO_x concentrations

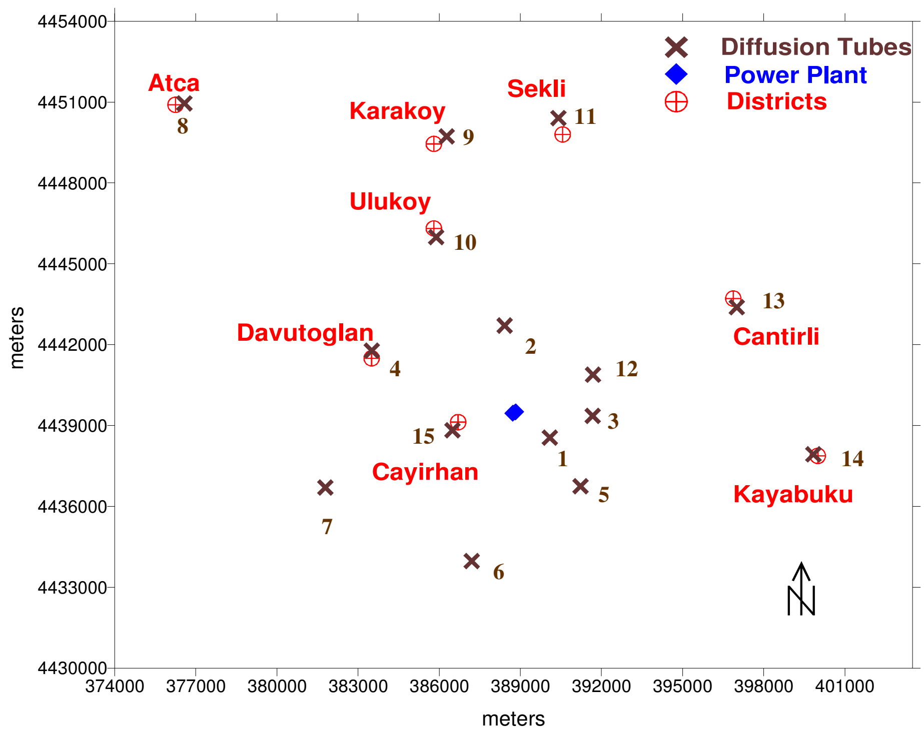


Figure 4.4 Locations of the diffusion tubes for measuring SO_2 and NO_x concentrations

Model performance evaluation is a way to determine the accuracy of the model for predicted results. Dispersion models require several input data. Some of the input data are based on assumptions and calculations using empirical formulas. The accuracy of these assumptions affects the accuracy of model results.

Figure 4.5 illustrates diffusion tubes used for measurements by the consulting company and Figure 4.6 shows the setting of diffusion tubes at measurement locations. The diffusion tubes were located in the measurement locations and stayed there for a month. At the end of the month, the tubes were collected and sent for analysis to the laboratory.

SO_2

NO_x

Figure 4.5 Diffusion tubes for measuring SO_2 and NO_x concentrations

Figure 4.6 Diffusion tubes settings at measurement locations

In Table 4.14 gives the results of the ambient air pollution measurements conducted at 15 locations. These data obtained from measurements was used in this study to control the model predictions. For SO_2, the maximum concentration recorded was 97.08 µg/Nm^3 at Çayırhan city. For NO_x, the maximum concentration recorded was 49.94 µg/Nm^3 at the measurement point located Northeast direction of the power plant.

Table 4.14 Results of ambient air pollution measurements

Locations	**SO_2 (µg/Nm^3)**	**NO_x (µg/Nm^3)**
1	34.68	12.67
2	30.13	13.87
3	28.64	9.71
4	34.82	13.11
5	37.34	6.94
6	29.38	6.96
7	20.26	5.04
8	37.95	5.77
9	24.91	5.57
10	37.26	11.14
11	20.90	4.88
12	36.07	49.94
13	28.43	7.63
14	20.16	7.63
15	97.08	22.97

CHAPTER 5

RESULTS AND DISCUSSIONS

The study area is an area of 25 km x 30 km enclosing Çayırhan Thermal Power Plant and 8 villages. In the study area, there are different types of emission sources. Çayırhan Thermal Power Plant has 4 stacks and these stacks were used as "point sources". There are 2 coal stockpiles feeding the boilers of the power plant and these coal stockpiles were used as "area sources" located at the power plant. Also, 8 villages in the study area were used as "area sources". Figure 5.1 shows the locations of these emission sources on the topographical map of the study area.

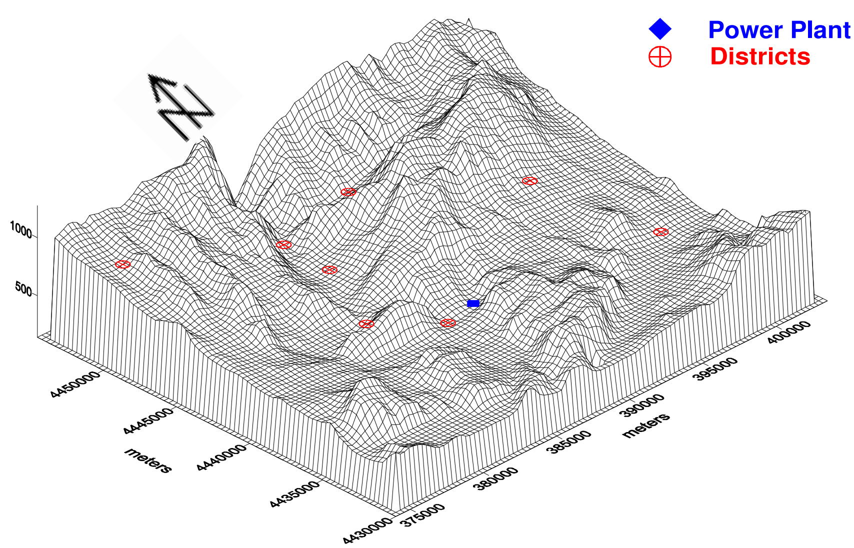


Figure 5.1 Locations of emission sources on topographical map of the study area

ISCST3 and AERMOD models were used in order to estimate concentrations of air pollutants, namely SO_2, NO_x and PM_{10}. Results of two models are compared for two different averaging periods:

- Annual average (long term)
- Daily average (short term)

Emission sources are grouped in order to comprehend the effects of Çayırhan Thermal Power Plant and villages on the pollution distribution over the study area. 4 stacks of power plant and 2 coal stockpiles grouped as power plant sources and 8 villages formed domestic heating sources.

The emissions from villages and coal stockpiles were estimated by using CORINAIR emission factors and AP 42 emission factors, respectively. In the study region, people use coal having 1.39% by weight total sulphur for domestic heating during winter. There are 8 villages located in the region. Çayırhan is the most populated city with 8636 people and Çantırlı is the smallest village with 148 people.

Industrial Source Complex Short Term Version 3 was developed by the U.S. EPA. It is a modified steady-state Gaussian plume model. Until the year 2005, EPA has recommended ISCT3 for regulatory modeling studies. Since the year 2005, EPA has been recommending AERMOD modeling system instead of ISCST3 for regulatory purposes. AERMOD is also a steady-state plume model. It improves estimates of dispersion in the planetary boundary layer by accounting for varying dispersion rates with height, refined turbulence based on current planetary boundary layer theory and advanced treatment of mixing height, plume rise and complex terrain. The both models are regulatory models. Therefore, it is not possible to modify or make changes in the algorithms of the models.

In section 4.2.1, the differences in main features of two air dispersion models were explained. Because of these differences, modeling studies resulted in comparable outcomes. As a result, different maximum concentration values, different maximum concentration locations and different ground level concentration distribution graphs were obtained as result of modeling executions.

5.1 Modeling Results for SO_2

Air dispersion modeling results for ground level concentrations of SO_2 is presented in Figure 5.2 to 5.15 according to source groups and averaging periods.

5.1.1 Annual Dispersion of SO_2

Table 5.1 summarizes the annual SO_2 results predicted by the models. As can be seen from the table, the maximum SO_2 concentrations predicted by both models are very close to each other which show that these two models basically are using the similar algorithms. The average of the results obtained from the models on the annual basis is below the TAQPR annual limits.

Table 5.1 Maximum annual SO_2 concentrations predicted by ISCST3 and AERMOD

Sources	**Maximum annual SO_2 Concentrations, μg/Nm^3**		**TAQPR Limit, μg/Nm^3**
	ISCST3	**AERMOD**	
All sources	50	49	150
Only the power plant	41	43	150
Only domestic heating	49	41	150

The annual average ground level concentrations of SO_2 estimated by ISCST3 and AERMOD are given in Figure 5.2 to 5.7.

Figure 5.2 and Figure 5.3 show the annual average concentration of SO_2 due to all sources. Both ISCST3 and AERMOD found very close maximum annual concentration results for SO_2 considering all sources as active. The maximum annual concentration estimated by ISCST3 is 50 $\mu g/Nm^3$ at southwest of Çayırhan. However, the maximum annual concentration estimated by AERMOD is 49 $\mu g/Nm^3$ which occurred at south of Sekli. The long term limit for SO_2 given by TAQPR is 150 $\mu g/Nm^3$. In everywhere of the study area, the annual average concentrations are below this limit. The ground level concentration map plotted by AERMOD is more uniformly distributed than by ISCST3, especially around the villages.

Figure 5.4 and Figure 5.5 show the effect of Çayırhan Thermal Power Plant on annual average concentration of SO_2. ISCST3 and AERMOD estimated the maximum annual concentration due to power plant at northern parts of the plant as 41 $\mu g/Nm^3$ and 43 $\mu g/Nm^3$; respectively. The ground level concentration map plotted by AERMOD shows that power plant effects can be observed at further distances. On the other hand, power plant affects more limited area according to ISCST3 result. Both models point out that emissions from the power plant are mostly effective on Sekli and Çantırlı. The maximum annual average ground level SO_2 concentrations due to Çayırhan Thermal Power Plant is below the long term ambient air concentration limits of SO_2 given by TAQPR, which is 150 $\mu g/Nm^3$.

Figure 5.6 and Figure 5.7 show the annual average SO_2 concentration distributions in towns located at the study area due to domestic heating. ISCST3 run resulted in 49 $\mu g/Nm^3$ and AERMOD run resulted in 41 $\mu g/Nm^3$ as maximum annual average concentration of SO_2 originated from towns. The highest sources of SO_2 pollution is Çayırhan and Sekli among the other towns. Çayırhan is the most crowded town in the area of interest. Therefore, high SO_2 concentrations are observed around Çayırhan due to its higher population than the other towns. However, Sekli and Karaköy are not crowded as Çayırhan but they are located close to high hills. Therefore, moderately high SO_2 concentrations are encountered around these two towns. SO_2 is only emitted during winter months due to domestic heating in these towns.

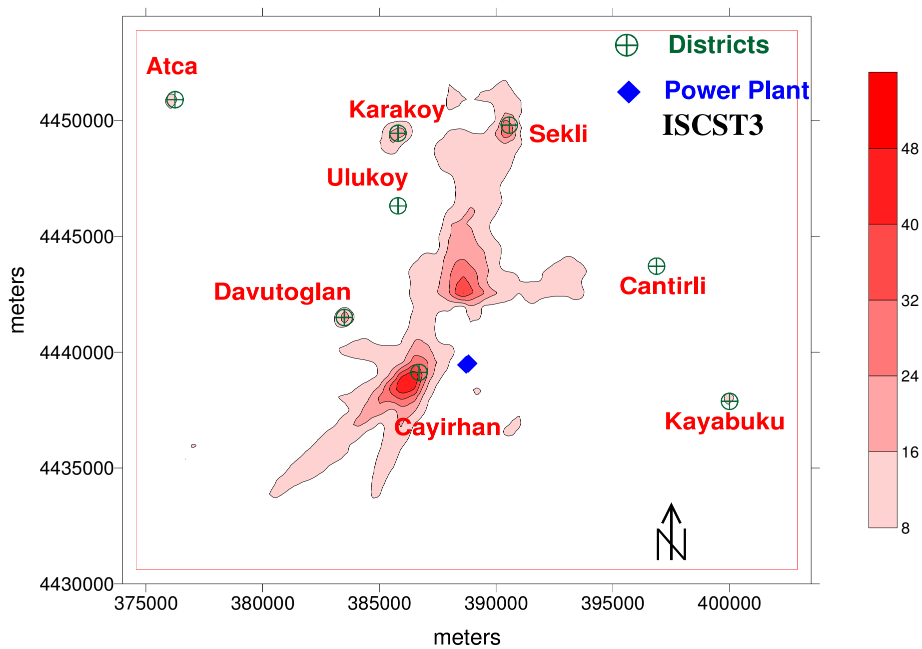


Figure 5.2 ISCST3 annual average ground level concentrations (µg/Nm^3) of SO_2 due to all sources

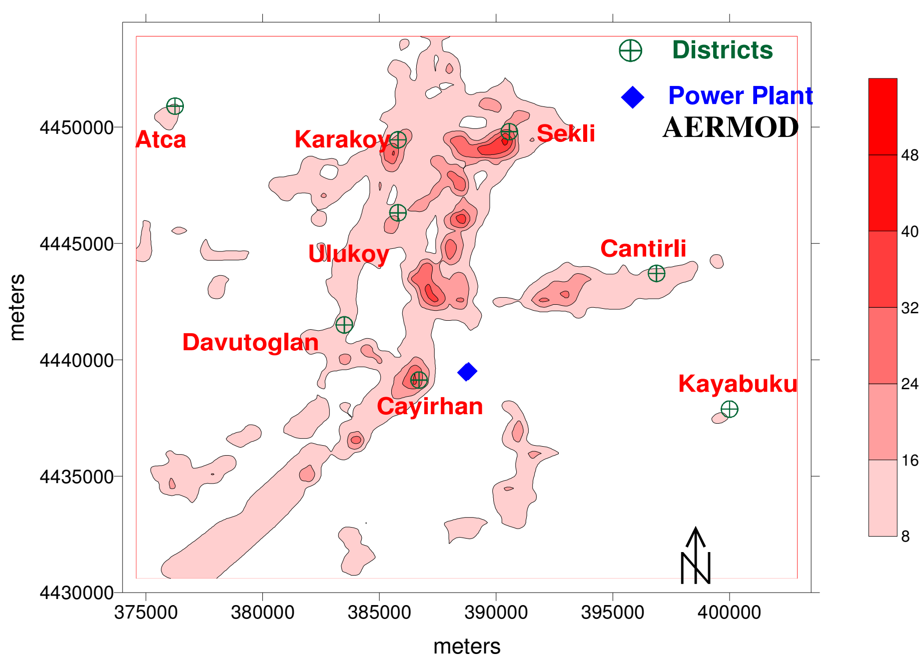


Figure 5.3 AERMOD annual average ground level concentrations (µg/Nm^3) of SO_2 due to all sources

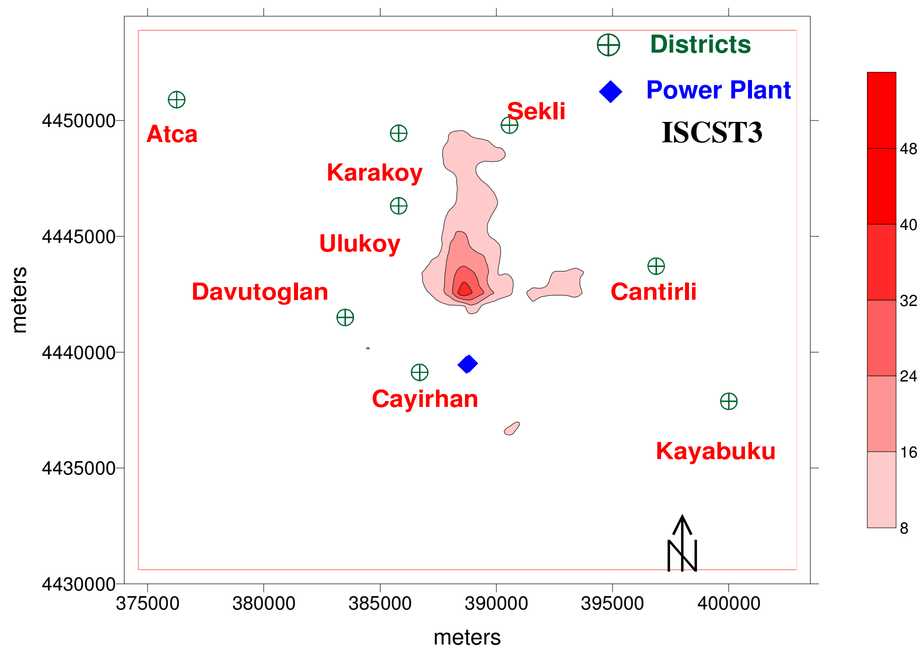


Figure 5.4 ISCST3 annual average ground level concentrations (µg/Nm^3) of SO_2 due to power plant

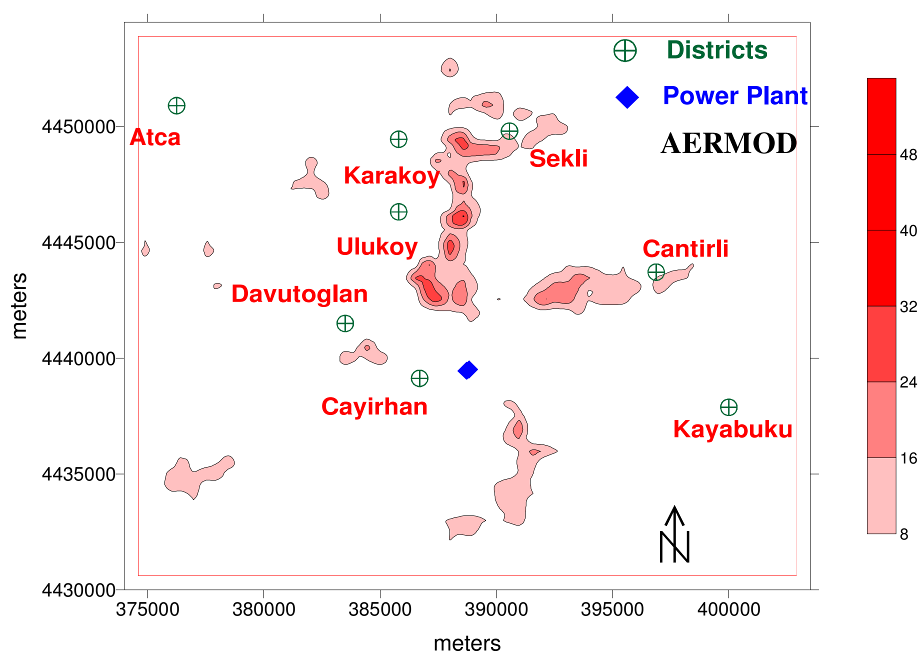


Figure 5.5 AERMOD annual average ground level concentrations (µg/Nm^3) of SO_2 due to power plant

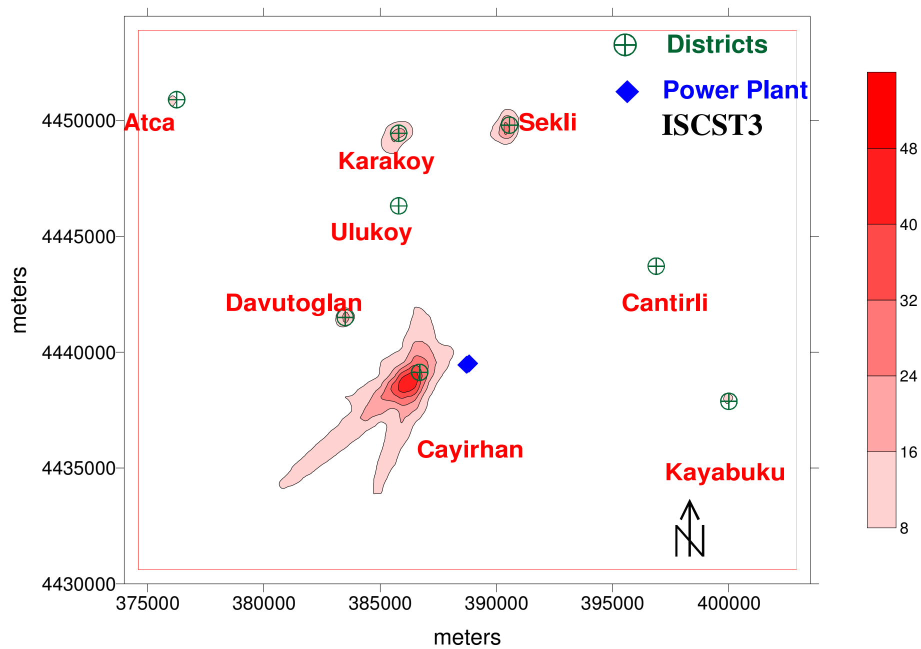


Figure 5.6 ISCST3 annual average ground level concentrations (μg/Nm^3) of SO_2 due to domestic heating

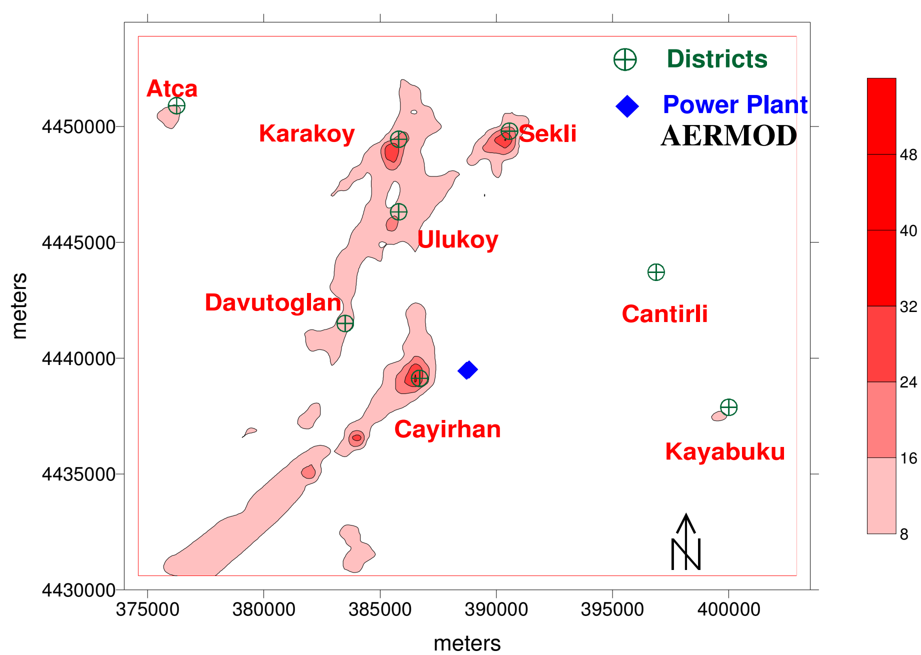


Figure 5.7 AERMOD annual average ground level concentrations (μg/Nm^3) of SO_2 due to domestic heating

Figure 5.8 and Figure 5.9 show the contribution of power plant and domestic heating to the SO_2 concentrations at the residential areas according to estimation of the models ISCST3 and AERMOD, respectively. These contributions are calculated according to numerical results given in Table B-1 of Appendix B. Both models have good correlation between each other in estimating SO_2 pollution at the residential areas. This was expected because of the basic similarities of the model algorithms. Except Çantırlı, domestic heating is the major SO_2 source at all cities. The first reason is that Çayırhan Thermal Power Plant operates Flue Gas Desulphurization system working with minimum 95% efficiency. The second reason is high coal consumption in villages during winter period. Çantırlı is the smallest town in the region. Therefore, the amount of coal used for domestic heating is very small. Also, the elevation of Çantırlı is 748 meters which is a significant elevation for plume descend. These aspects make SO_2 emissions effective on Çantırlı town. Although there are other residential areas closer to the power plant, SO_2 emissions do not contribute on these areas considerably. The meteorological and the topographical properties of the study area are the major reasons for this. For example, Çayırhan, the most populated town, is very close to power plant. However, according to the both models, not only the elevation difference between the town and the power plant but also high stack height of the power plant (100 meters) make effects of the SO_2 emissions of the power plant very weak at the Çayırhan town.

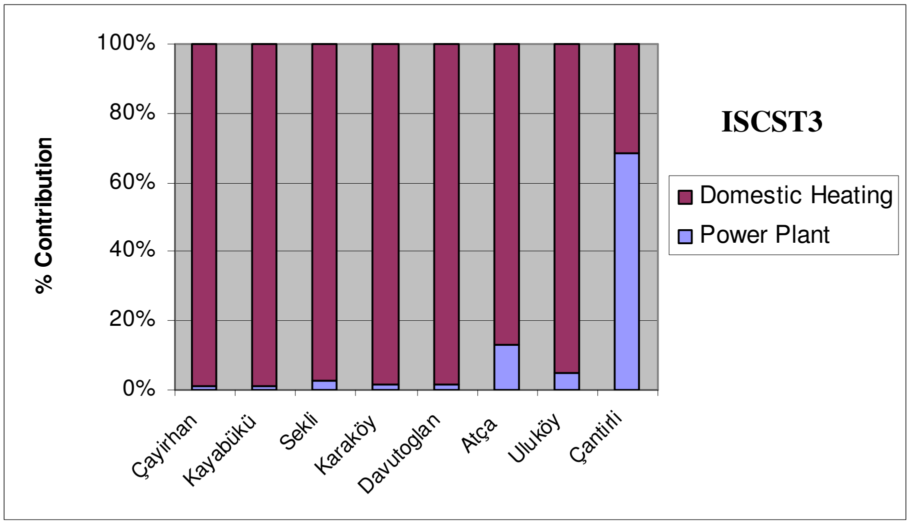


Figure 5.8 Contribution of the power plant and the domestic heating to the annual average SO_2 concentrations at the villages according to ISCST3

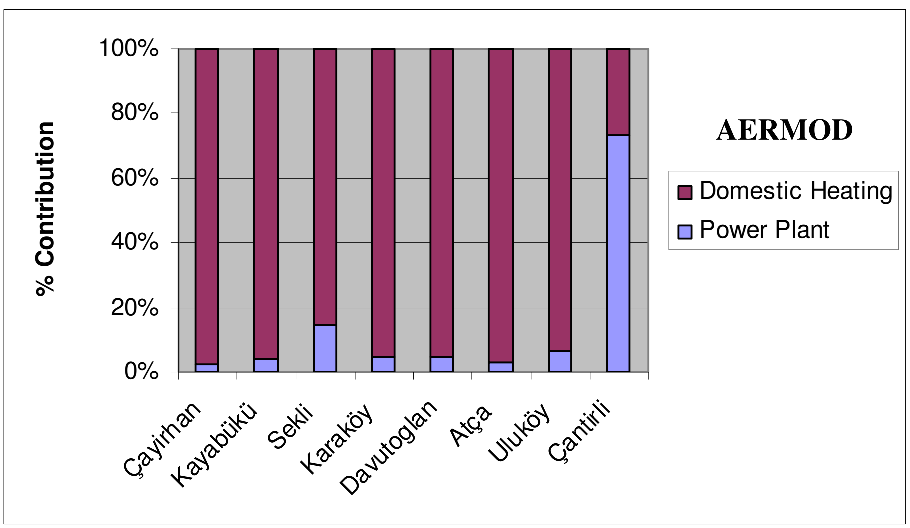


Figure 5.9 Contribution of the power plant and the domestic heating to the annual average SO_2 concentrations at the villages according to AERMOD

5.1.2 Daily Dispersion of SO_2

The daily average ground level concentrations of SO_2 estimated by ISCST3 and AERMOD are given in Figure 5.10 to 5.15.

Figure 5.10 and Figure 5.11 show the daily average concentration of SO_2 due to all sources. The maximum daily SO_2 concentrations are very different for ISCST3 and AERMOD. The maximum daily concentration estimated by ISCST3 is 375 $\mu g/Nm^3$ at northern of Çayırhan. On the other hand, the maximum daily concentration estimated by AERMOD is 591 $\mu g/Nm^3$ at southwest of Çayırhan where 3750 m away from the center of Çayırhan town. The reasons of this considerable difference in the results of two models are explained in Table 4.9. The limit of ambient concentration of SO_2 given by TAQPR is 400 $\mu g/Nm^3$ as short term limit. The results of ISCST3 point out that all the daily average concentrations of SO_2 are below 400 $\mu g/Nm^3$. However, the results of AERMOD show that daily average SO_2 concentrations are above short term limit for 11 days. The 12th maximum daily SO_2 concentration is 391 $\mu g/Nm^3$. These 11 days were in December and January as expected because in these cold seasons coal is used for heating purposes in the household. Emissions of power plant have trace contributions to these 11 highest concentrations. Ground level SO_2 concentrations are significantly higher than 125 $\mu g/Nm^3$ which is daily limit value set by Directive 1999/30/EC.

Figure 5.12 and Figure 5.13 show the effect of Çayırhan Thermal Power Plant on daily average concentration of SO_2. ISCST3 estimated the maximum daily concentration of SO_2 due to power plant as 282 $\mu g/Nm^3$ and AERMOD estimated this quantity as 337 $\mu g/Nm^3$. Both models found the highest concentration at the same point (X: 388500, Y: 4442500). According to the results of both models, Sekli and Çantırlı are the mostly affected towns. The maximum daily average ground level SO_2 concentrations due to Çayırhan Thermal Power Plant is below the short term ambient air concentration limits of SO_2 (400 µg/Nm^3) given by TAQPR and is above the daily limit values of SO_2 (125 µg/Nm^3) given by Directive 1999/30/EC. The power plant has FGD systems and they work with high efficiency (min 95%) and capture the most of the SO_2 generated due to combustion.

Figure 5.14 and Figure 5.15 show the effects of emissions from towns located at study area on daily average SO_2 concentration distributions due to domestic heating. ISCST3 resulted in 375 µg/Nm^3 and AERMOD resulted in 591 µg/Nm^3 of SO_2 as maximum daily average concentration originated from towns. These results indicate that emissions from towns cause the highest SO_2 concentrations in the study area. Moreover, there are no control measures from houses in towns to prevent high SO_2 emissions and pollutants can not be transported because the stacks are too short.

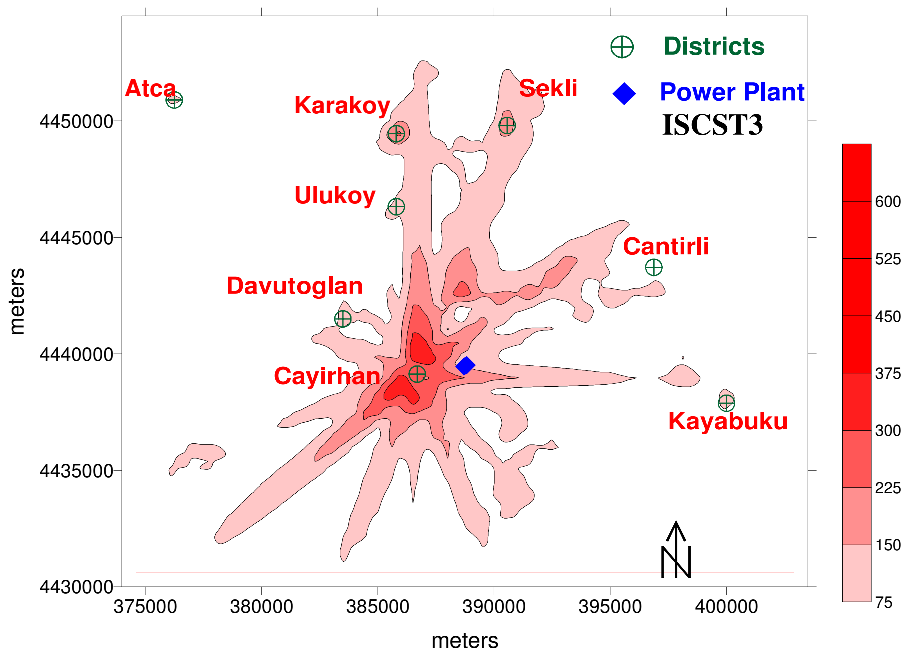


Figure 5.10 ISCST3 daily average ground level concentrations (μg/Nm^3) of SO_2 due to all sources

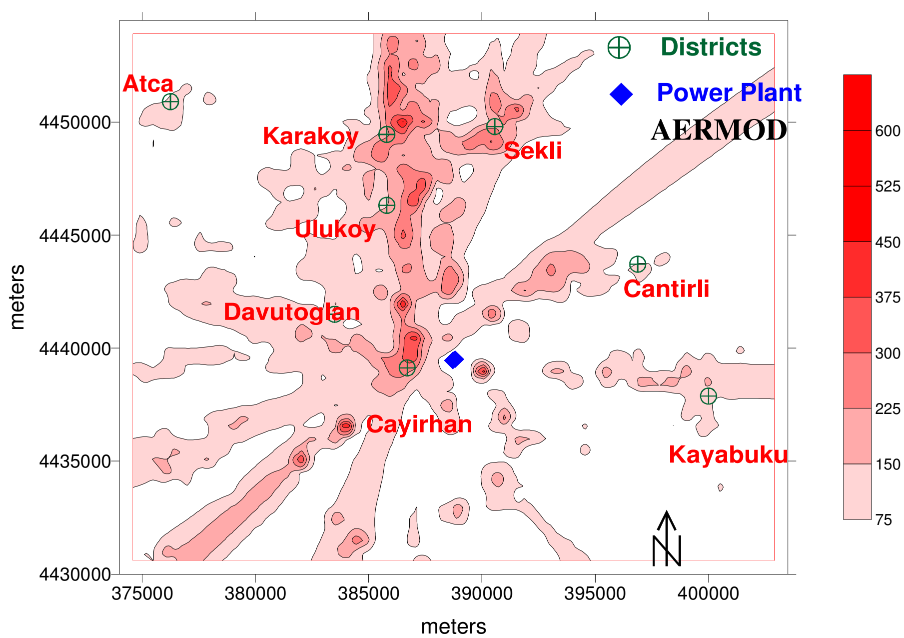


Figure 5.11 AERMOD daily average ground level concentrations (μg/Nm^3) of SO_2 due to all sources

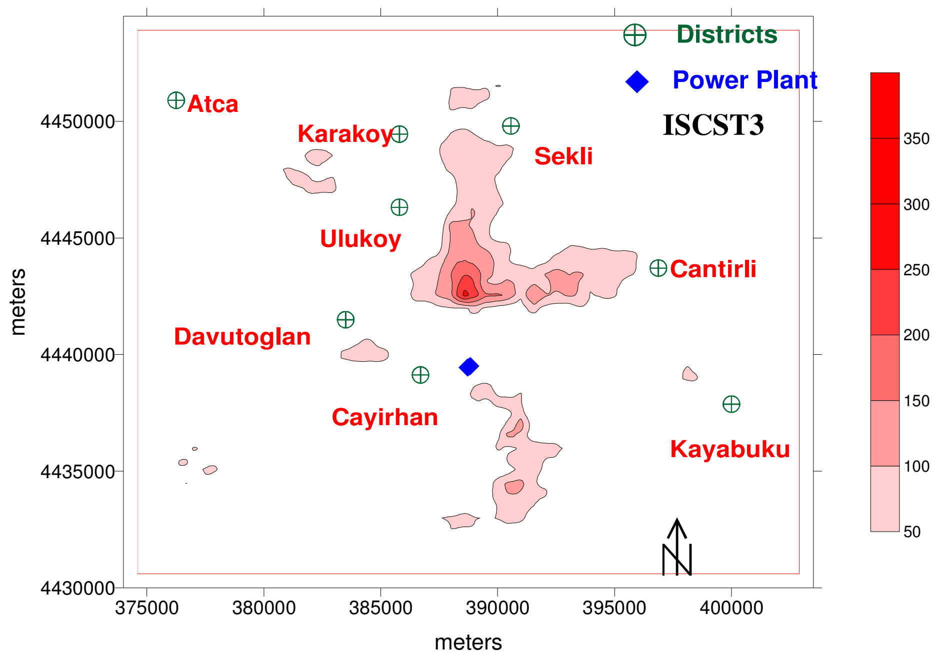


Figure 5.12 ISCST3 daily average ground level concentrations (μg/Nm^3) of SO_2 due to power plant

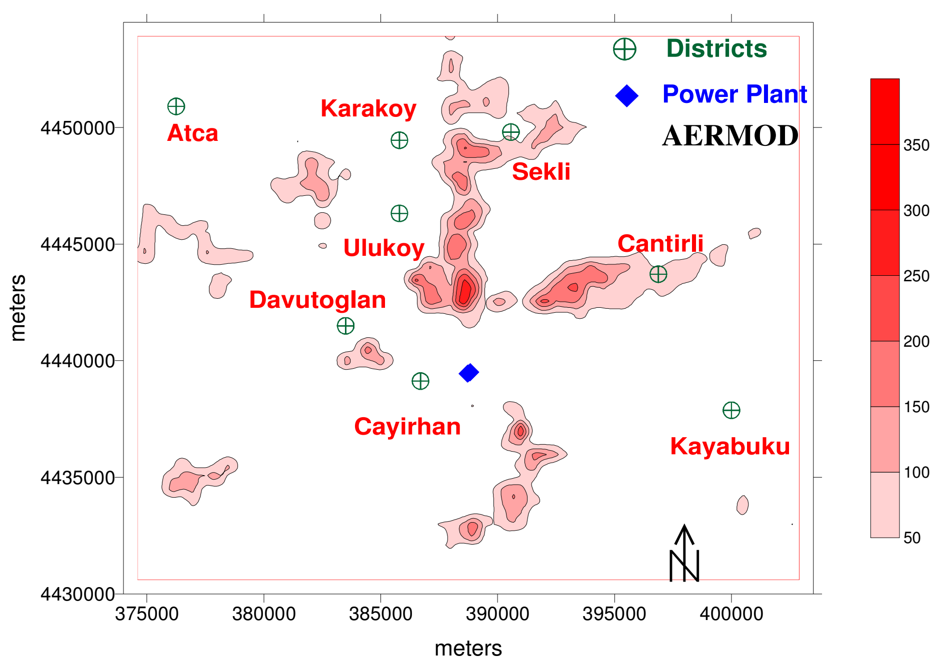


Figure 5.13 AERMOD daily average ground level concentrations (μg/Nm^3) of SO_2 due to power plant

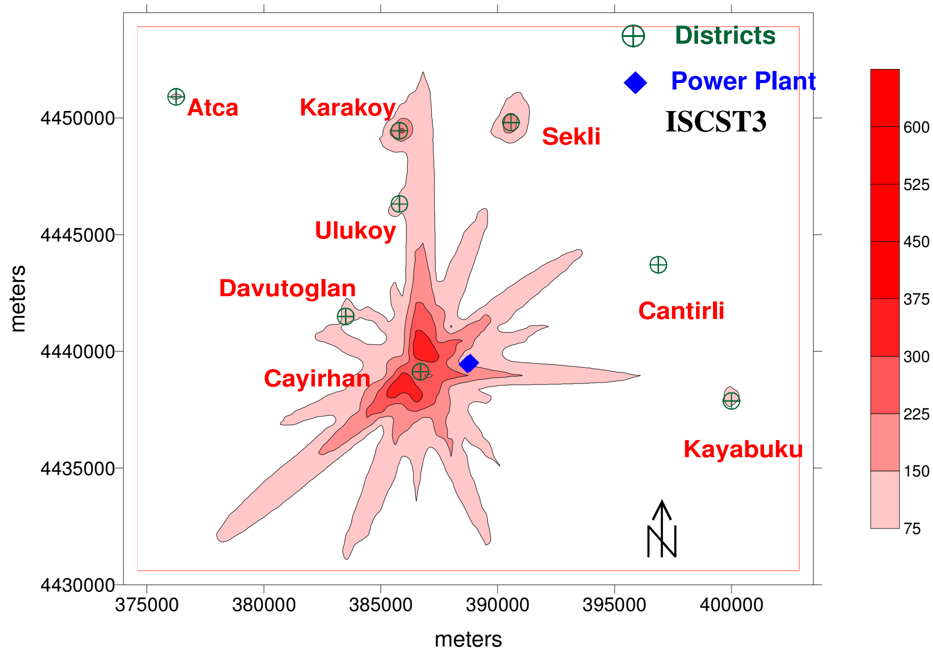


Figure 5.14 ISCST3 daily average ground level concentrations (μg/Nm^3) of SO_2 due to domestic heating

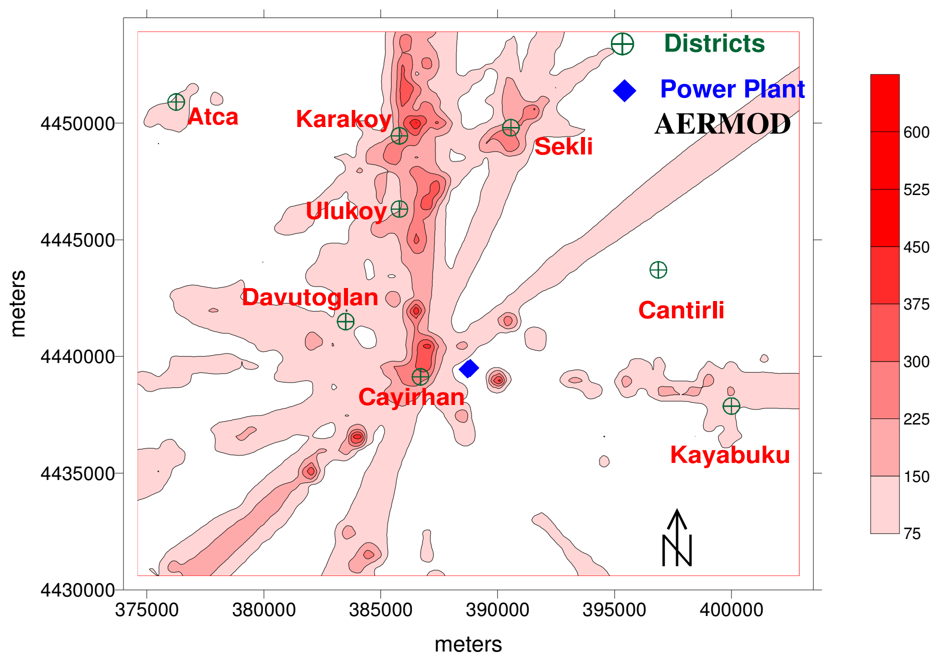


Figure 5.15 AERMOD daily average ground level concentrations (μg/Nm^3) of SO_2 due to domestic heating

5.2 Modeling Results for NO_x

Air dispersion modeling results for ground level concentrations of NO_x is presented in Figure 5.16 to 5.29 according to source groups and averaging periods.

5.2.1 Annual Dispersion of NO_x

The table 5.2 summarizes the annual average NO_x concentrations predicted by the models. As can be seen from the table, maximum annual NO_x concentration was seen due to the Çayırhan Thermal Power Plant (almost 90% of the total concentration). This was an expected result because there is no measure taken in order to reduce NO_x emissions from the power plant. Also, high combustion temperatures resulted in high NO_x emissions from the boiler of the power plant. As the combustion temperature increases, the formation of thermal NO_x also increases. On the other hand, low combustion temperatures do not result in significant NO_x emission in domestic heating. As a result, in the study area, high ground level NO_x concentrations were found to be due to the power plant.

Table 5.2 Maximum annual NO_x concentrations predicted by ISCST3 and AERMOD

Sources	**Maximum annual NO_x Concentrations, µg/Nm^3**		**TAQPR Limit, µg/Nm^3**	**Directive 1999/30/EC, µg/Nm^3**
	ISCST3	**AERMOD**		
All sources	82	89	100	40
Only the power plant	82	88	100	40
Only domestic heating	9	8	100	40

The annual average ground level concentration maps of NOx estimated by ISCST3 and AERMOD due to all sources are shown in Figure 5.16 to 5.21.

As can be seen from these figures, the maximum annual concentration estimated by ISCST3 is 82 µg/Nm^3 at 3030 m north of power plant and the maximum annual concentration estimated by AERMOD is 89 µg/Nm^3 at 6500 m north of power plant. In the TAQPR the long term limits for NO and NO_2 are specified as 200 and 100 µg/Nm^3, respectively. The major nitrogen oxide in the atmosphere is NO_2. Therefore, NO_x concentration results will be compared with limit values of NO_2 given by TAQPR. In everywhere of the study area, the annual average NO_x concentrations are below this limit. However, annual NO_x concentrations are above the 40 µg/Nm^3, which is the limit value set by Directive 1999/30/EC, 15 times according to AERMOD and 11 times according to ISCST3.

Figure 5.18 and Figure 5.19 show the effect of Çayırhan Thermal Power Plant on annual average concentration of NO_x. According to results of both models, the NO_x concentrations are mainly resulted from Çayırhan Thermal Power Plant. ISCST3 and AERMOD estimated the maximum annual concentrations due to power plant at northern parts of the plant as 82 µg/Nm^3 and 88 µg/Nm^3; respectively. Sekli and Çantırlı are the most affected villages by the emissions of Çayırhan Thermal Power Plant. The ground level NO_x concentration map of ISCST3 is more characteristic than the ground level NO_x concentration map of AERMOD. The maximum annual average ground level NO_x concentrations due to Çayırhan Thermal Power Plant is below the long term ambient air concentration limits (100 µg/Nm^3) of NO_x given by TAQPR. According to ISCST3 and ARMOD results, annual NO_x concentrations are above the European Union limit value 13 and 11 times, respectively.

Figure 5.20 and Figure 5.21 show the effects of towns located in the study area on annual average NO_x concentration distributions due to domestic heating.

Çayırhan, Sekli and Karaköy are the highest emission sources of NO_x among other villages. ISCST3 estimated 9 µg/Nm^3 and AERMOD estimated 8 µg/Nm^3 as maximum annual average concentration of NO_x originated from domestic heating. AERMOD results show that NO_x due to domestic heating from villages spreads wider in the area. In ISCST3 results, effects of villages on ground level NO_x concentrations are seen as more local effects. This can be due to differences in the number of assumptions made in both models.

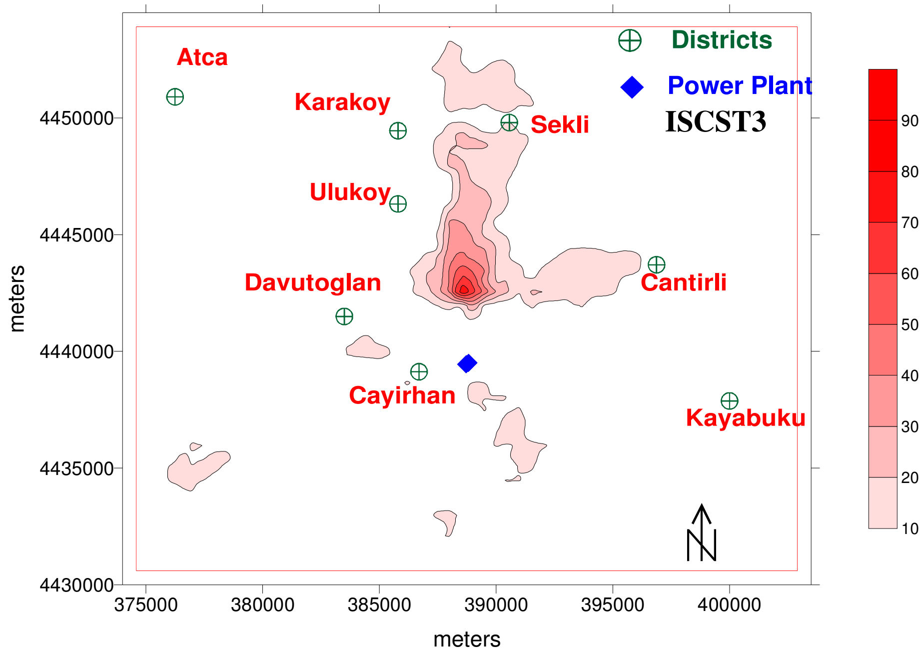


Figure 5.16 ISCST3 annual average ground level concentrations (μg/Nm^3) of NO_x due to all sources

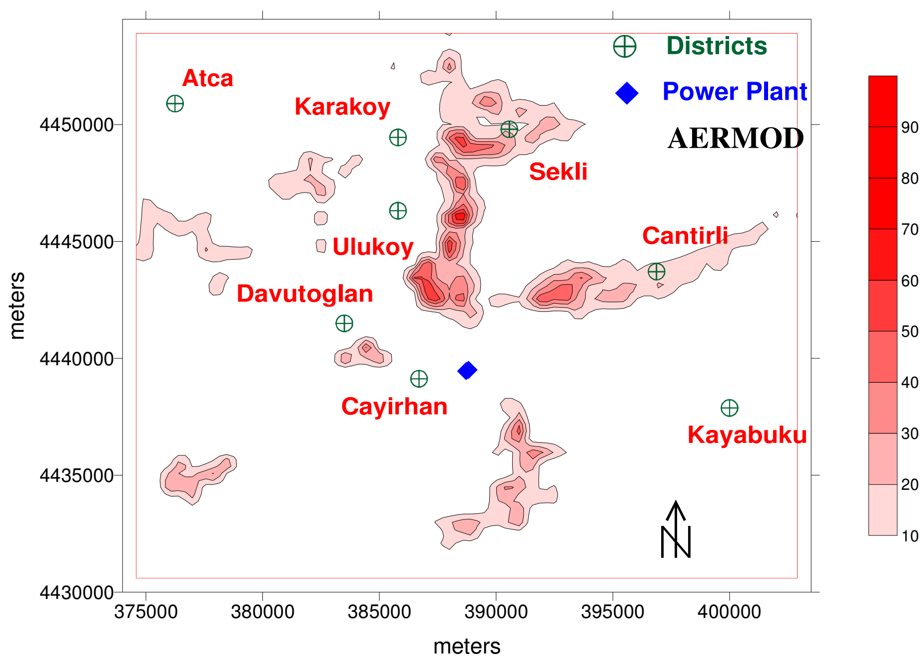


Figure 5.17 AERMOD annual average ground level concentrations (μg/Nm^3) of NO_x due to all sources

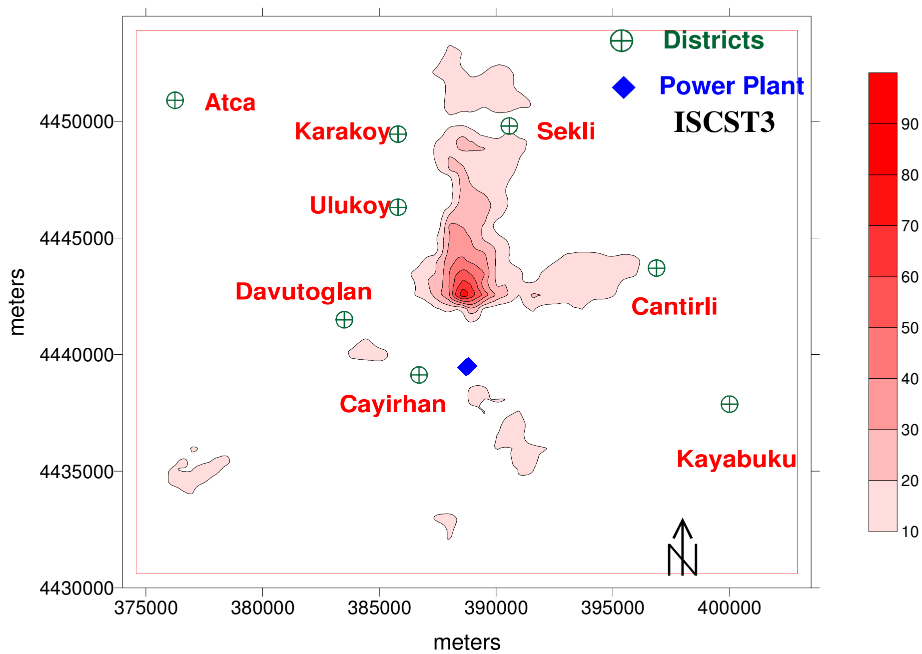


Figure 5.18 ISCST3 annual average ground level concentrations (μg/Nm^3) of NO_x due to power plant

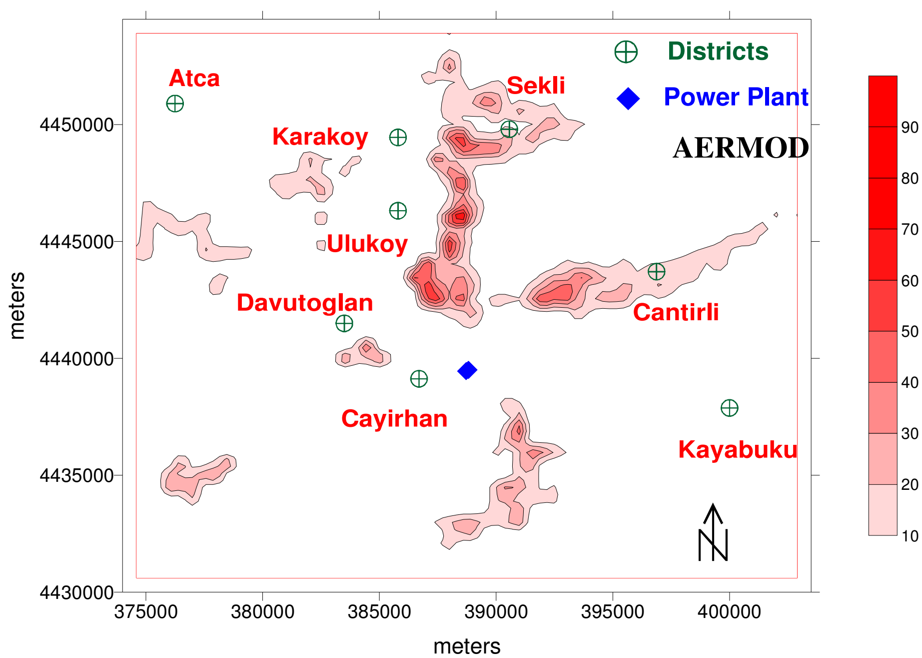


Figure 5.19 AERMOD annual average ground level concentrations (μg/Nm^3) of NO_x due to power plant

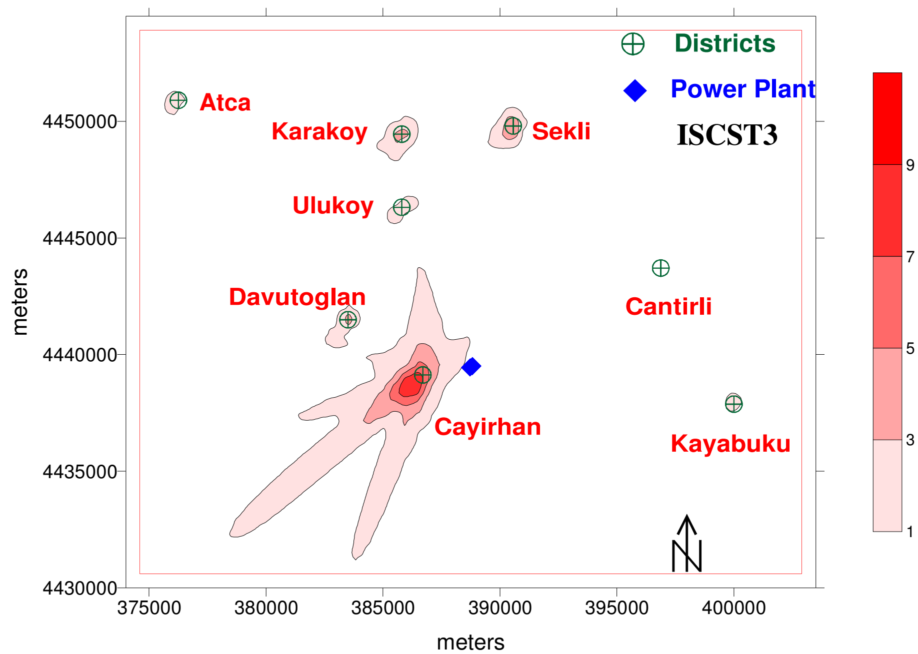


Figure 5.20 ISCST3 annual average ground level concentrations (µg/Nm^3) of NO_x due to domestic heating

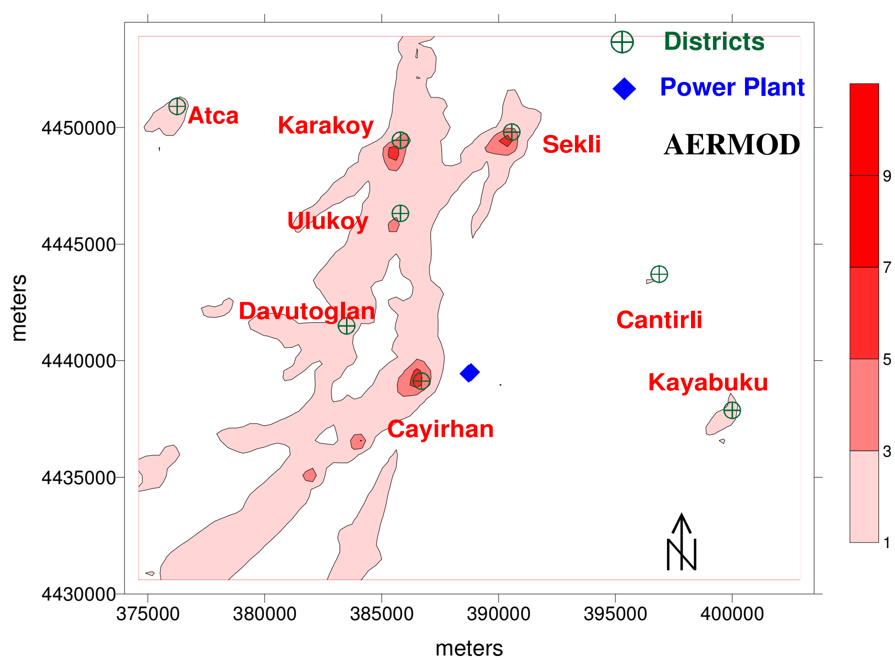


Figure 5.21 AERMOD annual average ground level concentrations (µg/Nm^3) of NO_x due to domestic heating

Figure 5.22 and 5.23 show the contribution of the power plant and the domestic heating sources to the NO_x pollution at the residential areas estimated by ISCST3 and AERMOD, respectively. These contributions are calculated according to numerical results given in Table B-2 of Appendix B. As in the case of SO_2, both models pictured out very similar contribution pattern. However, estimation of AERMOD shows higher contributions of the power plant than that of ISCST3. The AERMOD treatment avoids potential underpredictions suffered by ISCST3 due to its "all or nothing" treatment of the plume. AERMOD's use of "convective updrafts and downdrafts in a probability density function" approach demonstrates effects of the power plant at far away locations more significantly. According to ISCST3, the power plant contributes effectively to the NO_x pollution at Atça and Çantırlı and according to AERMOD, the power plant contributes effectively to the NO_x concentrations at Atça, Çantırlı and Sekli. All these 3 residential areas have significantly high elevated topography which makes them affected from the power plant emissions. As expected, high elevation areas are probably affected more than low elevated locations because the plume hits the higher locations first.

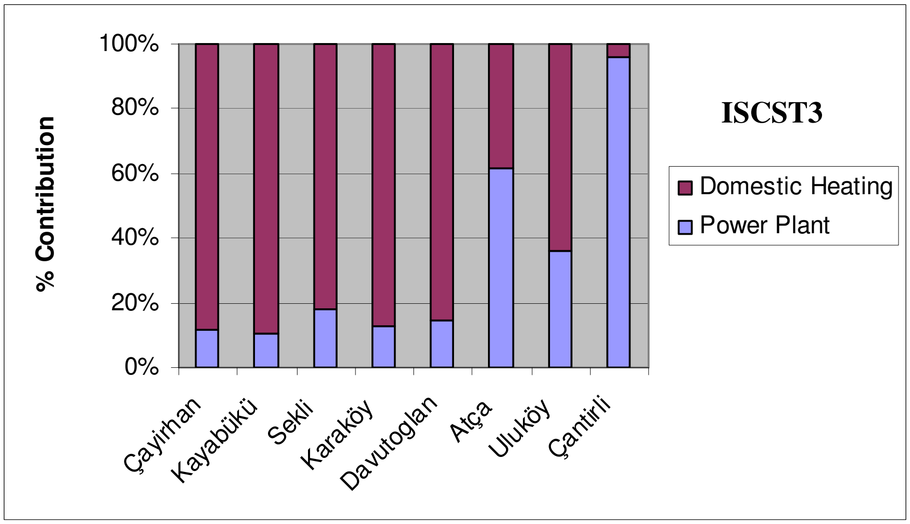


Figure 5.22 Contribution of the power plant and the domestic heating to the annual average NO_x concentrations at the villages according to ISCST3

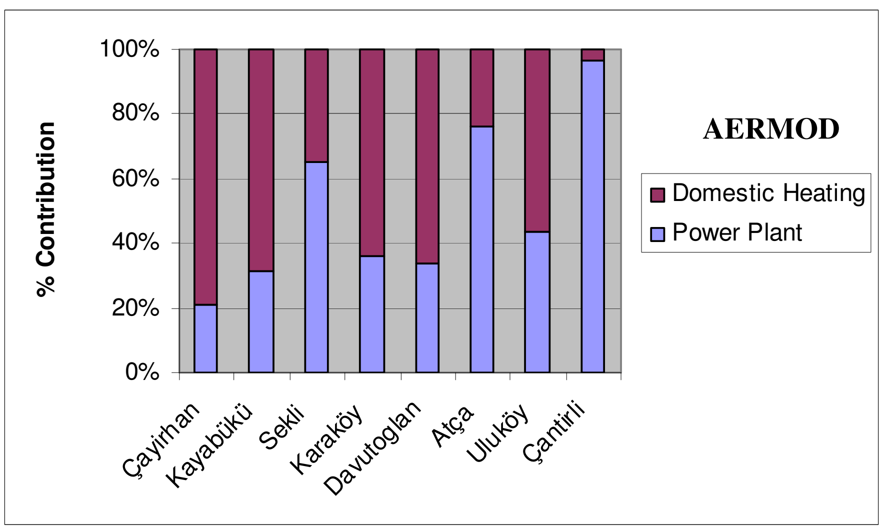


Figure 5.23 Contribution of the power plant and the domestic heating to the annual average NO_x concentrations at the villages according to AERMOD

5.2.2 Daily Dispersion of NO_x

The daily average ground level concentrations of NO_x estimated by ISCST3 and AERMOD are given in Figure 5.24 to 5.29.

The daily average concentrations of NO_x due to all sources are presented in Figure 5.24 and Figure 5.25. The results are very high due to high NO_x emission rates of Çayırhan Thermal Power Plant. The maximum daily average concentration estimated by ISCST3 is 570µg/Nm^3 at the northern part of the power plant. However, maximum daily average concentration estimated by AERMOD is 695µg/Nm^3 at the same point (X: 388500, Y: 4442500). The short term limit for NO_2 is 300µg/Nm^3 according to the TAQPR. The short term limit is the maximum daily average value or is the value, which should not exceed statistically the 95% of all monitoring results when all monitoring values are sorted in descending order. According to ISCST3 results, 95% of the maximum daily average concentration values of NO_x are below 263 µg/Nm^3 and 95% of the maximum daily average concentration values of NO_x estimated by AERMOD are below283 µg/Nm^3. Although maximum daily average NO_x concentrations are considerably very high, in the study area these concentrations are below the short term limit of NO_2. The short term limit of ambient concentration of NO_2 given by TAQPR is 300 µg/Nm^3.

Figure 5.26 and Figure 5.27 show the effect of Çayırhan Thermal Power Plant on daily average concentration of NO_x. ISCST3 estimated the maximum daily concentration of NO_x due to power plant as 570 µg/Nm^3 and AERMOD estimated 695 µg/Nm^3 as maximum daily average concentration of NO_x. Both models found the highest concentration at same point (X: 388500, Y: 4442500). According to the results of ISCST3, power plant does not affect villages significantly. However, AERMOD shows that NO_x emissions from power plant cause about 250 – 300 µg/Nm^3 ground level NO_x concentrations at Sekli and Çantırlı.

Figure 5.28 and Figure 5.29 show the effects of towns located in the study area on daily average NO_x concentration distributions due to domestic heating. ISCST3 resulted in 70µg/Nm^3 and AERMOD resulted in 110 µg/Nm^3 as maximum daily average concentration of NO_x originated from villages. The second highest NO_x concentration is 97µg/Nm^3 which is estimated by AERMOD. ISCST3 shows that Çayırhan, Sekli and Karaköy have considerable NO_x emissions. AERMOD points out that all villages emit relatively high NO_x emissions except Çantırlı town.

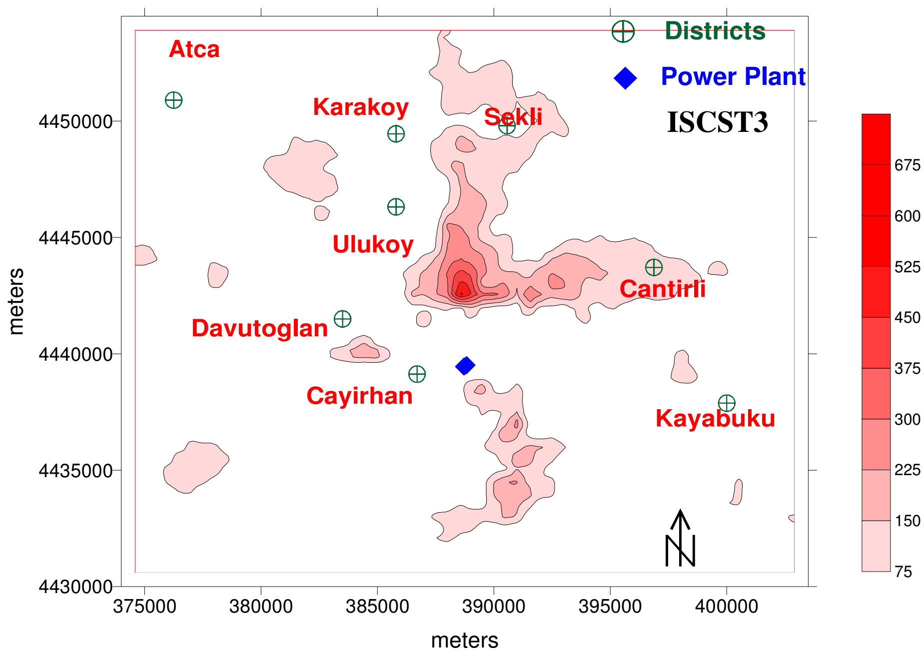


Figure 5.24 ISCST3 daily average ground level concentrations (μg/Nm^3) of NO_x due to all sources

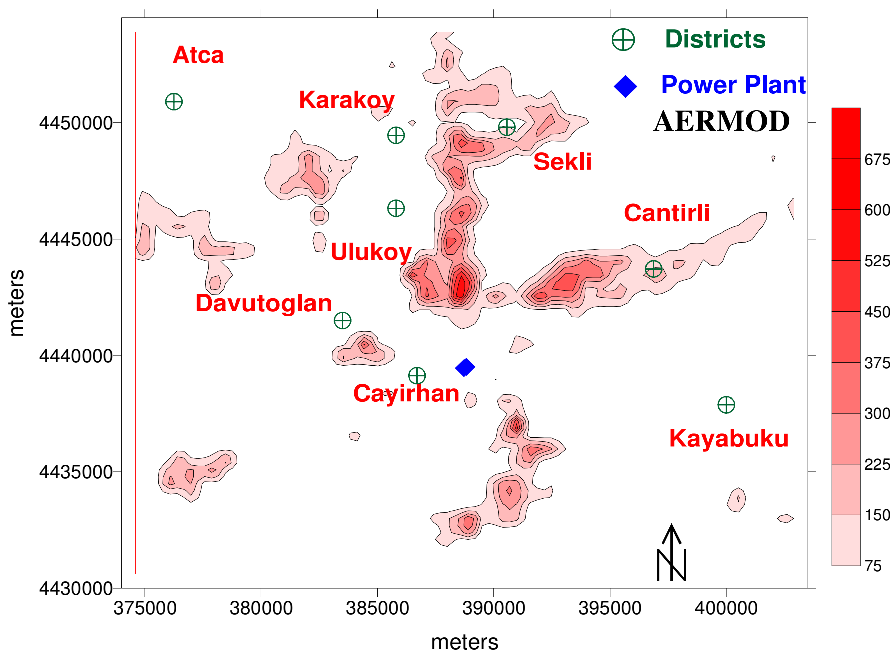


Figure 5.25 AERMOD daily average ground level concentrations (μg/Nm^3) of NO_x due to all sources

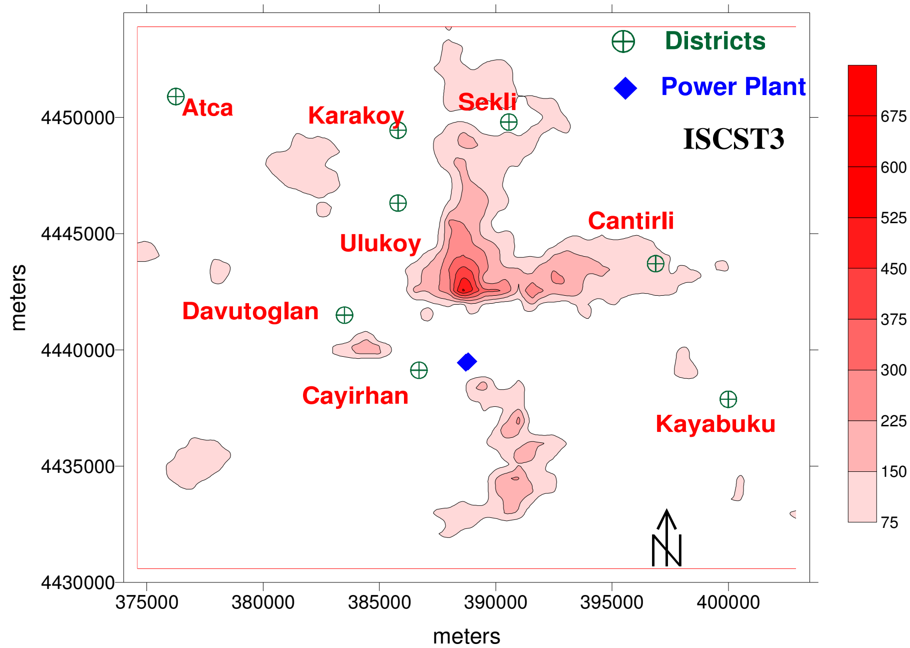


Figure 5.26 ISCST3 daily average ground level concentrations (µg/Nm^3) of NO_x due to power plant

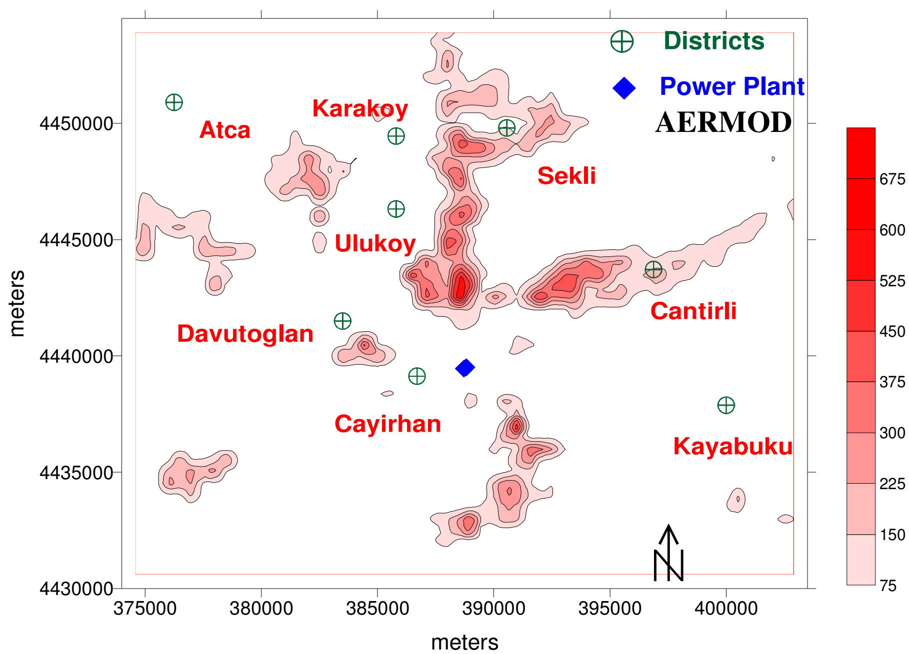


Figure 5.27 AERMOD daily average ground level concentrations (µg/Nm^3) of NO_x due to power plant

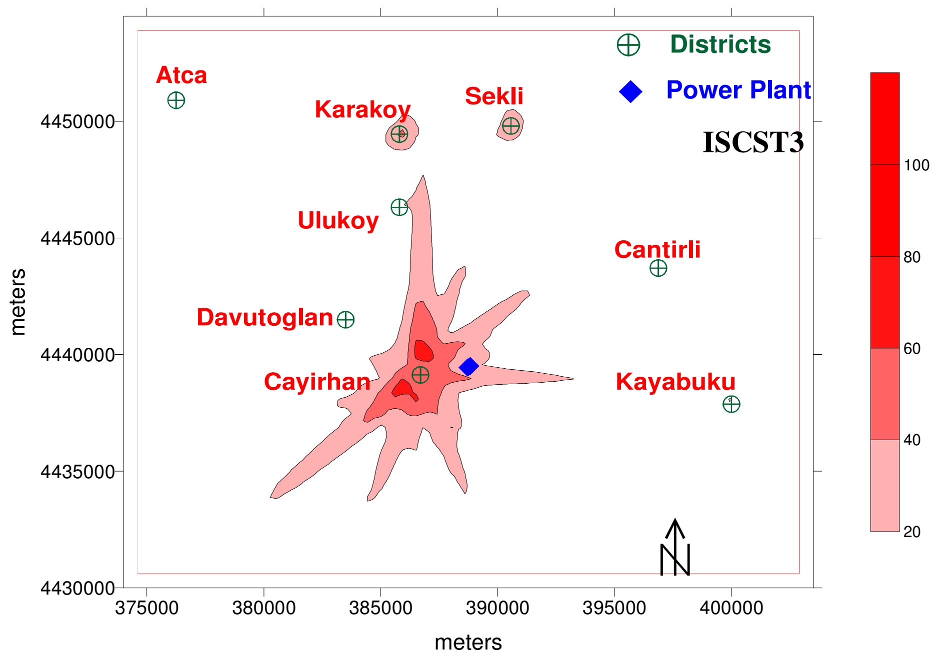


Figure 5.28 ISCST3 daily average ground level concentrations (μg/Nm^3) of NO_x due to domestic heating

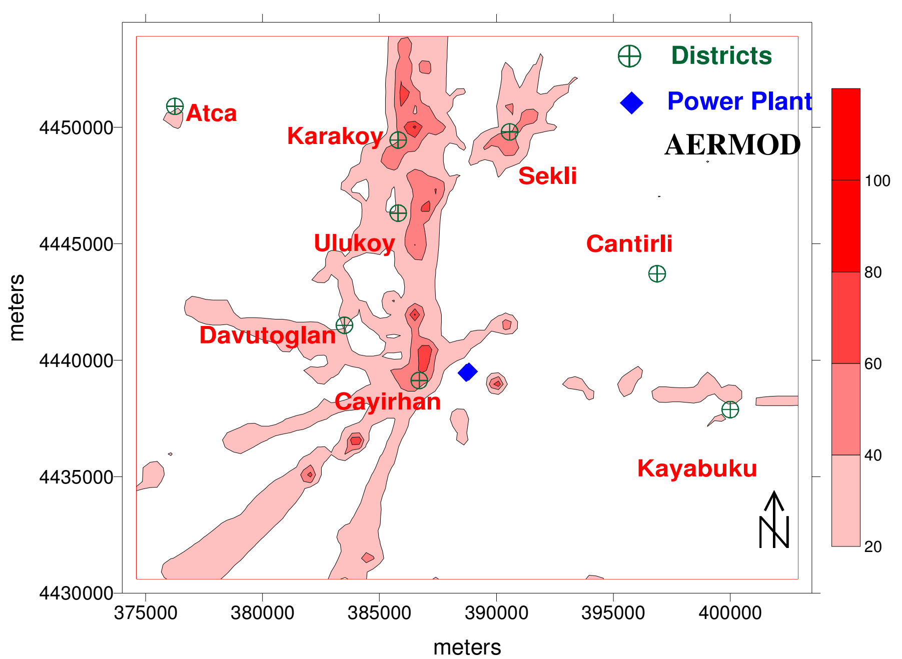


Figure 5.29 AERMOD daily average ground level concentrations (μg/Nm^3) of NO_x due to domestic heating

5.3 Modeling Results for PM_{10}

Air dispersion modeling results for ground level concentrations of PM_{10} is presented in Figure 5.30 to 5.43 according to source groups and averaging periods.

5.3.1 Annual Dispersion of PM_{10}

Table 5.3 summarizes the annual PM_{10} results predicted by the models. The table shows that the both the power plant and domestic heating sources have caused the maximum annual PM_{10} concentrations close to each other. The particulate matter emission rate of Çayırhan Thermal Plant is very low, although coal consumed in power plant has 29.52% by wt ash content. The reason is that electrostatic precipitators are working with 99.9% efficiency. All the highest annual PM_{10} concentrations predicted by the models are below the limit value set by the Turkish Air Quality Protection Regulation.

Table 5.3 Maximum annual PM_{10} concentrations predicted by ISCST3 and AERMOD

Sources	**Maximum annual PM_{10} Concentrations, µg/Nm^3**		**TAQPR Limit, µg/Nm^3**	**Directive 1999/30/EC , µg/Nm3**
	ISCST3	**AERMOD**		
All sources	31	26	150	40
Only the power plant	29	19	150	40
Only domestic heating	28	24	150	40

The annual average ground level concentrations of PM_{10} estimated by ISCST3 and AERMOD are given in Figure 5.30 to Figure 5.35. Modeling results are presented according to emission sources.

Figure 5.30 and Figure 5.31 show the annual average concentration of PM_{10} due to all sources. The maximum annual PM_{10} concentration estimated by ISCST3 is 31 µg/Nm^3 at coal stockpiles located in power plant site. However, the maximum annual concentration estimated by AERMOD is 26 µg/Nm^3 at 3850 m southwest of Çayırhan town. The long term limit given TAQPR and Directive 1999/30/EC are 150 µg/Nm^3 and 40 µg/Nm^3, respectively. In everywhere of the study area, the annual average concentrations are considerably below these limits.

Figure 5.32 and Figure 5.33 show the effect of Çayırhan Thermal Power Plant on annual average concentration of PM_{10} at the study area. Both ISCST3 and AERMOD estimated the maximum annual concentration due to power plant at coal stockpiles located in power plant site of the plant as 29 µg/Nm^3 and 19 µg/Nm^3; respectively. According to ISCST3 results, effects of Çayırhan Thermal Power Plants can be observed only at Çayırhan. On the other hand, according to AERMOD results, effects of power plant can be observed at Çayırhan, Sekli and Çantırlı. The maximum annual average ground level PM_{10} concentration due to Çayırhan Thermal Power Plant is below the long term ambient air concentration limit of PM_{10} given by TAQPR and Directive 1999/30/EC.

Figure 5.34 and Figure 5.35 show the effects of villages located in the study area on annual average PM_{10} concentration distributions due to domestic heating. ISCST3 runs resulted in 28 µg/Nm^3 and AERMOD runs resulted in 24 µg/Nm^3 as maximum annual average concentration of PM_{10} originated from towns. ISCST3 shows that PM_{10} can not disperse for long distances. According to AERMOD results, effects of emissions from domestic heating on PM_{10} concentrations can be observed at receptors far away from the villages. The annual average ground level

PM_{10} concentrations due to domestic heating in towns is below the long term ambient air concentration limits of PM_{10} given by TAQPR and Directive 1999/30/EC.

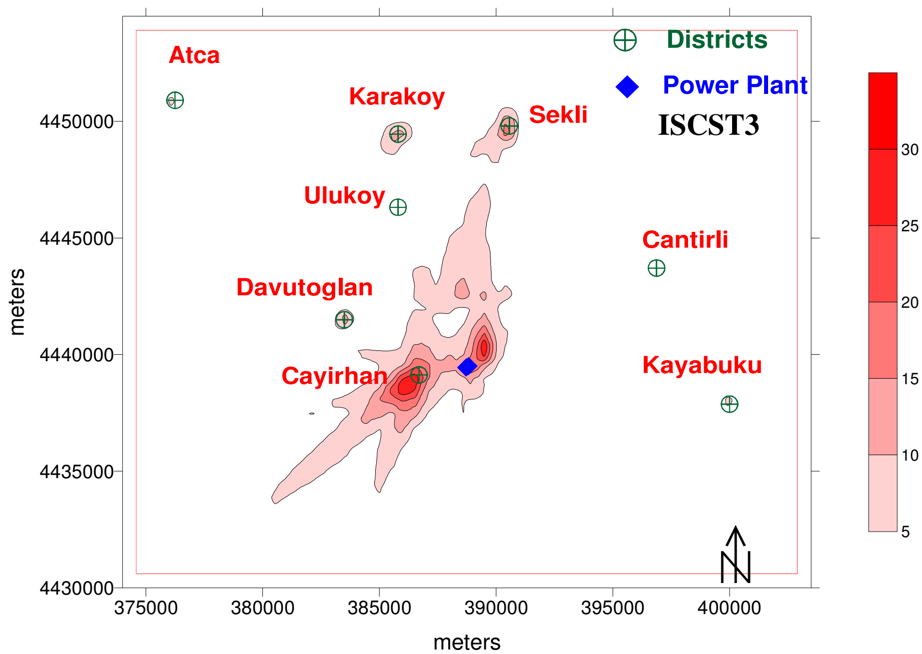


Figure 5.30 ISCST3 annual average ground level concentrations (µg/Nm^3) of PM_{10} due to all sources

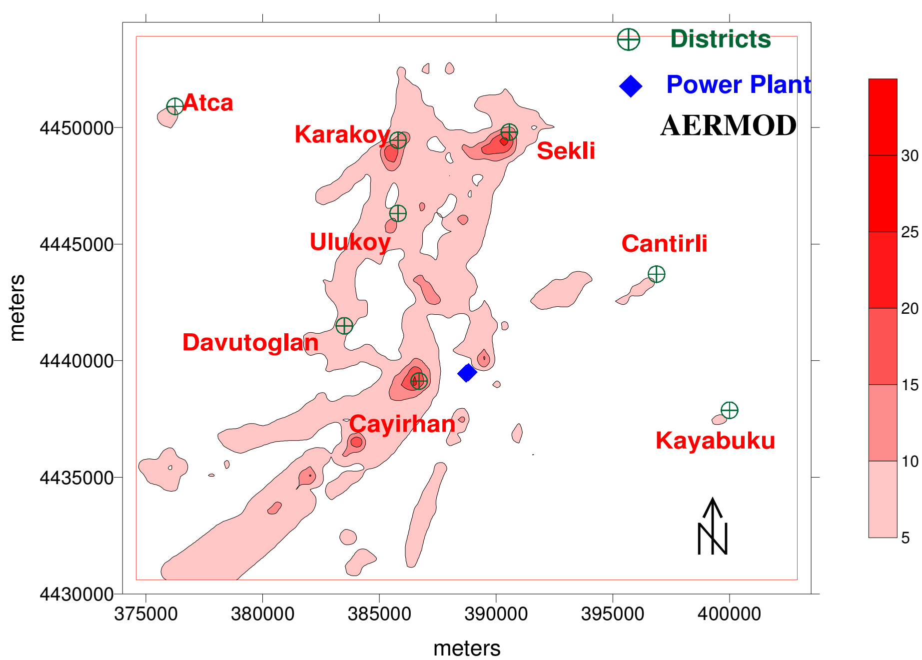


Figure 5.31 AERMOD annual average ground level concentrations (µg/Nm^3) of PM_{10} due to all sources

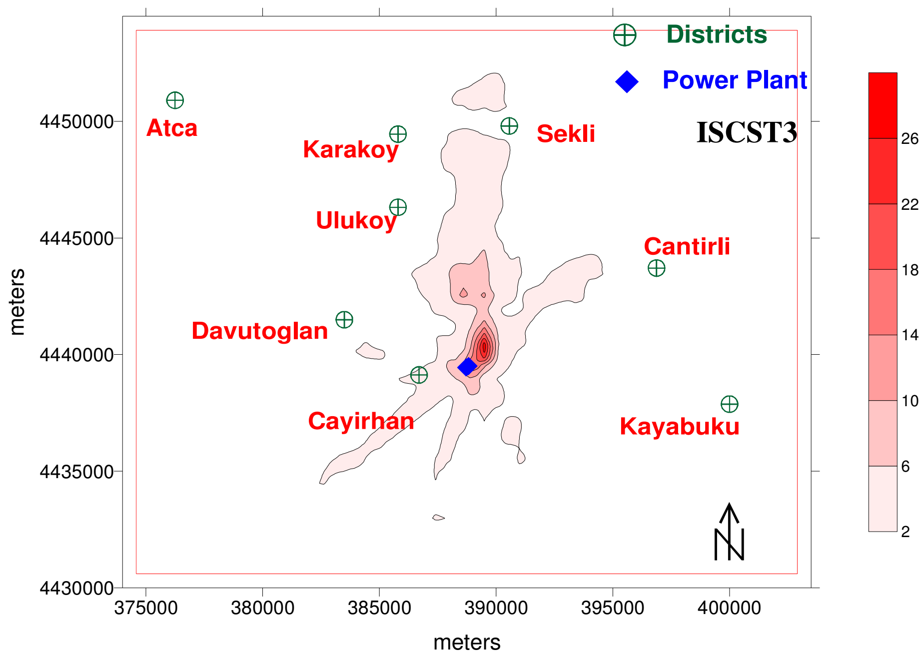


Figure 5.32 ISCST3 annual average ground level concentrations (µg/Nm^3) of PM_{10} due to power plant

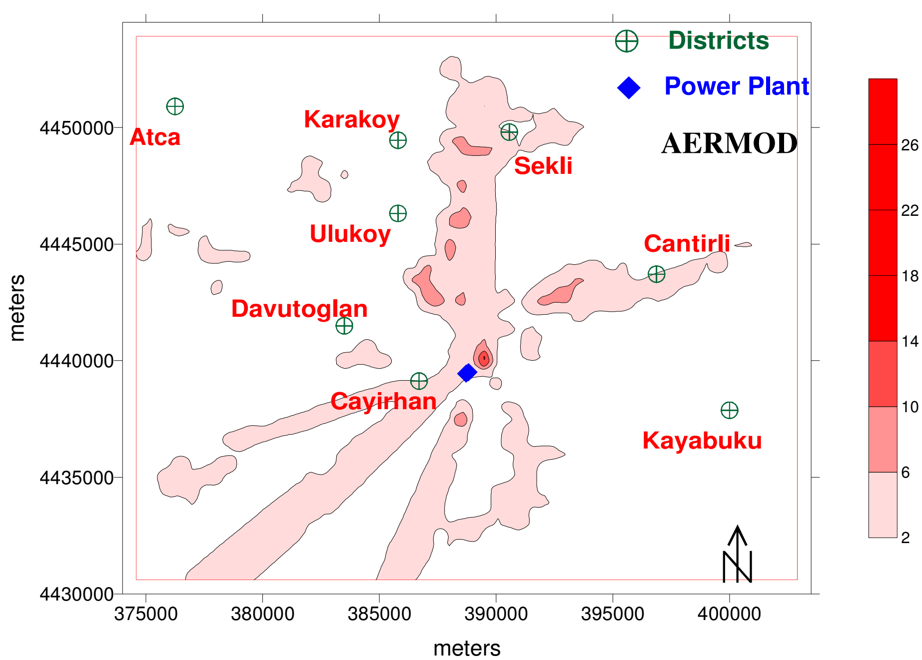


Figure 5.33 AERMOD annual average ground level concentrations (µg/Nm^3) of PM_{10} Due to Power Plant

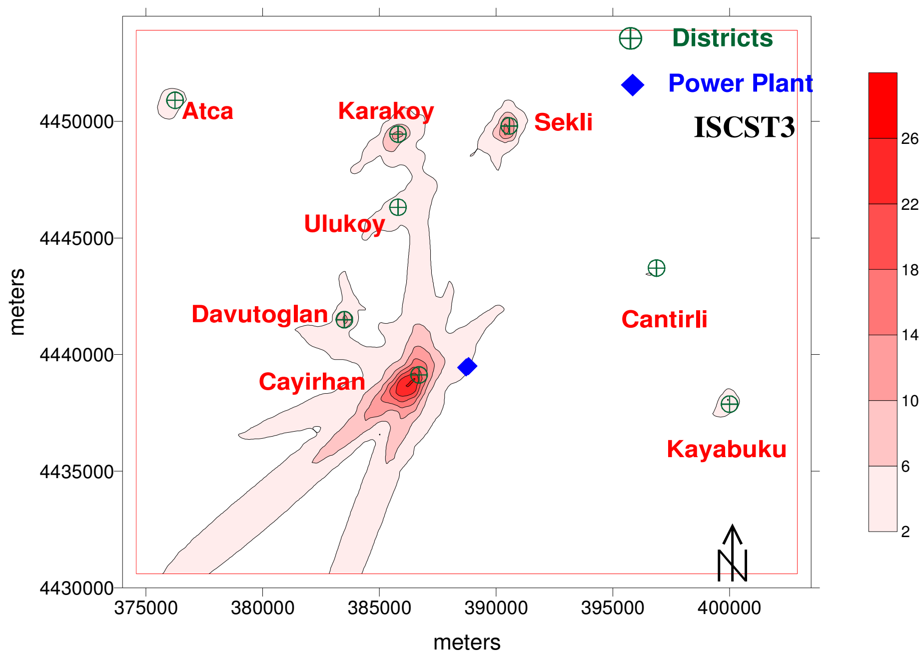


Figure 5.34 ISCST3 annual average ground level concentrations (μg/Nm^3) of PM_{10} due to domestic heating

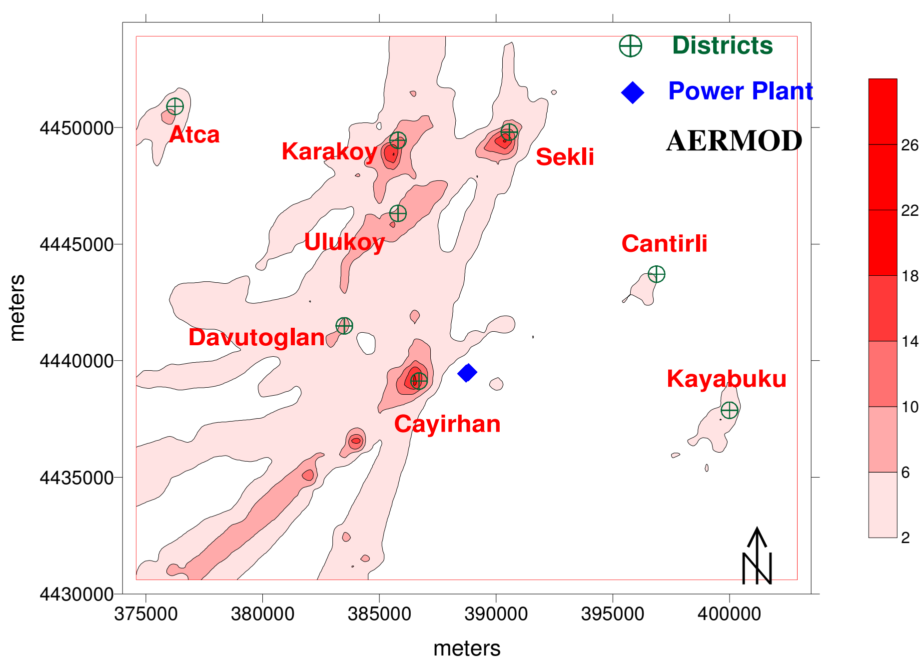


Figure 5.35 AERMOD annual average ground level concentrations (μg/Nm^3) of PM_{10} due to domestic heating

Figure 5.36 and 5.37 show the contribution of the power plant and the domestic heating to the PM_{10} pollution at the residential areas estimated by ISCST3 and AERMOD, respectively. These contributions are calculated according to numerical results given in Table B-3 of Appendix B. Both model resulted similar contribution pattern for the region. Sekli and Çantırlı are the most affected cities by PM_{10} emissions of the power plant. Although Sekli is very far away from the power plant, it is located at the dominant wind direction and the elevation of Sekli is 710 meters. Therefore, PM_{10} emitted from the power plant can descend on Sekli according to the both models. On the other hand, Çantırlı is located at opposite direction of the dominant wind. The reasons of high contribution of the power plant to PM_{10} concentrations at Çantırlı are that the city is close to the power plant and its elevation is very high (748 meters). The major source of the PM_{10} concentrations at the other cities is domestic heating. PM_{10} emission of the power plant does not have significant effect on the residential areas except Çantırlı and Sekli.

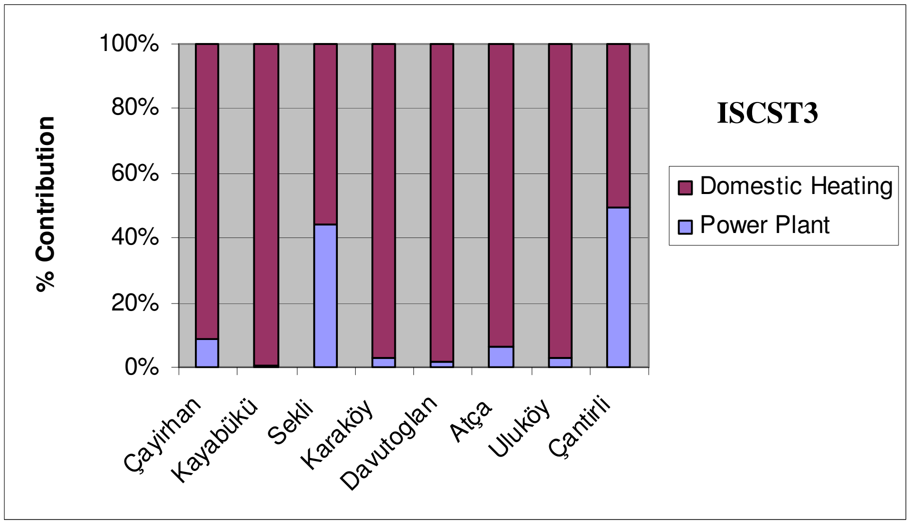


Figure 5.36 Contribution of the power plant and the domestic heating to the annual average PM_{10} concentrations at the villages according to ISCST3

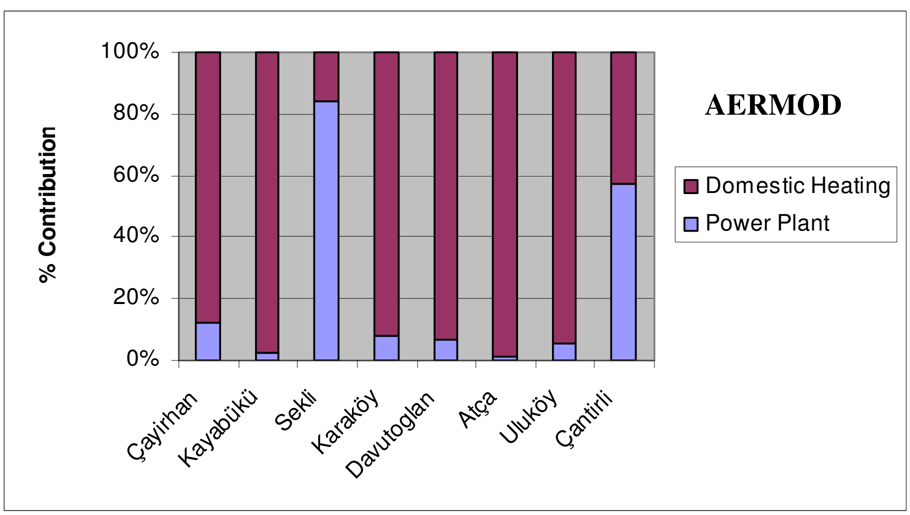


Figure 5.37 Contribution of the power plant and the domestic heating to the annual average PM_{10} concentrations at the villages according to AERMOD

5.3.2 Daily Dispersion of PM_{10}

The daily average ground level concentrations of PM_{10} estimated by ISCST3 and AERMOD are given in Figure 5.38 to Figure 5.43. During the runs of the models, dry or wet deposition of PM_{10} has not been taken into consideration. This might have decreased the ground level concentration of PM_{10}.

Figure 5.38 and Figure 5.39 show the daily average concentration of PM_{10} due to all sources. The maximum daily PM_{10} concentrations are very different for ISCST3 and AERMOD Models. The maximum daily concentration estimated by ISCST3 is 219 µg/Nm^3 at southwest of Çayırhan. On the other hand, the maximum daily concentration estimated by AERMOD is 358 µg/Nm^3 at southwest of Çayırhan where 3800 m away from the center of Çayırhan town. The limit of ambient concentration of PM_{10} is 300 µg/Nm^3 given by TAQPR and is 50 µg/Nm^3 given by Directive 1999/30/EC. The results of ISCST3 point out that all the maximum daily average concentrations of PM_{10} are below 300µg/Nm^3. However, the results of AERMOD show that daily average PM_{10} concentration at 1 point is above short term limit given by TAQPR. The 2nd maximum daily PM_{10} concentration is 298 µg/Nm^3. Moreover, daily PM_{10} concentrations are above 50 µg/Nm^3 which is the limit value for the daily PM_{10} concentration set by Directive 1999/30/EC.

Figure 5.40 and Figure 5.41 show the effect of Çayırhan Thermal Power Plant on daily average concentration of PM_{10}. ISCST3 estimated the maximum daily concentration of PM_{10} due to power plant as 116 µg/Nm^3 and AERMOD estimated 87 µg/Nm^3 as maximum daily average concentration of PM_{10}. According to the results of ISCST3, the residential villages are not affected by PM_{10} emissions of power plant except Çayırhan town. AERMOD presents that Çayırhan, Sekli and Çantırlı are affected by PM_{10} emissions of Çayırhan Thermal Power Plant. The maximum daily average ground level PM_{10} concentrations due to Çayırhan Thermal Power Plant is below the short term ambient air concentration limit (300 µg/Nm^3) of PM_{10} given by TAQPR. This is mostly due to Electrostatic Precipitators Units working with high efficiency.

Figure 5.42 and Figure 5.43 show the effects of villages located at study area on daily average PM_{10} concentration distributions due to domestic heating. ISCST3 resulted in 215 µg/Nm^3 at north of the Çayırhan town and AERMOD resulted in 339 µg/Nm^3 at southwest of Çayırhan town as maximum daily average concentration of PM_{10} originated from villages due to domestic heating. The results of AERMOD show that average PM_{10} concentration at 1 point is above short term limit (300 µg/Nm^3) given by TAQPR. The 2nd maximum daily PM_{10} concentration is 298 µg/Nm^3. In the study area, the main source of PM_{10} concentration is domestic heating. These results indicate that villages cause the highest PM_{10} concentrations in the study area. As in the ground level concentration maps of other pollutants, AERMOD presents better pollution distribution map. The effects of pollution sources are observed locally in ISCST3 results. However, AERMOD is able to present the effects of pollution sources at considerably far receptors. According to the results of the both models, maximum daily PM_{10} concentrations are above 50 µg/Nm^3 which is the limit value for the daily PM_{10} concentration set by Directive 1999/30/EC.

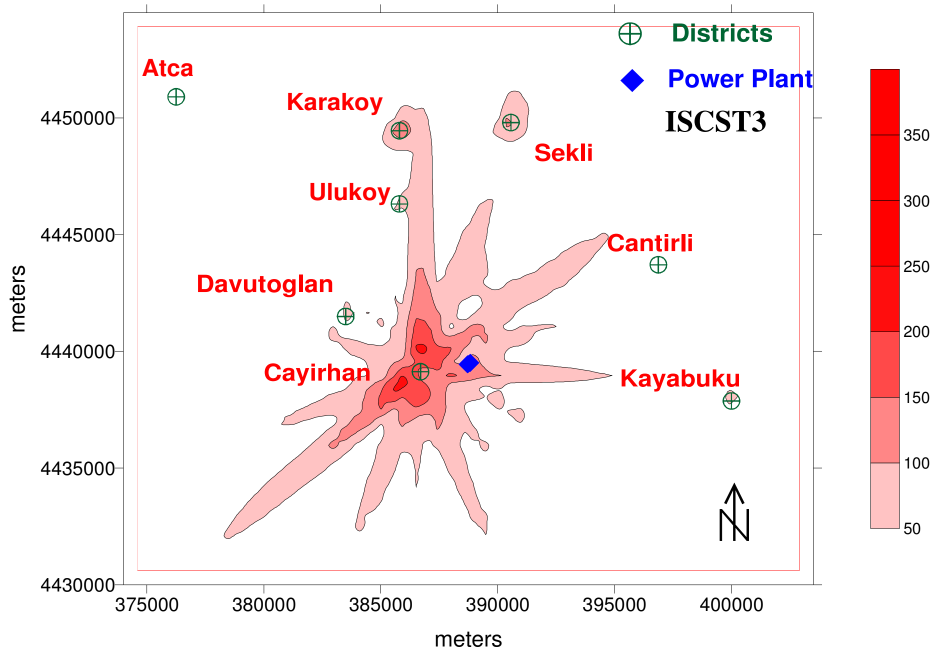


Figure 5.38 ISCST3 daily average ground level concentrations ($\mu g/Nm^3$) of PM_{10} due to all sources

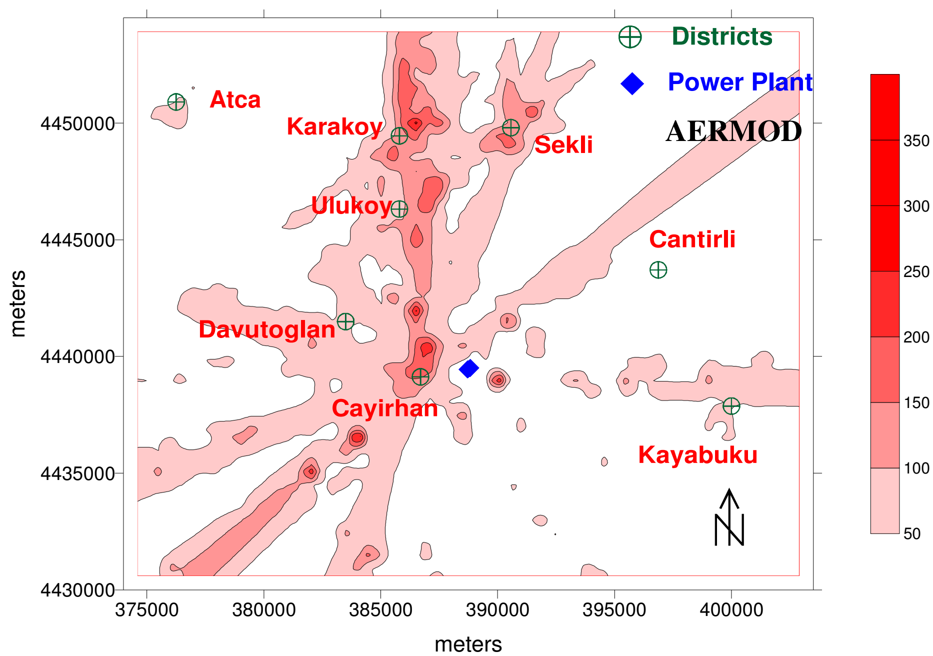


Figure 5.39 AERMOD daily average ground level concentrations ($\mu g/Nm^3$) of PM_{10} due to all sources

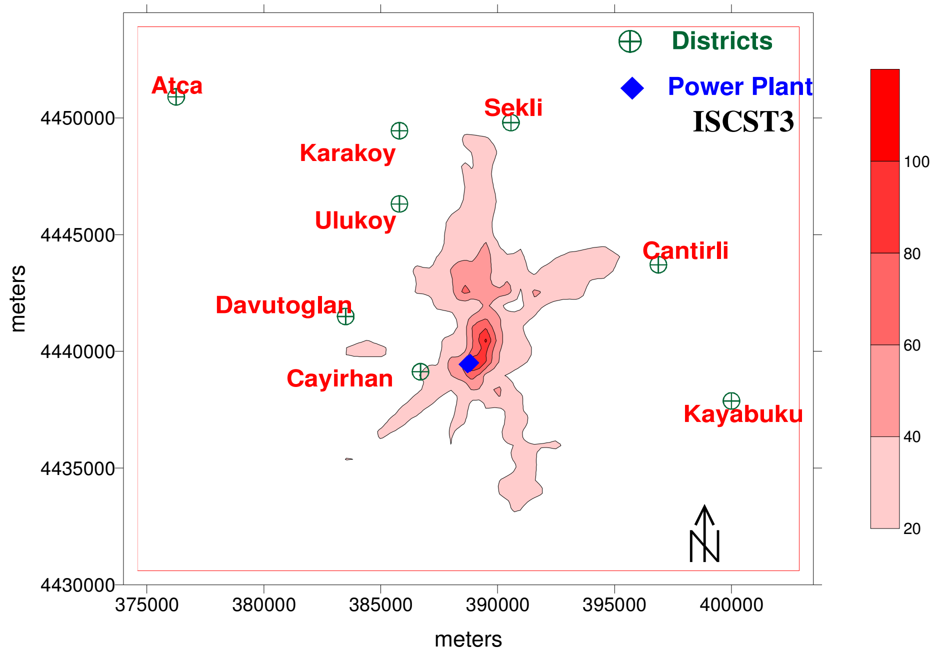


Figure 5.40 ISCST3 daily average ground level concentrations (µg/Nm^3) of PM_{10} due to power plant

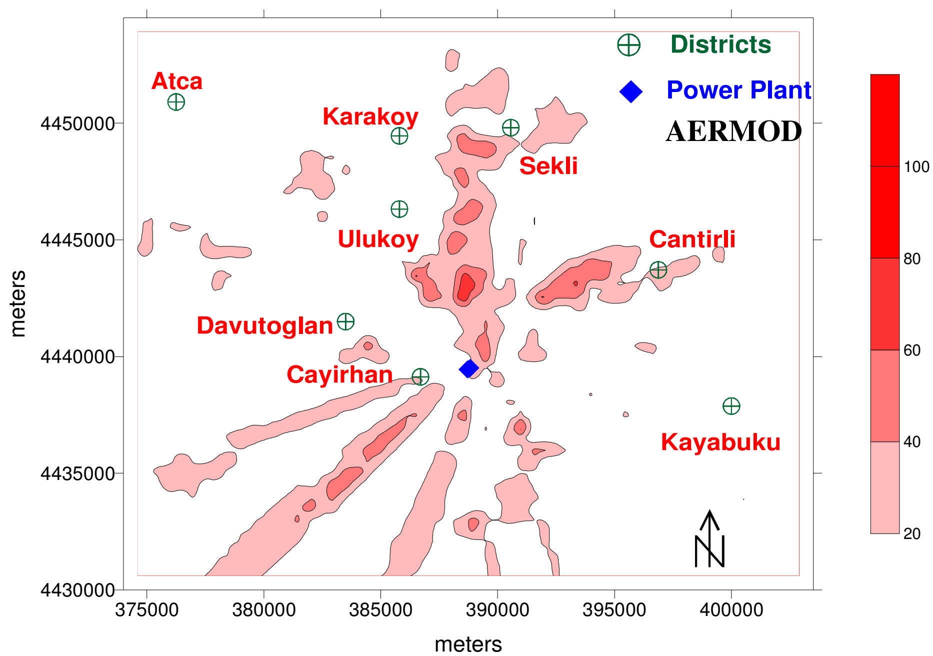


Figure 5.41 AERMOD daily average ground level concentrations (µg/Nm^3) of PM_{10} due to power plant

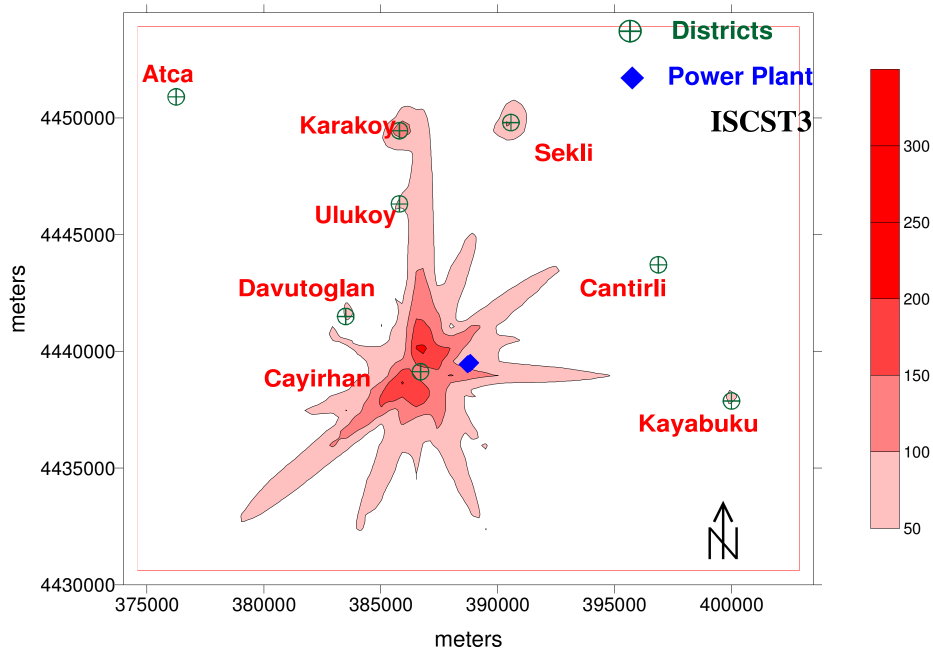


Figure 5.42 ISCST3 daily average ground level concentrations ($\mu g/Nm^3$) of PM_{10} due to domestic heating

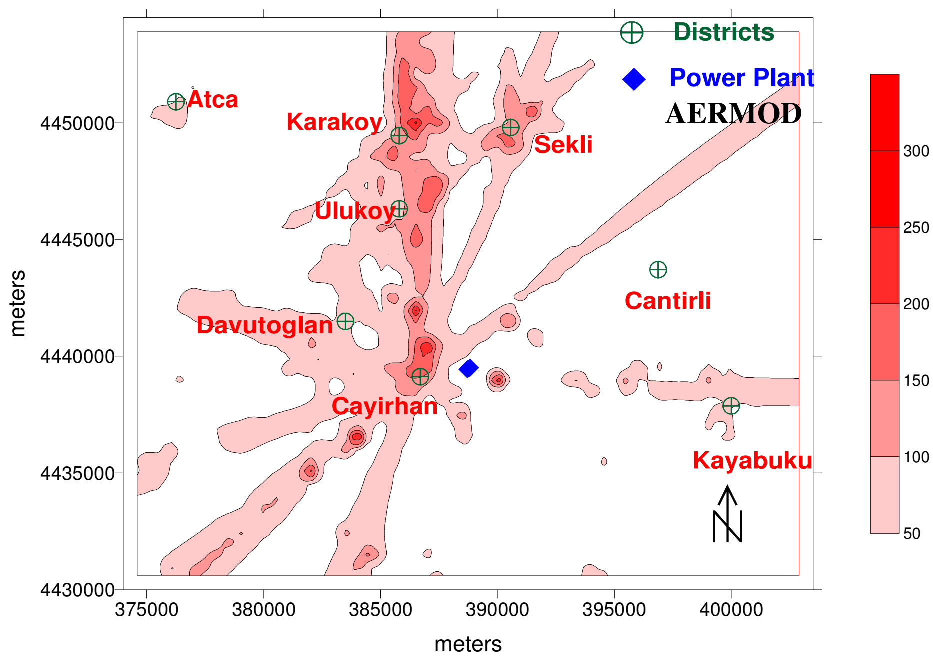


Figure 5.43 AERMOD daily average ground level concentrations ($\mu g/Nm^3$) of PM_{10} due to domestic heating

As mentioned in the previous section, although ISCST3 and AERMOD generates different results for the same cases, the general pattern of the ground level pollution concentration maps estimated by both models are similar to each other. The similarities were expected because the basic algorithms and assumptions of the models are similar. However, when the results are analyzed in detail, differences come into the picture. Mostly, AERMOD estimated higher pollution concentrations. In convective conditions, ISCST3 assumed a zero ground level concentration when the plume centerline is above the mixing lid. However, AERMOD considers three plume components: a “direct” plume that is advected to the ground in a downdraft, an “indirect” plume caught in an updraft that reaches the lid and eventually is brought to the ground, and a plume that penetrates the mixing lid and disperses more slowly in the stable layer aloft (and which can re-enter the mixing layer and disperse to the ground). Therefore, the AERMOD treatment avoids potential underpredictions suffered by ISCST3 due to its “all or nothing” treatment of the plume; AERMOD’s use of convective updrafts and downdrafts in a probability density function approach is a significant advancement over ISCST3 (U.S. EPA, 2003). Therefore, AERMOD gives mostly higher ground level concentrations than ISCST3.

Moreover, almost in all ground level pollution concentration maps, the results of AERMOD show that pollutants are able to travel further locations comparing the result of ISCST3. ISCST3 uses Briggs equations with stack-top wind speed and vertical temperature gradient in all stability conditions. However, AERMOD uses Briggs equations with winds and temperature gradient at stack top and half- way to final plume rise at stable conditions; in convective conditions, plume rise is superposed on the displacements by random convective velocities (U.S. EPA, 2003).

In AERMOD wind velocity and temperature changes above stack top is taken into account in the meteorological data of synoptic meteorological stations. Therefore, they are real wind velocities and temperature data. However, in the ISCST3, the wind velocity and air temperature measured at 10 meters level and the values of these parameters are calculated with Holland's formula. Therefore, this data is not real.

Also, ISCST3 uses Gaussian treatment for plum dispersion in horizontal and vertical direction. However, AERMOD uses Gaussian treatment for plume dispersion in horizontal and in vertical direction for stable conditions and non-Gaussian probability density function in vertical direction for unstable conditions. AERMOD's unstable treatment of vertical dispersion with a non-Gaussian probability density function is a more realistic portrayal of actual conditions (U.S. EPA, 2003).

In the study area, most polluted locations were at elevated positions of the investigation area. The wind allows for transport of air pollution over long distances. Through this pollution transport, even clean areas with no significant air pollution can be affected by air pollution transported from other regions which produce pollution. During transport of pollutants, transported air hits the elevated surfaces much more than the lower locations and deposits the pollutants there. Also, wind direction and wind speed are the other major reasons for the distribution of the pollutants. According to most of the results of the both models, high pollution concentrations are observed on South-East and North directions of the emission sources which are the dominant wind directions in the study area.

5.4 Model Performance Evaluation

The model performance evaluation is important part of modeling studies. Performance evaluation shows the accuracy of the estimations done by the models. The best way for the evaluation of the model performance is to compare the estimated results from the model with the measured values.

Comparison for PM_{10} results could not be made simply because there was only 1 measurement done for this parameter. Unfortunately, there is not enough ambient air measurement done in order to determine the accuracy of ground level concentration estimations of PM_{10}. Therefore, only SO_2 and NO_x results are considered for performance evaluation. The ambient air measurement results were only available for the month of November 2004. Therefore, the model was run for November 2004 and the monthly results were compared with the ambient air pollution concentration measurements of SO_2 and NO_x available in November 2004. SO_2 and NO_x concentrations were measured at 15 locations which were given in Figure 4.4. Performance evaluation of the models is done for each location separately.

5.4.1 Model Performance Evaluation for SO_2 Predictions

Ambient air measurements and predicted results with ISCST3 and AERMOD models for each location are given in Table 5.4. Also, Figure 5.44 shows the comparison between the measured and estimated ground level SO_2 concentrations.

Table 5.4 Ambient air measurements and predicted results of ISCST3 and AERMOD models for SO_2 concentrations

Location	Name of the location	Measured ($\mu g/Nm^3$)	ISCST3 ($\mu g/Nm^3$)	AERMOD ($\mu g/Nm^3$)
1	Rural	34.68	6.95	11.40
2	Rural	30.13	9.51	6.68
3	Rural	28.64	14.98	13.68
4	Davutoğlan	34.82	9.75	11.94
5	Rural	37.34	10.31	14.82
6	Rural	29.38	1.26	1.89
7	Rural	20.26	6.32	9.56
8	Atça	37.95	10.59	10.50
9	Karaköy	24.91	11.48	11.01
10	Uluköy	37.26	6.87	14.06
11	Sekli	20.90	6.95	16.52
12	Rural	36.07	14.01	15.61
13	Çantırlı	28.43	8.62	13.20
14	Kayabükü	20.16	19.84	10.91
15	Çayırhan	97.08	83.71	55.94

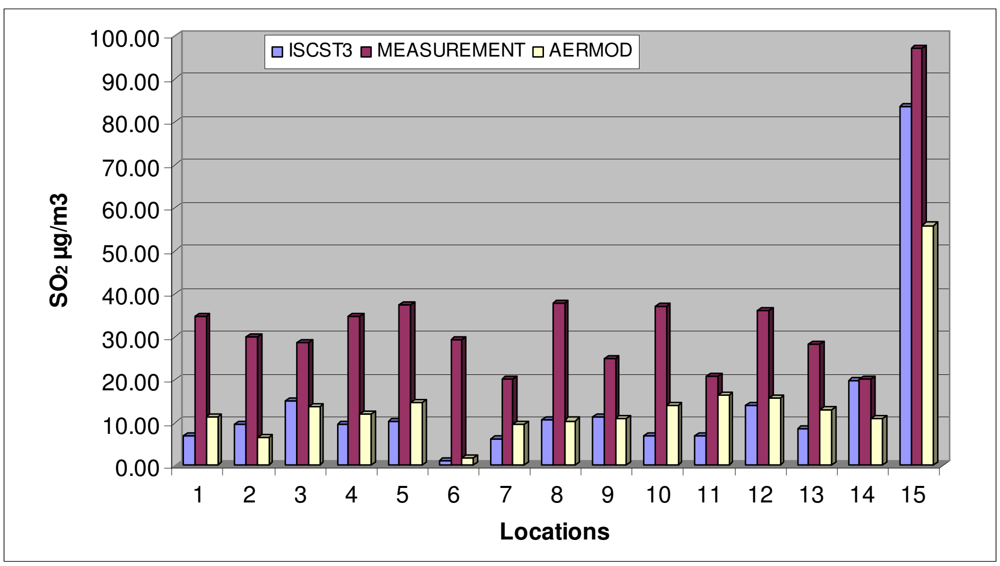


Figure 5.44 Comparisons of measured concentrations of SO_2 with predictions of ISCST3 and AERMOD

As seen in Figure 5.44, at six locations, ISCST3 estimates higher SO_2 concentrations than AERMOD and at nine locations AERMOD estimates higher SO_2 concentrations than ISCST3. Both models estimate SO_2 concentrations close to each other at most of the measurement points. Measurement point #15 presents the SO_2 concentration at Çayırhan town which has the largest population in the region. Moreover, Çayırhan town is the closest town to the power plant in the direction of the dominant wind. Because of these reasons, models and diffusion tubes resulted moderately high ground level SO_2 concentrations at Çayırhan.

Moreover, predictions of both ISCST3 and AERMOD were underestimating the measured values at all locations. The possible reason could be that models can not demonstrate long range transport of the SO_2 at the measurement points located out of residential areas. Therefore, although diffusion tubes measured comparatively higher results, the models were not able to estimate SO_2 concentration as high as measurements at rural terrains.

For the measurement points located in residential areas, the possible reason for underestimation probably might be the building downwash effect. In real situation, building downwash effect results in high pollution concentrations close to residential areas. Pollutant plume hits the buildings and cause high concentrations at these locations. This effect was not included in model runs and causes under predictions for both models.

Comparisons of the measured results with the predicted results at 15 locations are shown in log-log plots given in Figure 5.45 and Figure 5.46. Overall results seem to be good on log-log scale because the model results and the measurement results are located around the 45^0 line in the plots except one point which is the measurement point #6. This measurement point is located at the south direction of the power plant and dominant wind is blown from the opposite direction. Therefore, both models estimated very low concentrations at the measurement point #6 as compared to the measured result. All other model results show good correlations according to the plots.

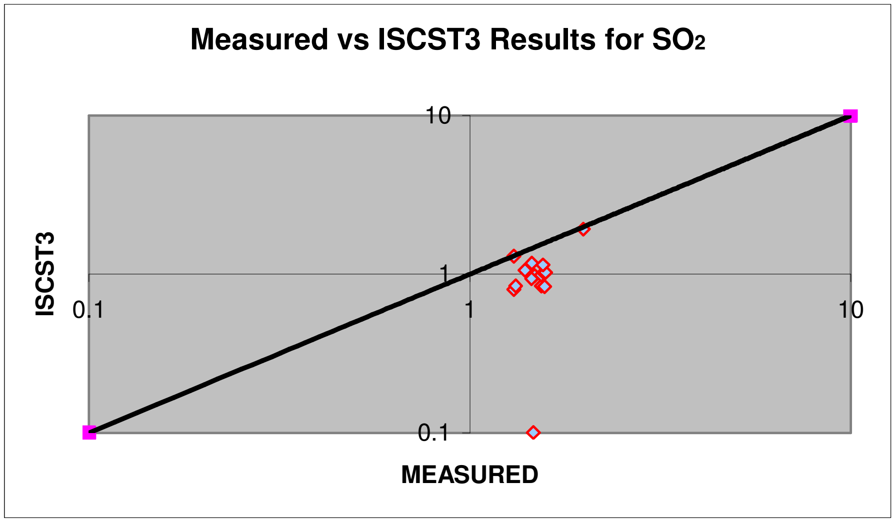


Figure 5.45 Comparisons of the measured and the predicted results of SO_2 concentrations for ISCST3 on log-log scale (November 2004)

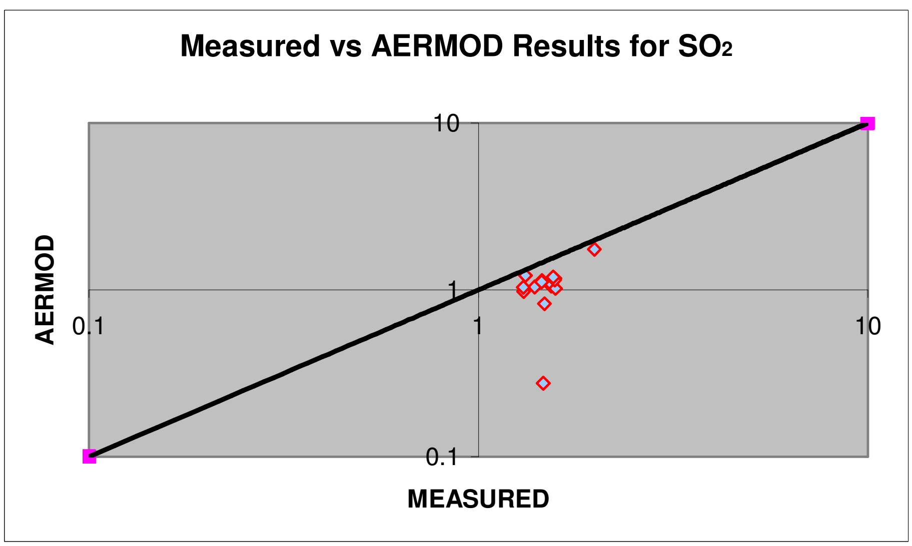


Figure 5.46 Comparisons of the measured and the predicted results of SO_2 concentrations for AERMOD on log-log scale (November 2004)

Figure 5.47 and Figure 5.48 show the comparisons of models and measured results on the real scale for ISCST3 and for AERMOD, respectively. The red line shows the linear trend line of the measured values. According to both plots, measured concentration results form a cluster below the ISCST3 model line for SO_2. Although, the trend lines of both plots are very similar to each other, AERMOD predictions are better than ISCST3 predictions because the correlation coefficient for the AERMOD is better.

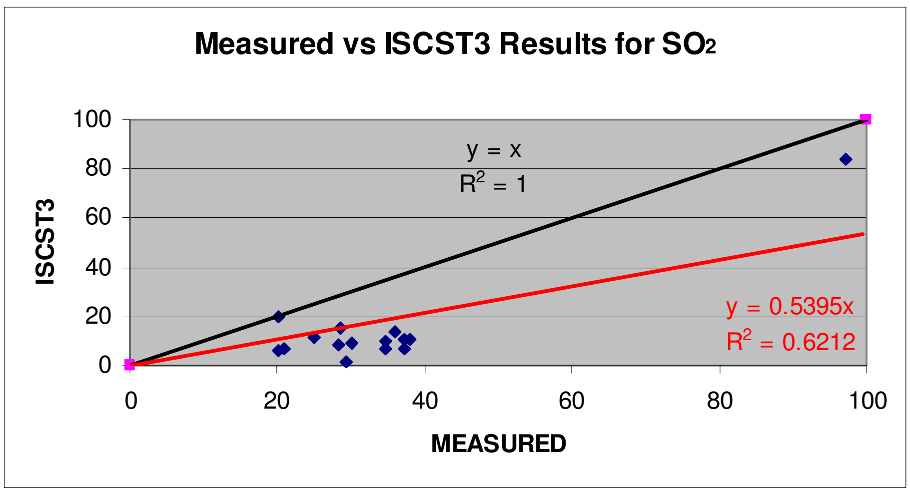


Figure 5.47 Comparisons of the measured and the predicted results of SO_2 concentrations for ISCST3 (November 2004)

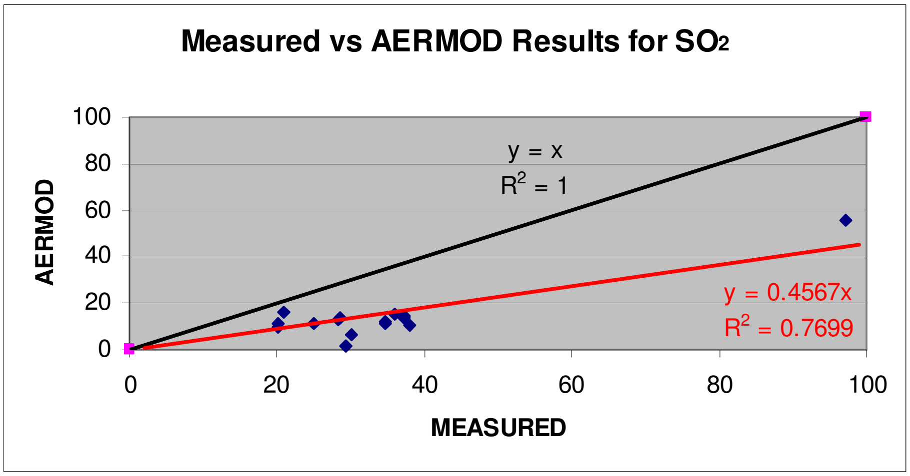


Figure 5.48 Comparisons of the measured and the predicted results of SO_2 concentrations for AERMOD (November 2004)

5.4.2 Model Performance Evaluation for NO_x Predictions

Ambient air measurements and predicted results of ISCST3 and AERMOD models for NO_x at each location are given in Table 5.5. Figure 5.49 also shows this comparison graphically for NO_x concentrations between observed and predicted values.

Table 5.5 Ambient air measurements and predicted results of ISCST3 and AERMOD models for NO_x concentrations

Location	Name of the location	Measured ($\mu g/Nm^3$)	ISCST3 ($\mu g/Nm^3$)	AERMOD ($\mu g/Nm^3$)
1	Rural	12.67	6.40	19.08
2	Rural	13.87	10.34	5.83
3	Rural	9.71	20.54	21.63
4	Davutoğlan	13.11	5.78	2.34
5	Rural	6.94	17.13	29.36
6	Rural	6.96	1.08	0.43
7	Rural	5.04	2.91	2.97
8	Atça	5.77	2.96	2.28
9	Karaköy	5.57	3.55	2.14
10	Uluköy	11.14	3.44	2.75
11	Sekli	4.88	5.67	15.70
12	Rural	49.94	19.59	29.80
13	Çantırlı	7.63	10.37	23.11
14	Kayabükü	7.63	4.01	2.21
15	Çayırhan	22.97	17.36	11.14

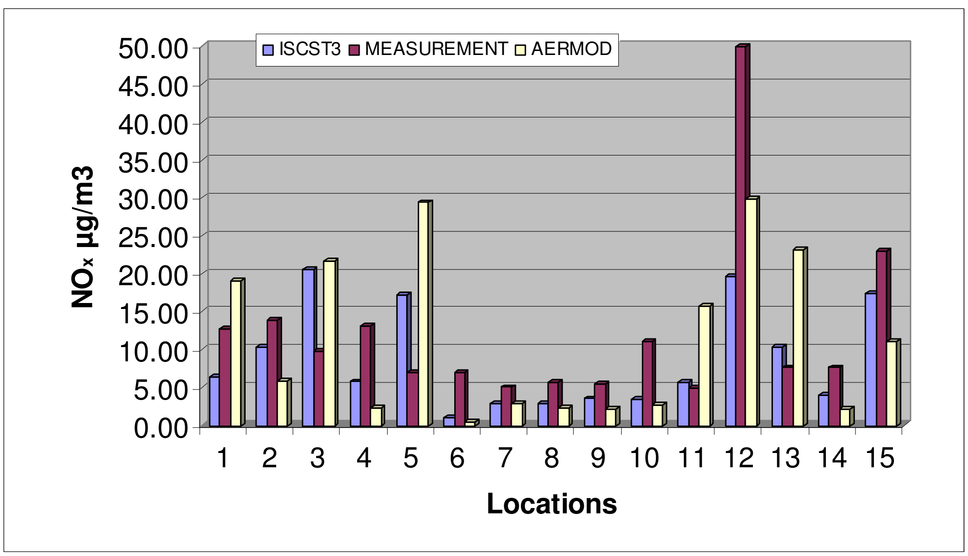


Figure 5.49 Comparisons of measurement concentrations of NO_x with predictions of ISCST3 and AERMOD

Except five measurement locations in Fig. 5.49, both models estimated NO_x concentrations close to each other. This shows the good agreement between the models. As seen in Figure 5.49, at 10 measurement locations, predictions of both ISCST3 and AERMOD underestimated the observation values. At 8 locations, ISCST3 estimated higher NO_x concentrations than AERMOD, and at 7 locations AERMOD estimated higher NO_x concentrations than ISCST3. At measurement point #12 which is an elevated point near the coal mine, the highest NO_x concentration was measured.

There are under and over predictions for NO_x concentrations at the measurement points. However, both models predicted under and over concentrations coherently with each other except measurement point #1. The measurement points #1, #3 and #5 are located at east and south east direction of the plant in the rural areas and these locations are not only very close to plant area, but also they have high elevations. Models show that emissions from power plant may descend over these points in high amounts. However, life time of NO_x in the atmosphere is short which is 1-2 days. NO_x is affected from wet and dry depositions (Baumbach, 1996). In the assumptions of the both models, these depositions were not considered in order to point out the worst case at the study area.

Measurement points #11 and #13 are locations far away from the power plant. ISCST3 does not account for convective turbulence. Downdrafts can potentially bring pollutants down to the surface early on with minimum dilution. However, in unstable atmospheres, convective mixing causes an elevated plume. Therefore, pollutants descend to further distances. AERMOD can demonstrate this effect in its calculations as seen at measurement points #11 and #13. On the other hand, at measurement points #4 and #6, ISCST3 predicted significantly higher ground level NO_x concentrations than AERMOD probably because of the same reason.

Comparisons of the measured results with the predicted results are shown in log-log plots given in Figure 5.50 and Figure 5.51. Similar to SO_2 results, overall predicted results of ground level NO_x concentrations seem to be good because the model results and the measurement results are located around the 45^0 line in the log-log plots except one point which is the measurement point #6 as it was the same measurement point in SO_2 evaluation. The reason is that this measurement point is located south of the power plant and dominant wind is blown from the opposite direction. Therefore, both models estimated very low concentrations at point #6 as compared to the measurement results. Other than this point, most of the model results show good correlations with the measured results according to the plots. However, it should not be forgotten that the plots are log-log plots.

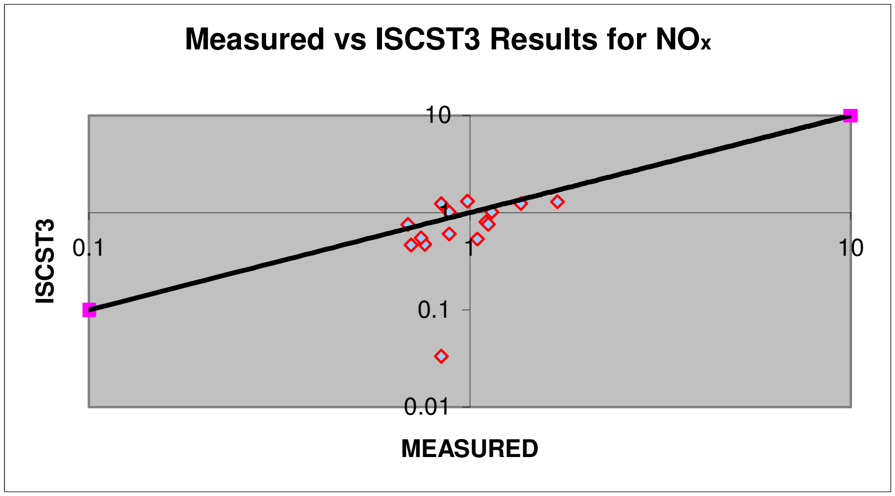


Figure 5.50 Comparisons of the measured and the predicted results of NO_x concentrations for ISCST3 on log-log scale (November 2004)

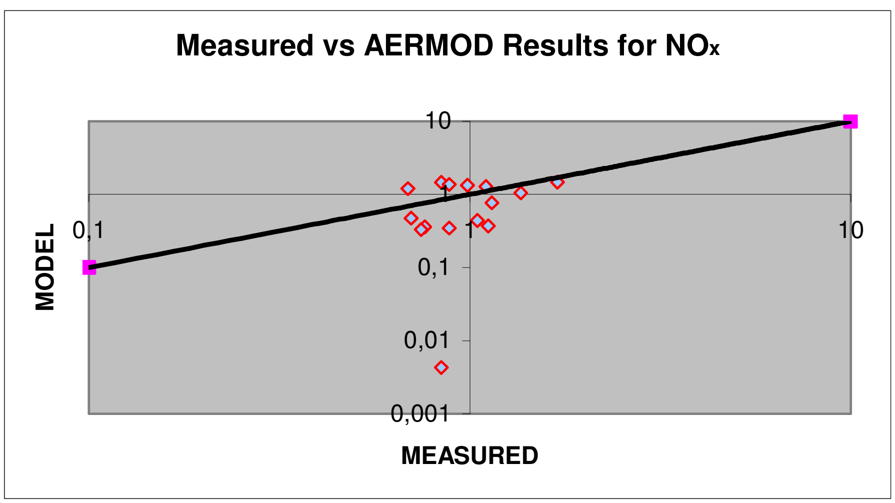


Figure 5.51 Comparisons of the measured and the predicted results of NO_x concentrations for AERMOD on log-log scale (November 2004)

The comparisons of models and measured results in real scale are shown in Figure 5.52 and Figure 5.53. The measurement point #12 and #15 are shown with yellow sign and these points are omitted while drawing the trend line. Measurement point #12 is located at north east of the Çayırhan Power Plant which is a rural area and measurement point #15 is located at Çayırhan town. In both plots, the red lines, which are the linear trend lines of the model's results, are very close to the 45^0 line. This indicates that model predictions are close to measured values. The trend line of the AERMOD is closer to the trend line of the ISCST3. This shows that AERMOD results are closer to measured results than ISCST3 results. Moreover, the slopes of both trend lines are similar to each other introducing that ISCST3 and AERMOD are using similar calculations while they are predicting the ground level concentrations of the pollutants.

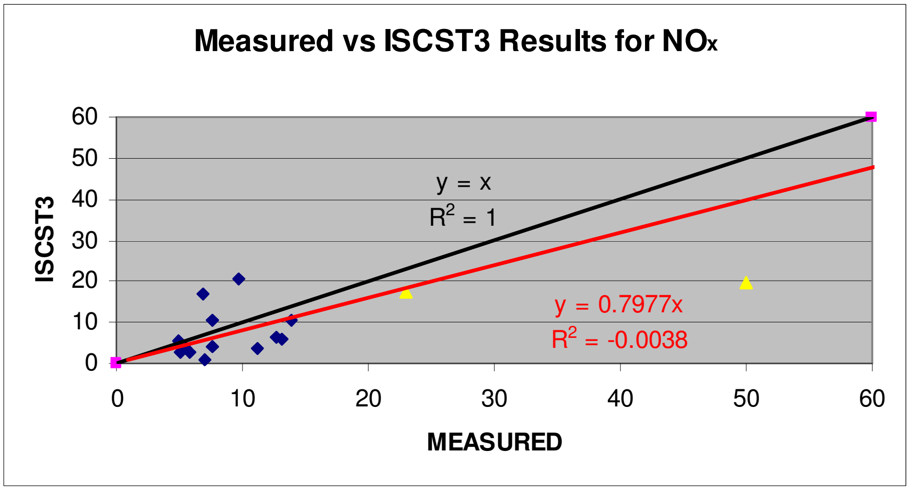


Figure 5.52 Comparisons of the measured and the predicted results of NO_x concentrations for ISCST3 (November 2004)

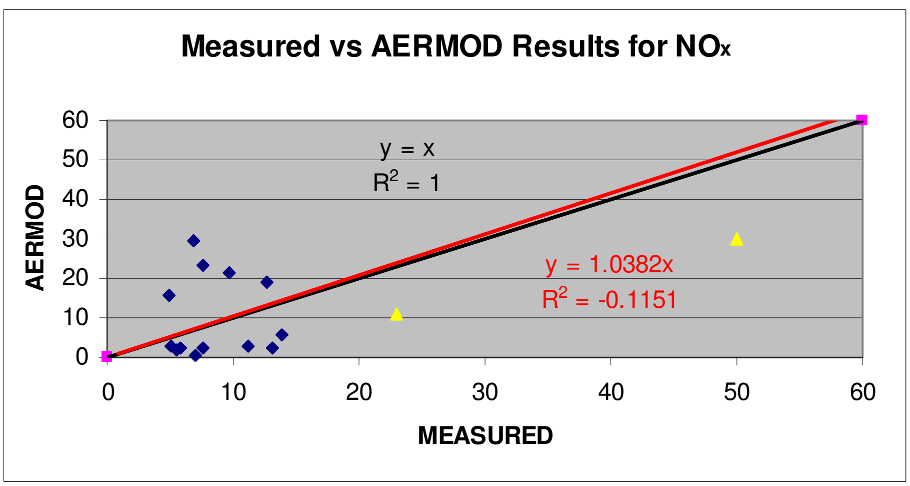


Figure 5.53 Comparisons of the measured and the predicted results of NO_x concentrations for AERMOD (November 2004)

CHAPTER 6

CONCLUSIONS

In this study, emission inventory of Çayırhan region is prepared including Çayırhan Power Plant, coal stockpiles, towns and villages located at the study area. Using this emission inventory as the source data, ground level concentrations of SO_2, NO_x and PM_{10} are estimated by using U.S. EPA approved dispersion models; ISCST3 and AERMOD. The dispersion model results were compared with each other. Moreover, the model predictions were also compared with the ambient air measurements to determine the accuracies of the models. Monthly average concentrations of SO_2 and NO_x at 15 points were measured in November, 2004 by an environmental consultant company by passive sampling. This real data was used for comparison.

The stack gas emission data was used as the source data in the models. However, emission data for the residential sources and coal stockpiles was not available in the study region. Therefore, emission factors were used in order to calculate the emissions to use as the source data in the models.

Coal used in the power plant has total sulphur content of 3.40% by weight. The emission data for the thermal power plant were obtained from Çayırhan Power Plant Environmental Coordinator (Ciner Group, 2005). The total emissions from Çayırhan Thermal Power Plant were:

- 443.016 kg of SO_2/hr
- 891.036 kg of NO_x/hr
- 108.936 kg of PM_{10}/hr

In ISCST3, effects of emissions from pollution sources were observed more locally than AERMOD and long distance effects can not be demonstrated. High concentration regions were seen in the pollution maps around the power plant vicinity. However, AERMOD is able to present the effects of pollution sources at considerably far receptors than ISCST3. Concentrations of pollutants were predicted at further distances from the power plant with AERMOD.

The ground level concentrations obtained with two dispersion models were not only compared with each other but also compared with results of ambient air pollution measurements for the month of November 2004. Predictions of both ISCST3 and AERMOD were underestimating the ground level SO_2 concentrations. However, AERMOD predictions are better than ISCST3 predictions. Overall results seem to be good on log-log scale because the model results and the measurement results are located around the 45^0 line in the plots.

There are under and over predictions for NO_x concentrations at the measurement points. However, both models predicted under and over concentrations coherently with each other. Similar to SO_2 results, overall predicted results of ground level NO_x concentrations seem to be good because the model results and the measurement results are located around the 45^0 line in the log-log plots.

Although ISCST3 and AERMOD generates different results for the same cases, the general pattern of the ground level pollution concentration maps estimated by both models are similar to each other. The similarities were expected because the basic algorithms and assumptions of the models are similar.

REFERENCES

Al-Rashidi, M.S., Nassehi, V., Wakeman, R.J., 2005. “Investigation of the efficiency of existing air pollution monitoring sites in the state of Kuwait” Advanced Separation Technologies Group, Vol. 138, No. 2, pp. 219 – 229.

ASU, Arizona State University, Department of Electrical Engineering http://www.eas.asu.edu/~holbert/wise/electrostaticprecip.html, 26.12.2007

Atımtay, A., Güllü, E., Yetiş, Ü., 1995. “Ankara Hava Kirliliği Envanter Çalışması” Yanma ve Hava Kirliliği Kontrolü III. Ulusal Sempozyumu, Ankara.

Atli, A., 2002. “Hava Kirliliği Dağılımının Belirlenmesinde ISCST3 Model Programının Kullanımı: AÇS Örneği” Ms.D. Thesis, Çukurova University, ADANA, Turkey.

Baumbach, G., 1996. “Air Quality Control: Formation and Sources, Dispersion, Characteristics and Impact of Air Pollutants: Measuring Methods Techniques for Reduction of Emissions and Regulations for Air Quality Control”, Spring-Verlag, New York.

Canpolat, R. B., 1999. “Calculation of Emission factors in Cement Plants in Turkey and a Modeling Study for a Cement Plant” Ms.D. Thesis, Middle East Technical University, Ankara, Turkey.

Chaudhary, M.T., 2003. “Air Pollution Modeling in İskenderun Region of Turkey”, Ph. D. Thesis, Middle East Technical University, ANKARA, Turkey.

Ciner Group, 2005. "Technical Notes, Environmental Coordinator of Energy and Mining Department of Ciner Group", Söğütözü, ANKARA

CORINAIR, 2005. “Emission Inventory Guidebook”, 3rd Edition, EEA., Copenhagen.

Council Directive, 1999. “Council Directive 1999/30/EC of 22 April 1999 relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air”, Official Journal of the European Communities

De Nevers, N., 1995. “Air Pollution Control Engineering”, McGraw-Hill, Inc., USA.

EIA, Energy Information Administration, Official Energy Statistics from U.S. Government, www.eia.doe.gov, 26.12.2007

Elbir, T., 2002. “Air Quality Modeling and Decision Making Studies for İzmir” Ph.D. Thesis, Dokuz Eylül University, IZMIR, Turkey.

Environment Canada, The Green Lane, http://www.ec.gc.ca, 26.12.2007

ENVY, 2005, “Çayırhan Termik Santrali Ortam Hava Kalitesi Ölçüm Raporu”, ENVY Enerji ve Çevre Yatırımları A.Ş., Ankara, Turkey

European Commission, 2006. “Integrated Pollution Prevention and Control, Reference Document on Best Available Technology for Large Combustion Plants” European Integrated Pollution Prevention and Control Bureau.

European Environment Agency (EEA), 2005. “The European Environment: State and Outlook 2005”, Copenhagen.

Federal Register, 2005. “Revision to the Guideline on Air Quality Models: Adoption of a Preferred General Purpose (Flat and Complex Terrain) Dispersion Model and Other Revisions; Final Rule” Environmental Protection Agency, Rules and Regulations, Vol. 70, No. 216.

Flagan, R.C., Senfeld, J.H., 1998. “Fundamentals of Air Pollution Engineering”, Prentice-Hall, Inc., New Jersey, USA.

Ghandour, E., 2001. “Study of Air Quality Determination in Adapazarı, Turkey: Comparison of Dispersion Model Predictions and the Results from an Urban Air Quality Measurement Network” Ms.D. Thesis, Hacettepe Technical University, Ankara, Turkey.

Godish, T., 2004. “Air Quality”, 4th Edition, CRC Press, Florida, USA.

INTUSER, Information Network on the Technology of Utilisation and Sustainability of Energy Resources, http://www.intuser.net/ufes23.php#top, 26.12.2007

Karppinen, A., Kukkonen, J., Konttinen, M., Rantakrans, E., Valkonen, E., HaK rkoK nen, J., Koskentalo, T., ElolaK hde, T., 1997. “Comparison of dispersion model predictions and the results from an urban air quality measurement network.” Air Pollution V. Computational Mechanics Publications, pp. 405 – 411.

Kumar, A., Bellam, N.K., Sud, A., 1999. “ Performance of an Industrial Source Complex Model : Predicting long-term concentrations in an urban area” Environmental Progress, Vol. 18, No. 2, pp. 93 – 100.

Miller, T.L., Noll, K.E., 1976. “Design of Air Monitoring Surveys Near Large Power Plants”, Power Generation: Air Pollution Monitoring and Control, Ann Arbor Science Publishers, Inc., Michigan, USA.

Ministry of Environment of New Zealand, 2004. “Good Practice Guide for Atmospheric Dispersion Modelling”, Wellington, New Zealand.

National Research Council, 2006. “Progress Toward Restoring the Everglades: The First Biennial Review”, National Academies Press, USA

Organisation for Economic Co-operation and Development (OECD), 2001. “OECD Environmental Outlook”, OECD Publications, Paris.

Rama Krishna, T. V. B. P. S., Reddy, M. K., Reddy, R. C., Singh, R.N., 2005. "Impact of an industrial complex on the ambient air quality: Case study using a dispersion model" NEERI Zonal Laboratory, Vol. 39, No. 29, pp. 5395 – 5407.

Schnelle, K. B. J., Brown, C. A., 2002. "Air Pollution Control Technology Handbook", CRC Press, Florida, USA.

Sivacoumar, R., Bhanarkar A.D., Goyal, S. K., Gadkari, S. K., Aggarwal, A. L., 2001. "Air pollution modeling for an industrial complex and model performance evaluation" National Environmental Engineering Research Institute, Vol. 111, No. 3, pp. 471 – 477.

State Hydraulic Works (SHW), http://www.dsi.gov.tr/hizmet/enerji.htm, 26.12.2007

Stern, A.C., Bouble, R.W., Fox, D.L., Turner, D.B., 1994. "Fundamentals of Air Pollution", 3rd Edition, Academic Press, INC. Florida USA.

TCEQ, Texas Commission on Environmental Quality, http://www.tceq.state.tx.us/assets/public/permitting/air/Announcements/Advisory/Agendas_Minutes/aermodmins12_15_03.pdf, 26.12.2007

TETC, Turkish Electricity Transmission Company, http://www.teias.gov.tr/istatistik/ 33.xls, 26.12.2007

Trinity, 1991. "Breeze AERMOD and ISC User's Guide, Version 5.1", Trinity Consultants.

TAQPR, 1986. "Turkish Air Quality Protection Regulation", Official Gazette numbered 16269, Ankara, MOE (Ministry of Environment).

U.S. Environmental Protection Agency, 1995a. "Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources" Research Triangle Park, North Carolina, AP 42 Team.

U.S. Environmental Protection Agency, 1995b. "User's Guide for the Industrial Source Complex (ISC3) Dispersion Model, Volume I" Research Triangle Park, North Carolina, Office of Air Quality Planning and Standards Emission, Monitoring and Analysis Division.

U.S. Environmental Protection Agency, 1999. "PCRAMMET User's EPA-454B-96-001" Research Triangle Park, North Carolina, Office of Air Quality Planning and Standards Emission, Monitoring and Analysis Division.

U.S. Environmental Protection Agency, 2003. "AERMOD: Latest Features and Evaluation Results EPA-454/R-03-003" Research Triangle Park, North Carolina, Office of Air Quality Planning and Standards Emission, Monitoring and Analysis Division.

U.S. Environmental Protection Agency, 2004a. "User's Guide for the AMS/EPA Regulatory Model-AERMOD" Research Triangle Park, North Carolina, Office of Air Quality Planning and Standards Emission, Monitoring and Analysis Division.

U.S. Environmental Protection Agency, 2004b. "User's Guide for the AERMOD Meteorological Preprocessor (AERMET)" Research Triangle Park, North Carolina, Office of Air Quality Planning and Standards Emission, Monitoring and Analysis Division.

Willmot, C.J., 1982. "Some Comments on the Evaluation of the Model Performance", Bullletin of the American Meteorological Society, pp. 1309-1313.

APPENDIX A

CALCULATION OF MONTHLY EMISSION RATES OF SO_2, NO_X AND PM_{10} FOR THE ÇAYIRHAN TOWN

The coal extracted at Çayırhan mine site has high sulphur content that is above the limits permitted and is not allowed to be used for domestic heating. Therefore, coal is obtained from Eskişehir Koyunağılı mine site for residential usage. According to CORINAIR (2005), lover heating value on a dry basis has to be used to calculate emission factors (CORINAIR, 2005). Lover heating value of Koyunağılı coal on dry basis is 5614 kCal/kg

Emission factors used in this study to estimate emissions from domestic heating sources are presented in Table A-1.

Table A-1 Emission factors used to estimate emission rates of residential sources around Çayırhan Thermal Power Plant (CORINAIR, 2005)

Fuel	Emission Factors (g/GJ)		
	NO_x	SO_2	PM_{10}
Coal	130	698	400

In that table, emission factors of NO_x and PM_{10} were given empirically. However, emission factor of SO_2 was calculated regarding to below formula (CORINAIR, 2005):

$$EF_{SO_{2,k}} = 2 \times \overline{Cs_k} \times (1 - \overline{\alpha_{S,k}}) \times \frac{1}{H_k} \times 10^6$$

$EF_{SO_{2,k}}$ emission factor for SO_2 for fuel type k [g/GJ]

$\overline{Cs_k}$ average sulphur content of fuel type k (mass S/mass fuel [kg/kg])

H_k average lover heating value for fuel type k [MJ/kg]

$\overline{\alpha_{S,k}}$ average sulphur retention in ash

1 kcal = 4186,8 J

Sulphur retention in ash is the difference between the sulphur dioxide concentration calculated from the total sulphur content of fuel (c_{max}) and the sulphur dioxide concentration of the flue gas (c_{eff}) divided by the sulphur dioxide concentration calculated from the total sulphur content of the fuel. Total sulphur content of the coal is 1.39% by weight and combustible sulpher content is 0.82% by weight.

$$\alpha_s = (c_{max} - c_{eff})/c_{max}$$

Where;

$\overline{Cs}$ = 0.0139

H = 5614 kcal/kg = 23.51 MJ/kg

$\overline{\alpha_S}$ = (1.39 – 0.82) / 1.39 = 0.41

As a result;

EF_{SO_2} = 698 g/GJ

SO_2 Emission Rate of Çayırhan Town

There are 3292 households in Çayırhan. As assumed, 500 kg coal is consumed in November and March. The area occupied by households at Çayırhan is 785714.29 m^2.

3292 households x 0.5 tons/households.month = 1646 tons/month
= 1646000 kg/month

Lover Heating Value (LHV) = 23.51 MJ/kg = 0.0235 GJ/kg

SO_2 Emission Rate = Coal Amount x LVH x EF / Area
= 1646000 kg/month x 0.0235 GJ/kg x 698 g/GJ / 785714.29 m^2
= 1.33E-05 g/s.m^2

NO_x Emission Rate of Çayırhan Town

NO_x Emission Rate = Coal Amount x LVH x EF / Area
= 1646000 kg/month x 0.0235 GJ/kg x 130 g/GJ / 785714.29 m^2
= 2.47E-06 g/s.m^2

PM_{10} Emission Rate of Çayırhan Town

PM_{10} Emission Rate = Coal Amount x LVH x EF / Area
= 1646000 kg/month x 0.0235 GJ/kg x 400 g/GJ / 785714.29 m^2
= 7.6E-06 g/s.m^2

APPENDIX B

Table B-1 Contribution of sources to the maximum annual SO_2 concentrations

Locations	Sources	Maximum Annual SO_2 Concentrations, µg/Nm^3		TAQPR Limit, µg/Nm^3
		ISCST3	AERMOD	
Çayırhan	All sources	47.19	35.26	150
	Only the power plant	0.57	0.85	
	Only domestic heating	46.62	34.41	
Kayabükü	All sources	13.9	7.92	150
	Only the power plant	0.14	0.32	
	Only domestic heating	13.76	7.6	
Sekli	All sources	19.41	19.41	150
	Only the power plant	0.58	2.87	
	Only domestic heating	18.83	16.54	
Karaköy	All sources	22.68	21.45	150
	Only the power plant	0.31	1.06	
	Only domestic heating	22.37	20.39	
Davutoğlan	All sources	28.59	16.7	150
	Only the power plant	0.44	0.75	
	Only domestic heating	28.15	15.95	
Atça	All sources	7.08	8.41	150
	Only the power plant	0.92	0.23	
	Only domestic heating	6.16	8.18	
Uluköy	All sources	8.51	16.15	150
	Only the power plant	0.41	1.07	
	Only domestic heating	8.10	15.08	
Çantırlı	All sources	6.35	7.69	150
	Only the power plant	4.35	5.64	
	Only domestic heating	2.00	2.05	

Table B-2 Contribution of sources to the maximum annual NO_x concentrations

Locations	Sources	Maximum Annual NO_x Concentrations, µg/Nm^3		TAQPR Limit, µg/Nm^3
		ISCST3	AERMOD	
Çayırhan	All sources	9.85	8.13	100
	Only the power plant	1.17	1.72	
	Only domestic heating	8.68	6.41	
Kayabükü	All sources	2.85	2.05	100
	Only the power plant	0.29	0.64	
	Only domestic heating	2.56	1.41	
Sekli	All sources	6.65	8.84	100
	Only the power plant	1.18	5.76	
	Only domestic heating	5.47	3.08	
Karaköy	All sources	4.79	5.94	100
	Only the power plant	0.62	2.14	
	Only domestic heating	4.17	3.8	
Davutoğlan	All sources	6.16	4.49	100
	Only the power plant	0.91	1.52	
	Only domestic heating	5.25	2.97	
Atça	All sources	2.99	1.99	100
	Only the power plant	1.85	1.52	
	Only domestic heating	1.14	0.47	
Uluköy	All sources	2.36	4.98	100
	Only the power plant	0.85	2.17	
	Only domestic heating	1.51	2.81	
Çantırlı	All sources	9.13	11.74	100
	Only the power plant	8.76	11.36	
	Only domestic heating	0.37	0.38	

Table B-3 Contribution of sources to the maximum annual PM_{10} concentrations

Locations	Sources	Maximum Annual PM_{10} Concentrations, µg/Nm^3		TAQPR Limit, µg/Nm^3
		ISCST3	AERMOD	
Çayırhan	All sources	29.34	22.00	150
	Only the power plant	2.61	2.72	
	Only domestic heating	26.73	19.28	
Kayabükü	All sources	7.93	4.48	150
	Only the power plant	0.05	0.12	
	Only domestic heating	7.88	4.36	
Sekli	All sources	1.47	1.55	150
	Only the power plant	0.65	1.30	
	Only domestic heating	0.82	0.25	
Karaköy	All sources	13.19	12.69	150
	Only the power plant	0.37	1.00	
	Only domestic heating	12.82	11.69	
Davutoğlan	All sources	16.44	9.81	150
	Only the power plant	0.30	0.67	
	Only domestic heating	16.14	9.14	
Atça	All sources	3.76	4.76	150
	Only the power plant	0.23	0.07	
	Only domestic heating	3.53	4.69	
Uluköy	All sources	4.78	9.15	150
	Only the power plant	0.14	0.51	
	Only domestic heating	4.64	8.64	
Çantırlı	All sources	2.28	2.75	150
	Only the power plant	1.13	1.58	
	Only domestic heating	1.15	1.17	