AIR POLLUTION MODELING

IN ISKENDERUN REGION OF TURKEY

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ABSTRACT

AIR POLLUTION MODELING IN ISKENDERUN REGION OF TURKEY

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The Gulf of Iskenderun is a region in southeastern Turkey where steel industries are concentrated. It houses ISDEMIR, the 2nd largest integrated steel mill of Turkey, and a number of foundries and re-rolling mills. As a result of concentrated industrial activities without taking care of their impacts on the environment, the air pollution in this area has risen to high levels. This may have adverse effects on the human health and ecosystem in this region

In this study the emission inventory of air pollutants in Iskenderun region has been prepared for the first time. The types of sources included in this study were industrial, domestic heating and traffic on inter-city as well as urban roads. Pollutants included were Particulate Matter (PM), SO_2, NO_X, CO, and non-methane volatile organic compounds (NMVOC). The results of the emission inventory revealed that the annual emissions of PM, SO_2, NO_X, CO and NMVOC were 19,951 tons, 40,833 tons, 10,764 tons, 109,938 tons and

5665 tons, respectively. Industrial sector was responsible for more than 95% of the total emissions of PM and SO_2. Moreover, 68% of NO_X and 73% of CO emissions were also due to industries. However, industries were responsible for only 4% of the total NMVOC emissions. Traffic sources were responsible for 31% of NO_X and 27% of CO in the total annual emissions from the Iskenderun Region.

The dispersion modeling of pollutants from all sources in Iskenderun Region were studied to estimate the ground level concentrations of PM, SO_2, NO_X and CO. The ISCST3 model, developed and approved by the U.S. EPA was used. The dimensions of study area were 25 km x 50 km. The local terrain was complex because of having the Mediterranean Sea and Amanos Mountains range along with a flat land. Topographical data was included into the modeling calculations. The meteorological data showed that the dominant wind directions were from S and W. Dry and wet depositions of the pollutants were also considered.

The concentration maps developed on the basis of results of modeling calculations showed that the ground level concentrations at some places in the study area were above the Turkish Air Quality Protection Regulation of 1986, WHO Guidelines, and the EC Regulation limits. On the other hand, the modeling results showed that the pollutant concentrations in urban areas like Iskenderun, Dortyol and Payas were mainly due to domestic heating activities and urban traffic. However, Dortyol and Payas have some impacts due to emissions from re-rolling steel mills and ISDEMIR, which are located to the south and southwest of these towns. Statistical analyses showed that the accuracy of the model in predicting the ground level concentrations of SO_2 was 67%. The model calculations under predicted the observed concentrations of SO_2.

Four different air quality management scenarios for domestic heating and industrial sources were studied to evaluate the possibilities of reducing ground

level concentrations of pollutants. Results of these scenarios showed that the control of PM emissions from ISDEMIR and replacing fuel oil used by all of the re-rolling steel mills having 6% by wt. sulfur with a fuel oil having 1.5% by wt. sulfur, would greatly improve the quality of air not only in Dortyol and Payas but in whole of the Iskenderun Region. The annual average ground level concentrations of PM and SO_2 will decrease by 70% and 40%, respectively.

Increasing the stack heights of other industries from 25m to 50 m will lead to 30% reduction in the annual average ground level SO_2 concentrations in Dortyol and Payas. The use of natural gas for domestic heating will totally eliminate the PM and SO_2 problems in the urban areas of the Iskenderun Region. Based on the results of this study, suggestions have been listed for the "Clean Air Plan" in the region

Keywords: Air pollution assessment, Emission inventory, Air pollution modeling, ISCST3, Air quality, emissions from iron and steel industries.

ÖZ

TÜRKİYE' DE İSKENDERUN BÖLGESİNDEKİ HAVA KİRLİLİĞİNİN MODELLENMESİ

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İskenderun Körfez Bölgesi, Türkiye'nin güney doğusunda bulunan ve demir-çelik endüstrisinin en yoğun olduğu bir bölgedir. Bu bölgede, Türkiye'nin ikinci en büyük entegre demir-çelik tesisi olan ISDEMIR ve daha birçok demir-çelik haddehaneleri bulunmaktadır. Bölgede demir-çelik endüstrisinin yoğun olarak bulunması ve bu tesislerde çevre kirliliğini azaltıcı önlemlerin alınmamasından dolayı, özellikle hava kirliliği problemi önemli boyutlara ulaşmıştır. Bu kirlilik bölgede yaşayan insanların sağlığı ve ekosistem üzerinde zararlı etkiler yapmaktadır.

Bu çalışmada, İskenderun bölgesinde hava kirleticileri için daha önce yapılmamış olan ve ilk kez bu çalışmada ele alınan bir "emisyon envanteri" gerçekleştirilmiştir. Emisyon envanterine dahil edilen emisyon kaynakları: endüstriyel kaynaklar, evsel ısınma kaynakları ve bölgedeki hem şehirlerarası hem de şehiriçindeki yollardaki trafiktir. Emisyon envanteri yapılan kirleticiler: Partiküler Madde (PM), SO_2, NO_x, CO ve uçucu hidrokarbonlardır (NMVOC).

Emisyon envanteri sonuçları atmosfere yılda 19951 ton partiküler madde, 40883 ton SO_2, 10764 ton NO_x, 109938 ton CO ve 5665 ton NMVOC atıldığını göstermiştir. Emisyon kaynakları arasında endüstriyel kaynakların, PM ve SO_2 için toplam emisyonun %95'inden sorumlu olduğu anlaşılmıştır. Bu oran NO_X ve CO için sirasi ile %68 ve %73 olarak bulunmuştur. Ancak, toplam NMVOC emisyonunun sadece %4'ü endüstriden kaynaklanmaktadır. Trafikten kaynaklanan NO_X ve CO oranları, toplam emisyonun sırasıyla %31 ve %27 si olarak tesbit edilmiştir.

İskenderun bölgesinde emisyonlardan kaynaklanan PM, SO_2, NO_X ve CO için yer seviyesi konsantrasyonları, "Dağılım Modeli" kullanılarak hesaplanmıştır. Kullanılan model A.B.D.'de EPA tarafından geliştirilen ve onaylanan ISCST3 (3.sürüm) (Industrial Source Complex-Short Term) modelidir. Modelleme için göz önüne alınan alan 25 km x 50 km büyüklüğündedir. Bölgede topografik koşullar, bir tarafta Akdeniz'in diğer tarafta Amanos dağlarının bulunmasından dolayı oldukça komplekstir. Bu çalışmada topografya verileri de modellemeye dahil edilmiştir. Meteoroloji verileri, hakim rüzgar yönlerinin Guney ve Batı olduğunu göstermiştir. Ayrıca, kirleticiler için yaş ve kuru çökelme de modellemede göz önüne alınmıştır.

Modelleme çalışması sonunda elde edilen sonuçlardan eş konsantrasyon eğrileri çizilerek, hava kirliliği haritaları hazırlanmıştır. Çalışma bölgesi içindeki bazı alanlarda Türk Hava Kalitesi Korunması Yönetmeliği(1986)'nde, Dünya Sağlık Teşkilatı ve Avrupa Birliği yönetmeliklerinde verilen sınır değerlerin aşıldığı görülmüştür. Diğer taraftan İskenderun, Dörtyol ve Payas gibi kentsel alanlarda hava kirliliğinin büyük ölçüde evsel ısınma ve şehiriçi trafik kaynaklı olduğu bulunmuştur. Ancak, Dörtyol ve Payas gibi yerleşim bölgelerindeki hava kirliliğinde, bu bölgelerin güney ve günebatısında yerleşik olan İSDEMİR ve demir-çelik haddehanelerinden kaynaklanan kirliliğin de etkili olduğu görülmüştür. Model sonuçları İskenderun'da hava kirliliği ölçüm istasyonunda yapılan SO_2 ölçümleri ile karşılaştırılmıştır. Ayrıca model sonuçları ile istatistiksel analiz yapılmış ve bu analizler sonunda modelin, yer seviyesindeki

SO_2 konsantrasyonunu %67 doğrulukla hesaplayabildiği bulunmuştur. Modelle bulunan değerler ölçüm değerlerinin altındadır.

İncelenen hava kirleticilerinin yer seviyesi konsantrasyonlarını azaltabilme olasılıklarını değerlendirmek amacıyla, evsel ısınma ve endüstriyel emisyon kaynakları için dört değişik "Hava Kalitesi Yönetim Senaryosu" geliştirilmiştir. Bu senaryoların incelenmesi sonucunda ISDEMIR'dan çıkan PM emisyonları kontrol edilirse ve demir-çelik haddehanelerinde %6 kükürt içeren fuel-oil yerine %1.5 kükürt içeren fuel-oil kullanılırsa, sadece Dörtyol ve Payas civarında değil, tüm İskenderun Körfez Bölgesi'nde hava kalitesinin iyileşebileceği görülmüştür. Bu senaryoların uygulanması ile yıllık ortalama PM ve SO_2 konsantrasyonlarında sırası ile %70 ve %40 oranında azalma sağlanacaktır.

Demir-çelik haddehanelerinin baca yüksekliği 25 m den 50 m ye çıkarıldığında Dörtyol and Payas'ta yıllık ortlama SO_2 kontrasyonu %30 oranında azalacak, evsel ısınmada kömür yerine doğal gaz kullanıldığında ise şehirlerde PM ve SO_2 problemi ortadan kalkacaktır. Bu çalışma sonunda bölgede yapılması gereken "Temiz Hava Planı" için de öneriler geliştirilmiştir.

Anahtar Kelimeler: Hava kirliliği tesbiti, Emisyon envanteri, Hava kalitesi modellemesi, ISCST3 modeli, Hava kalitesi, Demir-Çelik endüstrisinden kaynaklanan emisyonlar.

Dedicated to the memories of my late father,
Chaudhary Muhammad Saleem (1939-2001).
Who will live forever in my heart.

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LIST OF ABBREVIATIONS

°C	Degree Celsius
CO	Carbon monoxide
$CaCO_3$	Limestone
EAF	Electric arc furnace
EEA	European Environment Agency
EPA	Environmental Protection Agency
ERDEMIR	Eregli Iron and Steel Mill
g	gram
GJ	Giga Joule
h	hour
ISDEMIR	Iskenderun Iron and Steel Mill
ISCST	Industrial source complex short-term model
ISCLT	Industrial source complex long-term model
K	Kelvin
KARDEMIR	Karabuk Iron and Steel Mill
Kg	kilogram
Kj	Kilo joule
L	Liter
LPG	Liquefied petroleum gas
m	Meter
mm	Millimeter
m/s	Meter per second
mbar	Millibar
MJ	Million Joule
MOE	Ministry of Environment
MWe	Megawatt electric

MWth	Megawatt thermal
NAAQS	National ambient air quality standards (USA)
NESHAP	National emission standard for hazardous air pollutants (USA)
NMVOC	Non-methane volatile organic compounds
NO_X	Nitrogen oxides ($NO + NO_2$)
O_3	Ozone gas
PM	Particulate matter
RMSE	Root mean square error
s	seconds
SDM	State Department of Meteorology (Turkey)
SIS	State Institute of Statistics (Turkey)
SO_2	Sulfur dioxide gas
TAQPR	Turkish Air Quality Protection Regulations
Ton	metric ton
UNCED	United Nations Conference on Environment
UNEP	United Nations Environment Program
WHO	World Health Organization
μg	Microgram
y	year

CHAPTER 1

INTRODUCTION

Clean air is considered to be a basic requirement for human health and their wellbeing. Air pollution has become an alarming problem with industrialization, and protection of air quality turned into a topic of great interest since early 1960's. The United Nations Conference on Environment and Development (UNCED) held in 1992 at Rio de Janeiro, Brazil, adopted the Framework Climate Convention (Agenda 21) which underlined the need of air pollution control. Also, the declaration of Habitat II (United Nations Conference on Human Settlements held in June 1996, at Istanbul, Turkey) emphasized the "sustainable development" and "sustainable human settlements" for the protection of environment. In sustainable human settlements **clean air** was one of the most important considerations put forward among the other environmental issues. The promises made in Istanbul in 1996 were again discussed in the special session of UN General Assembly held on June 6-8, 2001, which was regarded as "The Istanbul+5" meeting and the decisions taken five year ago were reviewed in this meeting.

Although new technologies for air pollution control and effective legislation have improved the quality of air we breathe, but the pressure on environment is still increasing. Economic development coupled with population growth and industrialization is causing the climate to change and build up of pollutants in the environment. It has been made clear by various scientists that unless the loading of pollutants to the environment beyond its carrying capacity is

prevented especially through anthropogenic sources, the situation will get worse.

The changes in the concentrations of gases in the atmosphere are mainly caused by human activities. The major part of air pollution in the atmosphere is due to energy production and other industrial activities. These industrial activities generate pollutants like CO_2, CO, NO_x, SO_2, particulate matter (PM), VOC, organics, HF, HCl, dioxins and other pollutants. The continuous increase in the emission rate of these pollutants is a source of concern because of problems pertaining to changes in atmospheric chemistry, global warming, stratospheric ozone depletion, acid deposition, acid rain and effects on human health, vegetation and animals.

Harmful substances emitted to the atmosphere affect both human health and ecosystems. Indoor and outdoor air pollution are estimated to be responsible for nearly 5% of the global burden of disease. Air pollution intensifies and/or, causes asthma and other allergic respiratory diseases (UNEP, 2002). It has been estimated that in developing countries about 1.9 million people die annually due to exposure to high concentrations of suspended particulate matter (SPM) in the indoor air environment of rural areas, while the excess mortality due to outdoor levels of SPM and SO_2 amounts to about 500 000 people annually (WHO, 1999). Evidence is also emerging that particles with median aerodynamic diameter less than 2.5 μm (PM2.5) affect human health significantly (WHO, 1999). Acid deposition is one of the causes of acidification of soil and water that results in declining fish stocks, decreasing bio diversity in acid-sensitive lakes and degradation of forest and soil. Excessive nitrogen (as nitrate and/or ammonium) promotes eutrophication, particularly in coastal areas. Moreover, acid rain damages ecosystems, provokes corrosion of monuments and historic buildings and reduces agricultural yields (UNEP, 2002).

Without proper controls of the pollutants emitted to the environment, industry is a major source of pollution. Consequently, industrial operations can affect the

health of workforces, the environment and the health of nearby and some times very far located populations. Iron and steel industry is regarded as one of the basic industries for the development of any country. On the other hand, iron and steel industries are one of the major sources of air pollution, which is included in the list of industries with significant health impacts (WHO, 2000).

In Turkey there are three major integrated iron and steel industries. Namely, ERDEMIR, KARDEMIR and ISDEMIR located in Eregli-Zonguldak, Karabuk, and Iskenderun, respectively. The Gulf of Iskenderun, the proposed study area, is the most industrialized region of southeast Turkey. As a result of concentrated industrial activities without taking care of its impacts on environment, significant increase in air pollution has been observed that has risen to a level visible by naked eye. High levels of air pollution have adverse affects on vegetation and on human health of the inhabitants of Iskenderun, Payas, Dortyol and other rural areas. The region contains several industrial sources, such as:

- ISDEMIR (the 2nd largest integrated iron and steel mill of Turkey)
- Yazıcı Demir Çelik (a medium sized iron and steel works)
- OYSA (a cement grinding, mixing and packaging factory)
- A number of foundries and steel re-rolling mills along with other industries.

Out of the emissions from industries, NO_2, SO_2, CO and PM are designated as criteria pollutants in NAAQS (National Ambient Air Quality Standards, of USA). Coke oven emissions are included in Hazardous Pollutants in NESHAP (National Emission Standards for Hazardous Air Pollutants, of USA), (De Nevers, 1995).

1.1 Objectives of the Study

As mentioned above the Iskenderun region is the most industrialized region of the southeast Turkey. The population of this area is 415,000 according to the census of 2000 (SIS, 2002). This region is also regarded as the citrus depot of Turkey. In this region the average annual humidity is around 70 % that may also increase air pollution problem. The only air pollution monitoring station is in the premises of Sağlık Ocak No.1 in the city of Iskenderun; therefore, real status of air pollution in the region cannot be estimated.

The main objectives of this study are:

- To prepare an emission inventory of the region, which has not been done in this region previously,
- To find the contributions of several sources to the air pollution in the region,
- To estimate the ground level concentrations of pollutants by dispersion modeling and to prepare ground level concentration maps,
- To list suggestions, based on modeling results, for the development of a "clean air plan" for the Iskendern Region, which is also necessary according to Turkish Air Quality Protection Regulation (TAQPR), (MOE, 1986)

1.2 Scope of the Study

This study was focused on the measurement and estimation of emissions from several types of sources and their contributions in the ground level concentrations at different locations. The scope of study was not limited only to industrial emissions; it included also the emissions from domestic heating and traffic sources both in urban areas and on inter-city highways.

Pollutants under the investigation for emission inventory in this study were particulate matter (PM), sulfur dioxide (SO_2), nitrogen oxides (NO_X), carbon monoxide (CO) and non-methane volatile organic compounds (VOC). The emissions from industrial sources were measured in the stacks while the emissions from domestic heating and traffic sources were estimated by using CORINAIR emission factors (EEA, 2001).

After preparing the emission inventory, the dispersions of pollutants were studied by using the USEPA's Industrial Source Complex Short Term Model Version 3 (ISCST3) (US EPA, 1995a). Based on the results of modeling calculations, the ground level pollution concentration maps for PM, SO_2, NO_X and CO were prepared and were superimposed on the geographical map of the study area. NMVOC were not included in the dispersion studies because of their reactive nature. This gave a clear picture of the ground level concentrations of all the pollutants. The results of the modeling study were compared with the measured concentrations of total PM and SO_2 to evaluate the degree of accuracy. Statistical methods, root mean square error (RMSE) and index of agreement (d) were used for this purpose, which are widely used to evaluate the model performance.

1.3 Location and Physical Characteristics of the Region

The Iskenderun Region is located between the Mediterranean Sea and Amanos mountain range where peaks reach up to 1700 m high above sea level. The geographical location of the region is shown in Figure 1.1. This region forms a narrow coastal area between the sea and mountains.

1.3.1 Population

There are 415,000 inhabitants residing in the study area (SIS, 2002). Major population centers are Iskenderun, Dortyol and Payas with populations of 160,000, 54,000 and 32,000, respectively. The rest of 169,000 people live in several sub-urban areas and villages scattered in the study area. During winters most of the dwellings use coal for domestic heating, which is a source of pollutant emissions.

1.3.2 Highways and Urban Traffic

There are two major inter-city highways passing through the study area, the Iskenderun-Adana Motorway and the Highway. Both of these roads stretch through the entire length of the study area, and connect the Iskenderun region with other parts of the country. Vehicle count data for both of these roads was available from the General Directorate of Highways in Ankara. The urban traffic is also included in the study. The traffic counts were not available for the urban areas under consideration. However, with some assumptions that will be explained in the later chapters the problem was solved.

1.3.3 Industry

Industrial complexes are located at about 17 km north of Iskenderun city. There are three industrial zones in the area along with ISDEMIR, two in the north and the other in the south of ISDEMIR. Re-rolling steel mills are concentrated in the Dortyol and Payas Organized Industrial Estates, located in the north of ISDEMIR. The Iskenderun Organized Industrial Estate located in the south of ISDEMIR contains a medium-sized foundry and a re-rolling mill. These industries use fossil fuels, iron ores (hematite, magnetite, pyrite) and steel scrap for their production and were suspected to emit large amounts of pollutants including SO_2, NO_x, CO, CO_2, VOC and particulate matter.

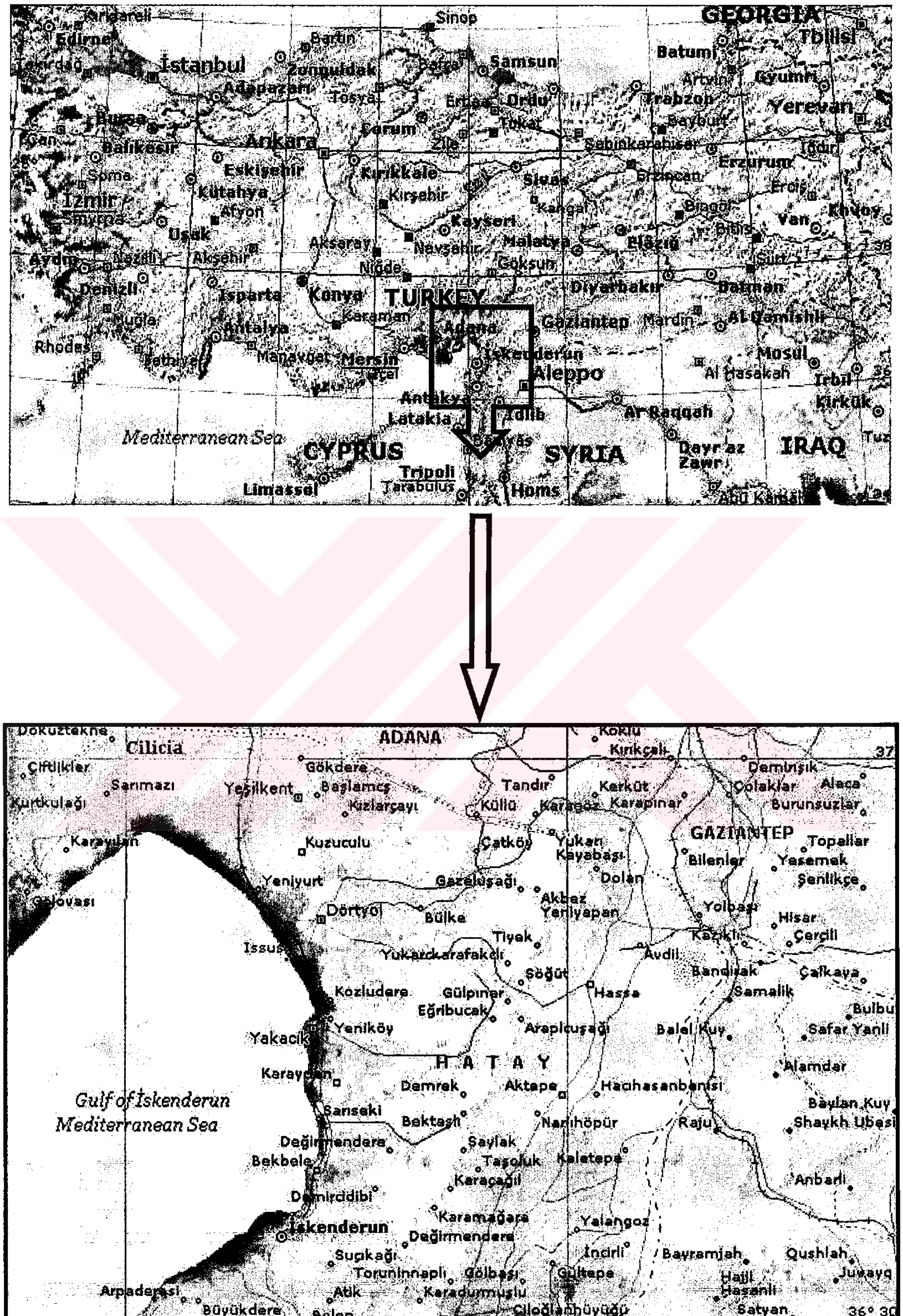

Figure 1.1 Map of the Iskenderun Region

Major industries located in the area are ISDEMIR, Yazıcı Demir Çelik, OYSA Cement Factory and some re-rolling mills. Among these industries, the largest one is ISDEMIR which produces iron and steel from iron ores. It is an integrated plant with a production capacity of 2,200,000 tons/year. ISDEMIR is the 2nd largest integrated iron and steel works of Turkey after ERDEMIR. The production capacities and annual production rates of integrated steel industries making iron and steel from iron ores in Turkey are given in Table 1.1. As can be seen from this table, 37% of the total integrated iron and steel production capacity is installed at ISDEMIR and in year 2001, 30% of Turkish steel from integrated industries was produced at ISDEMIR.

Table 1.1 Production capacities and annual productions of integrated steel plants in Turkey (http://www.erdemir.com.tr)

Steel Mills and Locations	Production Capacity (tons)	Production (tons)		
		1999	2000	2001
ERDEMIR (Ereğli)	3,000,000	2,610,733	2,388,011	2,962,255
ISDEMIR (Iskenderun)	2,200,000	1,890,500	1,965,100	1,575,000
KARDEMIR (Karabuk)	700,000	640,356	875,425	740,080
TOTAL	**5,900,000**	**5,141,589**	**5,228,536**	**5,277,335**

During year 2001 the shares of production of different types of steel in Iskenderun region in year 2001 are given in Table 1.2. The total production was 3,517,796 tons/year. Out of the total steel production, 45% was provided by ISDEMIR as shown in Figure 1.2.

Table 1.2. Production capacities of steel industries in Iskenderun

Company	Type of Industry	Production Capacity (tons)	Production(tons)		
			1999	2000	2001
ISDEMIR	Integrated	2,200,000	1,890,500	1,965,100	1,575,000
EKİNCİLER*	Electric arc	1,000,000	744,165	404,227	-
YAZICI	Electric arc	817,000	781.810	824,271	837,796
All Re-rolling Mills	Re-heating	-	-	-	1,105,000
Total					**3,517,796**

* The company has stopped production since August 2000.

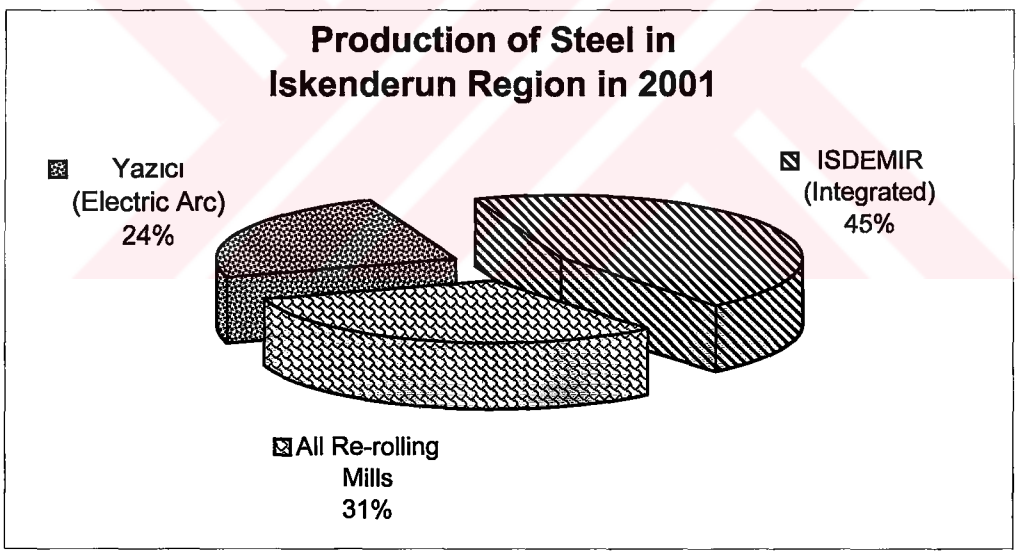

Figure 1.2 Annual production of steel in Iskenderun region during 2001

CHAPTER 2

PRODUCTION OF IRON AND STEEL

Since the main industry in the Iskenderun region is the iron and steel, therefore, details of the iron and steel making processes are summarized in this chapter. Inputs, outputs and emissions from several processes involved in making iron and steel are given in the coming sections.

Iron (Fe) is the 4th most abundant element in the earth's crust, outranked only by aluminum, silicon and oxygen. It is the world's least expensive and most useful metal. Civilization has developed rapidly only after humans have discovered how to extract iron from its ores.

Iron ore deposits were formed by many different processes, e.g., weathering, sedimentation, hydrothermal, and chemical. Iron ores occur in igneous, metamorphic, and sedimentary deposits. Normally, iron ore contains 25 to 68% by weight iron. The principle iron ores are Hematite (Fe_2O_3, 69 % iron by weight), Magnetite (Fe_3O_4, 72 % iron by weight), Geothite ($HFeO_2$, 62 % iron by weight), Siderite ($FeCO_3$, 48 % iron by weight), Ilmenite ($FeTiO_3$, 37 % iron by weight) and Pyrite (FeS_2, 46% iron by weight) (Kirk and Ohmer, 1995).

2.1 Preparation of Raw Materials

Iron ore coming from the mines must be properly sized. A gyratory crusher is normally used for primary crushing down to approximately 300 mm. Secondary crushing down to 25 mm is done in a cone crusher. Fine grinding is accomplished by rod mills followed by either ball or pebble mills. Iron ores of different characteristics and compositions can be blended to a more uniform composition. This can be accomplished during handling operations involved in transporting ore to its point of use, or through special blending facilities, such as stacking and reclaiming (Kirk and Ohmer, 1995).

2.1.1 Agglomeration of Ore Particles

Iron ore concentrates are often too fine to be used directly in iron making processes; therefore, they must be agglomerated. The agglomerating methods typically used in the iron ore industry are pelletizing and sintering.

Palletizing

In the palletizing process, the iron ore must be ground to a very fine size (<75 μm (-200 mesh)). The ground ore is mixed with the proper amount of water and binder, normally bentonite, hydrated lime, or organic material, and then is rolled into small balls of 9-15 mm in diameter in a balling drum or disk. These green (wet) pellets are dried, then are heated to 1200-1375°C to bond the small particles, and finally are cooled. The heating can be done on a traveling grate, in a shaft furnace, or by a combination of a traveling grate and a rotary kiln.

Sintering

Sintering consists of igniting a mixture of iron ore, iron bearing dust, limestone and coke fines on a traveling grate to produce a clinker-like aggregate (sinter) suitable for use in the blast furnace. The iron-bearing fines can include iron ore fines (sinter feed), iron ore concentrates, flue dust, or other steel mill

wastes. The traveling grate is shaped like an endless loop of conveyor belt forming a shallow trough with small holes in the bottom. The bed of material on the grate is first ignited by passing under an ignition burner that is fired with natural gas and air; then, as the grate moves slowly toward the discharge end, air is pulled down through the bed. As the coke fines burn in the bed, the heat generated sinters the particles. At the discharge end of the machine, the sinter is crushed to remove extra large lumps, then cooled, and finally screened. The main objectives of sintering are (ISDEMIR, 2001):

- Agglomeration of fine particles to an appropriate size for use in blast furnace.
- Reduction of sulfur content of iron ore by oxidation.
- To produce a charge material for blast furnace that posses enough strength and facilitate passage of gases/air through different layers of inputs.

2.1.2 Coke

Coal is converted to coke in coke furnaces, by heating it above 800°C in the absence of oxygen. In the process of making iron, carbon is provided by the coke, which typically consists of 85-90% fixed carbon, less than 2% volatile matter, 5-13% ash, 0.6-1.3% sulfur, and 2-10% moisture. Coke is most often sized to between 15 and 75 mm. Coke is the preferred form of carbon because (http://www.steel.org):

- The carbon is required as the reductant, and in addition provides heat through combustion with air.
- It provides structural support within the furnace by creating stable areas of permeability for the ascending gases, especially in the softening/melting zone.
- High mechanical strength of coke is important for smooth operations in blast furnace.

2.1.3 Pre-Heated Air

Air for the hot blast may also be considered as a raw material. The air is preheated in stoves to between 900 and 1300°C, using flue gas from blast furnace. Over 1.5 ton of air is required to produce 1 ton of hot metal (pig iron). Oxygen may also be added to the hot blast to increase flame temperature (Kirk and Ohmer, 1995).

2.2 Iron Making Processes

Iron making refers to those processes, which reduce iron oxides to iron. By the nature of the processes, the iron produced usually contains carbon and/or other impurities, which are removed in downstream processing. There are three principal categories of iron making processes, in the order of commercial importance: blast furnace, direct reduction, and direct smelting. Blast Furnace is the process used at ISDEMIR

Blast Furnace

The blast furnace is the "predominant method" for making iron. Established for centuries as the premier iron making process, blast furnace iron making both enabled and profited from the Industrial Revolution. Although the fundamental principles of operation are unchanged, the blast furnace has evolved into a highly efficient and productive process (Kirk and Ohmer, 1995).

The blast furnace is a large, countercurrent, chemical reactor in the form of a vertical shaft, which is circular in cross section. Iron ore, coke, and fluxes constitute the burden, which is charged continuously into the top. Pressures in the shaft are controlled to 100-300 kPa (1-3 atms) gauge. Preheated air (hot blast) is blown in through water-cooled nozzles (tuyeres) around the circumference of the furnace near the bottom. The oxygen in the air reacts with

the coke to form hot reducing gases (mostly carbon monoxide) which ascend through the burden and furnish the following (Kirk and Ohmer, 1995):

- Provide heat for melting.
- React with the iron ore to reduce it to iron; and
- Heat the ore, coke, and fluxes to reaction temperatures.

Nitrogen in the hot blast is heated by the coke combustion, and aids in heat transfer to the burden. The gases leaving the top of the furnace (top gas) are cleaned, cooled, and used as fuel to preheat the air for the hot blast.

Molten iron (hot metal or pig iron) and slag (molten oxides) are produced and accumulate in the bottom of the furnace. The hot metal and slag are drained semi-continuously through a tap hole (tapping, or casting) into a trough. The slag floats over the molten iron because of its lower density as compared to iron. Therefore, the hot metal is separated from the slag by a weir/dam arrangement at the end of the trough, then flows through runners to a refractory-lined rail car. The hot metal is then transported to a nearby site for further processing (Kirk and Ohmer, 1995). A schematic diagram of the blast furnace is shown in Figure 2.1 and processes taking place in the blast furnace are shown in Figure 2.2.

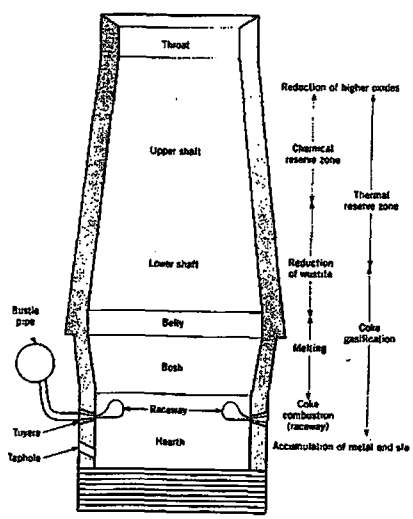

Figure 2.1 The blast furnace

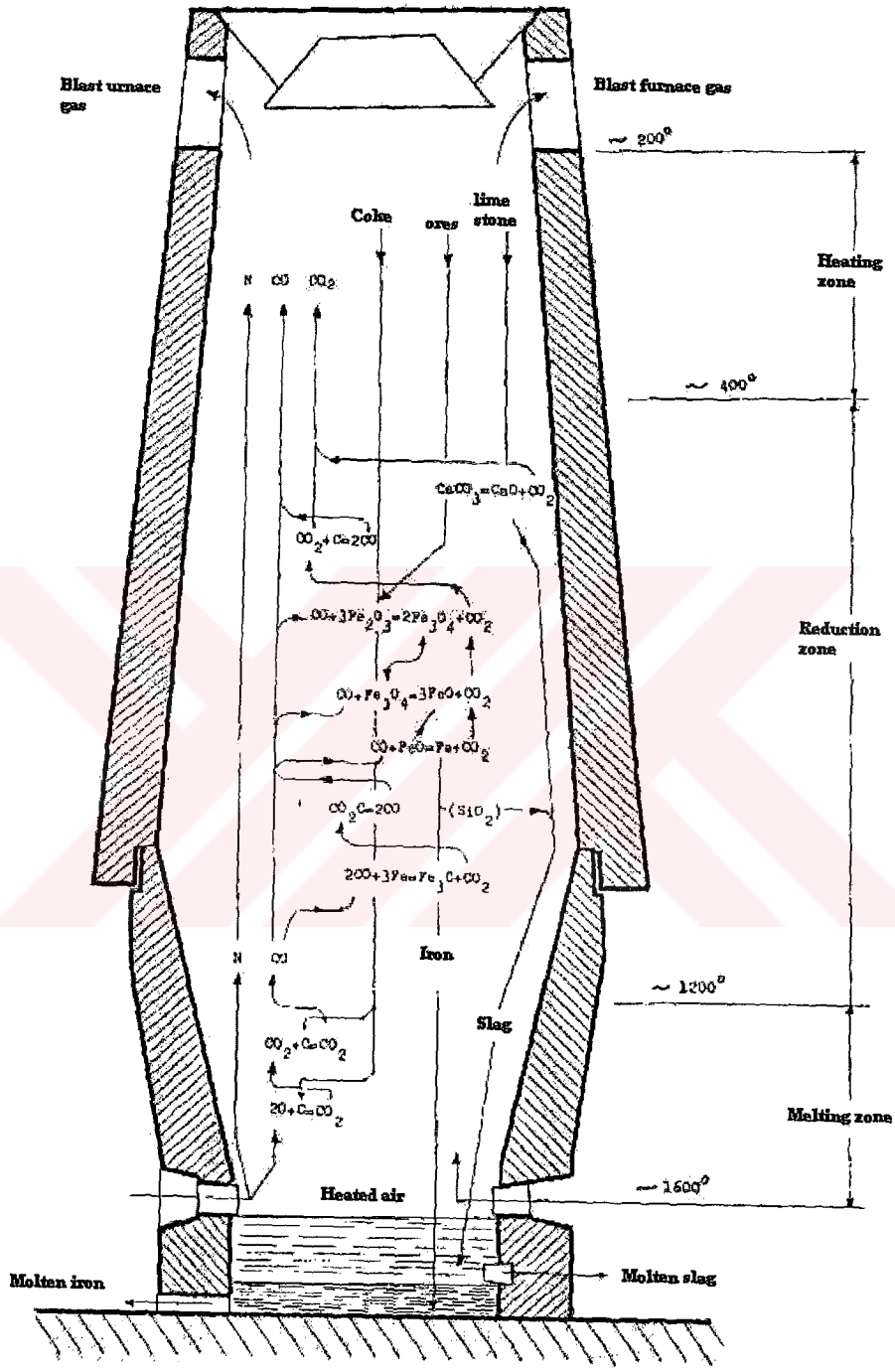

Figure 2.2 Processes inside a Blast Furnace

2.3 Raw Material Inputs and Pollution Outputs for Iron and Steel Works

The iron and steel industry is also ranked as one of the top five releasers for NO_2, PM (particulate matter), and SO_2. Emission of pollutants is described below:

- The release of carbon monoxide occurs during iron making (in the burning of coke, CO produced reduces iron oxides in the ore), and during steel making (in either the basic oxygen furnace or the electric arc furnace)
- Nitrogen dioxide is generated during steel making
- Particulate matter may be emitted from the coke making (particularly in quenching operations), iron making, basic oxygen furnace (as oxides of iron that are emitted as sub-micron dust), or from the electric arc furnace (as metal dust containing iron particulate, zinc, and other materials associated with the scrap)
- Sulfur dioxide can be released in iron making or sintering (EPA, 1995)

Numerous outputs are produced during the manufacture of coke, iron, and steel, forming of metals into basic shapes, and the cleaning and scaling of metal surfaces. These outputs categorized by various processes (US EPA, 1995) are given below:

A. *Coke making*

Inputs:

- Coal, heat (generally coke gas or blast furnace gas is used as fuel in coke batteries), quench water

Outputs:

- Coke

- Process residues from coke, by-product recovery, coke oven gas by-products such as coal tar, light oil, ammonia liquor, and the remainder of the gas stream is used as fuel
- Charging emissions (fine particles of coke generated during oven pushing, transport, loading and unloading of coke)
- Ammonia, phenol, cyanide and hydrogen sulfide
- PM, SO_2, NO_X, CO and VOC from fuel used in coke ovens
- Benzene release in coke by-product recovery operations
- Naphthalene residues, generated in the final cooling tower
- Tar residues
- Sulfur compounds, emitted from the stacks of the coke ovens
- Wastewater from cleaning and cooling (contains zinc, ammonia, still lime)
- Coke oven gas condensate from piping and distribution system

B.Sintering

Inputs:

- Coal, iron ores, $CaCO_3$, gaseous or liquid fuel

Outputs:

- Sinter
- Gaseous pollutants; SO_2, NO_X, CO, CO_2
- Particulate matter

C. Iron Making

Inputs:

- Iron ore (in the form of pellets), coke, sinter, coal, limestone, heated air

Outputs:

- Iron and slag
- Residual sulfur dioxide or hydrogen sulfide
- Particulates captured from the gas, including the dust collected from air pollution control equipment
- Iron is the predominant metal found in the process wastewater
- Blast furnace gas (CO, CO_2, SO_2, NO_X)

D. Steel Making

Inputs:

- In the steel making process that uses a basic Oxygen Furnace (BOF), inputs include molten iron, metal scrap, and high-purity oxygen.
- In the steel making process that uses an Electric Arc Furnace (EAF), the primary inputs are scrap metal, electric energy and graphite electrodes.
- For both processes, fluxes and alloys are added, and may include: fluorspar, dolomite, and alloying agents such as aluminum, manganese, and others.

Outputs:

- Steel of different grades and slag
- From Basic Oxygen Furnace: PM and sludge (a waste containing metals)
- From Electric Arc Furnace: PM and sludge; generally, 9 kg of dust per ton of steel is expected, but as much as 18 kg of dust per ton of steel may be generated depending on the scrap that is used
- Metal dusts (consisting of iron particulate, zinc, and other metals associated with the scrap and flux (lime and/or fluorspar)) not associated with the EAF
- Carbon monoxide (CO)

- Nitrogen oxides (NO_X) and ozone (O_3), which are generated during the melting process

Dust generation in the electric arc furnace (EAF), and its disposal, have also been recognized as a serious problem. However, it has a potential for pollution prevention through material recovery. EAF dust is a waste that contains high concentrations of lead and cadmium, therefore it can be used in other industries. About 550,000 tons of EAF dust is generated annually in the U.S. (U.S. EPA, 1995).

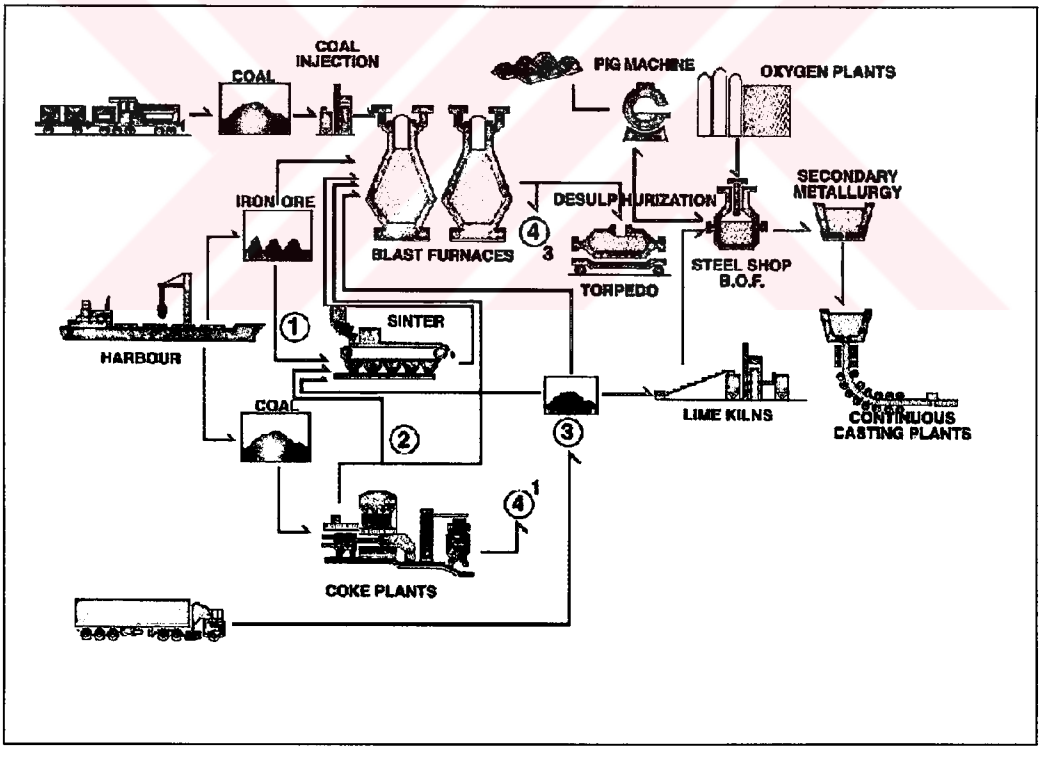

Figure 2.3 A schematic diagram of an integrated steel mill

CHAPTER 3

REVIEW OF LITERATURE

Anthropogenic air pollution originates from a variety of sources, including households, vehicles, small and medium sized industries, construction, fugitive emissions, abrasion and erosion of road services, brake linings, tires, agriculture and forest burning.

Air pollution is one of the most challenging environmental problems in urban as well as some rural areas, especially in view of its adverse effects on human health. In developing countries around the world an estimated 0.5 to 1.0 million people die prematurely each year as a result of exposure to urban air pollution and millions of cases of respiratory illness are associated with air pollution. The economic damage from urban air pollution including its effects on structures, crops and vegetation and forests is estimated to be US$1 billion to US$4 billion annually in cities in Asia, and to US$6 billion in urban areas of Central Asian States (World Bank, 2001). Keeping in view the severity of the problem of air pollution several international organizations such as World Health Organization (WHO), World Bank, United Nations Environment Programme (UNEP) etc. have developed strategies to tackle this problem.

3.1 Ambient Air Quality Monitoring and Assessment

Some of the methodologies and systems used for the assessment of ambient air quality are discussed below. This system is devised by WHO (WHO, 2000). The criteria pollutants like PM, SO_2, NO_2, CO, O_3, etc. have a variety of potentially acute and chronic population health impacts. Therefore, there is a need to establish a network of air quality monitoring.

Air Quality Assessment *Tools*

The three main air quality assessment tools are:

- Ambient monitoring
- Models

Emission inventories/measurement

The ultimate purpose of monitoring is not merely to collect data, but to provide the information necessary for scientists, policy makers and planners to make informed decisions on managing and improving the environment. Monitoring fulfils a central role in this process, providing the necessary sound scientific basis for policy and strategy development, objective setting, and compliance measurement against targets and enforcement action as shown in Figure 3.1 (WHO, 2000).

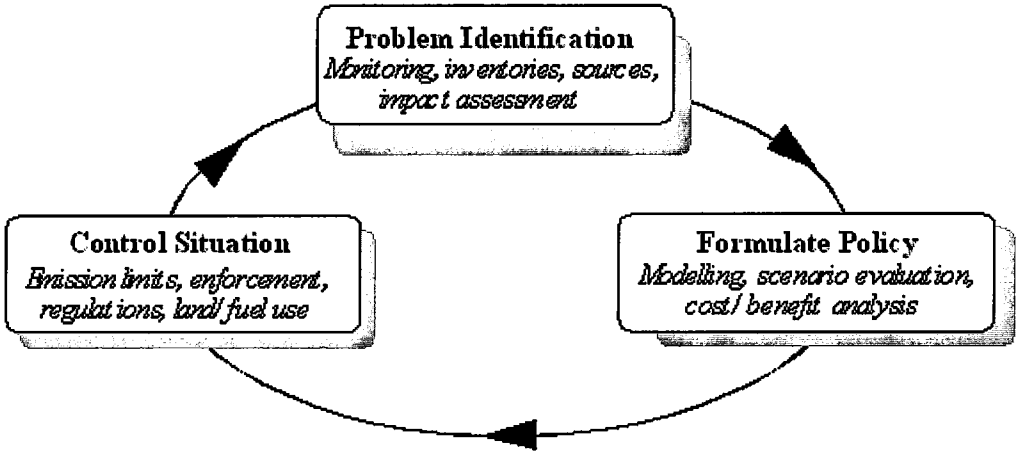

Figure 3.1 Role of several players in air quality assessment (WHO, 2000)

However, the limitations of monitoring should be recognized. In many circumstances, measurements alone may be insufficient or impractical for the purpose of fully defining population exposure in a city or country. No monitoring programme however, well funded and designed, can hope to comprehensively quantify patterns of air pollution in both space and time. At best, monitoring provides an incomplete but useful picture of current environmental quality. Monitoring therefore often needs to be used in conjunction with other objective assessment techniques, including modeling, emission measurement and inventories, interpolation and mapping.

Conversely, reliance on modeling alone is not recommended. Although models can provide a powerful tool for interpolation, prediction, and optimization of control strategies, they depend on the availability of reliable emission data. A complete inventory for a city or country may need to include emissions from point, area and mobile sources; in some circumstances, assessment of pollutants transported into the area under study may also need to be considered. It is important, also, that the models utilized are appropriate to local conditions, sources and topography, as well as being selected for compatibility with available emission and meteorological data sets.

Inventories will, for the most part, be estimated using emission factors appropriate to the various source sectors (verified by measurement), and used in conjunction with surrogate statistics such as population density, fuel use, vehicle kilometers or industrial throughput. Emission measurements will usually only be available for large industrial point sources, or from representative vehicle types under standardized driving conditions.

All three assessment tools are interdependent in scope and application. Accordingly, monitoring, modeling and emission assessments should be regarded as complementary components in any integrated approach to exposure assessment or determining compliance against air quality criteria. Thus, for a

reasonably complete picture of population exposure, ambient monitoring data will need to be supplemented by corresponding information from microenvironment and individual exposure surveys.

Objectives of a Monitoring System

- Determining population exposure and health impact assessment.
- Informing the public about air quality and raising awareness.
- Identifying threats to natural ecosystems.
- Determining compliance with national or international standards.
- Providing objective inputs to Air Quality Management, traffic and land-use planning.
- Source apportionment and identification.
- Policy development and prioritization of management actions.
- Development/validation of management tools (models, Geographical Information Systems etc.).
- Assessing point or area source impacts.
- Trend qualification, to identify future problems or progress against management/control targets.

3.2. Air Quality Management in Turkey

Since 1986 Turkish Air Quality Protection Regulation (TAQPR) is effective in Turkey (MOE, 1986). According to this national legislation much detailed technological sets of emission limitations are available for industrial activities and combustion systems. TAQPR defines the short-term limits for SO_2 and PM as 400 and 300 $\mu g/m^3$ and long-term limits of 150 $\mu g/m3$ for both, respectively. However, some studies have shown these concentration limits have been exceeded in some cities (Elbir et al., 2001). National Legislation also regulates the 6 months winter period urban air quality as 250 $\mu g/m^3$ for SO_2 and 200

$\mu g/m^3$ for PM (MOE, 1986) Table 3.1 summarizes the air quality limits defined in this regulation.

Table 3.1 Emission Limits in the Turkish Regulation, WHO Guidelines, and EC Regulation

Pollutant	Existing Turkish Limits ($\mu g/m^3$)		Proposed Turkish Limits ($\mu g/m^3$)		Turkish Limits for Winter ($\mu g/m^3$)	WHO Guidelines ($\mu g/m^3$)	EC Regulation ($\mu g/m^3$)
	Short term	Long term	Short term	Long term			
SO_2	400	150 250*	250	100	250**	125 (ST) 50 (LT)	125 (ST) 50 (LT)
PM_{10}	300 400*	150 200*	200	100	200** (TSP)	-	80 (LT)
NO_2	300	100	200	100		200 (1 h) 40 (LT)	50 (LT)
NO	600	200	600	200			
HC		140	140				
CO	30,000	10,000	10,000	5,000		10,000 (8 h avg.)	

* Limits for Industrial area, ** 6 month average,
ST = Short term average , LT = Long term average

Currently the air quality limits are under the process of revision by the Ministry of Environment. For reasons of interest in international activities and trade, WHO (Europe) criteria and EC directives were also being closely followed in many case studies. This revision of Turkish regulations includes somewhat stricter short and long term SO_2, PM_{10}, NO_2, VOC and CO limits. However the proposed revision of the limits for these pollutants are also above the WHO guideline and EC regulation limits. According to the existing regulations all of the industries are required to obtain permissions from the Ministry of Environment for stack gas emissions. Moreover, after obtaining these permissions they must be renewed every two years. The basis for the award of these permissions is linked to compliance with the defined limits as **pollution**

loads as well as **concentrations of pollutants** in the stack gases. The limits for pollution loads from industrial premises are given in Table 3.2.

Table 3.2 Limits of Pollution loads from an industrial premises (MOE, 1986)

Parameter	Pollution Load Limits (kg/h)
PM	15
SO_2	60
NO_2	40
CO	1000

3.3 Air Pollution Assessment and Modeling

The particulate emissions from a large steel plant, located inside the town of Genoa (Italy) have been studied from May to December 1997. A two-stage continuous streaker samples and subsequent Particle-Induced X-ray Emission (PIXE) analysis with hourly resolution was used to follow both seasonal and daily trends. The principal component analysis (PCA) identified the group of elements produced by the smelter. Their average abundance and peak values as well as their hourly and seasonal variation have been calculated to determine the impact of the smelter on the air quality of the town. It was shown that about 60% of the particulate matter detected by PIXE in the Cornigliano area is emitted by the steel smelter (Parti et al., 1999).

Atimtay and Kayin (1997) calculated main sources of air pollution and their pollution load on Ankara City in a study in 1997. Two scenarios were evaluated for SO_2 emissions from heating sources, one for 12 months continuous emissions and the other for 6 months emissions. The study area was divided in to 1 km x 1 km grids defined in an area of 52 km x 42 km, the total number of grids was 596. Results obtained by using ISCST2 dispersion model revealed that the highest average SO_2 concentration was 337 $\mu g/m^3$ (6 months average) for winter season, which was below the short term limit of 400 $\mu g/m^3$ given in

the Turkish air Quality Protection Regulations of 1986. Moreover, the most polluted areas were found to be around Cebeci and Istanbul Yolu.

The short-term and long-term versions of the Industrial Source Complex Models (ISCST3 and ISCLT3) were evaluated for estimating long-term concentrations using sulfur 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 sulfur dioxide as compared to the ISCLT3 model (Kumar et al., 1999).

In the Shuaiba Industrial Area (SIA) of Kuwait (containing 183 sources of SO_2) together with its surrounding environment a yearlong case study was conducted. The objective of this study was to evaluate the effectiveness of using the Industrial Source Complex Short Term (ISCST) model to predict the temporal and spatial dispersion of a single pollutant from a large number of emission sources in a highly industrialized area. Trends in the predicted monthly average pollutant concentrations were found to compare favorably with experimental values obtained at a single monitoring station located within the SIA. The predicted and actual temporal locations of two maxima and two minima were coincident. Quantitative agreement between monthly average predicted and measured concentrations was excellent for seven months and reasons are provided for the differences for the remaining five months of the study, especially for July when the demand for air conditioning in Kuwait is expected to be high. The principal weakness in this evaluation of the effectiveness of the

ISCST model was the need to use SO_2 emission rates averaged over the year, rather than on a monthly basis. Despite this shortcoming, the ISCST model has been used to plot isopleths of SO_2 concentration for the SIA and its surrounding environment (Abdul-Wahab, 1999).

A study was performed by Matthew et al. (1999) to examine the performance of the United States Environmental Protection Agency's (EPA) non reactive Gaussian air quality dispersion model, the Industrial Source Complex Short-Term Model (ISCST3) in predicting concentrations of dioxins and furans, or CDD/Fs in both air and soil near the Columbus Municipal Solid Waste-to-Energy Facility (CMSWTE) in Columbus, Ohio, USA. During its 11 years operation, the CMSWTE was estimated to be emitting nearly 1 kg of CDD/F Toxic Equivalents (TEQs) per year, making it one of the highest single emitters of dioxin in the United States during its operation. An ambient air quality monitoring study conducted prior to its shutdown in December 1994 clearly identified high dioxin air concentration in the downwind direction during two sampling events. In one of the events, the CMSWTE stack was concurrently monitored for dioxins. A soil sampling study conducted in 1995/1996 was similarly able to identify an area of impacted soil extending mainly in the predominant downwind direction up to 3 km from the CMSWTE. Site-specific information, including meteorological data, stack parameters and emission rates, and terrain descriptions, were input into ISCST3 to predict ground-level 48-h concentrations which could be compared with the 48-h measured air concentrations. The results given by the model were:

1. Predicted and measured dioxin elevations in air and soil appear to generally be within a factor of 10 of each other, with both under and over predictions identified above. These elevations appear to be restricted to only within a few kilometers, 2-3 km, and this was also found in the dispersion and deposition modeling. The ISCST3 correctly identified the north/northeast quadrant as being the one with elevated soil concentrations.

2. The model didn't always correctly identify locations of high and low air concentrations. Use of iso-concentration lines was helpful in displaying model performance. From the soil modeling exercise, it appears as though the model over predicted soil concentrations to a greater degree the further downwind one went. This suggests that the plume being depleted by dioxins in a manner that was not duplicated by the ISCST3 modeling.
3. It was clear from the analysis that the stack emission profile of CDD/Fs is very different from the profiles measured in the soil and in the air. This could be explained by changes in the profile at some point between the stack and both air and soil measurement sites, or it could be that there were problems in the measurement of CDD/Fs in either the stack or the environmental media.

An emission inventory for PM, SO_2, NO_X, VOC and CO was prepared by Elbir et al. (2000) for Turkey. Types of sources included in that study were industrial, domestic heating and traffic. The results showed that Turkey was rather a large source of emissions at the European scale. The calculated emissions for year 2000 were 7 million tons of PM, 3.5 million tons of SO_2, 0.85 million ton of NO_X, 0.45 million ton of VOC and 1.8 million tons of CO. Moreover, the observed pollution levels of PM and SO_2 in big cities of Turkey were also compared with the Turkish Regulations, EC Regulations and WHO Guidelines, and was found that air pollution was above the limits defined in these standards especially during winter (Elbir et al., 2000).

A study was conducted in Jamshedpur, India, which is situated in the eastern part of the country. It is regarded as the steel city of India. The impact of NO_x emissions resulting from various air pollution sources, viz. industries, vehicles and domestic, was estimated using Industrial Source Complex Short-Term Gaussian dispersion model. The contributions of NO_x concentrations from industrial, vehicular and domestic sources were found to be 53, 40 and 7%, respectively. Further statistical analysis was carried out to evaluate the model

performance by comparing measured and predicted NO_x concentrations. The model performance was found to be good with an accuracy of about 68% (Sivacoumar et al., 2001).

In a study by Grimaldelli and Angius (2000) in Brescia, Italy, the ISCST3 and CALPUFF models were compared with the purpose of analyzing the differences between the results for a possible future application. The dimensions of study area were 25 km x 30 km, including the urban area of Brescia and several neighboring towns. Most of the city and the area to the south were located in the flat land of the Po Valley, but the foothills of the Alps to the north reach elevations of up to 1100 m above sea level. The source data were PM emissions from a steel plant located in the urban area of Brescia: an internal stack diameter of 5.4 m, an outflow velocity of 14.4 m/s, and an emission rate of 1.26 g/s. Stack height was varied during the simulations. When the two models were compared using the same meteorological input, the results were very similar. The main differences were observed in the regime of calm winds especially when these conditions persisted over several hours. It was emphasized that the availability of quality meteorological data for the area under study is of critical importance for a reliable performance of ISCST3 and CALMET/CALPUFF.

In a study by Brusascal et al. (2000) a steady state regulatory model (ISC3) and a Lagrangian particle model (SPRAY) driven by a mass-consistent model (MINERVE) were inter-compared in two Italian coastal sites, that can be considered representative of "simple" and "complex" coastal terrain conditions. The two studied models gave close results only in the site of Fusina, characterized by weak space/time variations of wind speed and direction. The areas interested by pollutant impact are similar but relevant differences are detected in pollutant patterns for the different statistical indexes prescribed by air quality standards. In the complex topographic and circulation conditions that characterize the site of Vado Ligure the results obtained by ISC3 and MS modeling system were completely dissimilar. Even seasonal and yearly average

concentrations depict different impact areas. It was concluded that steady state models implementing simple algorithms for complex terrain appear to be unable to reproduce relevant features of pollutant dispersion in conditions that can be considered typical for the Mediterranean coasts.

Elbir (2002) prepared an emission inventory by considering industrial and domestic heating sources in Izmir, Turkey. The 2nd phase of this study consisted of dispersion modeling of pollutants by using the ISCST3 and the CALPUFF models. The results of the emission inventory showed that industry is the major contributor in emissions. It was found that 91% of SO_2, 40% of PM, 90% of NO_X, 40% of VOC and 70% of CO emissions were from industries. A petroleum refinery and a petrochemical complex operating in the north of Izmir were found to be responsible for 72% of the total SO_2 emissions in that area. The SO_2 concentrations predicted by the model were compared with the observed ones to assess the performance of models. Statistical analyses showed that the accuracy of predictions were 72% for the ISCST3 and 68% for the CALPUFF.

3.4 Effects of Air Pollution on Human Health

Exposure to air pollution is as old as the use of fire by human beings. Air pollution, both indoors and outdoors, is a major environmental health problem affecting developed and developing counties alike. It comes from sources of dust, gases and smoke, and is generated mainly by human activities but also naturally. When inhaled, air pollutants affect the lung and respiratory tract but can also be taken up and transported by the blood stream throughout the body. Through deposition in the environment, air pollutants can also contaminate food and water.

The effects of air pollution on humans range from slight irritation of the eyes and mucous membranes up to death. However, the locations of effects are not

only restricted to the respiratory tract. Many different organs in the whole body are affected. Some of them are described below.

SO_2, a colorless gas with a sour taste in pure air from 0.6 mg/m^3, is an irritant gas for respiratory system and dissolves in mucous membranes of eye, mouth, nose and bronchi. The main effect is caused by repeated peak-like exposures. If SO_2 is adsorbed on fine particulate matter and inhaled by humans, its effects are synergistic. Penetration of acidic aerosol into the inner respiratory organs and formation of H_2SO_4 increase the susceptibility of human to chronic bronchitis and higher risk of acute diseases of respiratory system (Baumbach, 1996).

NO_2 is brown in color and is an oppressive odor irritant gas for respiratory system. It dissolves in mucous membranes. Ozone (O_3) is also a colorless gas with oppressive odor. It is the strongest oxidant and is a strong irritant to respiratory system. It penetrates into the inner lung due to poor aqueous solubility. O_3 also impairs lung functions by oxidation of enzymes, proteins, amino acids, lipids etc., and gives a greater susceptibility to infections and eye irritation (Baumbach, 1996).

CO is an odorless gas and has 200-300 times greater affinity to blood hemoglobin than O_2. Formation of carboxyhemoglobin (COHb) causes the obstruction of O_2 transport in the blood and thus the O_2 supply to the body. It affects especially on the central nervous system (brain) and the cardiovascular system. Some symptoms of presence of COHb in the blood are headaches, fatigue, drowsiness, weakening will power and interference with sleeping-waking behavior (Baumbach, 1996).

An estimated 3 million people die each year because of air pollution. This figure represents about 5% of the total 55 million deaths that occur annually in the world. It is possible, because of uncertainty in the estimates, that the actual death toll is anywhere between 1.4 and 6 million annually (WHO, 2000).

Studies in Sao Paulo, Brazil have shown that a 75 $\mu g/m^3$ increase in concentrations of nitrogen dioxide (NO_2) was related to a 30% increase in deaths from respiratory illness in children under five years of age (WHO, 2000).

In 1993, in New South Wales in Australia a study was conducted to investigate the relationship between outdoor air pollution (mainly from steel complex) and the respiratory health of children aged 8 to 10 years. The average annual outdoor air pollution for the selected areas was 18.6-43.7 $\mu g/m^3$ for PM10 and 4.2-23.6 $\mu g/m^3$ for SO_2. The proportion of children reported to have the main outcome symptoms was: chest colds, 3.0%-9.7%; night cough, 12.3%-30.5%; and wheeze, 3.4%-11.3%. There was no significant association of diseases found with SO_2 (Lewis et al., 1998).

A study in the Anshan Iron and Steel Complex in China showed a significant excess of lung cancer for workers exposed to a variety of dusts. A standardized proportional mortality ratio (SPMR) study of 8887 deaths during 1980-1989 among male workers of the complex indicated a 37 % excess risk of lung cancer compared to residents of the city. A nested case control study was then conducted in that complex. Results suggested that risks were increased for all occupations in which there was exposure to dusts, with the highest risk seen among coke oven workers (Xu et al., 1996).

In Czech Republic, maternal exposures to sulfur dioxide (SO_2), total suspended particle (TSP), and NO_x in each trimester of pregnancy were estimated as the arithmetic means of all daily measurements taken by all monitors in the district of birth of each infant. Low birth weight (prevalence 5.2%) and prematurity (prevalence 4.8%) were associated with SO_2 and somewhat less strongly with TSP (Bobak, 2000).

Ibald (2001) has studied the association between blood pressure, meteorology, and air pollution in a random population sample. Blood pressure measurements of 2607 men and women aged 25 to 64 years were taken. Continuous concentrations of total suspended particulates and sulfur dioxide were associated with an increase in systolic blood pressure of 1.79 mm Hg per 90 $\mu g/m^3$ of total suspended particulates and 0.74 mm Hg per 80 $\mu g/m^3$ of sulfur dioxide. In subgroups with high plasma viscosity levels and increased heart rates, systolic blood pressure increased by 6.93 mm Hg and 7.76 mm Hg in association with total suspended particulates.

In Norway a case study for Oslo, where a population weighted concentration function for particulate matter was available, based on a detailed dispersion model for the city was conducted in 1995. The objective of this study was to evaluate health effects and social costs of particulate pollution. The calculations indicated a total social cost of Nkr 1.7 billion per year, which is about Nkr 3,600 per capita in Oslo in 1994. For comparison, the GDP per capita in Norway was Nkr 200,000 in 1994. Thus, these results illustrate that air pollution brings about a major cost on society in the form of substantial health effects. Particularly as the long-term consequences of air pollution may be even more serious than indicated here, as life expectancy may be reduced. Still, uncertainty attaches to the functions used, and several assumptions have been made in the calculations, so the results must be taken as indications only (Knut, 1997).

A health impact assessment of air pollution in Austria, France and Switzerland revealed that car-related pollution kills more people than car accidents in these three countries. Long-term exposure to air pollution from cars causes an extra 21,000 premature deaths from respiratory or heart disease per year in adults over 30. In comparison, the total annual deaths from road traffic accidents in these countries are 9,947. Each year air pollution from cars in the three countries causes 300,000 extra cases of bronchitis in children, 15,000 hospital admissions for heart disease, 395,000 asthma attacks in adults and 162,000 in

children, and some 16 million person-days of restricted activities for adults over 20 years old because of respiratory disorders. The total cost of this health impact is €27 billion per year or 1.7 per cent of the combined GNP of the three countries. This is the equivalent of €360/person per year (UNEP, 2002).

In Latin American countries a study revealed that in 1992 about 76 million urban people were exposed to air pollutant concentrations exceeding WHO guidelines. In Sao Paulo and Rio de Janeiro, air pollution was estimated to be responsible for 4,000 premature deaths annually (UNEP, 2002). Studies in Brazil, Chile and Mexico have shown that a 10 μg/m3 increase of concentration of PM_{10} in the air causes a 0.6 to 1.3 per cent increase in mortality in people over the age of 65 (PAHO, 1998).

Air pollution is emerging as a key contributor to some respiratory and cardiovascular diseases in North America. Around 80 million US citizens are exposed to levels of air pollution that can impair health and more than 2 per cent of all deaths annually can be attributed to air pollution. More than 5.5 million children in North America are affected by asthma (UNDP, 1998).

CHAPTER 4

MATERIALS AND METHODS

The basic objectives of this study were to prepare an air pollution emission inventory of the Iskenderun region, and to perform dispersion modeling of pollutants using this inventory along with other inputs. The materials and methods adopted to accomplish these objectives are describes in this chapter.

The study area selected in this study is shown in Figure 4.1, whose dimensions are 25 km x 50 km. The reason to select these dimensions for study area was to cover all parts of the districts of Iskenderun and Dortyol. The dimensions of the study area extend beyond the boundaries of the district of Iskenderun into the districts of Belen in south and Kirikhan in southeast. In the North it is extended beyond the boundaries of Dortyol district and includes some parts of the districts of Erzin and Osmaniye. The ISDEMIR, the largest source of emissions in the Iskenderun Region is located almost in the center of this study area with other industrial sources surrounding it. These dimensions of the study area were useful in studying the pollutant dispersions especially ground level concentrations of the pollutants in the major residential centers of Iskenderun Region.

4.1 Emission Inventory

The emission inventory accounts the types and amounts of pollutants emitted from a wide variety of sources, including industrial, domestic heating, and

traffic on urban roads as well as on inter city roads. The emission inventory is used to describe and compare the contributions of several air pollution sources to the total pollution load, and to evaluate the control measures. This inventory is also used as an input to the dispersion modeling calculations and provides basis for preparation of a "clean air plan".

An emission inventory of the study area is prepared in this work by taking into account all the possible emission sources. These sources include all the industrial and residential sources, namely, the rural and urban residential areas, ISDEMIR and other industries in the Organized Industrial Estates of Iskenderun, Dortyol and Payas. Moreover, emissions from traffic sources on urban roads (Iskenderun, Payas and Dortyol), Iskenderun-Adana motorway and Iskenderun-Adana highway were also considered. A map of the study area showing locations of several types of sources is given in Figure 4.1.

Pollutants included in this study basically depends upon the raw materials and fuel used in industries, vehicles and domestic heating activities. The largest industrial installation in the study area is ISDEMIR, which is the 2nd largest integrated iron and steel complex of Turkey. It uses iron ores, coal, fuel oil and LPG as raw material and fuels. Other steel industries located in Organized Industrial Estates use fuel oil in their furnaces. On the other hand major fuel used for domestic heating is coal followed by fuel oil in some dwellings in the urban areas. Diesel and gasoline are fuels used in vehicles as usual. Therefore, five major pollutants, namely, PM, SO_2, NO_X, CO, and VOC are included in this study.

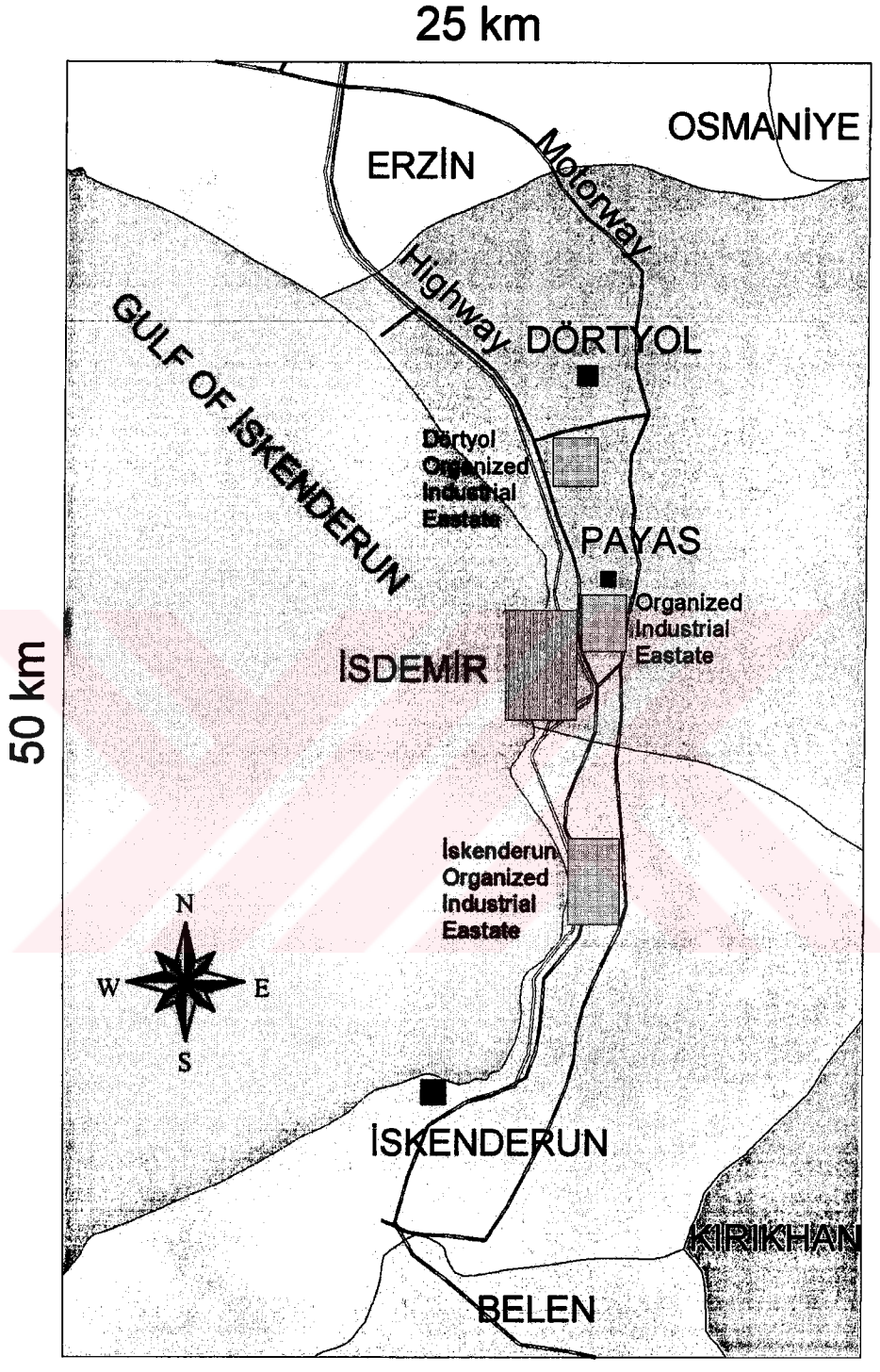

Figure 4.1 Locations of Industrial, domestic heating and traffic emission sources in Iskenderun Region

4.1.1 Emissions Measured

All of operating industries in the study area were visited for the measurement of pollutants in the stack gases. Parameters including PM, SO_2, NO_X, CO, CO_2, O_2, stack gas temperature, ambient temperature, internal diameter of stack, stack height and stack gas velocity were measured.

4.1.1.1 Measurement Techniques and Equipment

The following equipment and techniques were used in collecting data from industries.

Flue Gas Analyzer

For the measurement of the concentrations of gaseous pollutants (SO_2, NO_X, CO and O_2) and parameters such as stack gas temperature, ambient temperature and soot in the stack gases, MRU Model 95/3-CD Flue Gas Analyzer was used, which is maintained by Titaş A.Ş on regular basis. It is a portable analyzer, is approved by TÜV and also accepted by the Turkish Ministry of Environment (MOE, 1986). The instrument is equipped with a printer, gives results in mg/m^3 and ppm. The pollutant gases are measured with electrochemical cells and this method is accepted one for flue gas analysis by TAQPR (MOE, 1986).

Particulate Sampler

Isokinetic sampling is the technique used to take a representative sample of particulate matter in the stack gas. Zambelli Model 6000 was the equipment to collect isokinetic samples of the particulate matter from stack gases. Thimble filters made of cellulose acetate or glass fiber were used depending upon the

temperature of the flue gas. The standard TS-ISO-10780 (accepted by the Turkish Standards Institute) was followed for isokinetic sampling. The instrument has a pitot tube, a sampling tube, a vacuum pump for suction of sampling gas, a gas meter to measure the volume of gas sampled and an arrangement for collection of moisture present in the gas. It also measures stack gas temperature, absolute pressure in the stack and ambient pressure. Zambelli Model 6000 complies Pan European Standard ISO 9096. It is also equipped with a printer. During sampling it measures the stack gas velocity after every minute and automatically adjusts the sampling flow rate of gas in case of fluctuations in stack gas velocity. The difference in the initial and final weights of the filter gave the mass of PM collected on it. To calculate the concentrations of the PM in the stack gas the mass of collected PM and volume of gas sampled (dry basis) were used.

Stack Gas Velocity

For the measurement of stack gas velocity a Pitot tube was used. The pressure difference measured by the Pitot tube was used by the equipment to calculate the gas velocity by using the Bernoulli's equation. The gas velocity was measured at various locations along the diameter as defined by TS-ISO-10780.

4.1.2 Emissions Estimated

Whenever emission measurements cannot be made or are not available "Emission Factors" are used to estimate the emissions. The emission factors expresses the amount of emissions to be released per unit amount of fuel burned or per unit amount of heat released or per unit amount of material produced. For example:

Amount of Emissions = Amount of fuel used x Emission factor x 10^3 kg/ton

(ton/yr) (ton/yr) (kg of pollutant/ton of fuel)

Emission measurements for all pollutants included in this study except VOC were made at the stacks of the industries. Because of the unavailability of the equipment to measure VOC concentrations, therefore, by using relevant emission factors (CORINAIR, 1999) based on fuel type and consumption the VOC emissions from industries were estimated. On the other hand, it was practically impossible to measure the emissions from domestic heating sources and from traffic. Therefore, emissions from these sources were estimated by using appropriate emission factors depending upon the types and amounts of fuels used.

CORINAIR Emission Factors were consulted and the relevant ones for several types of sources are used in this study. It would have been better to use the emission factors developed locally, because other emission factors may not be indicative of local conditions. There are some emission factors developed in Turkey (1992) for domestic heating sources by Gazi University Ankara. However, these emission factors are somewhat old and have no international value. Therefore, internationally recognized emission factors were preferred. Emission factors developed by U.S. EPA are also available. A selection between U.S. EPA's Emissions Factors and European Emissions Factors (CORINAIR) had to be made for the estimation of pollutant emissions. The U.S. EPA's Emissions Factors are more detailed as compared to European ones for industrial emissions. Since the industrial emissions were measured at sources in this study, there was no need to use them. In case of emissions from domestic heating by coal, the U.S. emission factors gave very high values of emissions as compared to local conditions (checked with stoichiometric calculations), but the European emission factors gave values of emissions closer to local conditions. Therefore, CORINAIR Emission Factors were used for the estimation of emissions from domestic heating activities. For the sake of consistency the CORINAIR Emission Factors were also used for estimation of emissions from traffic sources.

Types and properties of several fuels used in the study area are summarized in Table 4.1.

Table 4.1 Properties of several types of fuels

Fuel Type	Heating Value (MJ/kg)	Sulfur (% by wt)	Ash (% by wt)	Density (kg/m^3)
Domestic Fuel oil[1]	41	1.5	0.1	950
Fuel oil No.6[1]	41	6	0.2	998
Coal[3]	26.7	0.6-3.6	8.5-11	1600
LPG(Liquefied)[2]	45.4	-	-	550
Natural gas[2]	49.8	-	-	0.68
Coke[3]	27.7	0.7	11	1200
Blast furnace gas[3]	2.4	Unknown	Unknown	1.31
Coke gas[3]	36.7	Unknown	Unknown	0.44

[1] TUPRAŞ, 2002
[2] BOTAŞ, 2002
[3] ISDEMIR, 2001

VOC Emissions from Iron and Steel Industries

In industrial emissions only VOC could not be measured at source. Therefore, they were estimated using the emission factors given in Table 4.2.

Table 4.2 Emission factors used to calculate VOC emissions from iron and steel industries (CORINAIR, 1999)

Fuel Type	VOC (g/GJ of energy produced)
Fuel Oil	5
LPG	2.1
Blast Furnace Gas	6
Coke Gas	2.5
Coke	0.05

Emissions from Domestic Heating

Emissions from domestic heating activities were estimated by using the emission factors given in Table 4.3.

Table 4.3 Emission factors used to calculate emissions from domestic heating (CORINAIR, 1999)

Fuel	Emission Factors					
	Units	PM	SO_2	NO_X	CO	VOC
Coal	kg/ton	1.5 * A	15 * S	2.9	1	2.5
Fuel oil	kg/m^3	0.3	17.24 * S	2.2	0.6	0.3
Natural gas	g/GJ	-	-	40	60	2.5

A: ash content of coal (% by weight), S: Sulfur content of fuel (% by weight)

Emissions from traffic sources

Emissions from traffic sources were calculated for driving conditions on highways as well as on urban roads. The vehicle count data on highways in the study area were obtained from the General Directorate of Highways in Ankara. The pollutant emissions from traffic on highways were calculated by using the vehicle count data recorded at several locations on highways in Iskenderun Region, by the Directorate of Highways in Mersin. The traffic count data in the urban areas of the Iskenderun Region had never been recorded. Therefore, the active urban traffic in the study area had to be assumed. The details about active urban traffic in the Iskenderun Region are given in Chapter 6. The appropriate emission factors used for traffic emission calculations are given in Table 4.4 and 4.5.

Table 4.4 Emission factors used to calculate emission from gasoline vehicles (CORINAIR, 1994)

Pollutant	Road Class	Emission Factors (g/km)	
		Two-stroke Motorcycle	Light-duty Vehicle
NO_X	Urban	0.03	3.00
	Rural	0.09	2.70
	Highway	0.14	3.20
CO	Urban	22.36	30.00
	Rural	25.49	15.00
	Highway	28.21	12.00
VOC	Urban	10.98	3.60
	Rural	8.40	1.70
	Highway	8.47	1.00

Table 4.5 Emission factors used to calculate emission from diesel vehicles (CORINAIR, 1994)

Pollutant	Road Class	Emission Factors (g/km)	
		Light-duty Vehicles	Heavy-duty Vehicles
PM	Urban	0.25	0.95
	Rural	0.25	0.82
	Highway	0.16	1.67
NO_X	Urban	1.60	8.70
	Rural	1.20	7.40
	Highway	1.25	6.00
CO	Urban	2.00	18.80
	Rural	0.80	7.30
	Highway	0.60	4.20
VOC	Urban	0.40	2.75
	Rural	0.25	0.37
	Highway	0.13	0.60

4.2 Dispersion Model Used

Air quality dispersion models can be regarded as tools for estimating potential concentration impacts from proposed as well as existing sources. The models can be categorized into four general classes: Gaussian, numerical, statistical (empirical), and physical. The numerical and Gaussian models dominate the field. Gaussian-based models are the most widely applied. Despite any of their

shortcomings in precisely describing a plume's diffusion in the atmosphere, their wide application is almost entirely due to their ease of application and the conservative estimates they provide.

4.2.1 ISCST3 Model

Industrial Source Complex Short Term Version 3 (ISCST3), a model developed by U.S. EPA was used to model the air pollution of the study area. The basis of the model is the steady-state Gaussian plume equation, which is used with some modifications to model several kinds of sources. The Industrial Source Complex (ISC) short-term model provides options to model emissions from a wide range of sources that might be present at a typical industrial complex and area surrounding it. Emission sources are categorized into four basic types of sources, i.e., point sources, volume sources, area sources, and open pit sources. The volume source option and the area source option may also be used to simulate line sources.

Basic Assumptions for Gaussian Dispersion Model

The basic assumptions for Gaussian dispersion model are the following:

1. The plume has a Gaussian distribution in both horizontal and vertical planes with σ_y and σ_z as the standard deviations of the concentrations of the plume in horizontal crosswind and vertical directions respectively.
2. The mean speed affecting the plume is u, which is the wind speed at the source level i.e. at the point where dispersion starts.
3. Uniform and continuous emission of Q g/sec of pollutant takes place.
4. Diffusion of pollutant in 'x' direction is negligible compared to diffusion in crosswind direction. This is true if emission is continuous and if wind speed is more than 1 m/sec.
5. Total reflection of the plume takes place at the earth's surface i.e. there is no deposition or reaction on the pollutants at the surface. Also the pollutants are

inert and passive so that there is no gravity fallout and there are no atmospheric chemical reactions.

6. Parameters governing the diffusion of the pollutant do not change in space and time i.e. steady-state conditions prevail.
7. The terrain underlying the plume is flat.

Why ISCST3

ISC model developed by the U.S. EPA is one of the most widely used in the world and accepted worldwide by the regulatory authorities, researchers and decision-makers for estimating concentrations of non-reacting pollutants up to 50 km away from the source. The basis for the model is Gaussian dispersion theory but with some enhanced features which were not available in the basic theory: like stack down wash, terrain adjustments, dry/wet deposition etc. This versatile model enables the user to estimate concentrations and/or depositions from nearly all type of sources emitting non-reactive pollutants.

4.2.1.1 Inputs to ISCST3 Model

There are two basic types of inputs that are needed to run the ISC models. They are;

- Input run stream file, and
- The meteorological data file.

The run stream setup file contains the selected modeling options (rural or urban, flat or elevated terrain), as well as source location and parameter data like: pollutant emission rate, stack height, gas temperature, gas exit velocity, internal diameter of stack, averaging time, concentration and/or deposition estimates etc. Receptor data provides the location where a predicted concentration is desired. Meteorological data file location and specifications, and output options are also specified in the run stream file.

Sources

Unlimited point, flare, area, line, volume, and open pit sources may be entered and modeled. 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.

Receptors

Concentrations can be calculated for all terrain elevations and for receptors above ground elevation. An unlimited number of receptor grids may be entered for each modeling run. So unlimited number of receptors can be modeled.

Earlier versions of ISC models were developed without any terrain consideration (i.e., for flat areas). In simple terrain option, receptors are located below the top of stack. While in complex terrain modeling option, the receptors are located at or above the stack top. If the receptors are located at elevations that are located between the stack top and the final height of the plume rise, these elevations are classified as intermediate terrain. Elevated terrain option is available in ISCST3 and was used for all modeling calculations in this study because on the eastern side of sources Amanos mountain range is located with altitudes as high as 1600 m. A detailed map of the study area containing elevations from mean sea level was obtained. The map of the study area is given in Figure 4.1, was used to input receptor elevations as well as location of sources, the elevation contours are not shown in this figure for the sake of simplicity.

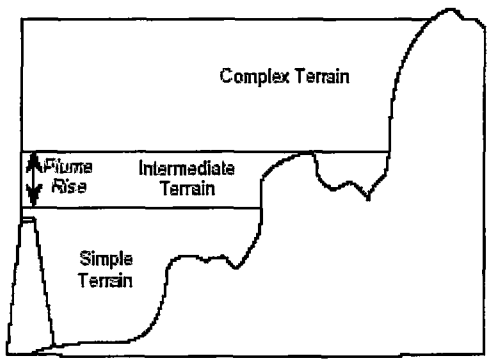

Figure 4.4 Terrain categories (Trinity Consultants, 1999)

The model makes the following assumptions about plume behavior in elevated terrain:

- The plume axis remains at the plume stabilization height above mean sea level as it passes over elevated or depressed terrain.
- The mixing height follows the terrain.
- The wind speed is a function of height above the surface.

Meteorological Data

The ISC Short Term model accepts hourly meteorological data records for wind speed, wind direction, stability class, temperature etc. Model uses these data 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 meteorological data. For deposition values, either the dry deposition flux, or the wet deposition flux, or the total deposition flux may be estimated. More details about the meteorological data input to the ISCST3 model are given in Chapter 5

4.2.3 ISCST3 Special Features

Following are the additional features in ISCST3, which are not available in ordinary Gaussian Dispersion model.

- Effects of stack-tip downwash are considered
- Direction-specific building downwash can be estimated
- Buoyancy-induced dispersion can be analyzed
- Pollutant thresholds of interest may also be specified
- Special options for $NO_X - NO_2$ conversion based on O_3 concentrations can be given
- The process of predicting concentrations from continuous releases in simple, intermediate, and complex terrain is simplified
- Dry and wet deposition of particulate matter from the plume to the surface can be modeled. The model can also simulate the dry and wet depletion (removal) of particulate or gaseous mass from the plume as it is deposited on the surface

4.2.4 Model Performance Evaluation

The evaluation of model-predicted values of pollutant concentrations is very important, because this shows the accuracy of predictions. During modeling study several assumptions are made that may cause error in the predicted values. In this study the model performance was evaluated by comparing the predicted and observed ground level concentrations of pollutants for the Iskenderun air quality monitoring station. This station is located in the northern part of Iskenderun city and is being operated by the Ministry of Health. At this station daily average concentrations of SO_2 are measured. Data from this monitoring station has been compared with the ISCST3 predicted concentrations in the evaluation of model performance.

Willmot and Wicks (1988) suggested how to evaluate the performance of a model by using an index of agreement (d) and root mean square error (RMSE) analyses. Sivacoumar (2001) and Elbir (2002) used these methods to check the accuracy of the concentrations predicted by the ISCST3.

The index of agreement (d) is expressed as (http://195.194.93.120/explanation.htm, and Elbir, 2002):

$$d = 1 - \frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}\left(|P_i - O| + |O_i - O|\right)^2}$$

Where

P_i = model predicted values

O_i = observed values

O = mean of observed values

For predicted concentrations to be good the value of d should be close to 1.

The systematic component of RMSE is defined as:

$$(RMSE)_S = \left[\frac{1}{n}\sum_{i=1}^{n}\{(a + bP_i) - O_i\}^2\right]^{\frac{1}{2}}$$

The unsystematic component of RMSE is:

$$(RMSE)_u = \left[\frac{1}{n}\sum_{i=1}^{n}\{(a + bP_i) - P_i\}^2\right]^{\frac{1}{2}}$$

Total RMSE is:

$$(RMSE)_T = \sqrt{(RMSE)_S^2 + (RMSE)_u^2}$$

Where

n = number of observations

a = intercept of linear regression line

b = slope of linear regression line

P_i and O_i are the predicted and observed concentrations, respectively.

For good predictions the value of $RMSE_T$ should be closer to zero. Besides these two methods, standard deviations and means for predicted and observed concentrations were also calculated for model performance evaluation.

CHAPTER 5

METEOROLOGY OF THE STUDY AREA

Meteorology is the basic factor governing the dispersion of air pollutants. Therefore, in any modeling study it should be given due attention. As a matter of fact air pollution episodes are a result of very stable meteorological conditions rather than excessive emissions from various sources. Meteorological data files are needed to be prepared very carefully to have reliable results of modeling studies.

5.1 An Overview of Meteorology of Iskenderun Region

The Gulf of Iskenderun is located in the southeastern part of Turkey on the Mediterranean cost. The State Department of Meteorology operates a measurement station in the city of Iskenderun, where they record several meteorological parameters such as ambient temperature, atmospheric pressure, wind speed, wind velocity, precipitation, relative humidity etc. on hourly basis. This is the only meteorological station in the study area. However, it is not a synoptic station, and upper air data is not measured here. There are seven synoptic stations in Turkey that measure upper air data in addition to surface meteorological observations. Upper air data are measured at 0200 hours and 1400 hours every day. The closest synoptic station to the Iskenderun area is in Adana.

For the estimation of morning and afternoon mixing heights, upper air data and surface meteorological observations are required. Since the upper air data is not measured at Iskenderun, there was a question of if upper air data measured at Adana synoptic station can be used for Iskenderun. For this purpose US EPA was contacted to seek guidance in this regard. US EPA recommended to use the surface meteorological data of Iskenderun and the upper air data measured at Adana to clculate the morning and afternoon mixing heights. This was aslo the practice in the USA and elsewhere. For a second opinion the Department Meteorological Engineering of the Istanbul Technical University, Istanbul was also contacted, they too recommended the same as mentioned above. Therefore, twice daily mixing heights for Iskenderun were estimated using upper air data of Adana and surface meteorological data of Iskenderun for the year 2001.

In order to get an idea of the meteorology of the region for the past 10 years, meteorological data for the period form 1991 to 2000 has been obtained from the State Department of Meteorology and is analyzed to understand the meteorology of Iskenderun Region.

Monthly averages of several meteorological parameters obtained for the Iskenderun station are given in Table 5.1. Annual averages of various parameters listed in Table 5.1 have been calculated from monthly averages of 10 years data. As can be seen from the table, the monthly average temperature ranges between 11.9 to 28.6° C. The maximum monthly average temperature is 28.6° C in August and the minimum temperature is 11.9° C in January. The annual average temperature for 10 years period is 20.1° C. The relative humidity ranges between 69% and 74% with an annual average of 66.9%. The annual average atmospheric pressure is 1013 mbar, and the total annual precipitation is 759 mm. Annually there are 224 cloudy days on the average. Although the maximum monthly average temperature in August is 28.6 ° C, the daily maximum temperature rises up to 40 ° C during the summers.

Wind roses were plotted in order to show the prevailing wind directions in the study area. Figure 5.1 shows the prevailing wind direction on annual basis. This wind rose has been plotted for the same data period as mentioned above. According to Figure 5.1 the prevailing wind directions are WNW, S and WSW. About 10.5% of the time wind blows from S, 9% of the time from WSW and 11% of the time from WNW.

Table 5.1 Monthly averages of several meteorological parameters for Iskenderun for a period of 1991-2000 (SDM, 2001)

Month	Temperature (°C)	Relative Humidity (%)	Wind Speed (m/s)	Atmospheric Pressure (mbar)	Precipitation (mm)
January	11.9	62	2.4	1018	79.7
February	12.0	61	2.4	1017.2	83.0
March	14.4	65	2.3	1014.6	82.9
April	18.3	70	2.2	1012.9	72.1
May	22.0	73	2.3	1011.7	64.0
June	25.5	73	2.6	1008.6	22.7
July	27.9	74	3.1	1005.6	16.0
August	28.6	73	2.7	1006.9	29.6
September	26.6	67	2.1	1010.6	42.5
October	23.1	63	1.7	1014.6	81.6
November	17.5	59	2.1	1017	86.0
December	13.5	63	2.5	1018.3	98.9
Averages	**20.1**	**66.9**	**2.4**	**1013.0**	**Total = 759**

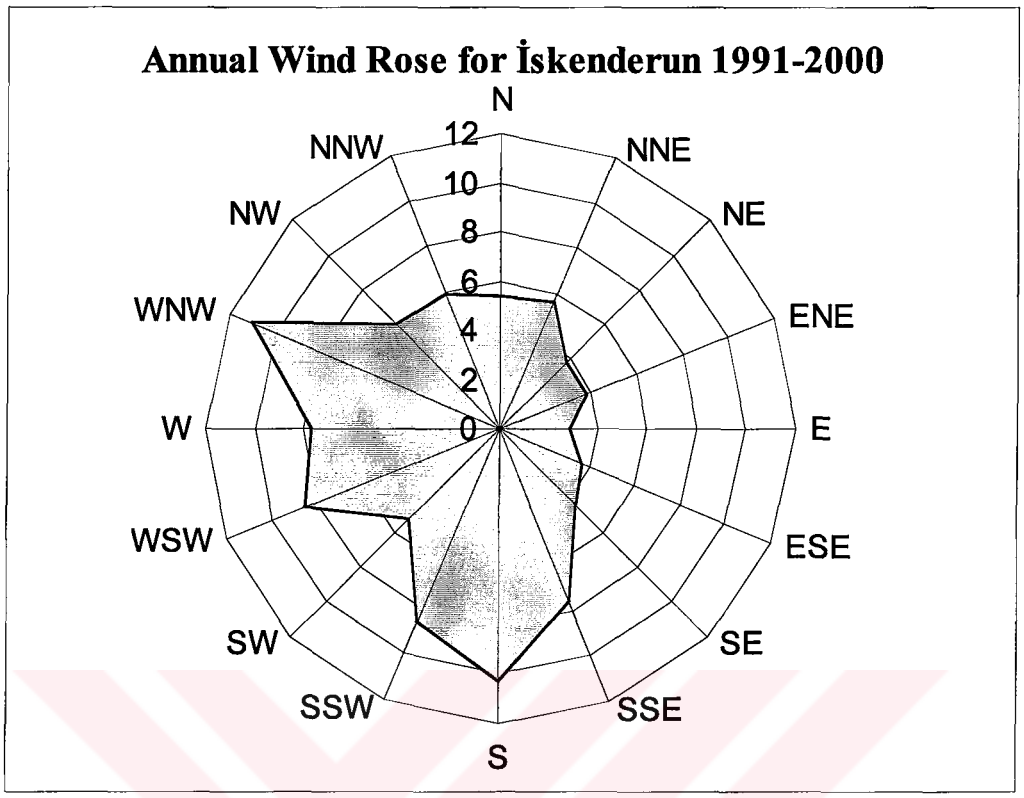

Figure 5.1 Annual Wind rose for Iskenderun for data period of 1991-2000

5.2 Meteorological Data of Year 2001

The air quality modeling of the Iskenderun region in this study is based on the emission inventory data for year 2001. Therefore, meteorological data of the same year was used in this modeling work. The meteorological data of the Iskenderun station for year 2001 was acquired from The State Department of Meteorology (SDM). This data consisted of sequential hourly records of values for temperature, atmospheric pressure, sunshine hours, cloud cover, ceiling height, precipitation, wind speed and wind direction. This is the type of data; namely the hourly meteorological data, required for the dispersion model (ISCST3) to be used. In addition to these parameters, data for morning and afternoon mixing heights calculated by using surface meteorological data of Iskenderun and upper air data of Adana were also obtained from the SDM.

Monthly average values of several meteorological parameters for Iskenderun meteorological station during year 2001 is shown in Table 5.2. As can be seen from the Table, relative humidity ranges from 54-73% with an annual average of about 63.6%. Average atmospheric pressure is 1012.7 mbar, which is typical for coastal areas. Annual precipitation was 771 mm which is moderately high. During summer maximum temperature rises up to 40 ° C. Generally the climate of Iskenderun region is harsh during summers because of high temperatures and humidity, while winters are not very cold with pleasant spring and autumn seasons.

The average values for the main meteorological parameters obtained for 10 years period is very close to the averages obtained for the year 2001.

Table 5.2 Monthly average values of several meteorological parameters for Iskenderun Meteorological Station for year 2001 (SDM, 2001)

Month	Temperature (° C)	Relative Humidity (%)	Wind Speed (m/s)	Atmospheric Pressure (mbar)	Rainfall (mm)
January	13.4	57.9	2.1	1019.9	22.7
February	13.3	58.2	2.3	1015.8	175.4
March	17.9	65.7	1.8	1014.0	76.2
April	19.8	63.6	2.3	1013.0	52.8
May	22.4	61.1	1.9	1010.0	147.0
June	26.4	64.6	2.6	1008.3	2.8
July	28.4	71.4	3.6	1005.3	0.9
August	29.4	73.6	3.0	1007.2	3.3
September	27.5	71.5	2.1	1010.2	43.3
October	23.4	61.8	1.7	1014.3	27.7
November	16.5	54.3	2.5	1017.9	96.1
December	13.3	59.8	2.7	1017.0	128.9
Averages	**21.0**	**63.6**	**2.4**	**1012.7**	**Total = 771**

In order to see the prevailing wind directions in the study area for year 2001, wind roses were plotted on annual and seasonal basis. These wind roses are given in Figures 5.2 to 5.6.

Figure 5.2 shows the annual prevailing wind directions, which are W, S and WNW. Average annual wind speed is 2.4 m/s. About 11% of the time the wind blows from S, 14% of the time from W, 10% of the time from WNW, and 5% of the time from NW. In addition to the annual wind rose, seasonal wind roses need to be plotted because the prevailing wind directions change drastically from season to season in Iskenderun. The climate in Iskenderun is a typical Mediterranean climate with very short spring and autumn and long summers. Therefore, depending on temperatures and experience of the local people, winter months are defined as November to February, the spring months as March to April, summer months as May to August and autumn months as September to October.

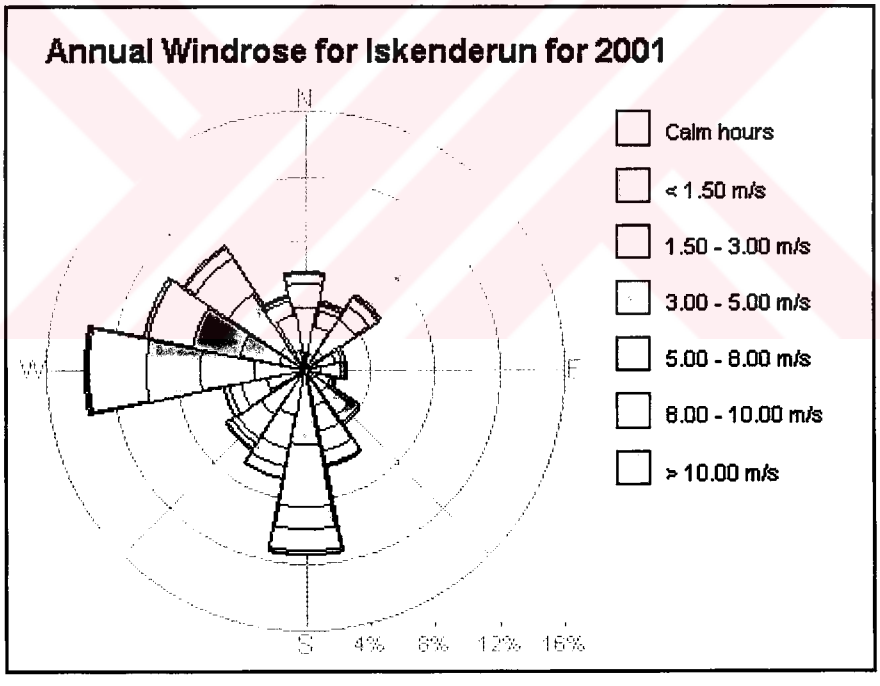

Figure 5.2 Annual wind rose for Iskenderun for year 2001

The wind-blowing pattern for the year 2001 was more or less the same with the one shown in Figure 5.1 for a data period of 10 years from 1991 to 2000. The only change in the prevailing wind direction was seen in a shift from WNW in 1991-2000 to W in year 2001. This small shift in the prevailing wind direction

may be due to different formats of data sets used to plot the two wind roses. Therefore, the model studies carried out for year 2001 are thought to represent the past 10 years as well with some minor changes.

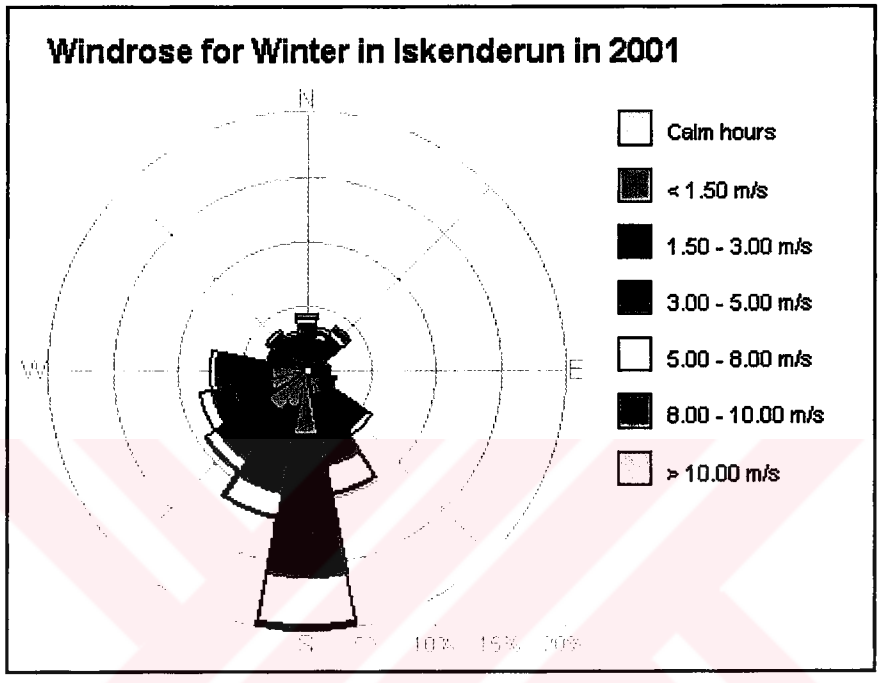

Figure 5.3 Wind rose for winter in Iskenderun for year 2001

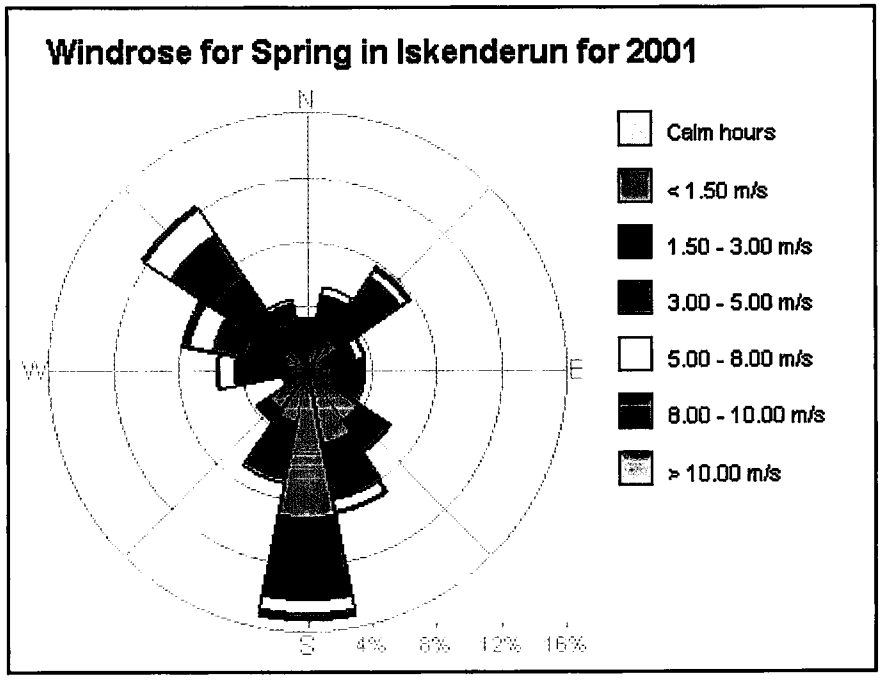

Figure 5.4 Wind rose for spring in Iskenderun for year 2001

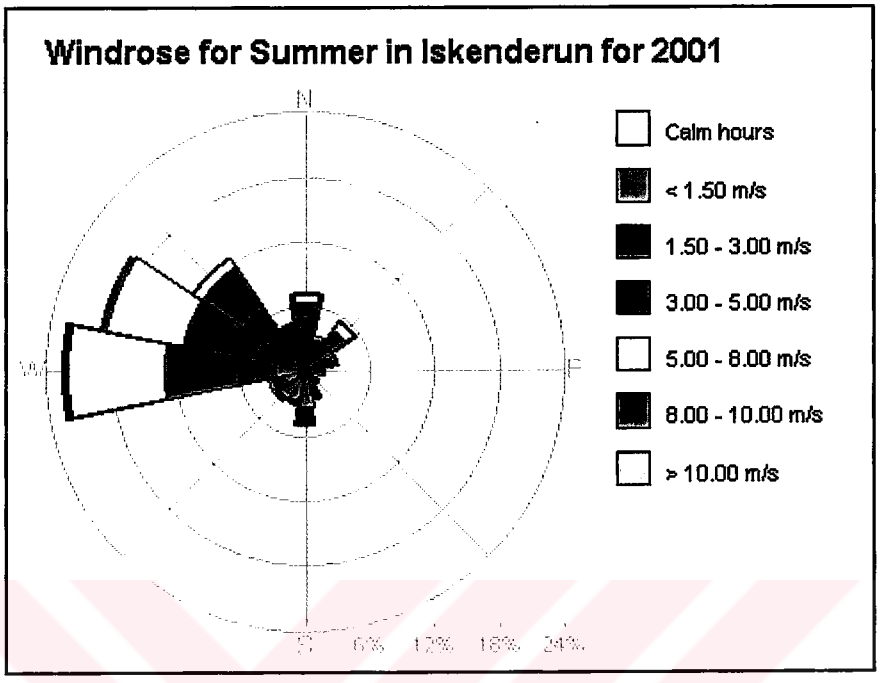

Figure 5.5. Wind rose for summer in Iskenderun for year 2001

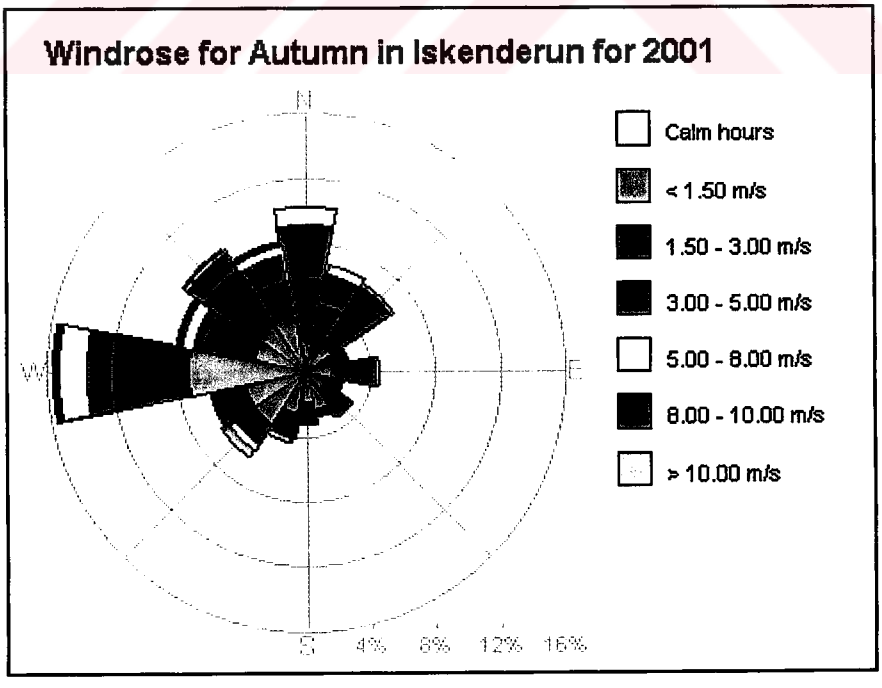

Figure 5.6 Wind rose for autumn in Iskenderun for year 2001

Figure 5.3 shows the wind rose for winter (November-February). The prevailing wind direction is S and the average wind speed for this period is 2.4 m/s. Wind rose for spring (March-April) 2001 is given in Figure 5.4. The prevailing wind directions are S and NW. The average wind speed during spring is found to be 2.1 m/s. Figure 5.5 shows the prevailing wind directions in summer (May-August) 2001 to be W and WNW with an average speed of 2.8 m/s. The wind rose for autumn (September-October) is given in Figure 5.6. The prevailing wind directions are W and N with average wind speed of 1.9 m/s. Wind blowing pattern for autumn is closer to that of summer. As can be seen from these wind roses, there is a tremendous difference in the prevailing wind directions from season to season.

Figure 5.7 shows the comparison of monthly average temperatures for the period of last 10 years (1991-2000) and for 2001. As can be seen from the figure, the temperatures are nearly same for 2001 and last ten years, except for March.

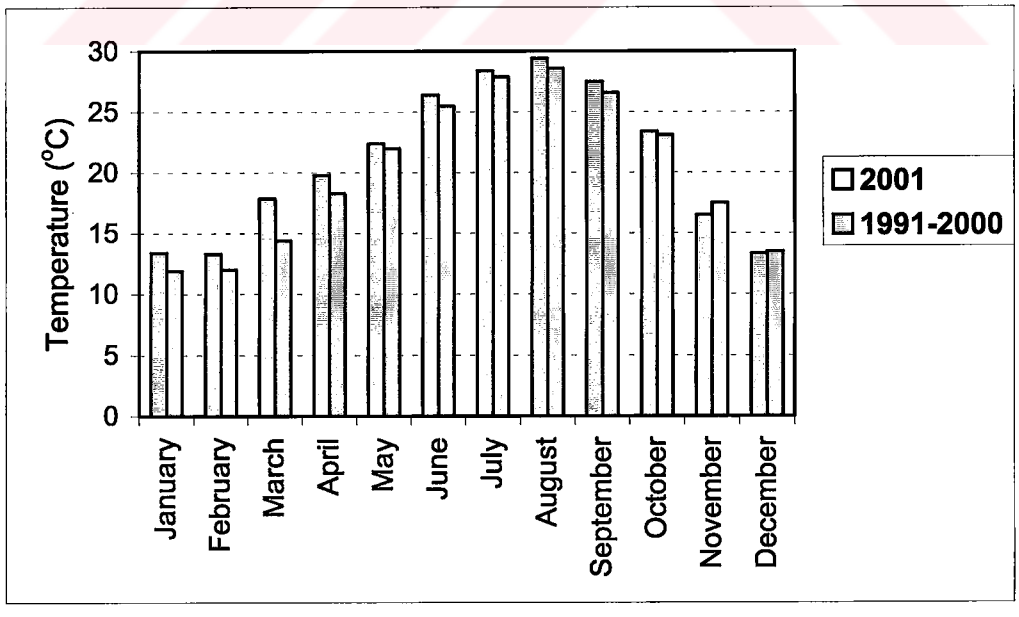

Figure 5.7 Comparison of monthly average temperatures for period 1991-2000 and 2001

Since the trends of prevailing wind directions and monthly average temperatures for 2001 and last ten years are not much different from each other, the meteorological data of year 2001 can be regarded as representative of the prevailing meteorological conditions of Iskenderun region.

5.2.1 Meteorological Data Required by ISCST3 Model

ISCST3 model uses a pre-defined ASCII formatted file that contains sequential hourly records of meteorological variables, which are available for year 2001. Meteorological data file should contain hourly values for wind direction, wind speed, ambient temperature, stability class, rural and urban mixing heights. This is a minimum set of meteorological data needed to run the model for calculation of ground level concentration of pollutants. For estimation of dry and /or wet deposition of pollutants, additional parameters are required in meteorological data file. The dry deposition algorithm requires additional meteorological input variables, such as surface friction velocity, Monin-Obukhov length and surface roughness length. The wet deposition algorithm also needs precipitation code and rate.

The surface friction velocity is a characteristic velocity based on (wind) shear stresses at the earth's surface. Monin-Obukhov length is a stability parameter that relates this velocity to the transport of heat. It is negative during the day when surface heating results in an unstable atmosphere and positive at night when the surface cools (stable atmosphere). The surface roughness length is a measure of the height of obstacles to the wind flow. It is not equal to the physical dimensions of the obstacles but is generally proportional to them.

5.2.2 Format of the Meteorological Data File

The first record of the meteorological data input file should contain the station number and the year for both the surface station and the upper air (mixing height) station. The rest of the records in the file include the sequential

meteorological data. The order of the meteorological variables for the formatted ASCII files is given in Table 5.3.

Table 5.3 Format of the meteorological data file

Variable	Units	Column
Year (last 2 digits)		1-2
Month		3-4
Day		5-6
Hour		7-8
Wind Direction	Degrees	9-17
Wind Speed	m/s	18-26
Ambient Temperature	K	27-32
Stability Class	(1=A…6=F)	33-34
Rural Mixing Height	m	35-41
Urban Mixing Height	m	42-48
Friction Velocity (Dry Deposition Only)	m/s	49-57
Monin-Obukhov Length (Dry Deposition Only)	m	58-67
Surface Roughness Length (Dry Deposition Only)	m	68-75
Precipitation Code (Wet Deposition Only)	00-45	76-79
Precipitation Rate (Wet Deposition Only)	mm/h	80-86

5.2.3 Meteorological Data Processing

Processing of meteorological data was necessary because some of the parameters were not available with SDM such as stability class. Moreover, site-specific variables needed for dry/wet deposition estimates were also to be added to data file. There are several meteorological data processors available, but the one developed and recommended by the U.S. EPA for ISCST model is PCRAMMET.

5.2.3.1 PCRAMMET Data Processor

PCRAMMET is a meteorological pre-processor used for preparing U.S. National Weather Service (NWS) data for use in the short term air quality dispersion models such as ISCST3, CRSTER, RAM, MPTER, BLP, SHORTZ, and COMPLEX1. The output file generated by PCRAMMET can directly be used as input meteorological data file in ISCST.

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.

The input data requirements for PCRAMMET depend on the dispersion model and the model options for which the data are being prepared. The minimum input data requirements for PCRAMMET are the twice daily mixing heights and hourly surface observations of wind speed, wind direction, dry bulb temperature, opaque cloud cover, and ceiling height. For dry deposition estimates, the station pressure is recommended, and for wet deposition estimates, the precipitation type and the amount are required for those periods during which precipitation was observed.

As an input to PCRAMMET, three separate files are required containing data about

1. Twice daily mixing heights

2. Hourly surface observations
3. Precipitation data

5.2.3.2 Pre-processing of the Meteorological Data

There is a specific format for each of the input file to PCRAMET, which is defined by the National Weather Service of the U.S. The meteorological data obtained from the State Department of Meteorology in Ankara was prepared on a different format than the format of NWS. Therefore, a manual pre-processing of local data was necessary to bring it to an acceptable format for use by PCRAMMET. The above mentioned three input files for this study were prepared according to formats mentioned in PCRAMMET User's Guide (EPA, 1999). Formats of hourly surface observations and precipitation data were CD144 and TD-3240 fixed block, respectively.

5.2.4 Meteorological Data files Prepared

Using PCRAMMET, separate meteorological data files were prepared for model runs on annual and seasonal basis for the year 2001 as:

- Annual
- Winter
- Spring
- Summer
- Autumn

All of these files contain additional variables needed for estimation of dry and wet depositions. Site-specific information required for calculating deposition values include the Monin-Obukhov length, surface roughness length, noontime

albedo, Bowen ratio, anthropogenic heat flux and fraction of net radiation absorbed at surface. Guidance from the PCRAMMET User's Guide (EPA, 1999) was used to determine each of the site-specific values. Namely, from the land use categories available in PCRAMMET User's Guide (EPA, 1999), it was assumed that ISDEMIR and other industries are located in rural area with average conditions. The appropriate values for these conditions for land use types in Iskenderun region, were taken from tables given in Appendix B of PCRAMMET User's Guide (EPA, 1999).

CHAPTER 6

RESULTS OF EMISSION INVENTORY

6.1 Emission Inventory

Preparation of emission inventory was the basic requirement for air pollution modeling because it was never prepared for the study area. Pollution loads on environment in the Iskenderun area were either measured or estimated covering three different types of sources as:

- Industrial Sources
- Residential Sources
- Traffic Sources

Relevant authorities were contacted to get permissions for stack gas measurements and for access to the necessary data.

6.1.1 Industrial Emissions

The study area houses several iron and steel industries and a cement plant (only grinding, mixing and packaging). In order to assess the emission of gaseous pollutants from iron and steel industries in the area, emission measurements were made during October-November 2001 in the stacks of almost all operating industries in the region. ISDEMIR is the largest iron and steel production facility among industries in this region and it is the 2nd largest integrated iron and steel works in Turkey. It produces pig iron and several steel products using iron ores and coal as raw materials. The flow sheets and the explanations about

the process were given in Chapter 2. All other metal industries in the region either use pig iron, steel bars or steel scrap as raw material, and fuel oil No. 6 as fuel. Some steel industries use electricity for electric arc furnaces. The measurements of stack gas composition for various pollutants, velocity and temperature were made in the stacks of the following industries:

- ISDEMIR, Iskenderun Demir ve Çelik A.Ş.
- YAZICI Demir Çelik Sanayi ve Ticaret A.Ş.
- NURSAN Çelik Sanayi ve Haddecilik A.Ş.
- KOÇ Haddecilik Sanayi ve Ticaret A.Ş.
- ATAKAŞ ŞAHİN Çelik Sanayi ve Ticaret A.Ş.
- PAY Metal Sanayi ve Ticaret A.Ş.
- İLHANLAR Haddecilik Sanayi ve Demir Ticaret Ltd. A.Ş.
- YOLBULAN Metal Sanayi ve Ticaret A.Ş. Unit A.
- YOLBULAN Metal Sanayi ve Ticaret A.Ş. Unit B.
- TOSYALI Demir Çelik Sanayi A.Ş.

6.1.1.1 Equipment Used

The equipment used for the stack gas measurements and analysis are explained below:

- MRU 95/3CD-Flue Gas Analyzer was used to measure gaseous pollutants in stack gases. It is a portable analyzer and TÜV approved. The parameters measured in the stack gas were CO, SO_2, NO_x, O_2, gas temperature, ambient temperature and soot. The instrument is equipped with a printer, gives results in mg/m^3 and ppm. Titaş A.Ş, Ankara, calibrated the instrument the day before going for measurements.

- ZAMBELLI Model 6000 was used for isokinetic sampling of particulate matter in stack gases. The instrument has a pitot tube to measure the gas

velocity, a sampling tube to sample the gas, a vacuum pump for suction of sample gas, a gas meter to measure the total volume of gas sampled and an arrangement for collection and determination of the amount of moisture present in the gas.

6.1.1.2 Characteristics of Stacks

Main features of industrial stacks located in the study area are briefly described here. More detailed information about the stacks and the results of the measurements are given in Appendices B.1 and B.2.

A. ISDEMIR Stacks

ISDEMIR consists of the following six units:

1. Coke and by products unit
2. Sintering unit
3. Blast furnaces
4. Steel making plant
5. Re-rolling mills
6. Energy production facility.

There are 57 stacks in ISDEMIR located in the above-mentioned units. Their internal diameter range from 0.6 to 20 meters at ground level and heights range from 6 to 187 meters from ground level. The major polluting stacks are located in coke, sintering, blast furnace and energy units. The velocity of gas in various stacks range between 3 to 35 m/s.

B. Stacks of Other Industries

All other iron and steel industries have one stack per plant except Yazıcı, which has 6 stacks. Internal diameters of stacks in these plants are 2.2 m at ground level in most of the industries. Stack heights are between 20 m and 25 m from ground level and the gas velocities range between 7 to 11 m/s. The cement plant called OYSA has 12 stacks. As a matter of fact this is not a plant making cement from raw materials. It is a plant, which grinds clinker coming from other factory, and after mixing the ground clinker with some additional materials makes cement. There is also a packaging unit inside it. Totally there are 26 stacks in all other industries.

6.1.1.3 Results of Air Pollutant Emissions

A. ISDEMIR

From the emission measurements in stacks of ISDEMIR the pollution loads of several pollutants for each unit were calculated according to the following formula.

Emission Load = Pollutant Conc. x 10^3 X Volume of Gas

(kg/h) (g/m^3) (m^3/h)

The results are presented in Table 6.1. Pollution loads are given both in kg/h and tons/year. Conversions from kg/h to ton/year are done on the basis of 24 hours a day and 330 days per year of operation in ISDEMIR. There is usually a maintenance period that lasts about a month. Therefore, 330 days of operation has been taken to calculate the yearly emission load in ISDEMIR.

Table 6.1 Pollution loads from the stacks of ISDEMIR

Unit	PM (kg/h)	SO_2 (kg/h)	NO_X (kg/h)	CO (kg/h)	PM (ton/y)	SO_2 (ton/y)	NO_X (ton/y)	CO (ton/y)
Coke and By Products	177	341	109	1265	1403	2704	866	10019
Sinter	758	1308	129	4043	6002	10359	1022	32021
Blast Furnace	512	-	46	4192	4054	-	364	33197
Steel Making	64	-	12	549	505	-	95	4349
Re-rolling Mills	102	491	96	-	805	3890	758	-
Energy Production	788	2006	427	-	6239	15884	3384	-
Total	**2400**	**4146**	**820**	**10049**	**19009**	**32836**	**6490**	**79585**

Table 6.1 shows that pollution loads of all the pollutants from ISDEMIR are very high as compared to the limits set by the TAQPR given in Table 3.2. Pollution loads exceed the limits by 160 times for PM, 69 times for SO_2, 20 times for NO_X and 100 times for CO. These emissions must be controlled by using the appropriate air pollution control technologies. As can be seen from this table, the largest pollution load is due to CO with 79,585 tons/year. The second largest pollution load is coming from SO_2 with 32,836 tons/year and the pollution load of PM with 19,009 ton/year follows SO_2. The lowest pollution load among pollutants here belongs to NO_X with 6,490 ton/year.

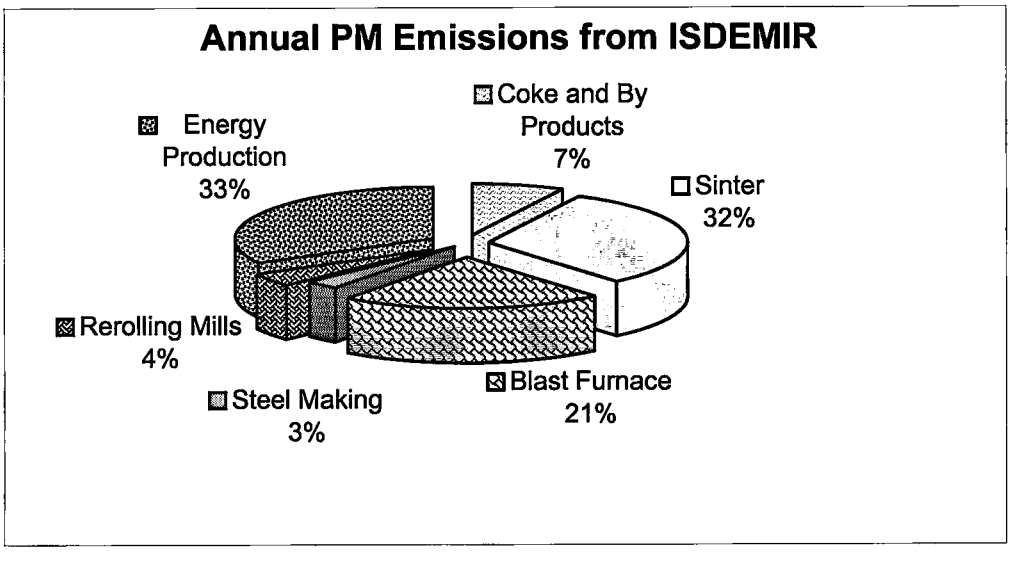

Figure 6.1 Contribution of various units to the annual PM emissions from ISDEMIR

Annual PM emissions from ISDEMIR are 19,009 tons. Figure 6.1 shows that energy production, sinter, and blast furnace units are major contributors in PM emissions with 33%, 32% and 21%, respectively. Although sinter and blast furnace units are equipped with dust control devices, the large amount of PM emission load shows that they are not working properly.

Figure 6.2 shows the contribution of various units to the annual SO_2 emissions of 32,836 tons. 48% and 32% of annual SO_2 emissions are originating from steel making and sinter units, respectively.

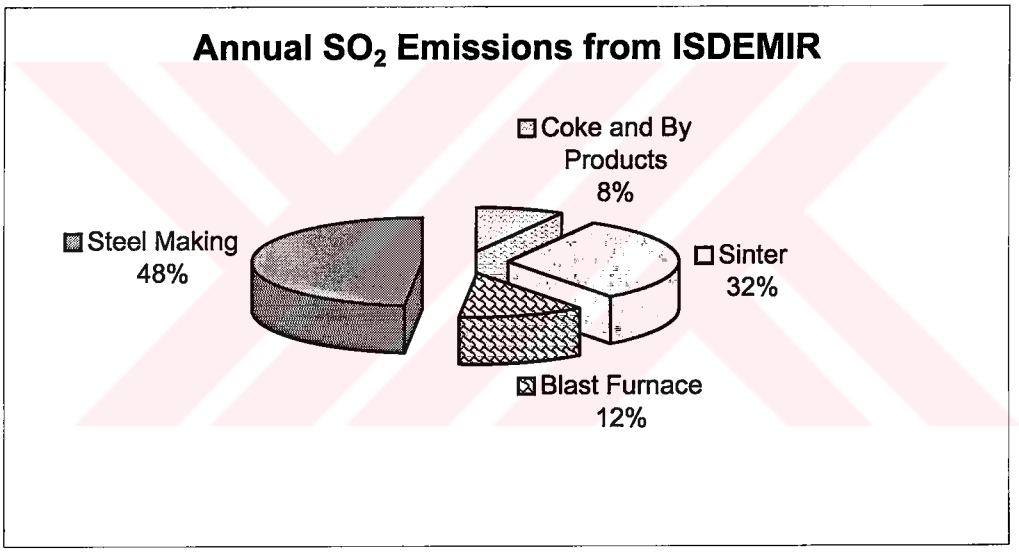

Figure 6.2 Contributions of various units to the annual SO_2 emissions from ISDEMIR

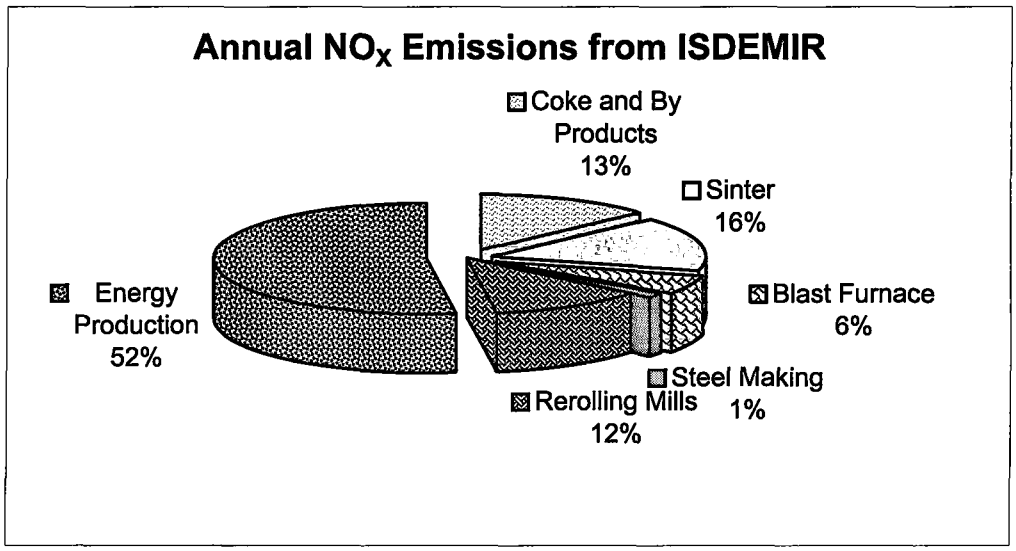

Figure 6.3 Contribution of various units to the annual NO_X emissions from ISDEMIR

Figure 6.3 shows that the energy production unit accounts for 52% of the total annual NO_X releases from ISDEMIR, followed by sinter, "coke and by products" and re-rolling mills units with 16%, 13% and 12% contributions, respectively.

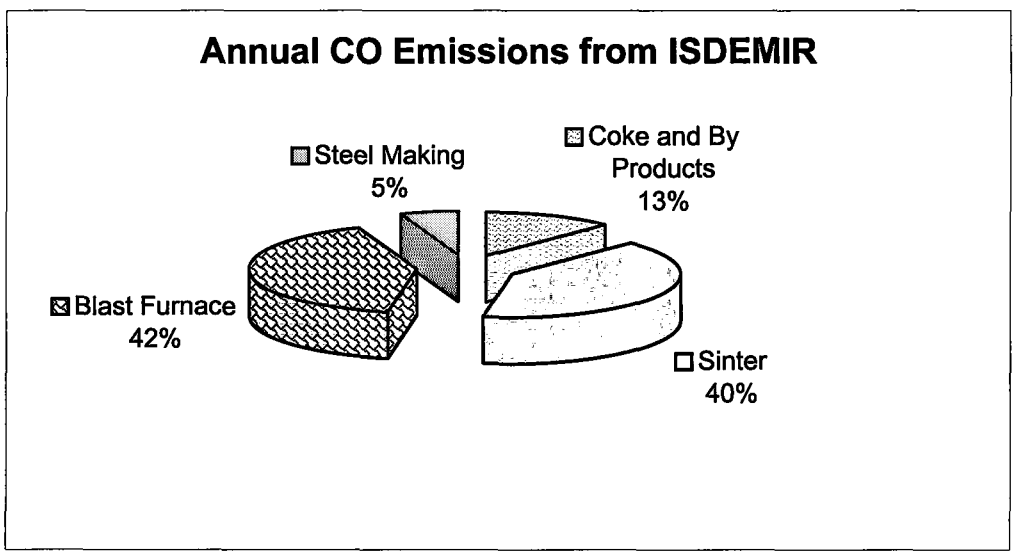

Figure 6.4 Contribution of various units to the annual CO emissions from ISDEMIR

Figure 6.4 shows the contribution of several units in ISDEMIR to the annual CO emissions of 79,585 tons. Blast furnaces and sinter units are responsible for 42% and 40% of the total annual CO emissions, respectively. As a matter of fact, this is a loss of energy for ISDEMIR because each gram of CO contains 10.1 kJ of energy. Therefore, annual emission of 79,585 tons of CO results in 8.04×10^{11} kJ (1.923×10^{11} kcal) of energy loss that is a huge quantity equivalent to 19,605 TOE (ton of oil equivalent). Measures should be taken to minimize this energy loss and use this un-burnt part of fuel.

Comparison of Emissions from ISDEMIR With Other Iron and Steel Industries

As mentioned in the previous sections that there are three integrated iron and steel industries in Turkey, namely, ERDEMIR, ISDEMIR and KARDEMIR. In order to see how the amounts of emissions from ISDEMIR with other integrated iron and steel industries in Turkey compare, the emission data from ERDEMIR was obtained. The amount of emissions from coke and by-products and sinter units of ERDEMIR and ISDEMIR are given in Table 6.1A. The emissions in Table 6.1A are expressed in grams of pollutant per kg of the products of coke and sinter units. The amounts of annual emissions from ISDEMIR given in Table 6.1 are converted from tons/y to g/kg by dividing the emissions with the amounts of production of coke and sinter. At ISDEMIR, coke and sinter productions during the year 2001 were 1,303,331 tons and 2,154,969 tons, respectively (Personal communications with ISDEMIR, 2003).

Table 6.1A Comparison of emissions from ERDEMIR and ISDEMIR

Industry	Unit	Pollutant Emissions (g/kg)			
		PM	SO_2	NO_X	CO
ERDEMIR	Coke	0.25	1.45	0.92	2.70
	Sinter	0.50	1.09	1.09	17.81
ISDEMIR	*Coke*	1.08	2.07	0.66	7.69
	Sinter	2.79	4.81	0.47	14.86

As given in Table 6.1A, the PM emissions from coke and sinter units of ISDEMIR were 4 times and about 6 times more than the emissions from the same units of ERDEMIR, respectively. High emissions of PM from ISDEMIR are attributed to very low efficiency of PM control systems. Moreover, after privatization of ERDEMIR, a large amount of investments were made for improving the PM control systems. The same is required for ISDEMIR.

As can be seen in Table 6.1A, SO_2 emissions from coke units of ISDEMIR and ERDEMIR are close to each other. But sinter unit of ISDEMIR emits almost five times more SO_2 as compared to the sinter unit of ERDEMIR. Both ERDEMIR and ISDEMIR do not have FGD systems, thus the difference in SO_2 emissions comes from the sulfur content of iron ores and coal used at these steel mills.

NO_X emissions from sinter unit of ISDEMIR are almost half of the NO_X emissions from the same unit of ERDEMIR. However, NO_X emissions from coke unit of ERDEMIR are about 1.5 times more than the CO emissions from coke unit of ISDEMIR.

CO emissions from coke unit of ISDEMIR are almost three times more than CO emissions from coke unit of ERDEMIR. However, CO emissions form sinter units of ISDEMIR and ERDEMIR are very close to each other.

Sivacoumar et al. (2001) reported NO_X emissions of 667 kg/h from TISCO (Tata Iron and Steel Company, Jamshedpur, India). TISCO is also an integrated iron and steel mill like ISDEMIR. NO_X emissions from ISDEMIR are found to be 820 kg/h (Table 6.1), which is close to that of NO_X emissions from TISCO.

VOC Emissions from ISDEMIR

VOC emission measurements in the stacks of ISDEMIR could not be made. Therefore, they are estimated by using CORINAIR Emission Factors. Possible

locations/units from where VOC emissions can be emitted were specified based on the process and fuel used in each unit of ISDEMIR. VOC releasing units in ISDEMIR along with type of fuels used are given in Table 6.2.

Table 6.2 VOC releasing units in ISDEMIR

Unit	Fuel Used
Coke and by products (coke ovens)	Blast furnace gas, coke gas
Sinter	Coke
Steel Making (Lime ovens)	Coke gas
Re-rolling Mills	Fuel oil, LPG, coke gas
Energy Production	Blast furnace & coke gas, pitch, mixed fuel

The annual consumption of several fuels in ISDEMIR, their calorific values and densities are given in Table 6.3. The quantity of coke given in Table 6.3 is used only at sinter unit; total annual consumption of coke in ISDEMIR is about 2,000,000 tons.

Table 6.3 Annual amounts and properties of fuels used in VOC emitting units of ISDEMIR

Fuel	Quantity (ton or Nm^3)*	Calorific Value (MJ/kg)	Density (kg/m^3)
Fuel Oil	421,376	41	950
LPG	173,568	45.4	550
Blast Furnace Gas	4,384,503,000	2.4	1.31
Coke Gas	515,661,000	36.7	0.44
Pitch	32,750	37.6	1200
Mixed Fuel	32,085	37.6	1200
Coke	136,000	27.7	

* Only LPG, Blast Furnace Gas and Coke Gas are given in Nm^3.

CORINAIR Emission Factors for VOC emissions from iron and steel industry as given in Chapter 4 were used in this study. The emission factors are again given here in Table 6.4 for the sake of quick reference.

Table 6.4 Emission factors used to calculate VOC emissions from iron and steel industry (CORINAIR, 1999)

Fuel Type	VOC Emission Factor (g/GJ of energy produced)
Fuel Oil	5
LPG	2.1
Blast Furnace Gas	6
Coke Gas	2.5
Coke	0.05

Since there were no emission factors available for pitch and mixed fuel, the emission factor for fuel oil was used for VOC emission calculations. The reason to use emission factor for fuel oil in calculations for pitch and mixed fuel is that both of these fuels are close to fuel oil in composition and calorific value.

VOC emissions from several units of ISDEMIR were calculated by using emission factors given in the Table 6.4 and the results are given in Table 6.5.

Table 6.5 VOC emissions from ISDEMIR

Unit	VOC Emissions	
	kg/h	ton/y
Coke and By Products	6.0	47.0
Sinter	0.03	0.2
Steel Making	0.8	6.3
Re-rolling Mills	13.1	104.0
Energy Production	6.4	51.0
Total	**26**	**208**

As can be seen from Table 6.5 the annual VOC emissions from ISDEMIR are 208 tons, the major contributor in it is found to be re-rolling mills with 104 ton/year, followed by the energy production and coke units with 51 and 47 ton/year VOC emissions, respectively.

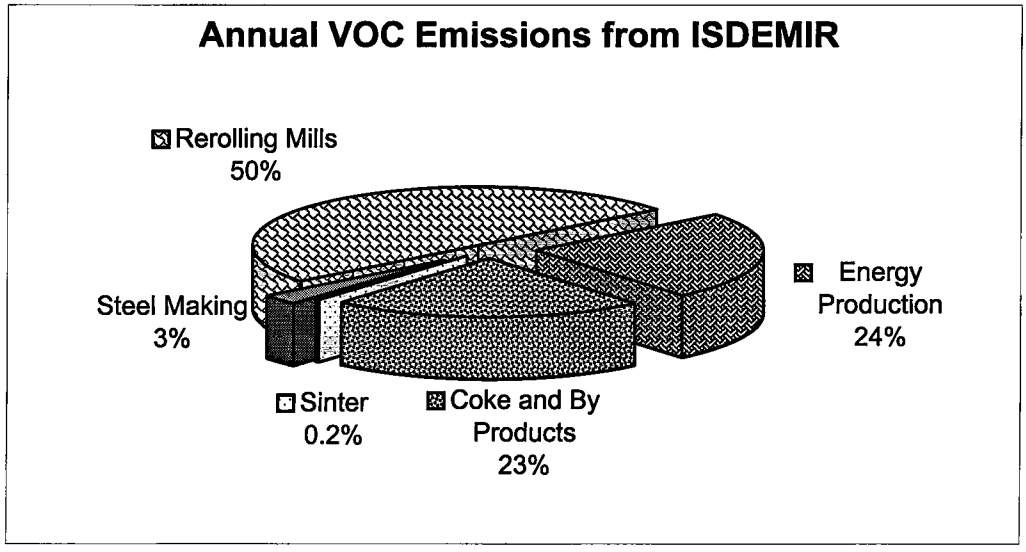

Figure 6.5 Contribution of various units to the annual VOC emissions from ISDEMIR

Figure 6.5 shows that 50% of VOC emissions from ISDEMIR are due to re-rolling mills which is followed by energy production and coke units with a contribution of 24% and 23%, respectively. The reason for the highest VOC emissions from re-rolling mills is due to annual consumption of 421,376 tons of fuel oil in the furnaces, and according to emission factors given in Table 6.4 the 2nd highest emission factor is for fuel oil. The highest emission factor is for blast furnace gas, but it is burnt at several different units and its heating value in very low as compared to that of fuel oil, which distributes VOC emissions due to blast furnace gas among these units.

B. Emissions from Other Industries

All other operational industries in the study area were visited for stack gas measurements. Stack gas concentrations for CO, SO_2, NO_X and PM were measured as well as the stack gas velocities. VOC emissions from these industries also could not be measured Therefore, VOC emissions are calculated based on the hourly fuel consumption and by using emission factors given in Table 6.4. The calculations of annual pollution loads in tons/year are based on:

- 24h/day x 330 days/year of operation in Yazıcı Steel
- 20h/day x 270 days/year of operation in Atakaş Şahin Steel
- 16h/day x 270 days/year of operation in Nursan, Koç, and Oysa Cement
- 10h/day x 270 days/year of operation in Pay, Ilhanlar, Yolbulan A, Yolbulan B, and Tosyali steel industries.

All of this information was collected from the relevant industries and plants.

Table 6.6 Pollution loads from other industries

INDUSTRY	PM (kg/h)	SO_2 (kg/h)	NO_X (kg/h)	CO (kg/h)	VOC (kg/h)	PM (t/y)	SO_2 (t/y)	NO_X (t/y)	CO (t/y)	VOC (t/y)
Yazıcı Iron & Steel	5.1	1.4	5.4	0.017	0.26	40.3	11	42.7	0.13	2.1
Nursan Steel	3.4	515	15	20	0.32	14.7	2225	64.8	86.4	1.4
Koç Re-rolling	0.8	161	11	1.4	0.32	3.5	696	47.5	6.0	1.4
Atakaş Şahin Steel	2.2	347	62	0.3	0.26	11.6	1874	334.8	1.6	1.4
Pay Metal	0.1	14	2.8	0.25	0.25	0.3	36	7.5	0.7	0.7
Ilhanlar Re-rolling	1.6	368	43		0.31	4.3	994	116.1	0	0.8
Yolbulan Metal A	0.8	51	2.2	0.07	0.21	2.2	138	5.9	0.2	0.6
Yolbulan Metal B	0.7	97	2.9	0.83	0.21	1.9	262	7.8	2.2	0.6
Tosyalı Steel	1.5	210	65	9	0.26	4.1	567	175.5	24.3	0.7
Oysa Cement	2.6		0.3	4.97	0.06	11.2	0	1.4	21.5	0.3
TOTAL	**19**	**1764**	**210**	**37**	**2**	**94**	**6802**	**804**	**143**	**10**

Table 6.1 shows that the SO_2 emissions from most of the units in "other industries" are above the limit set by the TAQPR as given in Table 3.2. These SO_2 emissions should be controlled to avoid health effects of SO_2 on the workers and people living near these industries.

As can be seen from Table 6.6 the largest pollution load is due to SO_2 with 6,802 tons/yr. The pollution load of NO_X with 804 tons/year follows this. Therefore, pollution loads of CO, NO_X, PM and VOC are not significantly high, only SO_2 is pronounced as a major pollutant from these industries.

Contributions of several industries to the annual SO_2 emission from the "other industries" are shown in Figure 6.6. Nursan Steel, Atakaş Şahin Steel and İlhanlar Re-rolling Plants account for 32%, 28% and 15% of the annual SO_2 emissions, respectively. It was noted that all metal industries except Yazici were using fuel oil No.6 with sulfur content of 6% by weight. This is the main reason for high amounts of SO_2 emissions from most of these steel industries. This fuel oil is supplied from the Batman Refinery. Since this is the closest refinery to this region, most of the products of this refinery are consumed in this area. As a matter of fact this is forbidden by the Ministry of Environment to use fuel oil No.6 in the industries in the urban areas. But this region still keeps using this product.

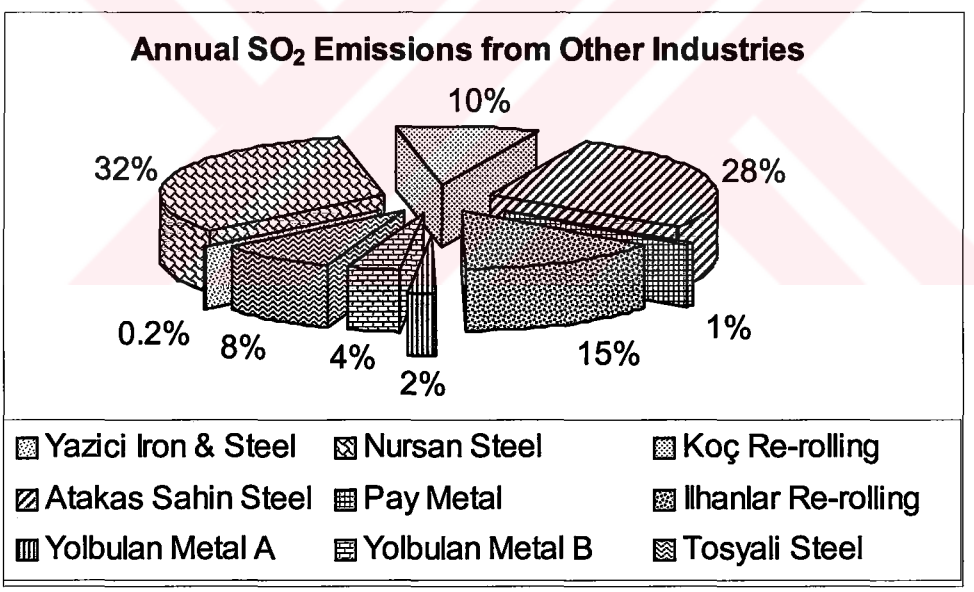

Figure 6.6 Contribution of several industries to the annual SO_2 emissions

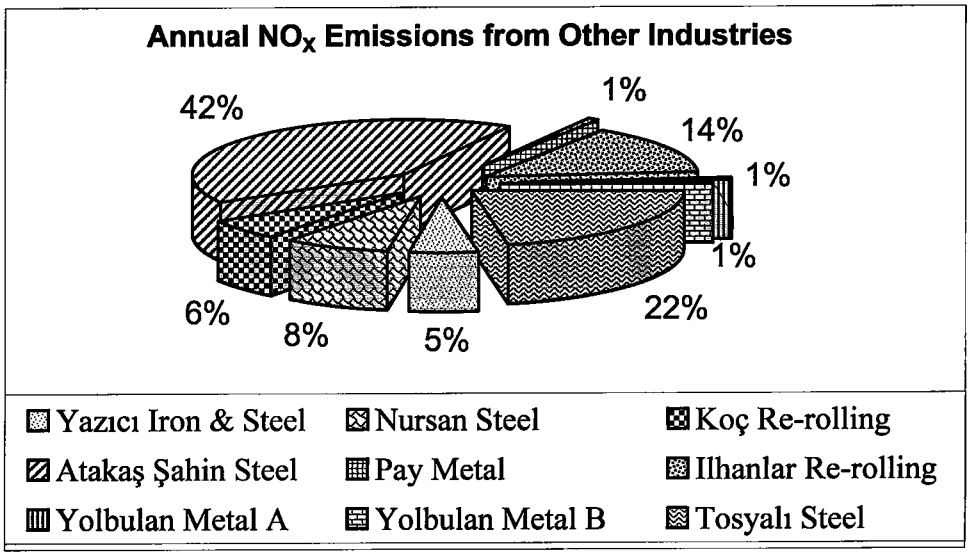

Figure 6.7 Contribution of several industries to the annual NO_X emissions

Contributions of several industries to the annual NO_X emissions from several "other industries" are shown in Figure 6.7, Atakas Sahin Steel, Tosyali Steel and Ilhanlar Re-rolling plants are responsible for 42%, 22% and 14% of the annual NO_X emissions.

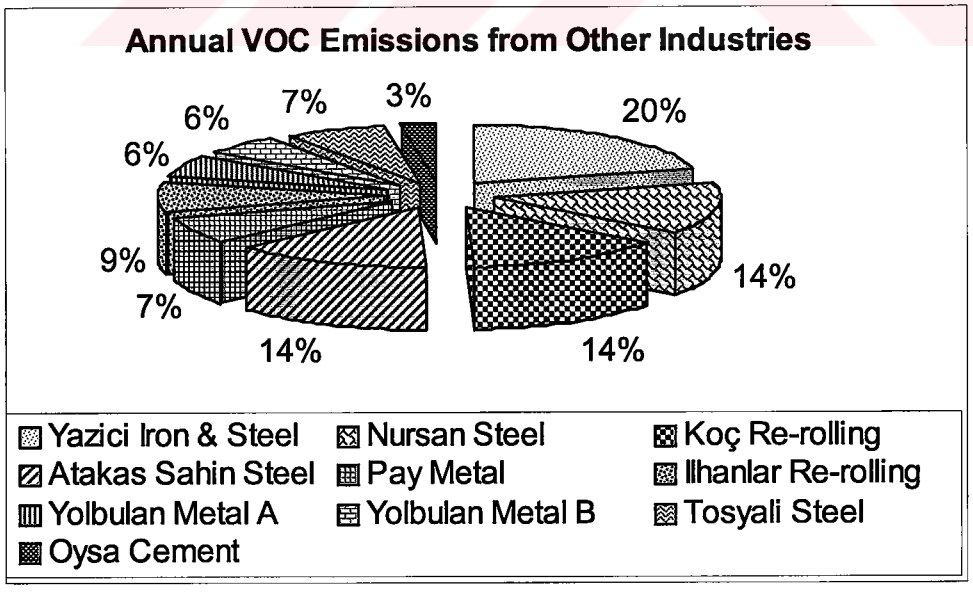

Figure 6.8 Contribution of several industries to the annual VOC emissions

Annual VOC emissions from the "other industries" are estimated to be 10 tons/year. As shown in Figure 6.8 the contribution of the Yazici Steel is 20% followed by the Atakaş Şahin Steel and Koç Re-rolling Mills with a share of 14% each in annual VOC emissions.

6.1.1.4 Total Industrial Emissions

The total emissions from all the industries operating in this region are calculated for each pollutant considered in this study. The pollution loads from all industrial sources are calculated by adding the pollution load of each industry. The results are presented in Table 6.7. As can be seen from this table CO emission to the atmosphere from the industries in Iskenderun area is very large with 88,169 tons/yr. This is followed by SO_2, PM and NO_X as being 42,677 tons/y, 21,124 tons/y and 7,962 tons/y, respectively.

Table 6.7 Annual Industrial Emissions

INDUSTRY	PM (ton/y)	SO_2 (ton/y)	NO_X (ton/y)	CO (ton/y)	VOC (ton/y)
ISDEMIR	19,009	32,836	6,490	79,585	208
All Other Industries	94	6,802	804	143	10
Total	**19,103**	**39,638**	**7,295**	**79,728**	**218**
ISDEMIR	99.5%	82.8%	89.0%	99.8%	96.0%
All Other Industries	0.5%	17.2%	11.0%	0.2%	4.0%

Table 6.7 shows that more than 99% of CO and PM emissions are coming from ISDEMIR. In order to show the contribution of ISDEMIR to the total industrial pollution load in the study area, pie charts illustrated in Figure 6.9 to 6.13 are prepared.

Figure 6.9 explains that almost 100% of the annual industrial PM emissions are due to ISDEMIR. Figure 6.10 show that ISDEMIR is responsible for 83% of the annual industrial SO_2 emissions. Figure 6.11 explains that ISDEMIR

accounts for 89% of the annual industrial NO_X emissions. Figure 6.12 shows that ISDEMIR is responsible for almost 100% of the annual industrial CO emissions Figure 6.13 shows that 96% of the annual industrial VOC emissions come from ISDEMIR.

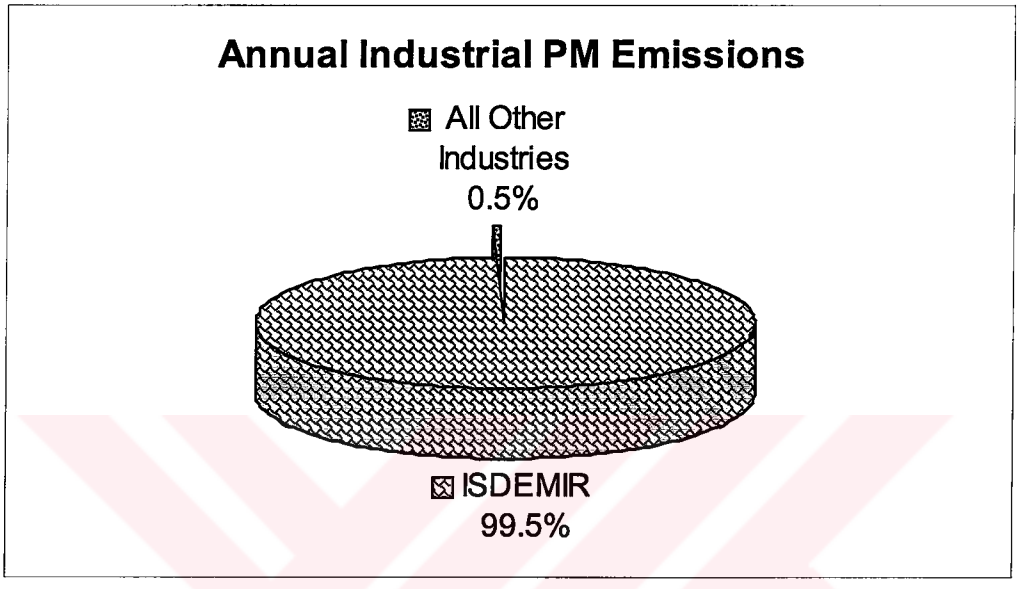

Figure 6.9 Annual industrial PM emissions

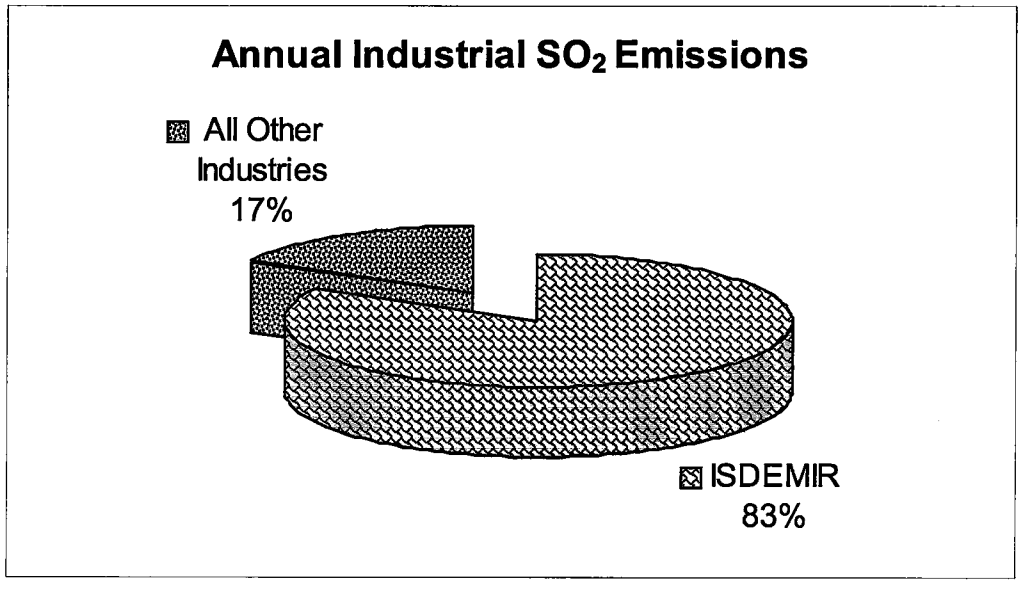

Figure 6.10 Annual industrial SO_2 emissions

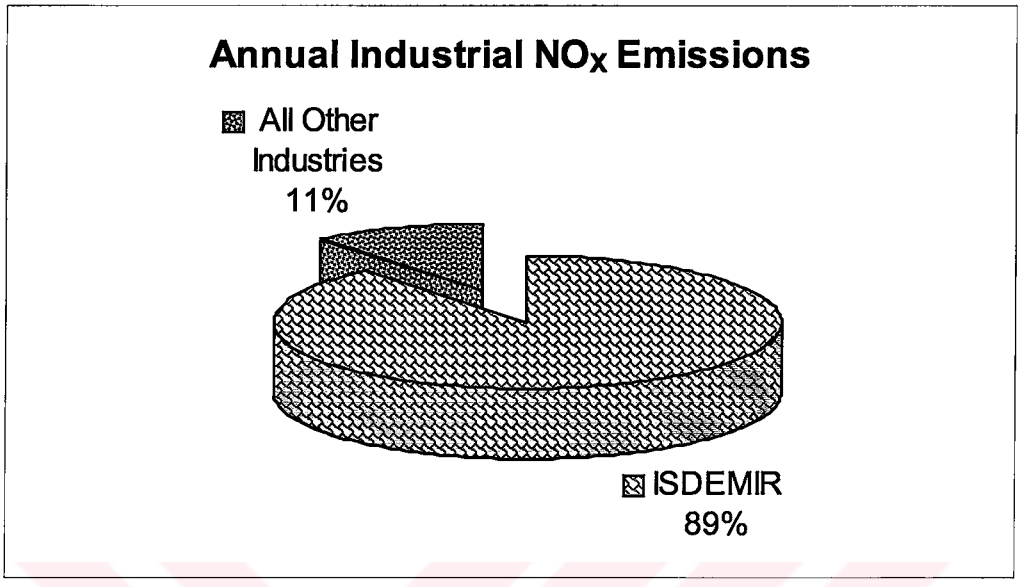

Figure 6.11 Annual industrial NO_X emissions

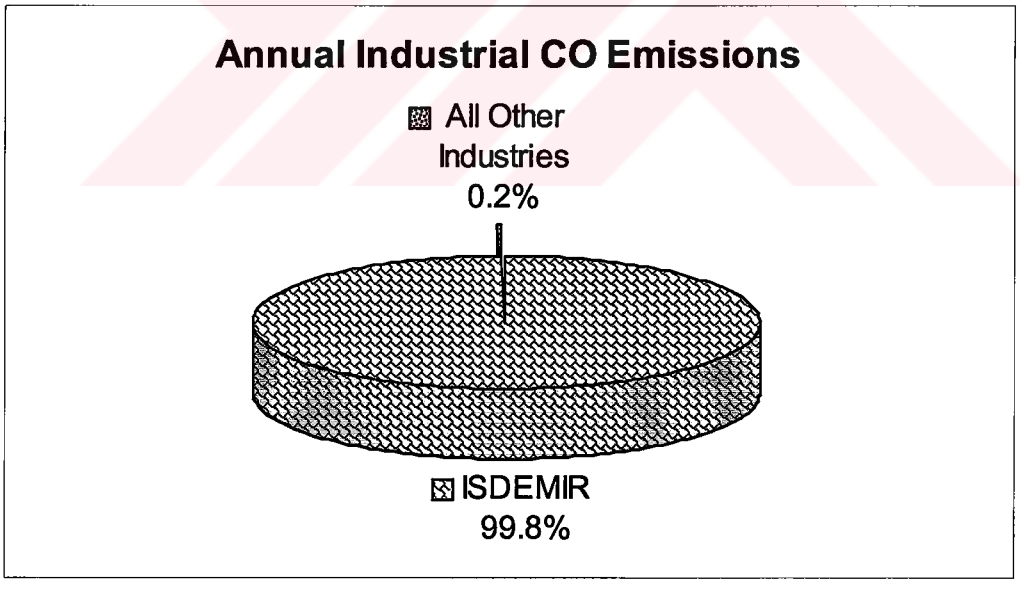

Figure 6.12 Annual industrial CO emissions

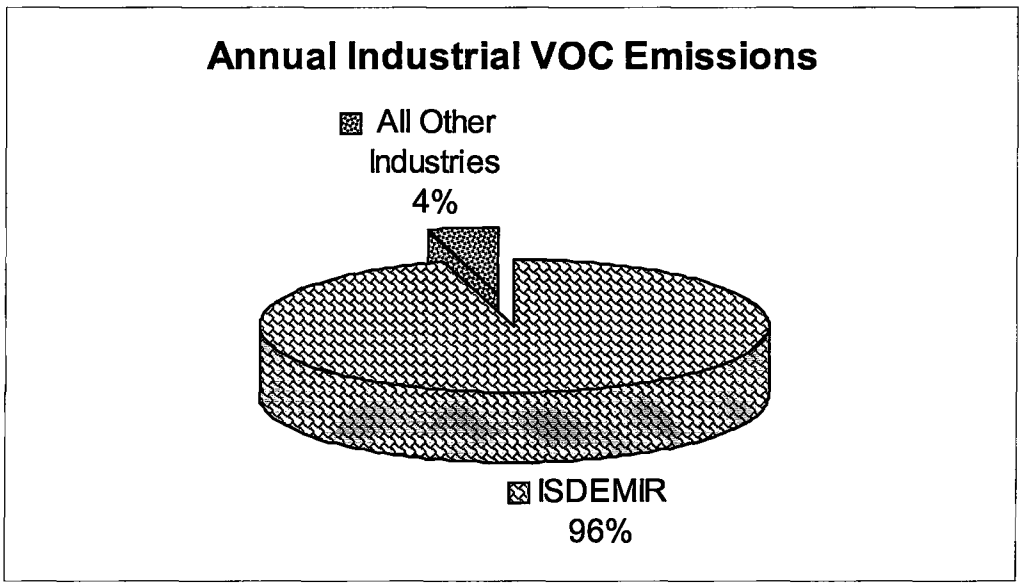

Figure 6.13 Annual industrial VOC emissions

6.1.2 Emissions from Domestic Heating

The second important source of emissions is the domestic heating during winter season. These emissions depend on many factors, such as severity of winter, population density, type and amount of fuel used and stoves or boilers used to burn fuel. Necessary data in this regard was collected from the following municipalities in the study area:

- Iskenderun
- Bekbele
- Denizciler
- Sariseki
- Karayilan
- Payas,
- Dortyol

Data collected from these municipalities included the number of dwellings, percentage of dwellings using coal for heating, type and amount of fuel used for heating. Table 6.8 gives the population and the number of dwellings in each

municipality. By dividing the population by the number of dwellings, the number of people living in each dwelling is obtained. This number, as can be seen from Table 6.8, ranges between 4.8 and 6.1. The average number of people per dwelling is calculated as 5.2. This number will be used later on for other estimations.

Table 6.8 Basic data about residential areas in the study area (Source: Relevant Municipalities).

City/Town	Population	No. of dwellings	No. of people per dwelling
Iskenderun City	164,600	31200	5.3
Bekbele	14,200	2800	5.1
Denizciler	20,645	4000	5.2
Sariseki	5,000	1036	4.8
Karayilan	15,300	3000	5.1
Payas	32,000	5254	6.1
Dortyol Town	52,000	10145	5.1
Total	**303,745**	**57,435**	**Average = 5.2**

The percentages of dwellings using coal and fuel oil for heating in various municipalities, and the average amount of coal or fuel oil used during winter months per dwelling are given in table 6.9

Table 6.9 shows that in the study area 60-65% of dwellings use coal while 10% of dwellings only in urban areas use fuel oil for heating. Annual consumption of fuel on the average is about 1 tone per dwelling. This number is taken for emission calculations

Table 6.9 Percentages of dwellings using coal and fuel oil in various municipalities (Source: Relevant Municipalities).

City/Town	Total No. of dwellings	% of dwellings using coal for heating	% of dwellings using fuel oil for heating	Coal/fuel Oil used in winter per dwelling (ton)
Iskenderun City	31,200	60	10	1
Bekbele	2,800	65		0.75-1
Denizciler	4,000	65		1
Sariseki	1,036	65		1
Karayilan	3,000	20		1
Payas	5,254	65		0.75-1
Dortyol Town	10,145	65	10	0.75-1
Total	57,435			

The municipalities did not know the numbers of dwellings in some of the rural areas and no information could be obtained on these houses. Therefore, the population of districts in the study area was used to calculate the total number of dwellings present in the urban and rural areas. These districts are Iskenderun and Dortyol, which the largest two districts covering almost 95% of the study area as can be seen from Figure 4.1. Therefore, the population of these districts was used in calculating the number of dwellings in the rural and urban areas of Iskenderun and Dortyol. The population data of the last census (year 2000) obtained from The State Institute of Statistics (SIS) was used in these calculations. The population divided by 5.2 people/dwelling gave approximately the total number of dwellings in the urban and rural areas. The results are given in Table 6.10.

Table 6.10 Population and housing data for Iskenderun and Dortyol

Place	Population (as of 2000)	Total No. of dwellings	No. of dwellings using coal	No. of dwellings using fuel oil
Dortyol Town	53,597	10,307	6,184	1,031
Dortyol Rural	72,661	13,973	9,083	
Iskenderun City	159,149	30,606	18,363	3,064
Iskenderun Rural	128,235	24,661	14,600	
Total	**413,642**	**79,547**	**48,231**	**4,095**

Number of dwellings using coal for domestic heating were estimated based on the information obtained from municipalities, i.e. about 60-65% of dwellings are heated by burning the coal. Similarly number of dwellings using fuel oil for heating were estimated based on 10% of total dwellings in the cities of Iskenderun and Dortyol. The rest 25% of the dwellings use either electricity or LPG or does not heat at all. Therefore, the number of dwellings using coal and fuel oil were calculated by multiplying the total number of dwellings by 60% in urban and by 65% in rural areas. Numbers of dwellings using fuel oil for heating were calculated by multiplying total dwellings with 10% in urban areas only. The results are also given in Table 6.10.

In Table 6.10 given above "Iskenderun Rural" area includes 2200 dwellings, which are the residential buildings for the employees of ISDEMIR. These dwellings are heated with steam that is produced in the iron and steel works. Therefore, there are no emissions from these dwellings during winter for residential heating. This number has been subtracted from the number of dwellings found by dividing the population by 5.2. (128,235/5.2 = 24,661; 24,661-2,200 = 22,461, and then 22,461 x 0.65 = 14,600 dwellings).

According to the information collected from the municipalities in the study area, coal is the major fuel for domestic heating in the area. In order to calculate the emissions from combustion of coal in residential areas, the chemical composition of the coal needs to be known. Therefore, coal samples were

collected from the sale points and were analyzed in the Coal Laboratories of the Department of Chemical Engineering of METU. The proximate analyses of the coal samples are given in Table 6.11. Coal #2 and #3 are low sulfur coals with S content less than 1% by weight. Coal #1 is most probably a domestic lignite coal with S content of 3.6% by weight.

Table 6.11 Analyses of coals used in the study area

Parameter	Coal # 1	Coal # 2	Coal # 3
Carbon (% by wt.)	81.16	61.57	60.54
Moisture content (% by wt.)	0.41	1.33	1.84
Sulfur (% by wt.)	3.6	0.6	0.75
Ash (% by wt.)	8.45	31.87	11.08
Volatile matter (% by wt.)	9.98	5.23	26.54
Calorific value (kJ/kg)	32,600	27,170	26,750

According to the information collected again from the municipalities, about 70% of coal used for heating consisted of coal # 2 and #3, and the rest (30%) was coal #1. Generally, low sulfur coal is used in high-income areas and high sulfur coal is used in low-income areas. Total annual consumption of coal is not exactly known. However, the data obtained from municipalities indicate that about 750 kg to 1000 kg of coal is consumed per dwelling on the average during winter months. Therefore, annual consumption of coal has been estimated for 48,231 dwellings as 45,000 tons/yr.

The other fuel used for domestic heating during winter is fuel oil. The properties of fuel oil used for domestic heating in this region have been obtained from TUPRAS (2002) and are given in Table 6.12. The calorific value of the fuel oil is about 41,000 kJ/kg. The sulfur content of this fuel oil is 1.5% by weight.

Each dwelling uses about 1 ton of fuel oil during winter months. Therefore, the annual consumption of fuel oil is estimated to be 4,100 tons. There are 4,095 dwellings using fuel oil in Iskenderun City and Dortyol Town.

Table 6.12 Properties of domestic fuel oil (Tupraş, 2002)

Parameter	Units	Value
Density	kg/L	0.95
Ash	% by weight	0.1
Sulfur	% by weight	1.5
Calorific Value	kJ/kg	41,000

In order to check the whether the assumptions made about amounts of fuels used for domestic heating in the study area are realistic or not, small analysis has been done. It is estimated that during winter 18,300 tons of coal and 3065 tons of fuel oil is used for domestic heating in Iskenderun City. According to planning of BOTAŞ, the optimistic demand of natural gas in the Iskenderun City will be 18 million Sm^3 (at 15° C temperature and 1.01325 bar pressure). A simple calculation is done to find the natural gas equivalent of the total fuels used for domestic heating.

Calorific value of coal = 26,750 MJ/ton

Calorific value of natural gas = 36 MJ/Nm^3

Calorific value of Fuel oil = 41,000 MJ/ton

1) Heat generated by 18,300 tons of coal = 18,300 tons *26,750 MJ/ton

= 489,525 x 10^3 MJ

Equivalent amount of natural gas = 489,525 x 10^3 MJ *1/36 MJ/Nm^3

= 13.6 million Nm^3

2) Heat generated by 3,065 tons of fuel oil = 3,065 tons * 41,000 MJ/ton

= 125,665 x 10^3 MJ

Equivalent amount of natural gas = 125,665 x 10^3 MJ *1/36 MJ/Nm^3

= 3.49 million Nm^3

Total amount of natural gas required to replace coal and fuel oil = 13.6 + 3.49

= 17.09 million Nm^3

=17.09 (273 +15)/273 million Nm^3

= 18 million Sm^3 (at 15° C, 1.01325 bar)

These calculations show that the amount of natural gas required to replace the coal and fuel oil for domestic heating is 18 million Sm^3 (at 15° C, 1.01325 bar), which is equal to the optimistic estimates made by BOTAŞ. However gas demand estimates made by BOTAŞ include also the gas required for cooking, but the amount of gas used for cooking is very small as compared to the one used for domestic heating. Therefore, it can be concluded that the estimates made for fuel consumption in domestic heating are close to reality and are reasonable.

6.1.2.1 Calculations of Emissions from Residential Sources

Since it is very difficult to make individual emission measurements for each dwelling to calculate the emission loads for various pollutants from residential sources, emission factors were used to make emission estimates from residential sources. Although there are emission factors developed by Durmaz and Yucel (1992) for local coals and stoves, they are quite old and do not have an international value. CORINAIR Emission Factors, as given in Chapter 4, were used in this study to estimate the emissions. The emission factors are again given here in Table 6.13 for the sake of clarity. The emission factors are given for coal and fuel oil separately. For example 2.9 kg of NO_X is emitted for a ton of coal burned. When SO_2 burning emissions are required for coal, 15 multiply the sulfur content of coal gives the result. For example if the S content of coal is 1% by weight, 15 kg of SO_2 is emitted for a ton of coal burned.

Table 6.13 Emission factors used to estimate emissions from domestic heating. (CORINAIR, 1999)

Fuel	Emission Factors					
	Units	PM	SO_2	NO_X	CO	VOC
Coal	kg/ton	1.5 * A	15 * S	2.9	1	2.5
Fuel oil	kg/m^3	0.3	17.24 * S	2.2	0.6	0.3

A: ash content of coal (% by weight), S: Sulfur content of fuel (% by weight)

The amount of emissions for each pollutant are calculated by using the following formula:

Amount of Emissions = (Amount of coal used)* (Emission factor * 10^3 kg/ton)

(ton/y) (ton/y) (kg of pollutant/ton of coal)

Similar calculations are applied to calculate the emissions from combustion of fuel oil by using the relevant emissions factors. Since emission factors are given for fuel oil on the basis of kg pollutant/m^3 of fuel oil, the volume of fuel oil is found by dividing the tons of fuel oil used by the density of the fuel oil. Generally, the amount of fuel oil used is expressed in daily life in tons. The density of fuel oil is 0.95 ton/m^3.

The climate of Iskenderun region is not severe in winters. Therefore, heating is done from 06:00 to 11:00 hours in the morning and from 18:00 to 23:00 hours in the evening for the months from November to February.

The total annual emissions from domestic heating calculated by using CORINAIR emission factors for each pollutant considered in this study are given in Table 6.14. As can be seen from the table, the largest amount of pollution is due to SO_2 with 1195 tons/yr. The next one is PM with 696 tons/yr. Then comes NO_X, VOC and CO in descending order.

Table 6.14 Annual emissions from domestic heating

Place	PM (ton/y)	SO_2 (ton/y)	NOx (ton/y)	CO (ton/y)	VOC (ton/y)
Dortyol Urban	93	172	20	6	15
Dortyol Rural	134	209	25	8	22
Iskenderun Urban	283	524	60	18	47
Iskenderun Rural	185	289	35	11	30
Total	**696**	**1,195**	**140**	**42**	**114**

6.1.3 Emissions Due to Traffic

The emissions due to traffic sources consist of emissions from the vehicles on urban roads as well as inter city roads in the study area.

6.1.3.1 Emissions from Urban Traffic

The urban areas in the "study area" are the city of Iskenderun and towns of Dortyol and Payas. No data on active traffic in urban areas was available. The only available data that could be obtained was the number of registered vehicles. There are two vehicle registration offices in the study area, one in Iskenderun and the other in Dortyol. The vehicle registration office located in Dortyol serves both Dortyol and Payas.

Since the urban traffic counts were not available in the study area, some assumptions had to be made in order to include the effect of urban traffic in the air quality modeling study. For the purpose of determining the active traffic (i.e. traffic on roads) in the urban areas of the Iskenderun region, the Transport Research Center at METU, Ankara was consulted. Upon their advice a small analysis of registered vehicles in Ankara, Iskenderun, Dortyol and Payas was performed. The analysis included the calculation of the number of vehicles per km^2 in Ankara and in each urban area in the study region. The results of this analysis are given Table 6.15.

Table 6.15 Analysis of registered vehicles in Ankara, Iskenderun, Dortyol and Payas

City	No. of Registered vehicles	Urban area (km^2)	No. of vehicle/km^2
Ankara	930,855	620	1,501
Iskenderun	45,436	27.5	1,652
Dortyol	9,923	18	551
Payas	5,923	8	740

Table 6.15 shows that number of vehicles/km^2 in Ankara is 1,501 and in Iskenderun is 1,652. These numbers are close to each other. Therefore, it was assumed that active traffic pattern in Iskenderun may be comparably close to the one in Ankara.

Generally, emission inventories where urban traffic is included as a source are scarce in Turkey. However, the emission inventory study of Ankara performed by Atimtay and Yetis (1993) included the urban traffic in the emission inventory and it was based on the traffic counts on roads. According to the results of that study, on the average 45% of registered vehicles were counted on road per hour during daytime. Since the number of vehicles per km^2 in Ankara and Iskenderun are found to be close to each other. Therefore, the same percentage was assumed to be applicable to Iskenderun. Hence, all of the calculations for emissions from urban traffic in Iskenderun are based on the assumption that during daytime on average 45% of registered vehicles were on road per hour.

Daytime traffic is taken as vehicle counts at 0700 though 2100 hours while nighttime traffic were the vehicle counts at 2200 to 0600 hours. The nighttime urban traffic density was assumed to be the same as the density on Iskenderun – Adana Highway, which is about 17% of the daytime traffic. This percentage has been obtained based on the traffic counts recorded by the General Directorate of Highways, Ankara.

As Dortyol and Payas are relatively small towns therefore, the active traffic pattern of a big city like Ankara cannot be applied to these towns. As given in Table 6.15 the number of vehicles/km^2 in Payas and Dortyol are about three times less than that of Iskenderun. Also the number of vehicles/km^2 in Dortyol and Payas collectively are less than in Iskenderun. Therefore, it can be assumed that active urban traffic in Dortyol and Payas is less than 50% of the one in Iskenderun. It has already been assumed in Iskenderun that 45% of the registered vehicles are in active urban traffic per hour. Less than 50% of 45%, which is about 20% has been assumed as the percentage of registered vehicles on road per hour during daytime in Dortyol and Payas.

The number of registered vehicles obtained from vehicles registration offices at Iskenderun, Dortyol and Payas included all kinds of vehicles. Since trucks and tractors would not operate regularly in the urban areas, they were deleted from the list. Moreover, the major means of public transportation are minibuses and vans in the study area. There is light bus traffic in the urban areas due to services provided to students and employees of different industries. The municipalities operate very few buses for public. Therefore, 75% of registered buses were excluded and only 25% of them were included in emission calculations from urban traffic sources. Moreover, a sensitivity analysis performed for the urban areas showed that, including 50% of registered buses in active urban traffic increased annual average ground level concentrations of PM by less than 1%, NO_X by 3% and CO by 2% as compared to no buses included in urban traffic. Therefore, considering 25% of registered buses in active urban traffic seems to be a reasonable assumption. Table 6.16 shows the basic data about vehicles and assumed number of vehicles on road per hour during daytime in urban areas of the Iskenderun Region.

Table 6.16 Number of registered vehicles (2001) and assumed to be on road per hour

City	No. of Registered Vehicles	No. of vehicles exclusive of tractors, trucks and 75% of buses	% of vehicles on road/h	No. of vehicles on road/h
Iskenderun	45,436	41,712	45	18,770
Dortyol	9,923	8,296	20	1,660
Payas	5,923	4,952	20	990

In order to calculate the emissions from the active traffic on annual basis, the number of vehicles that are on roads per year was needed to be calculated. The following formula was used to estimate the annual number of vehicles that are on urban roads in the study area.

$$TV = (HV) * F1 * 313 + (HV) * F1 * F2 * 52$$

$$TV = (HV) * F1 [313 + F2 * 52]$$

where:

TV = Total number of vehicles on road per year.

HV = Number of vehicles on road per hour.

F1 = A factor used to show the fraction of vehicles on road during daytime (on the average daytime was considered from 07:00 to 21:00 hours (15 hours) while the remaining 9 hours (21:00 to 06:00) were taken as nighttime). During night the traffic density was assumed to drop down to 17% of the daytime value.

Therefore the value of F1 is taken as $15*1 + 9 * 0.17 = 16.53$

F2 = A factor used to show the fraction of vehicles on road on Sunday. Traffic density on Saturdays was considered the same as weekdays. On Sundays the traffic density was assumed to fall down to 30% of that of weekdays. Therefore, the value of F2 is taken as 0.3.

Note: Out of 365 days in a year, 52 days are Sundays.

The emissions from urban traffic were calculated as follows:

Amount of Emission = (TV) * (Emission factor * 10^{-6} ton/g) * (Length of road)

(ton/year) (No./year) (g/km) (km)

CORINAIR Emission factors given in Chapter 4 (Tables 4.4 and 4.5) were used to calculate the emissions from urban traffic. The results of emission calculations for urban traffic are given in Table 6.17.

Table 6.17 Emissions from urban traffic

PLACE	Emissions of Pollutants (ton/y)			
	PM	NO_X	CO	VOC
ISKENDERUN	54	2,419	24,975	4,462
DORTYOL	7	314	3,237	578
PAYAS	3	116	1,203	215
TOTAL	**64**	**2,849**	**29,415**	**5,255**

6.1.3.2 Emissions from Highway Traffic

There are two major roads passing through the study area from north to south, they are:

1. Highway between Iskenderun – Adana (E-5).
2. Motorway between Iskenderun – Adana.

All of the inter city traffic in this region is on E-5 highway and motorway as theses highways connect this region to other parts of the country. Daily average number of vehicles on the highway and the motorway traveling between Iskenderun – Dortyol section was obtained from The General Directorate of Highways in Ankara. Results of vehicle counts are given in Table 6.18. It was assumed that on the average all of the vehicles on highways travel about 30 km

of distance in the study area instead of 50 km (the length of the study area), because there may be some vehicles that exit from the motorway or highway after travelling some distances less than 50 km.

Table 6.18 Number of vehicles traveling on Iskenderun – Adana highway and motorway on Iskenderun – Dortyol section (General Directorate of Highways Ankara, 2002).

Vehicle	Average Daily No. of Vehicles	
	Highway	Motorway
Car	1,975	2,007
Pickup	942	286
Minibus	1,034	574
Truck	3,046	1,093
Bus	155	296
Total	**7,152**	**4,256**

The analysis of traffic counts data on the highway and motorway in the study area obtained from the General Directorate of Highways, Ankara, revealed that on the average 83% of the total vehicles traveled during daytime hours (07:00-21:00) while 17% of vehicles traveled during night (21:00-07:00). Again CORINAIR emission factors were used to calculate the emissions from diesel and gasoline vehicles on highways. These CORINAIR emission factors are given in Chapter 4 in Tables 4.4 and 4.5.

Emissions on highways were calculated by using the following formula:

Z (Amount of Emissions) = (Emission factor) * (Number of vehicles)

(g/km-day) (g of pollutant/km) (number/day)

This will result in emissions of Z g/km-d, which is then converted to tons/year for 30 km length of road as traveled by multiplying Z by (30 km *365 d/y $*10^{-6}$ ton/g).

The emissions calculated by using the formula and conversion factors given above for these two major highways on the section between Iskenderun and Dortyol are given in Table 6.19 for different pollutants.

Table 6.19 Annual Traffic Emissions from Iskenderun – Dortyol section of highway and motorway

Road	PM (ton/y)	NO_X (ton/y)	CO (ton/y)	VOC (ton/y)
Highway	62	307	420	45
Motorway	27	173	333	32
Total	**89**	**480**	**753**	**78**

As can be seen in the table, the largest emission loads from traffic are for CO and NO_X with the amounts of 753 and 480 ton/y, respectively. This is an expected result because CO and NO_X are major pollutants among traffic emissions. After CO and NO_X comes PM and VOC with the amounts of 89 and 78 ton/y respectively.

As one can notice here there are no emission factors for SO_2 given by CORINAIR (Table 4.4 and 4.5) neither for gasoline nor for diesel vehicles. Therefore, the amounts of emissions for SO_2 in Table 6.19 do not exist.

6.1.3.3 Total Emissions from Traffic Sources

The total annual emissions from traffic sources on urban as well as inter-city roads are calculated by adding their respective totals. Table 6.20 shows the total emissions from traffic sources.

Table 6.20 Total emissions from traffic sources.

Source	PM (ton/y)	NO_X (ton/y)	CO (ton/y)	VOC (ton/y)
ISKENDERUN City	54	2,419	24,975	4,462
DORTYOL Town	7	314	3,237	578
PAYAS Town	3	116	1,203	215
Iskenderun-Adana Highway	62	307	420	45
Iskenderun-Adana Motorway	27	173	333	32
Total	**153**	**3,329**	**30,168**	**5,332**

Table 6.20 shows that more CO is the largest pollutant emitted from traffic in the study area with 30,168 ton/y followed by 5,332 ton/y of VOC and 3,329 ton/y of NO_X. This result is not surprising because CO, VOC and NO_X are the major pollutants associated with traffic. Principal amount of the pollutants is coming from urban traffic, because at lower speeds gasoline vehicles emit considerable amounts of CO and VOC.

6.1.4 Total Emissions from the Study Area

The summation of the annual emissions from industrial, domestic heating and traffic sources give the total pollution load in the study area. The total annual emission values from all the sources considered are summarized in Table 6.21.

Table 6.21 Total annual emission loads from all sources

Sources	Total Emission Loads (ton/y)				
	PM (ton/y)	SO_2 (ton/y)	NO_X (ton/y)	CO (ton/y)	VOC (ton/y)
Industrial	19,103	39,638	7,295	79,728	218
Domestic Heating	696	1,195	140	42	114
Traffic	153	-	3329	30,168	5332
Total	**19,952**	**40,833**	**10,764**	**109,938**	**5664**

The percentages of the contributions of each major source to the annual pollution loads are given in the Table 6.22 and are shown in Figures 6.14 to 6.18.

Table 6.22 Contributions of several sources in the annual pollution load in the study area

Sources	Contributions of Sources to Total Annual Emissions				
	PM (%)	SO_2 (%)	NO_X (%)	CO (%)	VOC (%)
Industrial	95.75	97.07	67.77	72.52	3.85
Domestic Heating	3.49	2.93	1.30	0.04	2.01
Traffic	0.76		30.93	27.44	94.14

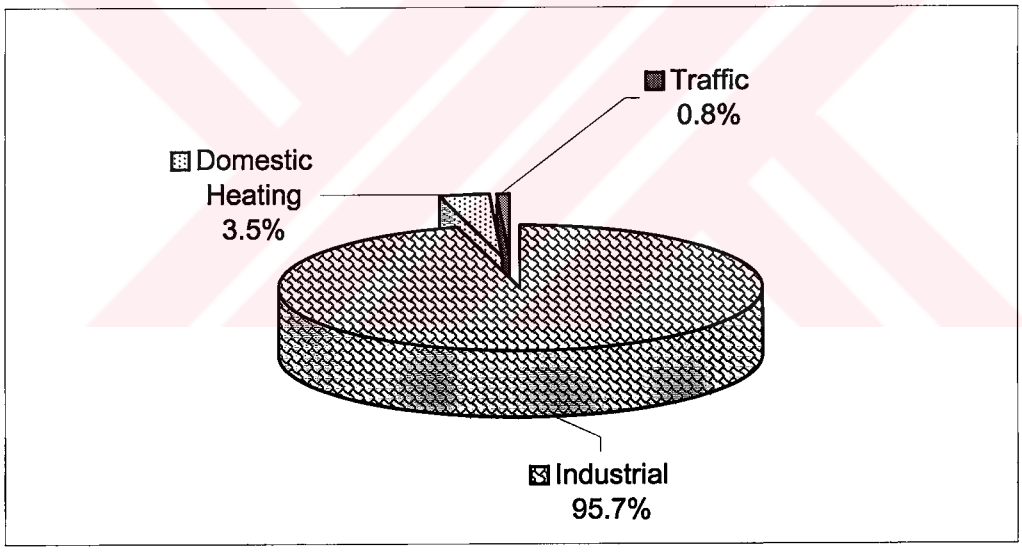

Figure 6.14 Contribution of various sources to the annual PM emissions

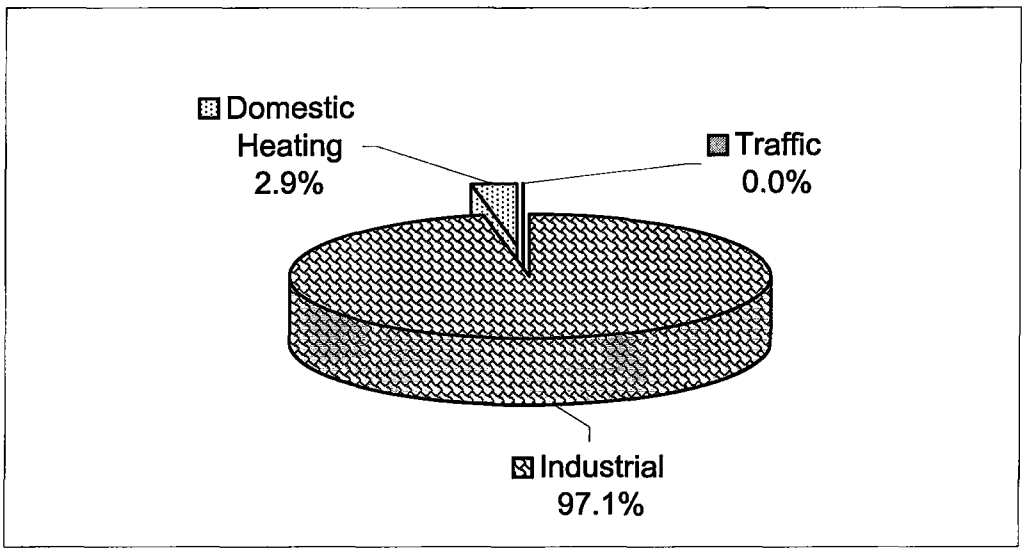

Figure 6.15 Contribution of various sources to the annual SO_2 emissions

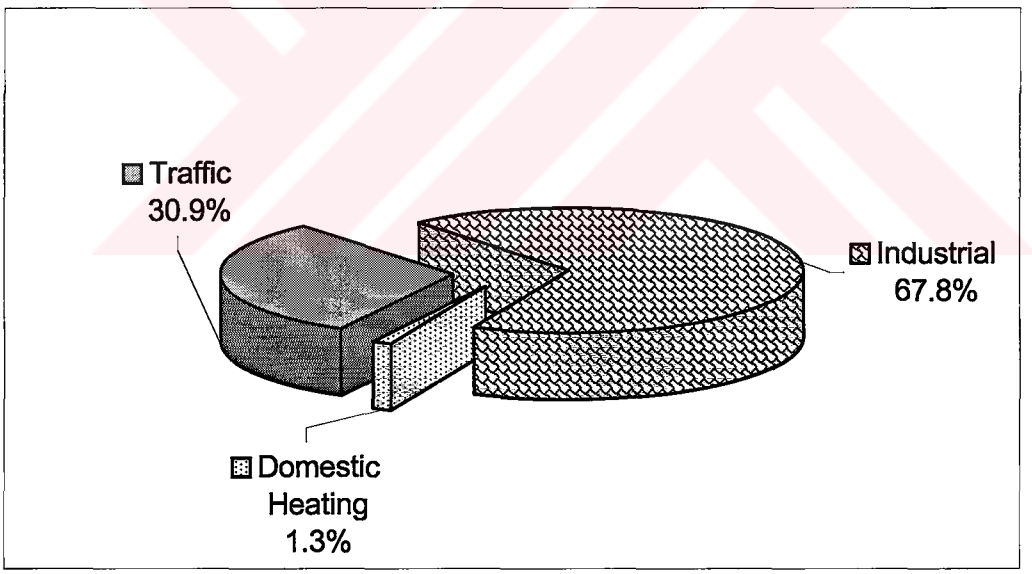

Figure 6.16 Contribution of various sources to the annual NO_X emissions

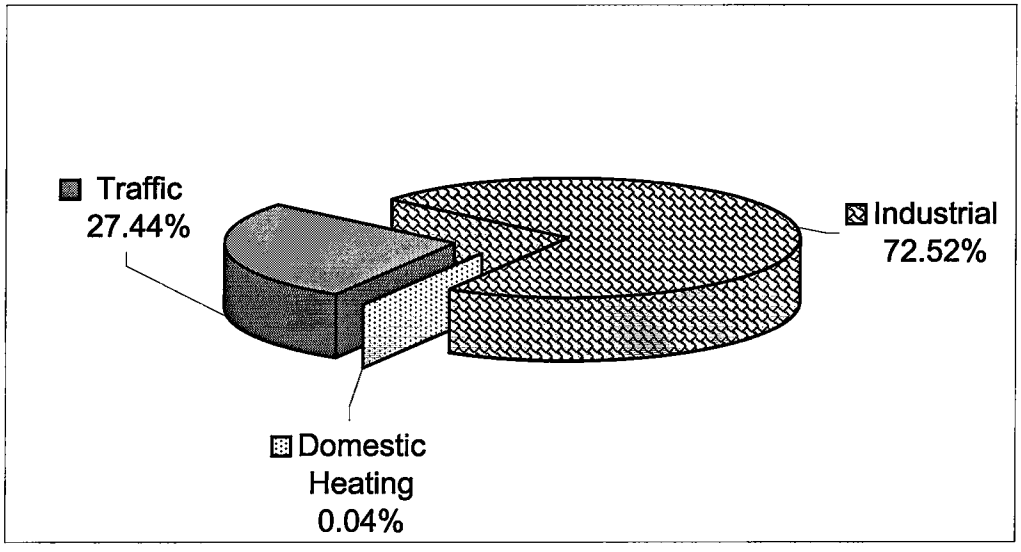

Figure 6.17 Contribution of various sources to the annual CO emissions

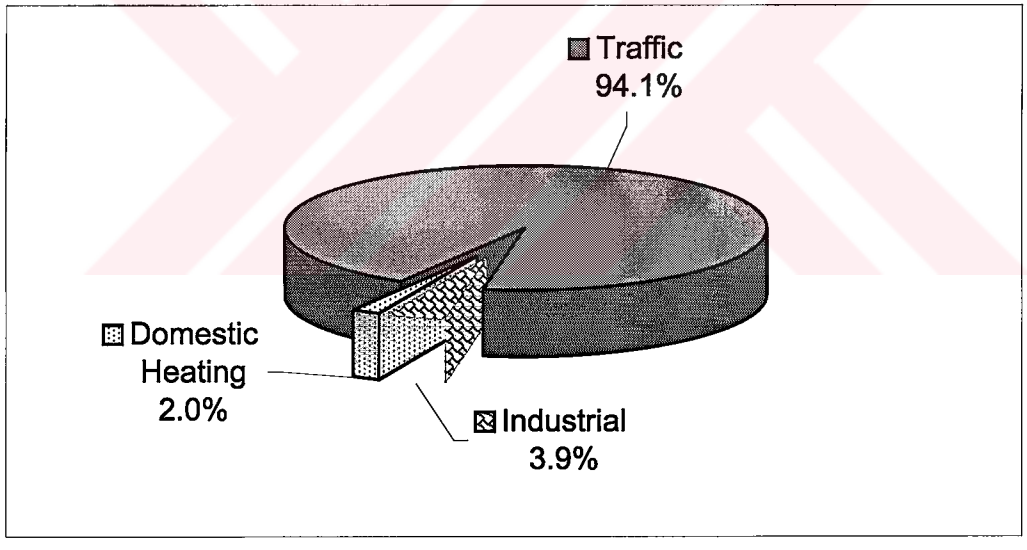

Figure 6.18 Contribution of various sources to the annual VOC emissions

All these figures show that industrial sector is the largest contributor in the pollution load in the study area, and this sector is responsible for 97% of the total SO_2 emission, 96% of the total PM emission, 73% of the total CO emission and 68% of the total NO_X emission. As far as VOC emissions are

concerned the share of traffic sources is 94% followed by 4% and 2% from industrial and domestic heating sources, respectively.

Therefore, if some clean air plans were to be made in this area, the major target to reduce pollution is the industrial sources.

CHAPTER 7

RESULTS OF MODELING FOR POLLUTION DISPERSION

The area of interest in this study is the Iskenderun Region covering an area with a width of 25 km and length of 50 km. This area contains emission sources as point, area and line sources. Industrial sources were modeled as point sources, which included stacks of ISDEMIR and other industries located in the organized industrial estates of Iskenderun, Dortyol and Payas. Area sources contained the dwellings in the city of Iskenderun, in the towns of Dortyol and Payas, and in other rural residential areas. Emissions from urban traffic in the city of Iskenderun and in the tows of Dortyol and Payas, as well as the traffic on Iskenderun – Adana highway and motorway were considered as line sources. There are 83 point, 82 area, and 79 line sources in the study area. The Amanos Mountain Range is located on the eastern side of the study area that has peaks as high as 1700 meters above sea level. Because of the Amanos mountain range the study area becomes a narrow coastal zone between Mediterranean Sea and mountains, which widens towards north. A topographical map of the study area is given in Figure 7.1. Locations of several sources in the study area are shown in Figure 7.2.

The modeling of air pollution in the study area is done by using ISCST3 model that has been developed by the U.S. EPA. This is the third version of the model. This model is widely used and accepted all over the world by researchers and regulatory agencies. The ISCST3 model requires two basic inputs, the meteorological data and the emission data. Meteorological data input files have

been prepared for the study area for the year 2001. Details about the meteorology of the study area are given in Chapter 5. Meteorological data file for annual and seasonal model runs were prepared for:

- Annual
- Winter
- Spring
- Summer, and
- Autumn

As needed by ISCST3 model these files contain sequential hourly meteorological parameters for the year 2001.

Air pollution emission inventory of the study area was prepared and given in Chapter 6. This inventory was used as emission data inputs to the ISCST3 model. A grid system of 1 km x 1 km was developed over the study area which had dimensions of 25 km x 50 km; hence 1326 receptor points were created. As model outputs average ground level concentrations of PM, SO_2, NO_X and CO were obtained on annual as well as seasonal basis. Maps showing the concentration contours were prepared for each pollutant. Topographical map of the study area was obtained that served the following purposes:

- Terrain data input to the ISCST3 model
- Location of exact positions of point, area and line sources present in the study area

Dry and wet depositions of PM on annual and seasonal basis were also estimated. For wet deposition estimates rainfall data was used. This data was obtained from the State Department of Meteorology and incorporated in the meteorological input data file. For estimations of dry and wet deposition particle data including size distribution, density and scavenging coefficients were required. Since particle size distribution could not be measured at emission sources, particle size distributions given in relevant chapters of the U.S. EPA's Guidebook on Emission Factors (U.S. EPA, 1995c) had to be used. Fractions of particles up to 15 μm were given in the U.S. EPA's guidebook.

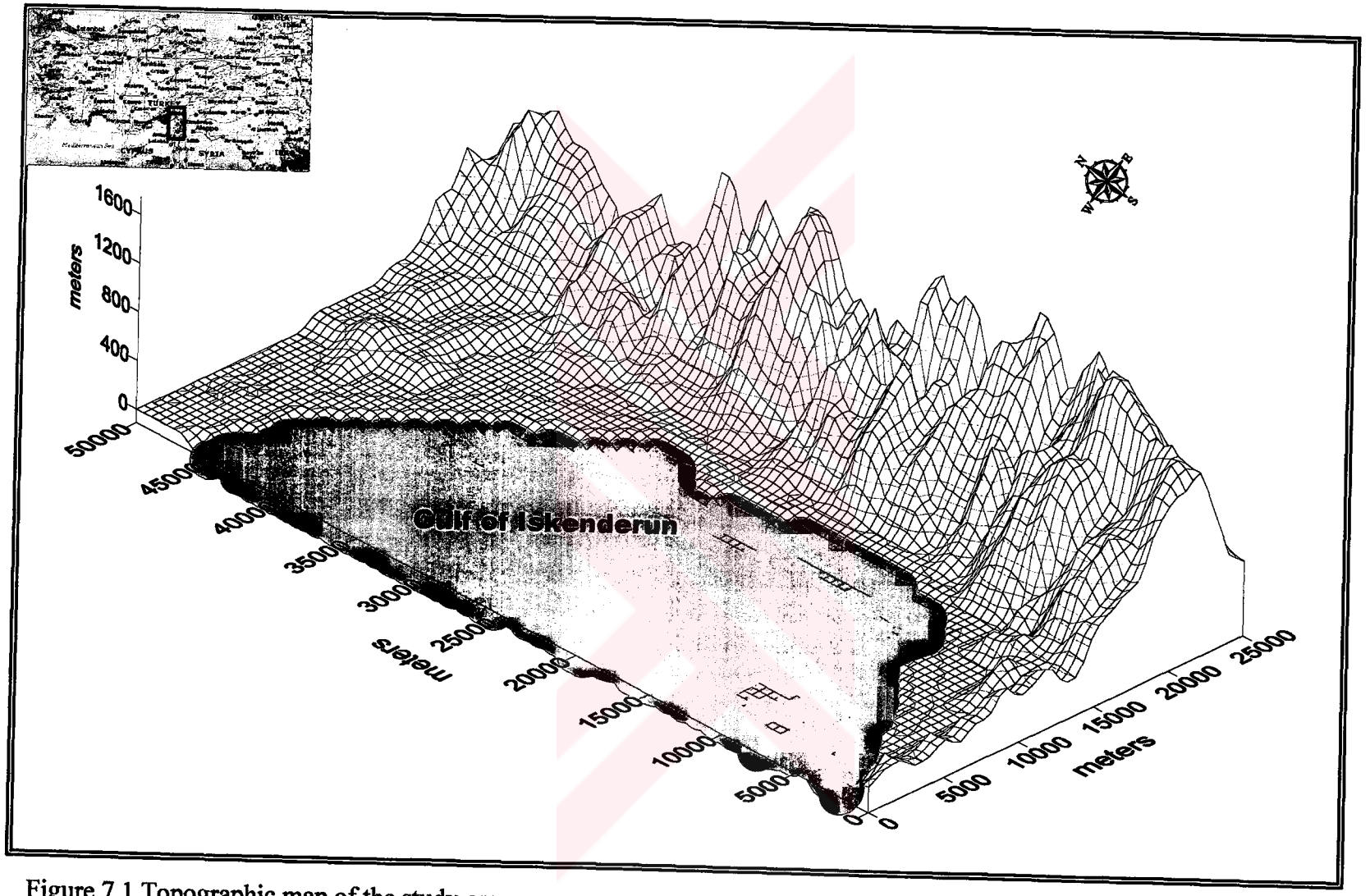

Figure 7.1 Topographic map of the study area

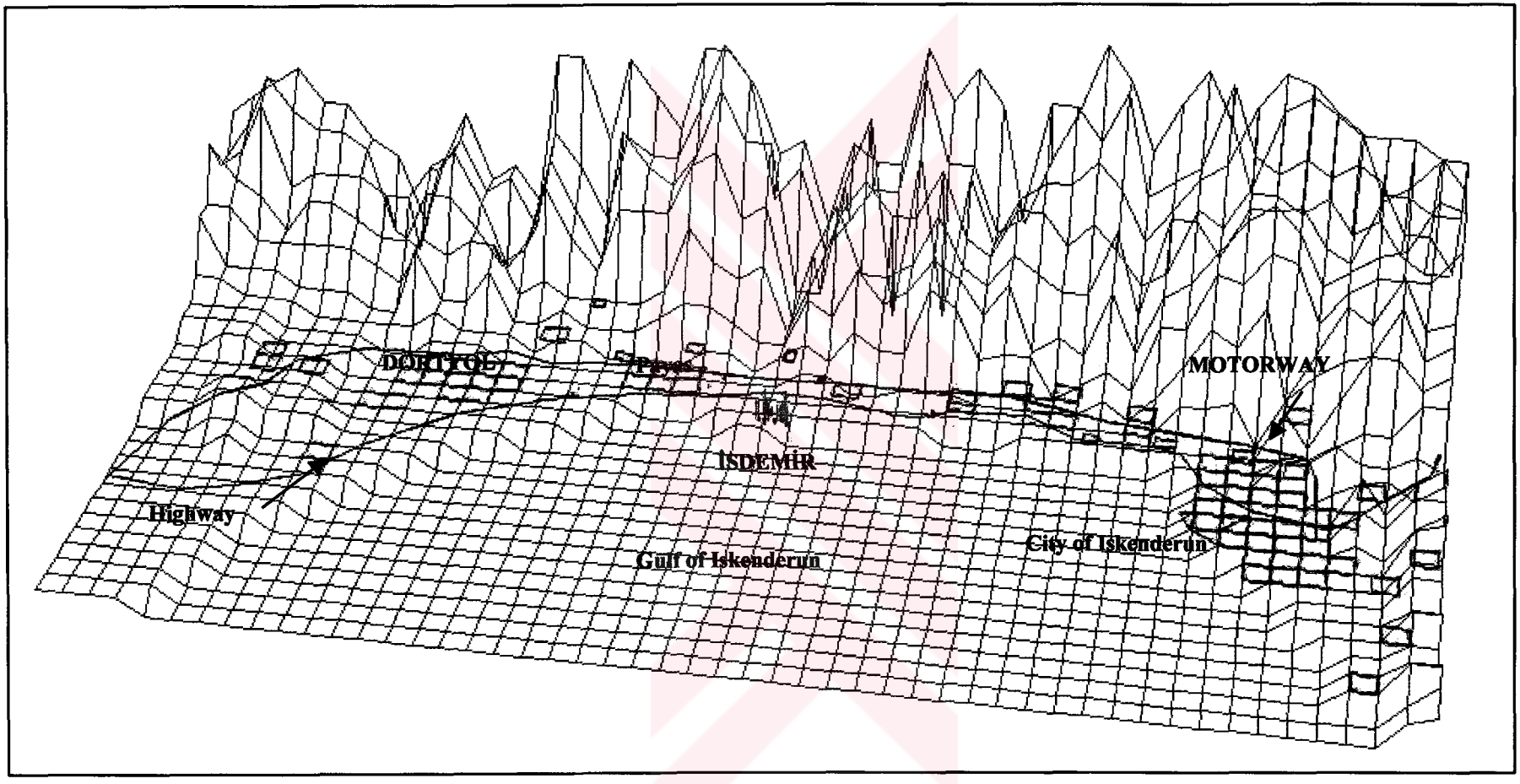

Figure 7.2 Locations of all emission sources modeled in the study area

Therefore, Particle sizes of 2.5, 5, 10, 15 and 20 μm were considered in this study. As given in the U.S. EPA's Guidebook almost 85% of particles emitted from different processes in steel production are smaller or equal to 15 μm, the remaining 15% of particles were assumed to be between 15-20 μm of diameter. This assumption had to be made, because ISCST3 model requires that the fractions of particle size distribution should always add up to 1. Moreover, particles greater than 20 μm have appreciable settling velocities, while particles less than 20 μm diameters disperse as gases (Stern, 1994).

Particles size distribution and their mass fractions for PM emissions from traffic were also taken into account and are given in Table 7.1.

Table 7.1 Particle size distribution in exhaust gases of diesel vehicles (U.S. EPA, 2002)

Particle Size (μm)	Mass fraction less than particle cutoff size
1.0	0.86
2.0	0.90
2.5	0.92
10.0	1.00

Particle density of 1 g/cm^3 was used in the calculations (U.S. EPA, 1995c). Liquid and frozen scavenging coefficients (due to rainfall and snowfall) for PM were taken from the User's Guide for ISC3 Dispersion Models, Volume II (U.S. EPA, 1995b), and are given in Table 7.2

Table 7.2 Scavenging coefficients for particulate matter (US EPA, 1995)

Particle Size (μm)	Liquid Scavenging Coefficient (h/mm-s)	Frozen Scavenging Coefficient (h/mm-s)
1.0	0.4E-04	1.33E-05
2.0	1.4E-04	4.67E-05
2.5	1.75E-04	5.83E-05
5	3.4E-04	1.13E-04
10	6.6E-04	2.2E-04
15	6.6E-04	2.2E-04
20	6.6E-04	2.2E-04

Since the annual rainfall recorded at the Iskenderun meteorological station is usually more than 750 mm (it was 771 mm in year 2001), the wet deposition of SO_2 was also estimated on annual and seasonal basis. Liquid scavenging coefficient for SO_2 was taken as 1.5E-05 h/mm-s (Stern, 1994). Dry deposition of SO_2 was not included in calculations as the wet deposition of SO_2 is always more effective as compared to dry deposition because of high solubility of SO_2 in water.

All the concentrations and depositions of pollutants given in the following sections are "ground level concentrations" and depositions since these concentrations are of utmost interest for the people living in Iskenderun area.

7.1 Modeling Results for PM

The results of dispersion modeling calculations for PM from all sources on annual, seasonal and daily basis are given in Figure 7.3 to 7.26.

7.1.1 Annual Dispersion of PM

The annual average ground level concentrations of PM estimated from all sources including industrial, residential heating and traffic sources are shown in Figure 7.3. As can be seen from the figure, the annual average PM concentration in most of the region is below 127 $\mu g/m^3$. The long-term limit given in the Turkish Air Quality Protection Regulation (TAQPR) is 150 $\mu g/m^3$. In most of the Iskenderun urban area the annual average concentrations of PM are between 10 and 40 $\mu g/m^3$. However, in the south and southeastern parts of Iskenderun City, in towns of Dortyol and Payas the PM concentration is between 40 to 70 $\mu g/m^3$. This concentration is below the limit defined in the TAQPR as well as EC Regulations limit of 80 $\mu g/m^3$. The proposed revision of TAQPR suggests reducing the long-term limit for PM to 100 $\mu g/m^3$. Even in this case the limits are not exceeded in urban areas. Almost all of the rural areas have average annual PM concentration between 10 and 40 $\mu g/m^3$. Further

investigations by running the model with discrete receptors revealed that the contributions of domestic heating sources in the annual average PM concentrations at city centers of Iskenderun, Dortyol and Payas are 84%, 78% and 59%, respectively. However, contribution of ISDEMIR in the annual average PM concentrations is only 2.8% in Iskenderun, but 37% in Payas and 19% in Dortyol. On the other hand the contribution of other industries in the annual average PM concentrations is minimal with 1% in Dortyol and Payas while 0.1% in Iskenderun. Figure 7.3A shows the contribution of several sources in the annual average ground level PM concentrations at the city centers of Iskenderun, Dortyol and Payas.

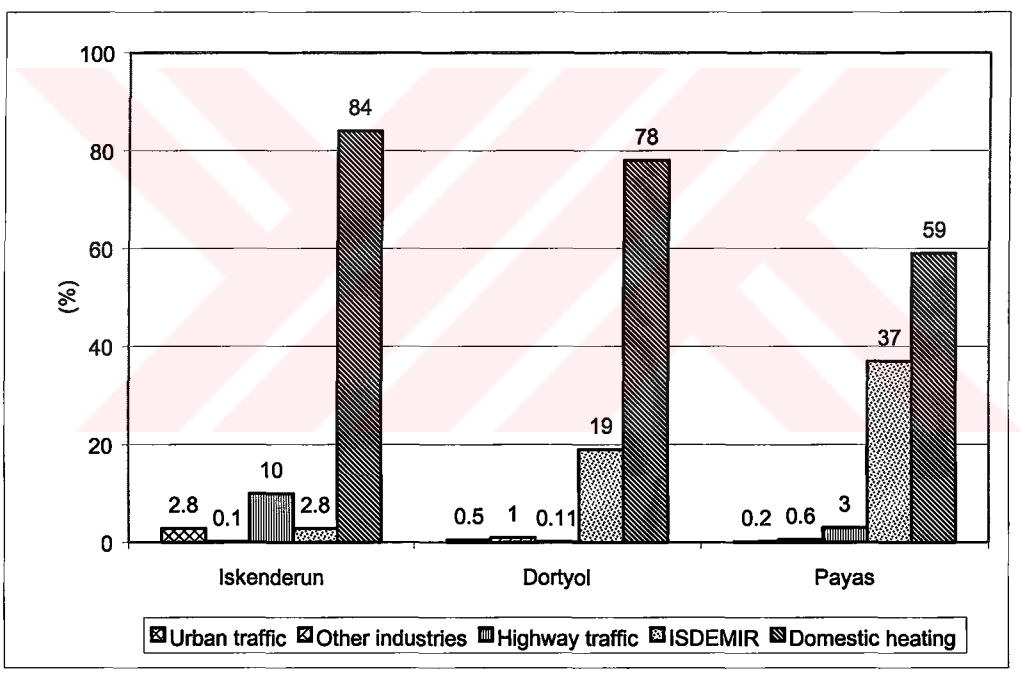

Figure 7.3A Contributions of several sources in the annual average PM concentrations in Iskenderun, Dortyol and Payas.

In the areas adjacent to ISDEMIR especially to the ESE of ISDEMIR the PM concentration rises to 127 $\mu g/m^3$ in a very small area of about 1.5 km^2. The areas surrounding this small section have concentration levels of 70-100 $\mu g/m^3$ the next concentration level outside this area is 40-70 $\mu g/m^3$. However, these high concentration areas are located at altitudes of 300-600 m and even 900 m above sea level in the mountains lying parallel to the coastline. Moreover, there

are no population centers located in this high concentration area. ISDEMIR accounts for 87% of the annual average PM concentrations in this zone of high concentration. This result can be attributed to the presence of tall stacks of ISDEMIR and dispersion of PM to long distances.

Figure 7.4 and 7.5 shows annual average PM concentration contours due to ISDEMIR and residential heating sources, respectively. Figure 7.4 shows that the contribution of ISDEMIR in the overall average PM concentration is the maximum near the area in the east of ISDEMIR. Figure 7.4 shows that the maximum concentration areas are located near ISDEMIR similar to Figure 7.3. The concentration ranges in the polluted areas are almost the same. Moreover, ISDEMIR has a little effect on PM concentrations in the towns of Dortyol and Payas, and the city of Iskenderun is the least affected from PM emissions of ISDEMIR as seen in Figure 7.4 and 7.27. Since the annual prevailing wind directions range from W to NW and S, the maximum concentration area development to the ESE of ISDEMIR is not surprising.

Figure 7.5 shows the annual average PM concentrations due to residential heating sources. As can be seen from the figure the highest concentrations are seen in the city of Iskenderun. The concentration ranges are from 10 to 50 $\mu g/m^3$, which are below the EC Regulation limit of 80 $\mu g/m^3$. Of course, the PM concentrations around these cities are basically due to domestic heating activities in the winter season. Basic fuel used in the study area for heating is coal and fuel oil.

Figure 7.6 and 7.7 show the annual average PM concentrations due to urban and highway traffic, respectively. The maximum concentration of PM due to highway traffic at some pockets along the highway reaches up to 12 $\mu g/m^3$. Other than these pocket areas the PM concentration along highways are quite low. The PM concentration due to urban traffic is very small with a maximum value of 4 $\mu g/m^3$.

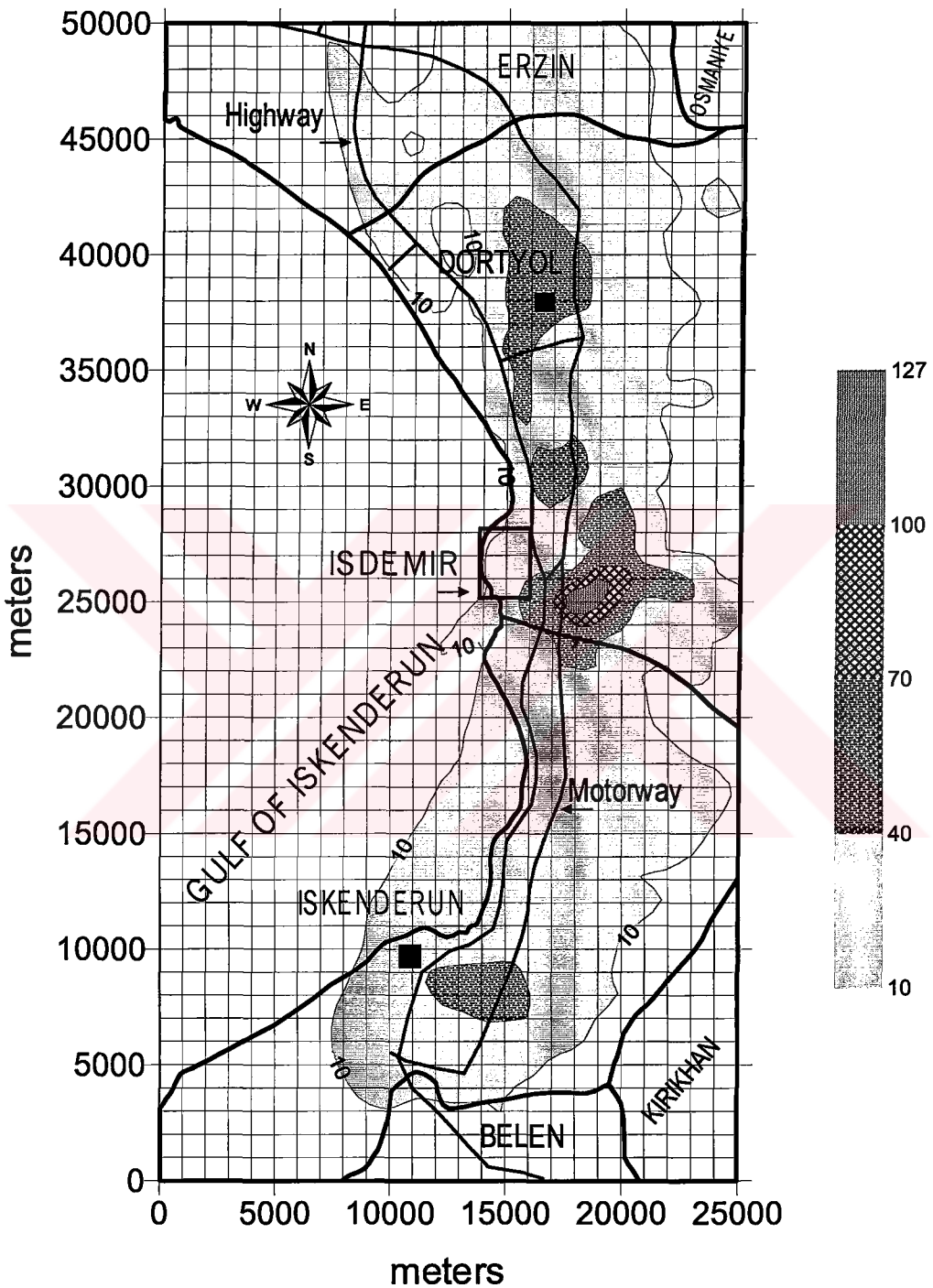

Figure 7.3 Annual average ground level concentrations ($\mu g/m^3$) of PM due to all sources

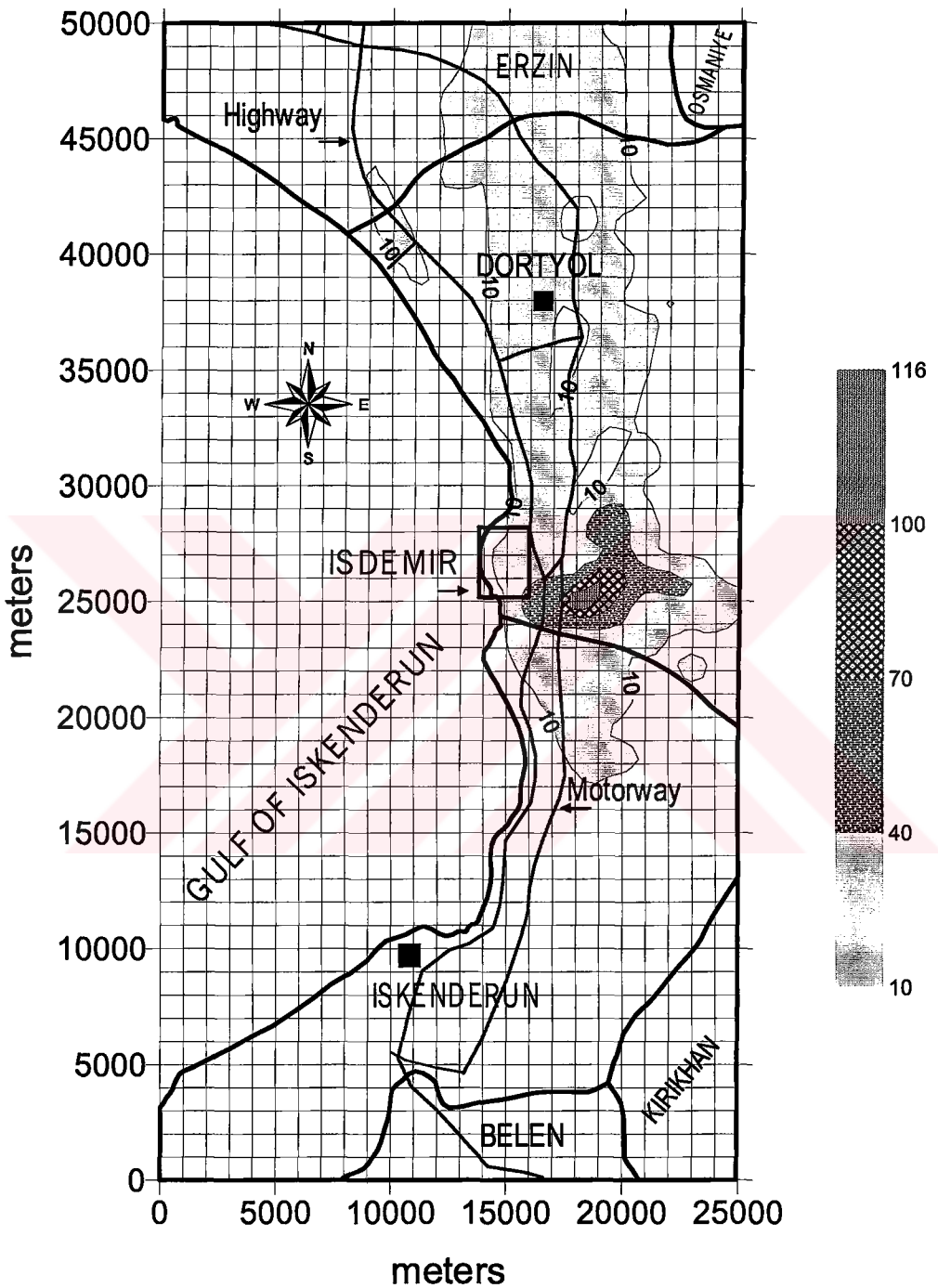

Figure7.4 Annual average ground level concentrations ($\mu g/m^3$) of PM due to ISDEMIR only

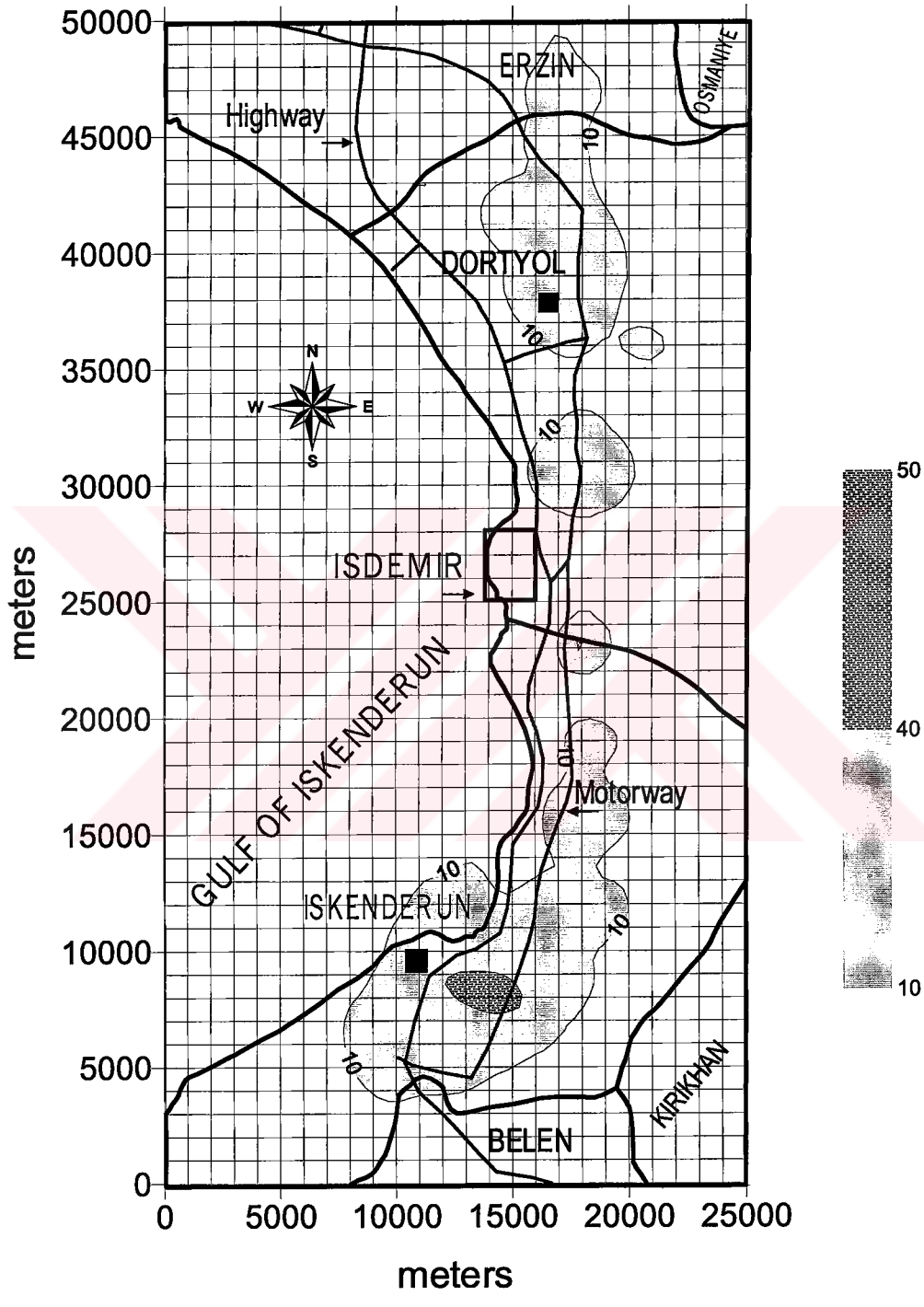

Figure 7.5 Annual average ground level concentrations ($\mu g/m^3$) of PM due to residential heating sources

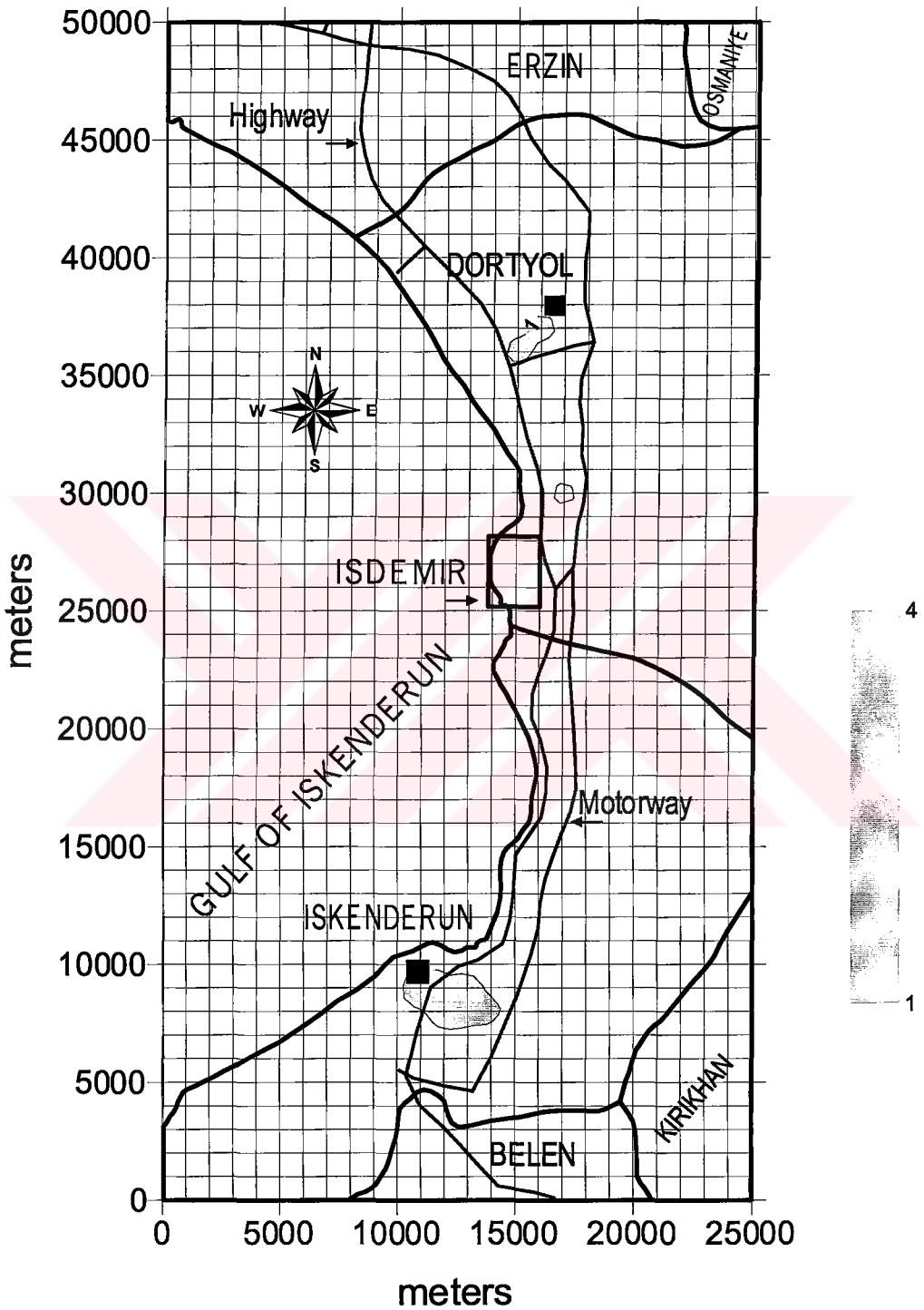

Figure 7.6 Annual average ground level concentrations ($\mu g/m^3$) of PM due to urban traffic sources.

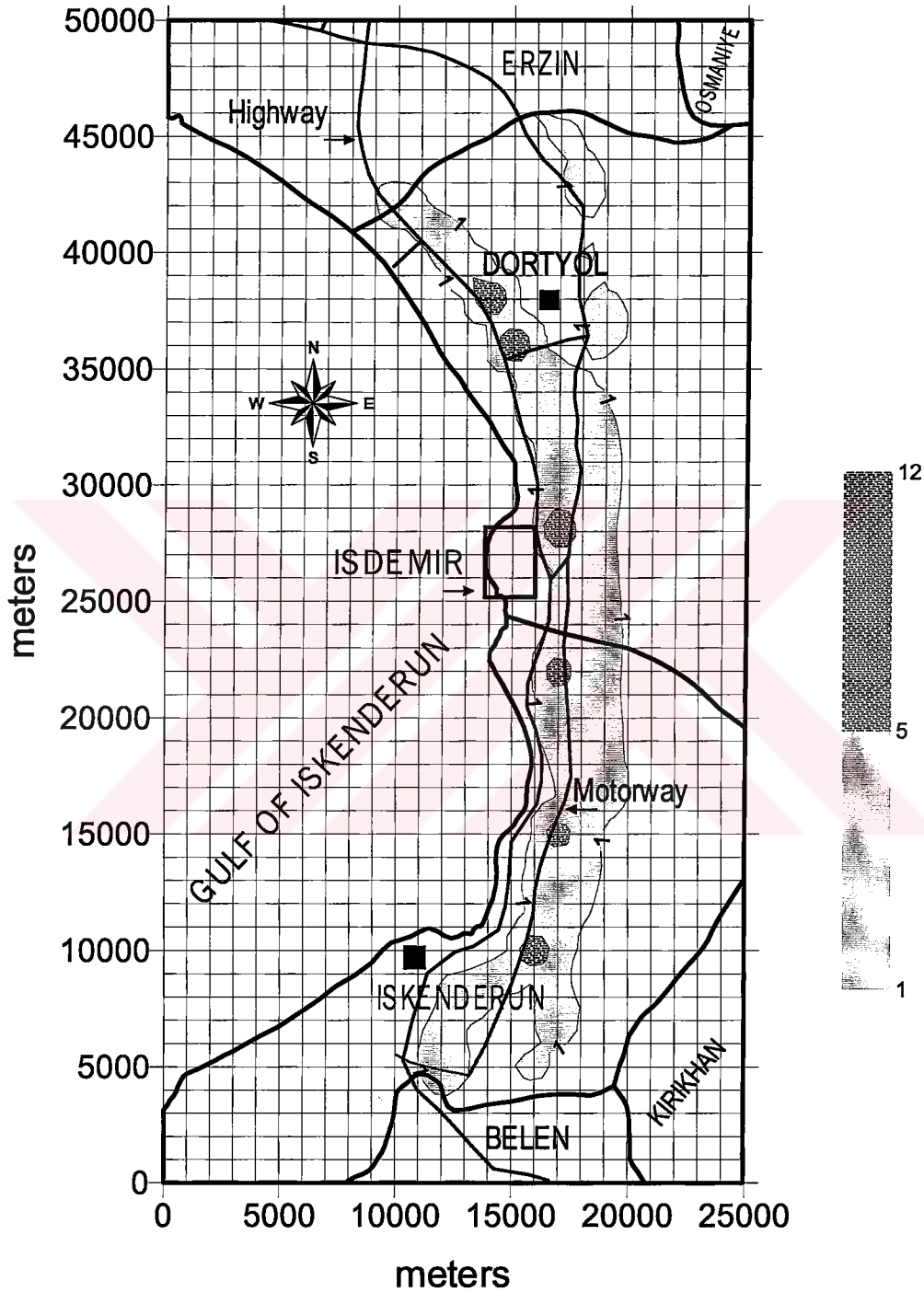

Figure 7.7 Annual average ground level concentrations ($\mu g/m^3$) of PM due to highway traffic sources.

7.1.2 Seasonal Dispersion of PM

Dispersion of PM is also modeled on seasonal basis and resulting concentration maps at ground level are presented in this section because wind directions change considerably from season to season. Figure 7.8 shows the winter average ground level concentrations of PM from all sources. In the southeastern part of the city of Iskenderun PM concentration rises up to 155 $\mu g/m^3$, which is surrounded by areas having concentration of 100-130 $\mu g/m^3$ and 70-100 $\mu g/m^3$. During winter most parts of the Iskenderun City has PM concentrations above 70 $\mu g/m^3$. Winter average PM concentration in some parts of the towns of Dortyol and Payas also reaches up to 155 $\mu g/m^3$. The reason of this high PM concentration in winter can be attributed to the usage of coal for domestic heating whose ash content is between 9% and 31% by weight. PM concentration limit for winter season set by TAQPR is 200 $\mu g/m^3$. Figure 7.8 shows that this limit is not exceeded anywhere in the study area, resulting from PM emissions from all sources. However, this limit is quite high as compared to international standards and is under consideration for revision to 150 $\mu g/m^3$ by the Ministry of Environment. Winter average PM concentrations of 10-40 $\mu g/m^3$ are maintained over almost all of the study area during winter.

Figure 7.9 shows the PM concentration contours in winter resulting from the emissions from ISDEMIR only. Maximum concentration area shifts in winter to E to ENE of ISDEMIR from ESE of ISDEMIR, which was identified for annual average concentrations. This is mainly due to the prevailing wind directions in winter being from S and WSW. The maximum concentration area is again located in the mountains at altitudes of 200-600 m from the sea level. Two small villages (Kozludere and Yenikoy) are located in the high concentration areas. Average PM concentration in these villages is in the range of 70 to 85 $\mu g/m^3$ which is again well below the limit of 200 $\mu g/m^3$. Some parts of the town of Dortyol also show a PM concentration of 40-70 $\mu g/m^3$ due to the emissions of ISDEMIR. On the other hand it is seen from the figure that the Iskenderun City and the surroundings are not affected from ISDEMIR at all.

Figure 7.10 shows the winter average PM concentrations due to domestic heating activities. Maximum PM concentration in some parts of the city of Iskenderun reaches up to 150 $\mu g/m^3$, and in Dortyol it rises up to 130 $\mu g/m^3$, which are below the limit set by the TAQPR. However, as mentioned before these limits are under revision. As it was shown in Figure 7.8, the winter average PM concentrations due to emissions from all sources were 100-155 $\mu g/m^3$ in Iskenderun and Dortyol. It is clear from these figures that domestic heating have the dominant effect on PM concentrations in Iskenderun, and have a major effect in Dortyol during winter season.

Figures 7.11 to 7.14 show seasonal average PM concentrations from "all sources" and from ISDEMIR only for spring and summer. Since domestic heating in the study area is not done after February, "all sources" include emissions from ISDEMIR, other industries and traffic in these seasonal estimations. Figure 7.15 and 7.16 show autumn average ground level concentrations of PM from all sources and from ISDEMIR, respectively. As can be seen from all of these figures that they are more or less identical, this can be attributed to very small amount of PM emissions from other industries and traffic. Therefore, almost all of the PM concentration during spring, summer and autumn is due to ISDEMIR. The maximum PM concentration reaches up to 205 $\mu g/m^3$ in autumn, which is the highest among seasonal and annual average PM concentrations. This high concentration zone is found towards E to ESE of ISDEMIR in the mountains. In general dispersion of PM is poor in autumn as compared to other seasons. The reasons for poor dispersion would be due to:

1. Low wind speed, which was 1.5 to 3 m/s for most of the time.
2. Combined effect of prevailing wind directions from W and W to N, and high mountains in the eastern side of sources.

It is clear from concentration maps for seasonal dispersion of PM that PM concentrations during spring, summer and autumn are mainly due to PM

emissions from ISDEMIR and the contributions of other industries and traffic are negligible as compared to ISDEMIR. However, during winter the PM emissions from domestic heating dominate especially in the residential areas.

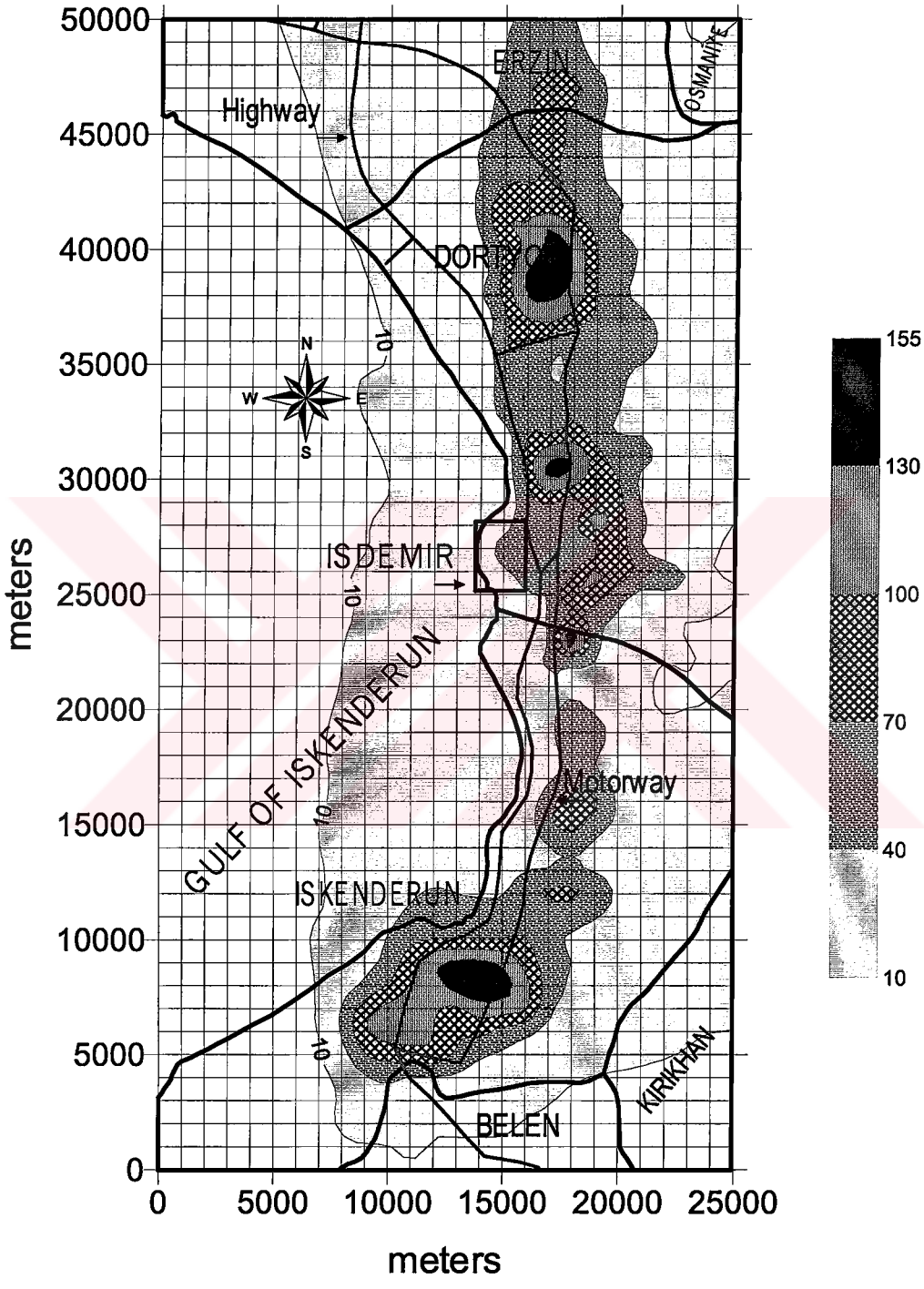

Figure 7.8 Winter average ground level concentrations ($\mu g/m^3$) of PM due to all sources

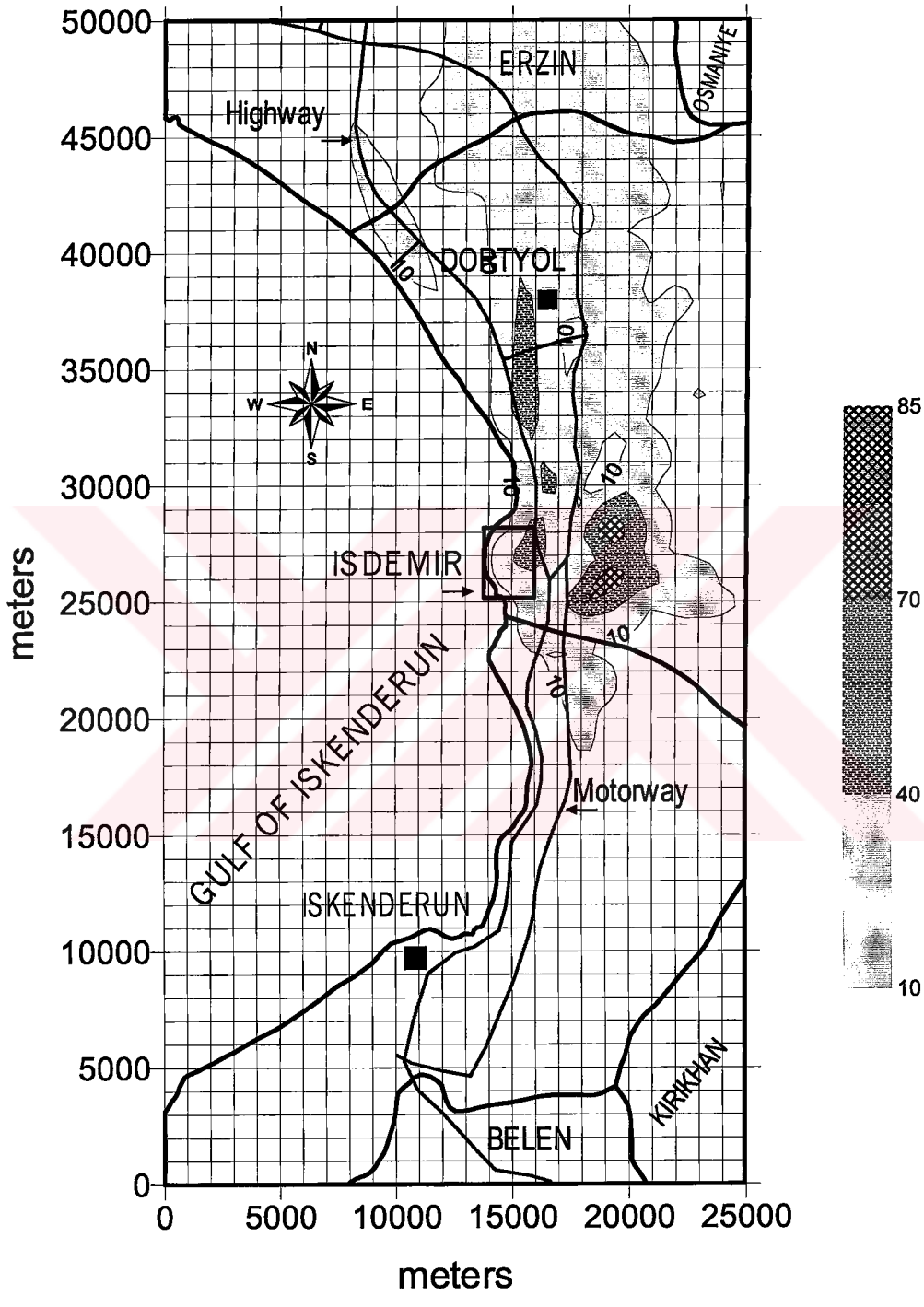

Figure 7.9 Winter average ground level concentrations ($\mu g/m^3$) of PM due to ISDEMIR

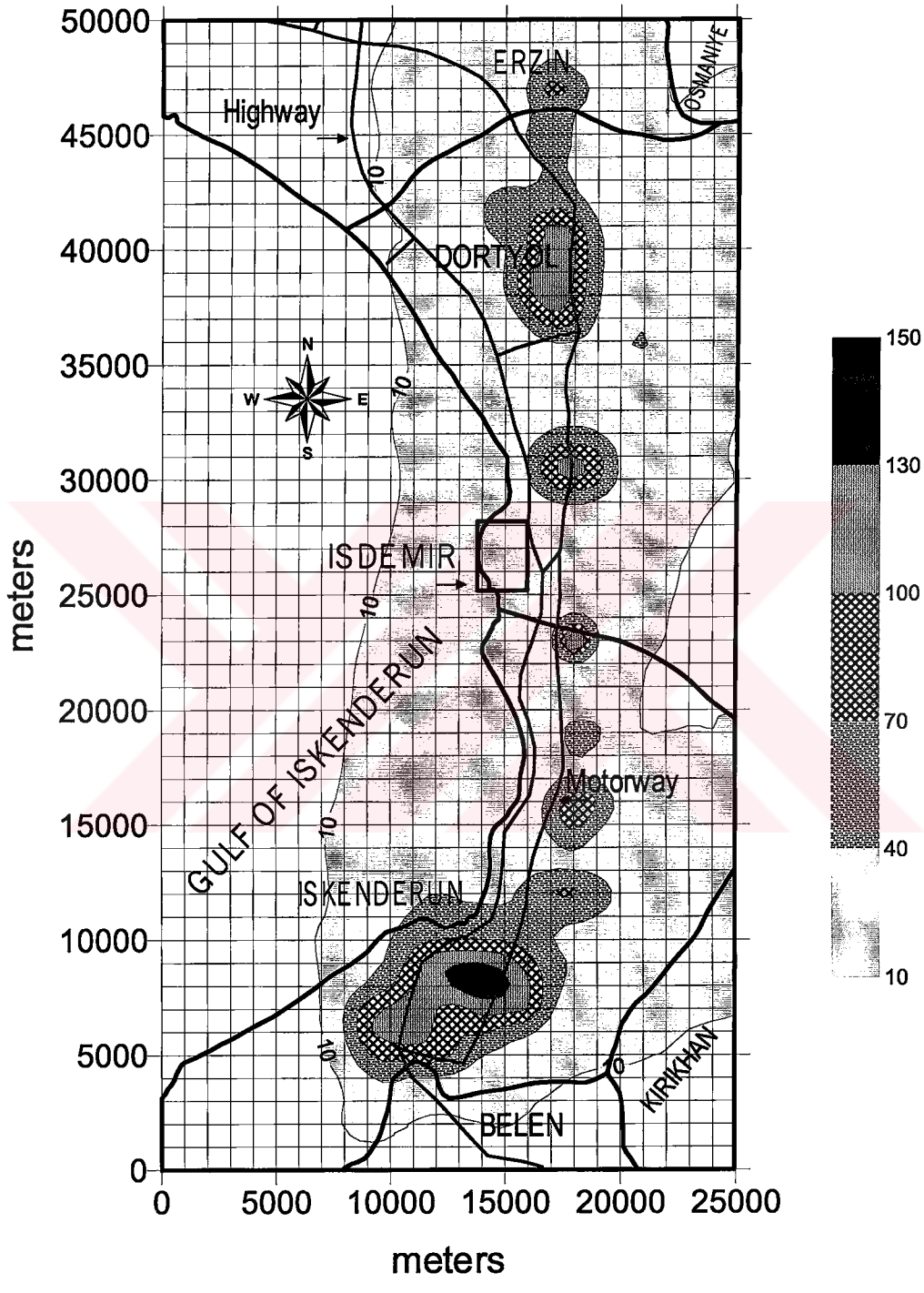

Figure 7.10 Winter average ground level concentrations ($\mu g/m^3$) of PM due to residential heating sources

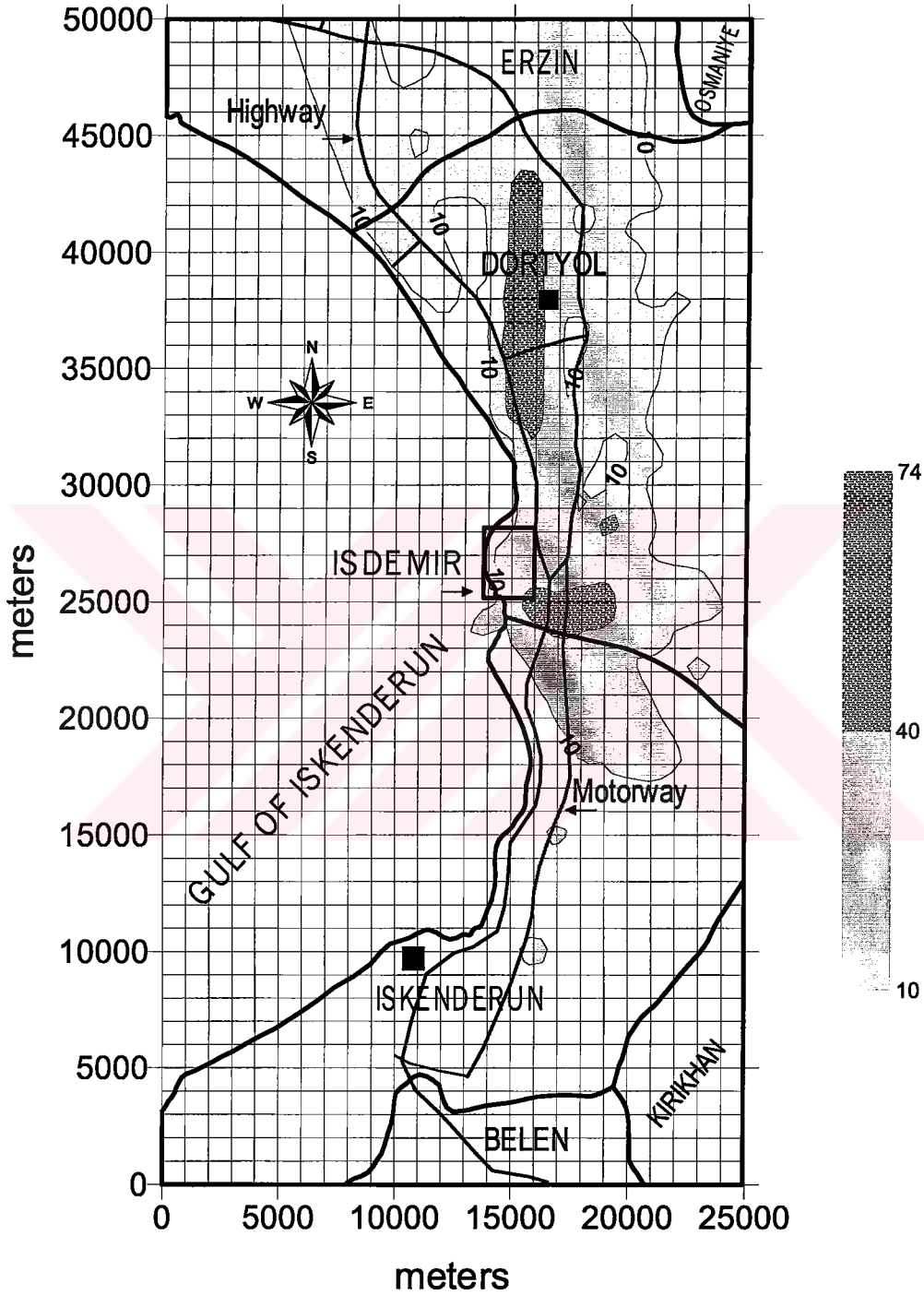

Figure 7.11 Spring average ground level concentrations ($\mu g/m^3$) of PM due to all sources

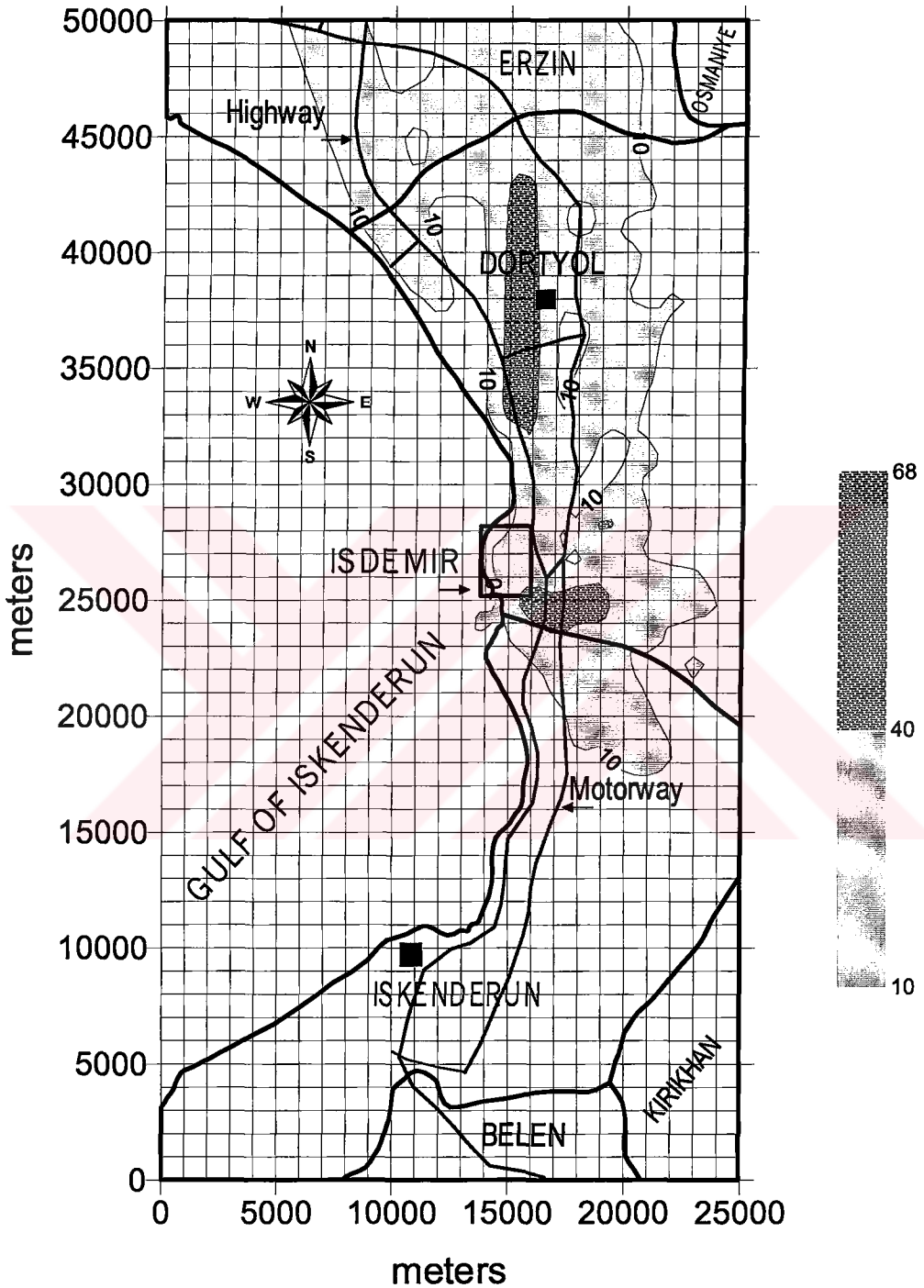

Figure 7.12 Spring average ground level concentrations ($\mu g/m^3$) of PM due to ISDEMIR

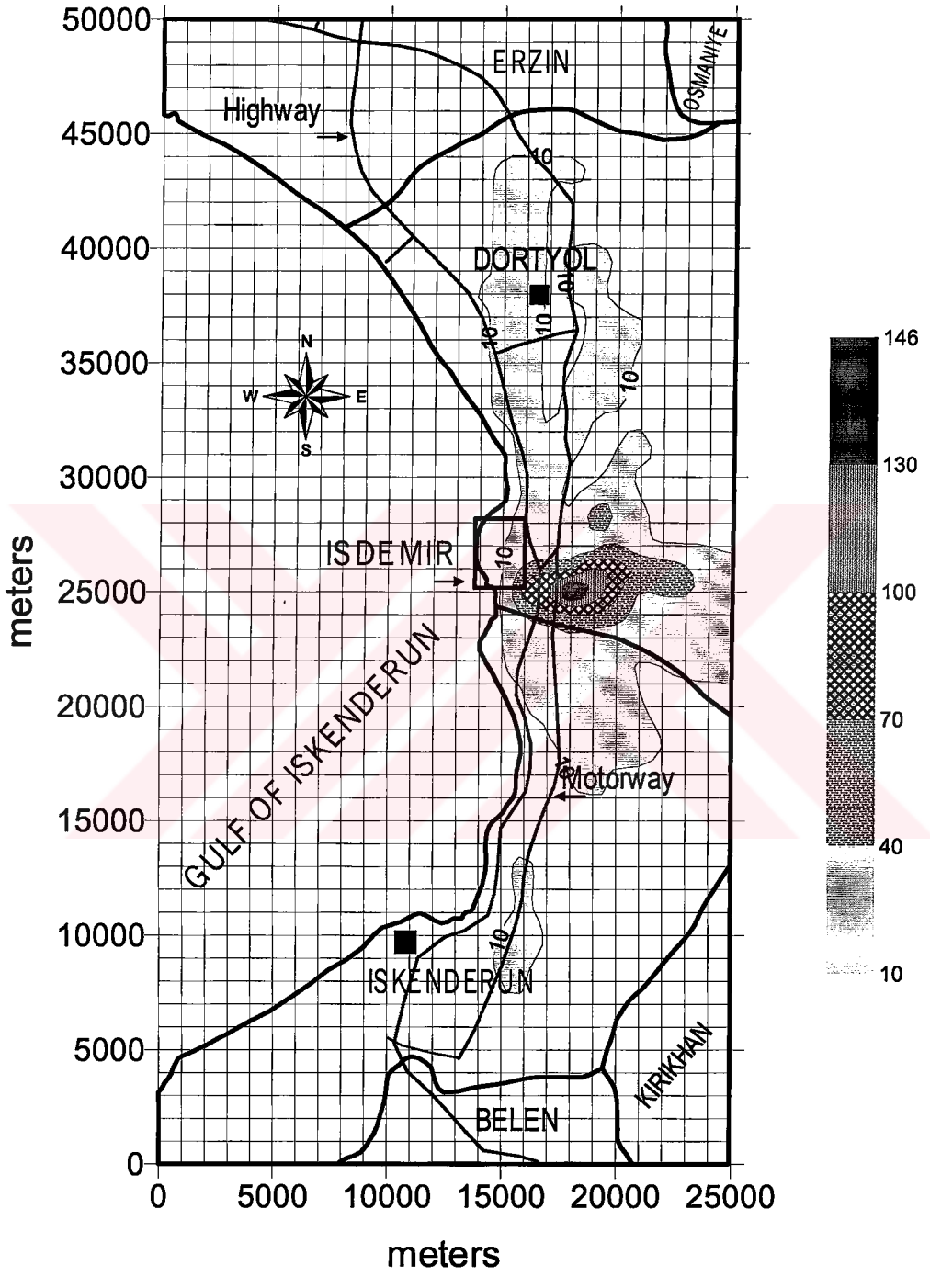

Figure 7.13 Summer average ground level concentrations ($\mu g/m^3$) of PM due to all sources

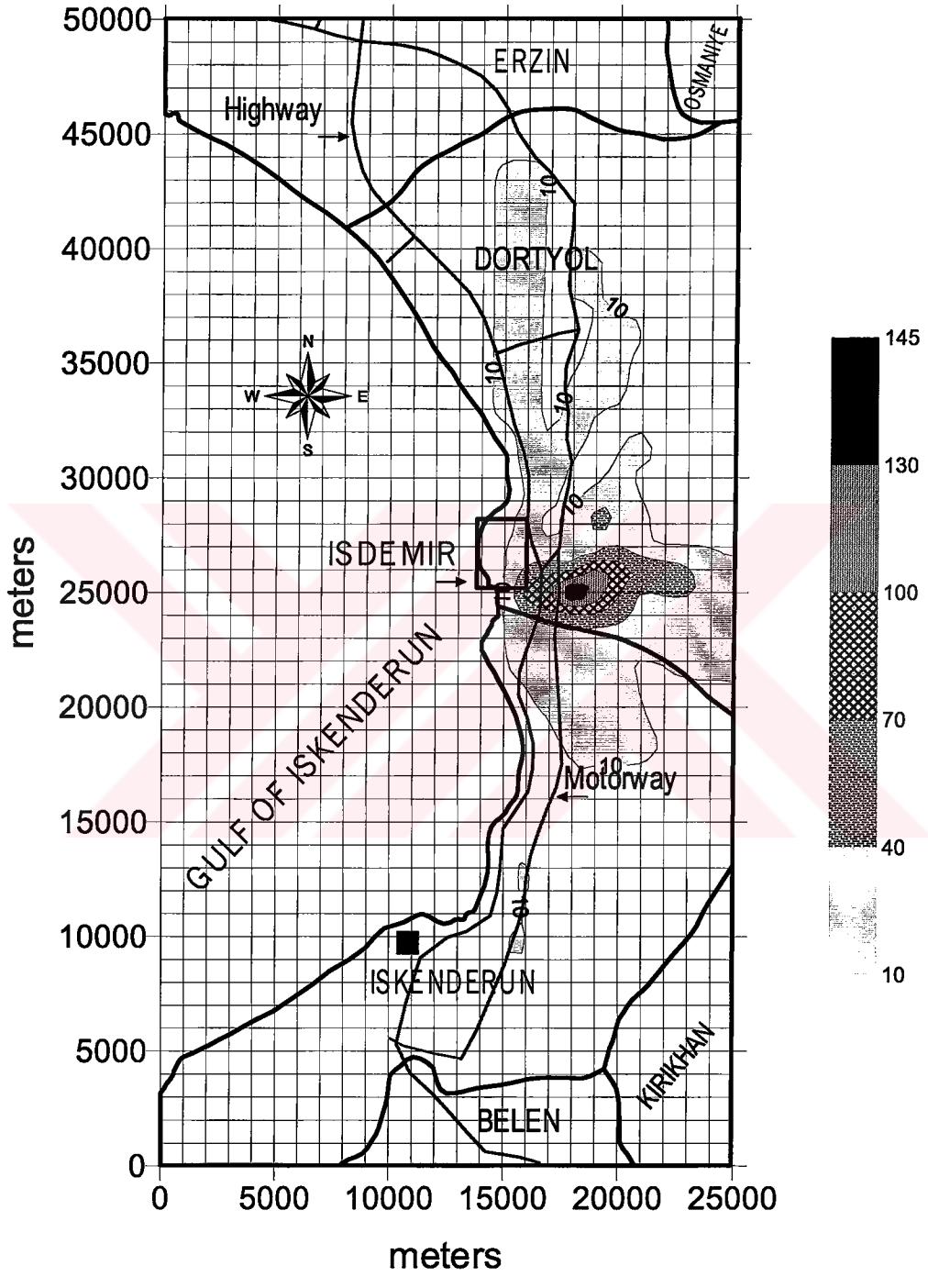

Figure 7.14 Summer average ground level concentrations ($\mu g/m^3$) of PM due to ISDEMIR

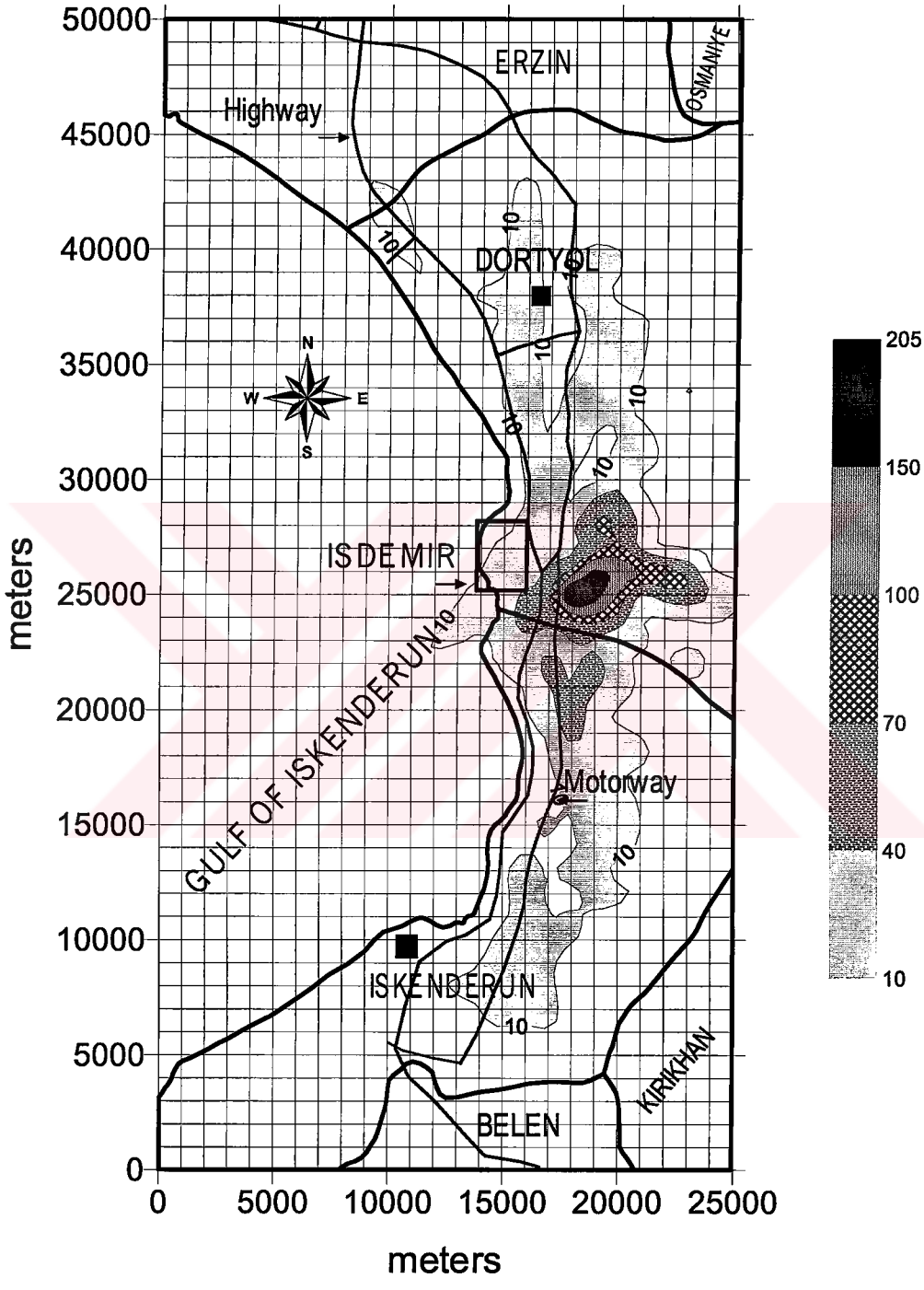

Figure 7.15 Autumn average ground level concentrations (μg/m^3) of PM due to all sources

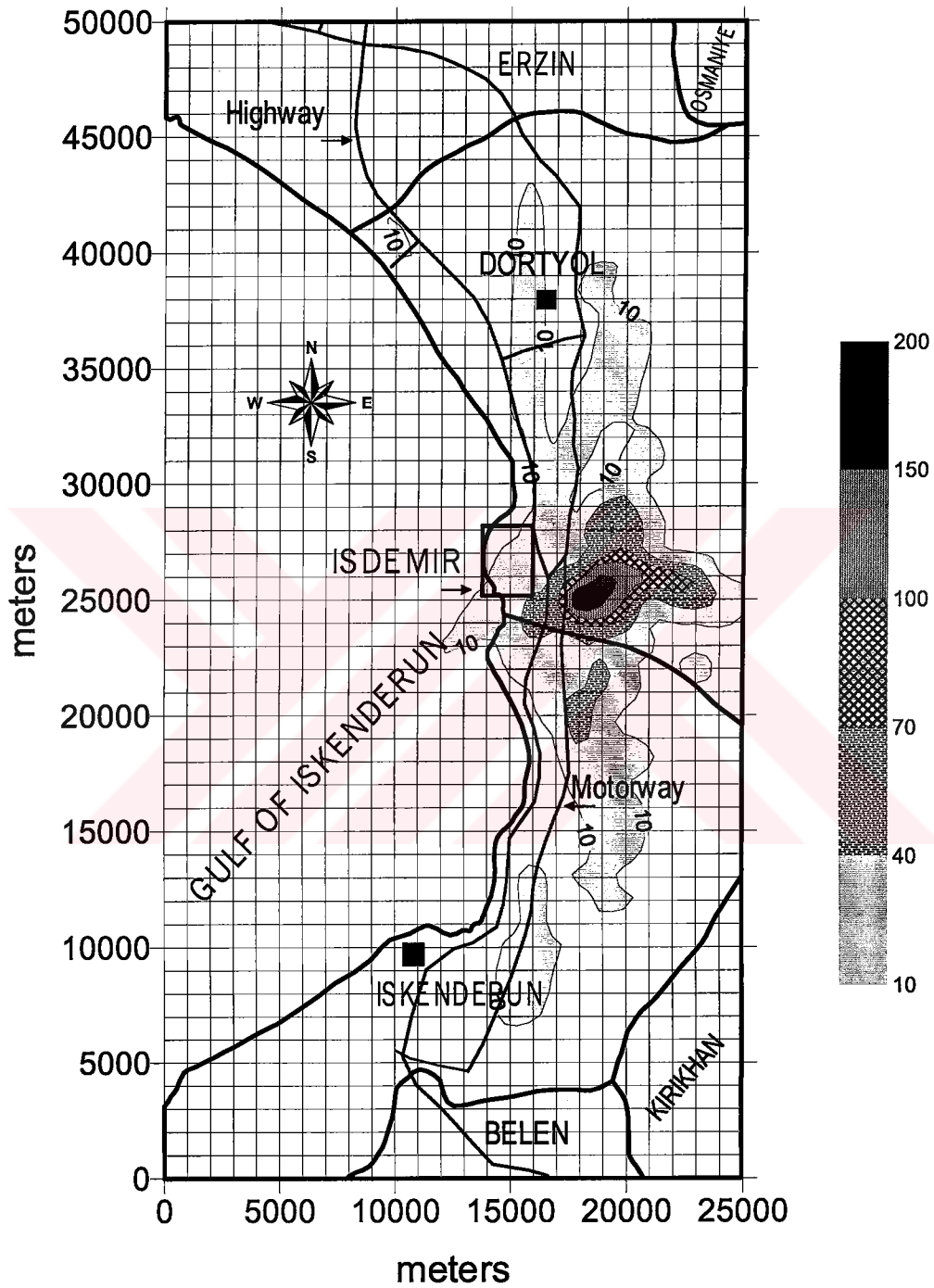

Figure 7.16 Autumn average ground level concentrations (μg/m^3) of PM due to ISDEMIR

7.1.3 Short Term Dispersion of PM

Dispersion of PM is also studied for short-term average concentrations (24 hour averages). Since exceptionally high pollutant concentrations were not observed in the region studied, the selection of specific days for "24-hour average" model runs was difficult. After analyzing the results of annual and seasonal model runs, certain days were selected for the short-term model runs. The selected days were the ones when "24 hour average" concentrations of pollutants were maximum. The days were selected from each of the four seasons by observing the changes in daily average concentrations of pollutants in different seasons. Following are the selected days for short-term model runs:

- January 18, 2001
- April 23, 2001
- July 31, 2001
- October 19, 2001
- November 28, 2001

Figure 7.17 shows the daily average concentration of PM due to all sources on January 18, 2001. The maximum PM concentration reached up to 600 $\mu g/m^3$. The zone of maximum concentration is located to the ESE of ISDEMIR. However, the zone of maximum concentration is situated at altitudes of 300-600 m above the sea level in the mountains. No population centers are located in this zone. The probable reason for that high concentration on January 18, 2001 is mainly due to the low wind speed. The prevailing wind direction on that day was from W and almost 50% of the time wind speed was less that 1.5 m/s. The maximum wind speed did not exceed 3.0 m/s. The limits for short term PM concentrations defined in the TAQPR are 300 $\mu g/m^3$ for residential areas and 400 $\mu g/m^3$ for industrial areas. As can be seen from Figure 7.17, almost all of the urban areas in the study area have PM concentrations below 300 $\mu g/m^3$. Only a very small zone in the southeast of Iskenderun City is having a PM concentration of 300 - 400 $\mu g/m^3$, which is above the existing limits in the

Turkish Regulations. In the proposed revision of the TAQPR the short-term limit for PM will be lowered to 200 $\mu g/m^3$. In that situation, the areas mentioned above will be exceeding the short-term limits. In the existing situation most of the urban areas in this study have daily average PM concentration of less than 200 $\mu g/m^3$, only in the southeaster parts of Iskenderun City the PM concentration will be above the new limit in the regulation.

Figure 7.18 shows the daily average PM concentration on November 28, 2001. As can be seen in the figure the maximum concentration reaches up to 455 $\mu g/m^3$ in the town of Dortyol. The dispersion of PM took place towards north. The reason of this northward dispersion was the prevailing wind direction being from S on that day. Moreover, almost 75% of the time wind speed was below 1.5 m/s and the maximum wind speed reached up to 3.0 m/s. In Iskenderun area and the surroundings the concentration was between 100-200 $\mu g/m^3$. However, in the city a concentration range of 200-300 $\mu g/m^3$ was seen covering an area of about 11 km^2. This can be attributed to calm weather conditions on that day.

Figure 7.19, 7.20 and 7.21 show daily average PM concentrations on selected days for spring summer and autumn seasons. As can be seen in these figures the high PM concentration areas located on the eastern side of ISDEMIR, because residential heating is not on except during winter season and the only dominant source of PM emissions was ISDEMIR. Prevailing wind directions and wind speeds again governed the PM dispersions towards E and ESE if ISDEMIR.

Results of model runs have shown that during the year 2001 there were 22 days when daily average concentration of PM exceeded the short-term limit of 300 $\mu g/m^3$ defined in the TAQPR. The location of these maximum concentrations were always near ISDEMIR in the directions from ESE to ENE of this steel mill at coordinates of X = 18,000 to 19,000 m and Y = 24,000 to 28,000 m. Moreover, there were 5 days during year 2001 when daily average PM concentrations exceeded the TAQPR's limit of 400 $\mu g/m^3$ defined as short-term

limit for industrial areas. This maximum concentration occurred at coordinates of X = 18,000 m and Y = 25,000 m.

It is seen that the daily concentrations are high even though they are for certain number of in a year.

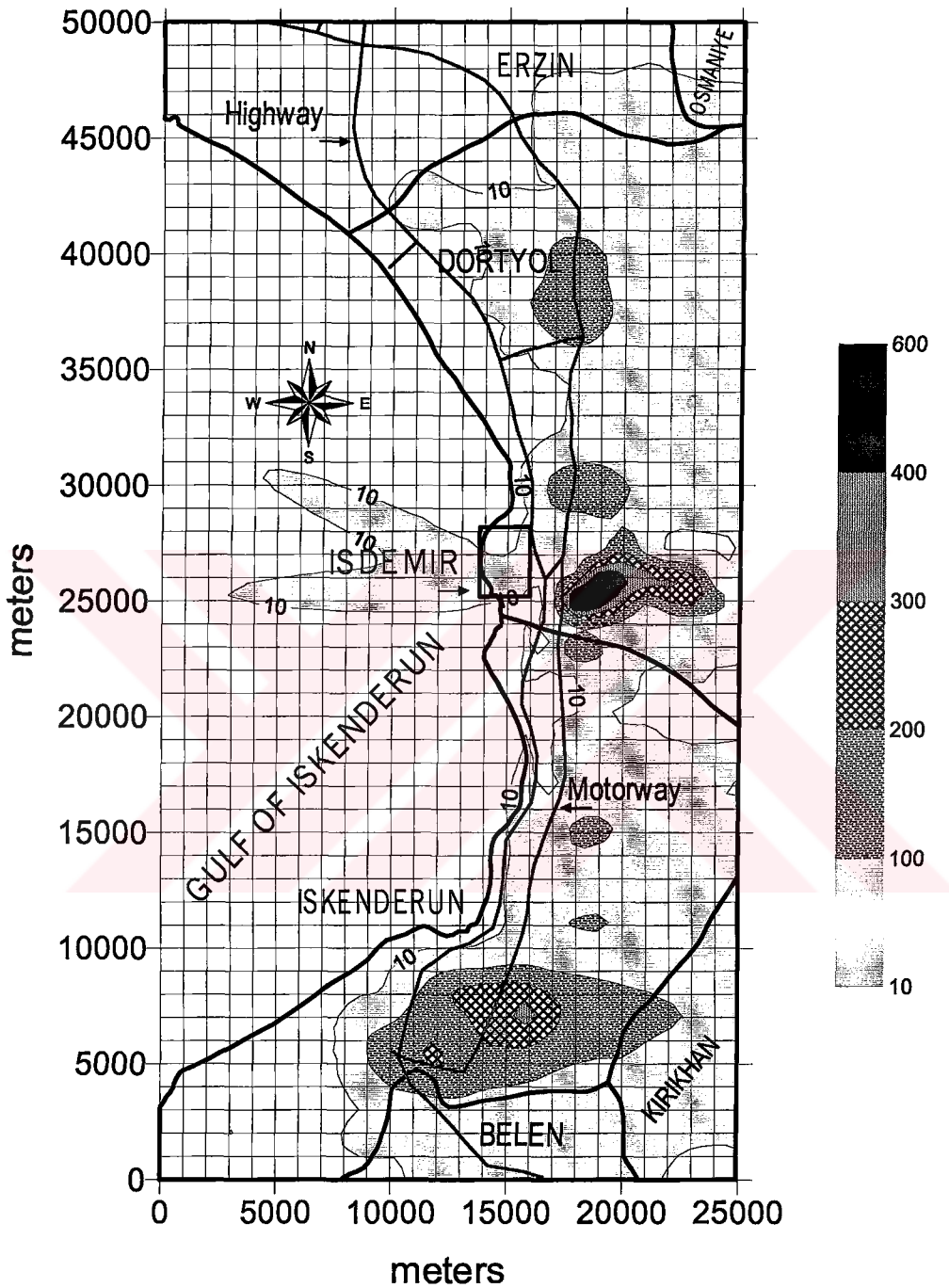

Figure 7.17 24-h average ground level concentrations ($\mu g/m^3$) of PM due to all sources on January 18, 2001

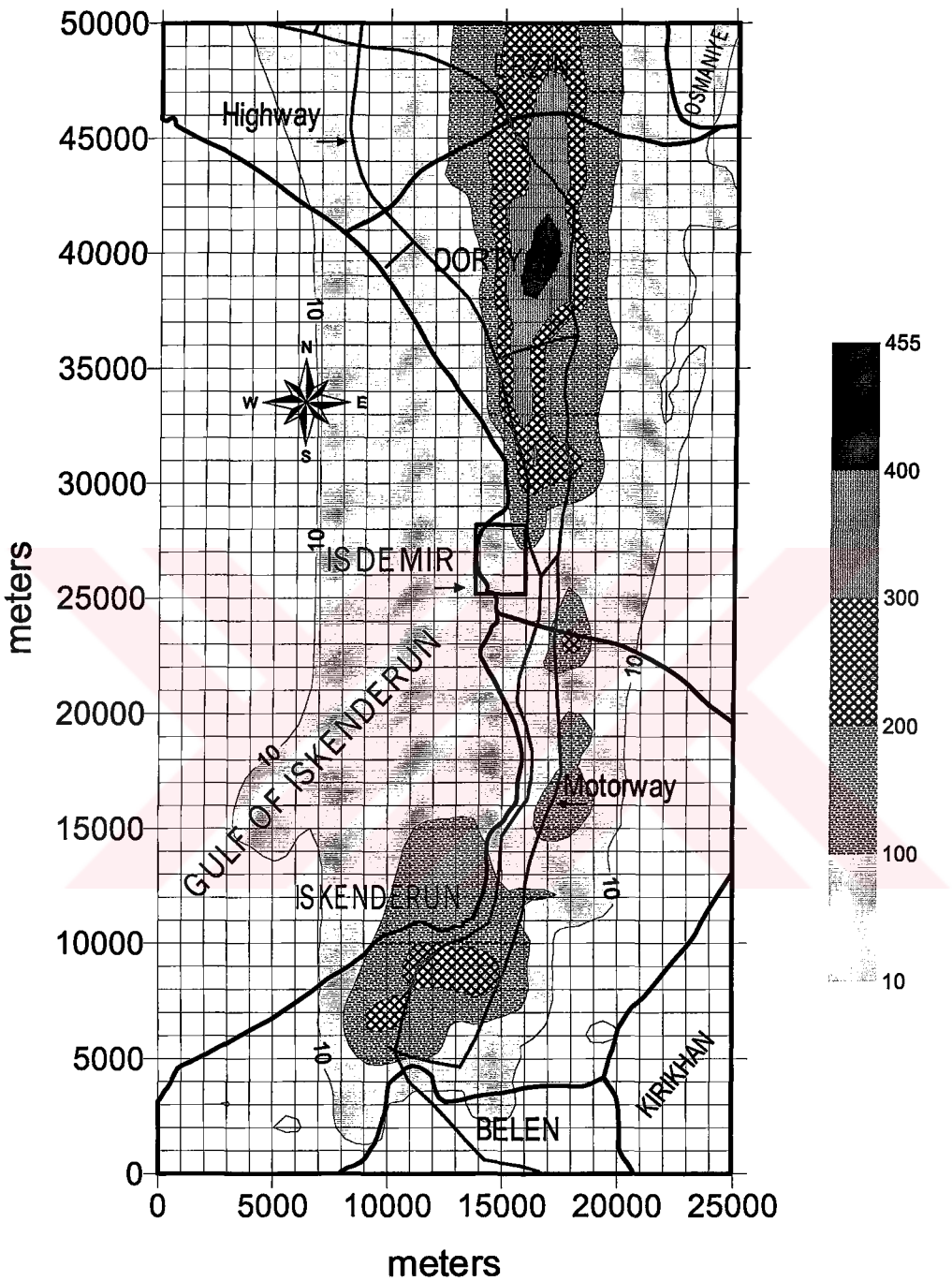

Figure 7.18 24-h average ground level concentrations ($\mu g/m^3$) of PM due to all sources on November 28, 2001

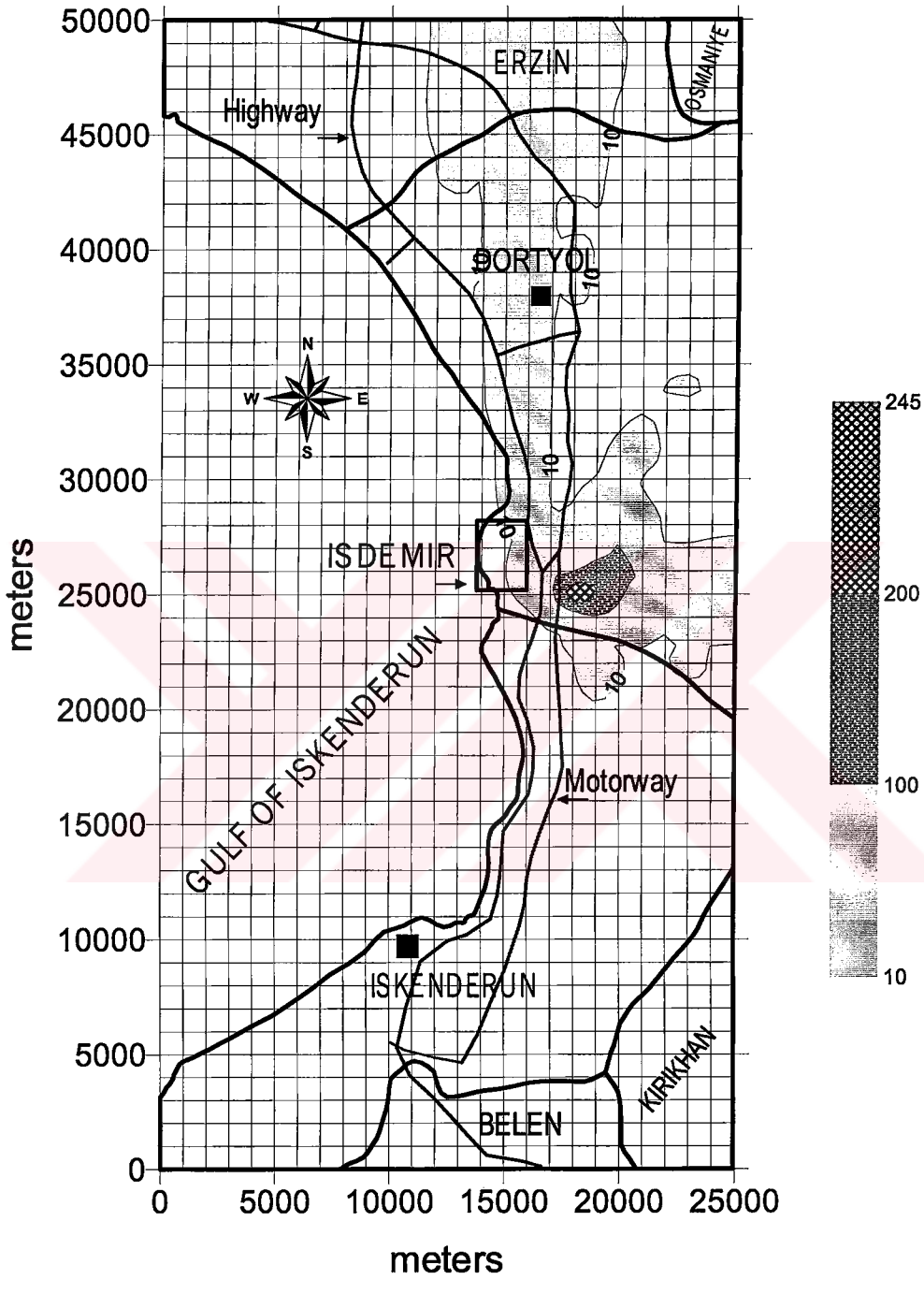

Figure 7.19 24-h average ground level concentrations ($\mu g/m^3$) of PM due to all sources on April 23, 2001

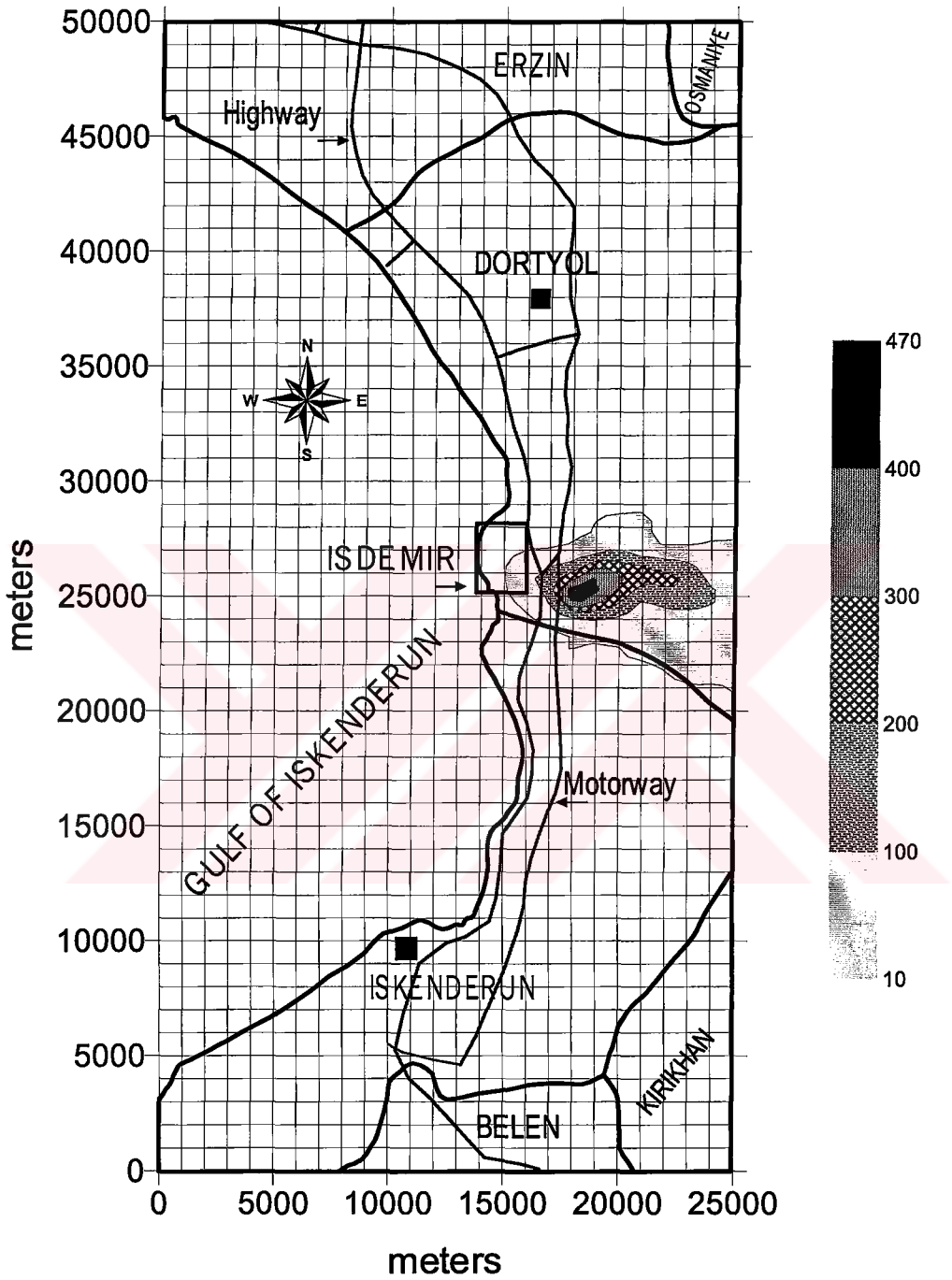

Figure 7.20 24-h average ground level concentrations ($\mu g/m^3$) of PM due to all sources on July 31, 2001

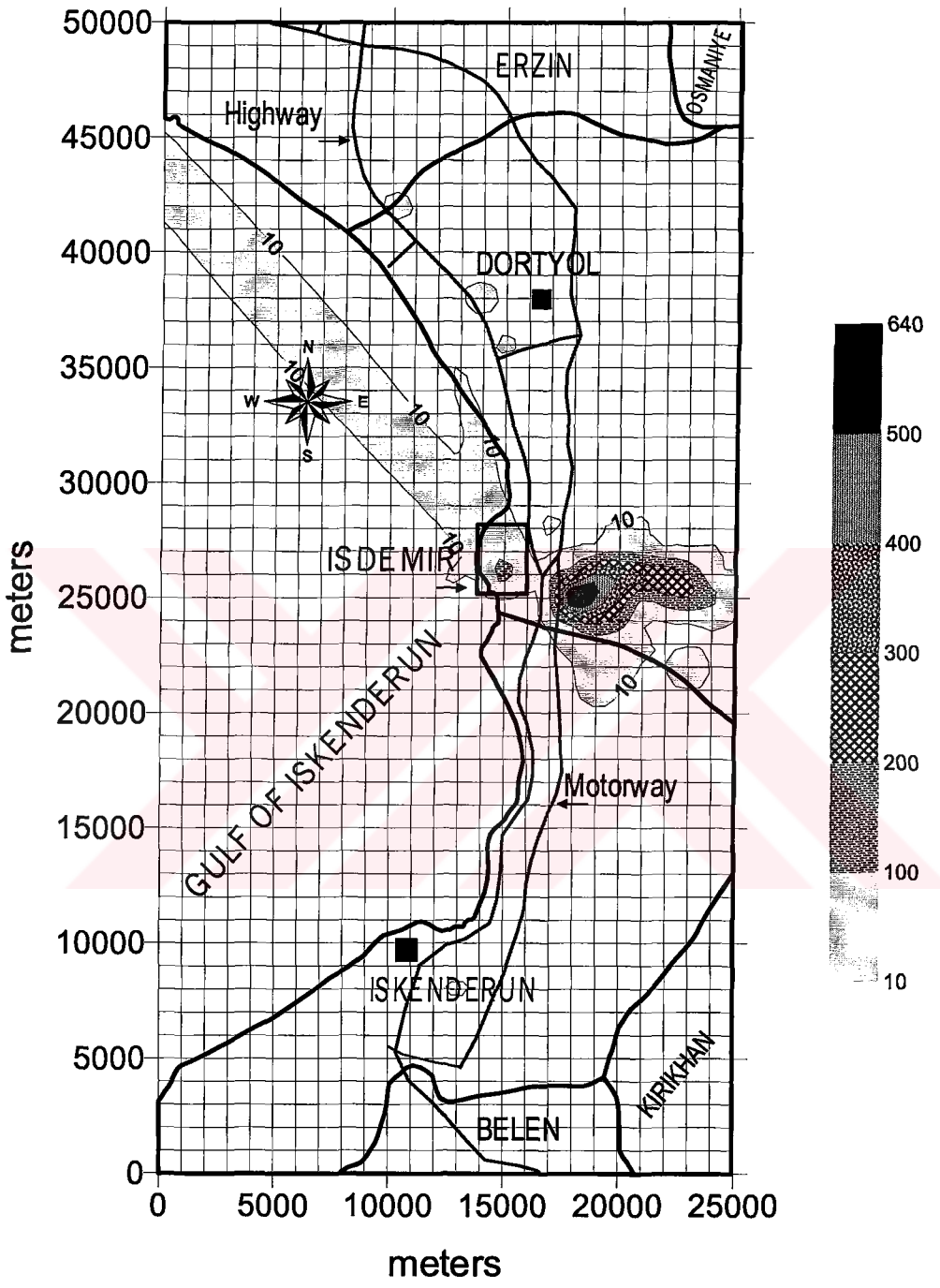

Figure 7.21 24-h average ground level concentrations ($\mu g/m^3$) of PM due to all sources on October 19, 2001

7.1.4 Deposition of PM

Figure 7.22 shows the annual deposition rate (combined effect of dry and wet depositions) of PM due to "all sources". Maximum deposition of 110-133 g/m^2-y occurs near the southeastern corner of the ISDEMIR's property. The center of PM deposition contours is located to the ESE of ISDEMIR as it is seen in Figure 7.22. PM starts depositing inside of ISDEMIR's property and up to 7-8 km in the ESE direction towards mountains. Inside the property of ISDEMIR, PM deposition ranges from 10 to 133 g/m^2-y. No residential center is located in this maximum deposition zone. Further analysis by running the model with discrete receptors revealed that in this zone of maximum deposition the share of dry deposition was 91% while wet deposition accounted for 9% of the total. Deposition of PM outside the zone of maximum deposition is much less. For example, depositions of PM have been found to be in a range from 10 to 35 g/m^2-y in Iskenderun, from 35-60 g/m^2-y in Dortyol and Payas.

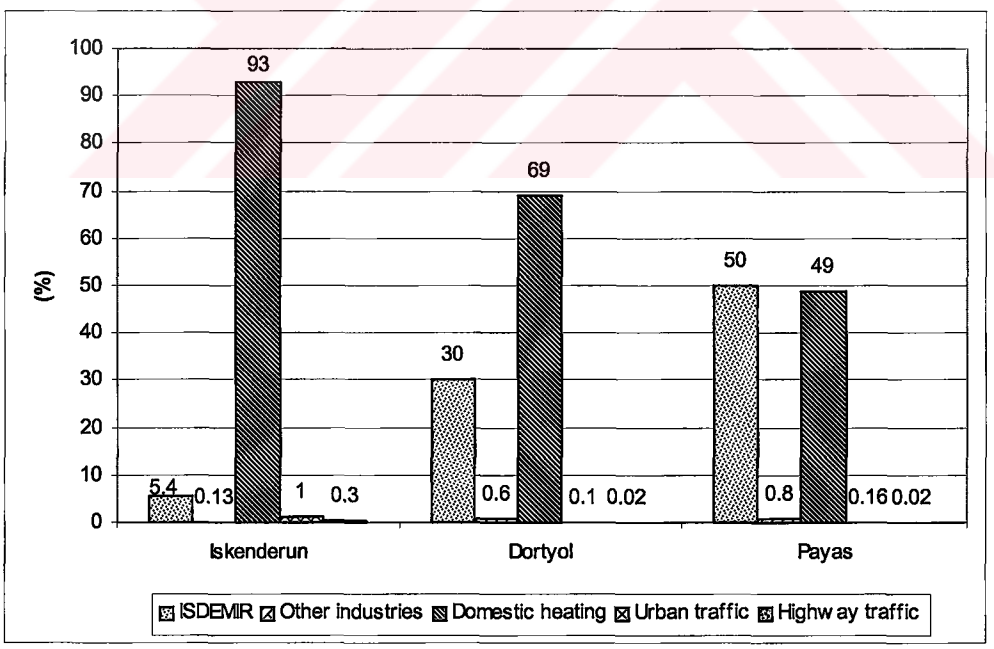

Figure 7.22A Contributions of several sources in the total annual deposition rate of PM in the urban areas.

Figure 7.22A shows the contributions of several sources in the total deposition of PM at the city centers of Iskenderun, Dortyol and Payas. As can be seen in the figure in Iskenderun, 93% of total deposition was found to be due to domestic heating; the shares of dry and wet deposition were 93% and 7%, respectively. In case of Dortyol 69% of total deposition was found to be due to domestic heating, 30% due to ISDEMIR and 0.5% due to other industries. Dry deposition accounted for 82% of total PM deposition in Dortyol.

In Payas the shares of ISDEMIR, domestic heating and other industries were 50%, 49% and 0.8% of the total PM depositions, respectively. Dry deposition made up 80% of total PM deposition in Payas. These PM deposition results reveal that dry deposition is more significant as compared to wet deposition, this would be due to the fact that dry deposition takes place 24 hours a day while wet deposition is effective only for the period of rainfall.

Figure 7.23 shows the rates of PM deposition due to ISDEMIR only. As can be seen from the figure, PM deposition takes place mainly towards the E and SE of ISDEMIR. Partly the deposition extends to the north towards Dortyol. Almost all parts of Dortyol receive a PM deposition rate of 10-35 g/m^2-y due to ISDEMIR. However, Iskenderun City does not receive PM depositions due to ISDEMIR.

In order to understand the contribution of domestic heating sources on the total PM depositions, the program has been run by taking the PM emissions due to domestic heating sources only into account. Figure 7.24 shows the annual deposition rate of PM due to residential heating sources, which range from 5 to 31 g/m^2-y in most of the residential areas. The highest deposition rates of 15-31 g/m^2-y are seen in Iskenderun and Dortyol areas as expected, because they are the major residential centers in the study area. While in Payas the highest PM deposition ranged from 20 to 25 g/m^2-yr.

The PM deposition due to urban as well as highway traffic was very small; the maximum deposition from traffic sources was less than 0.01 g/m^2-yr. Therefore graphs of deposition of PM due to traffic are not given here.

Dry and Wet Depositions

Total deposition of PM consists of dry and wet depositions. Figure 7.25 and 7.26 show annual dry and wet deposition rates due to all sources. As can be seen from these figures, dry deposition extends towards E to ESE of ISDEMIR, while wet deposition extends towards N of ISDEMIR. This is due to the fact that most of the rainfall in the study area occurs during winter and spring seasons, and the prevailing wind direction during this period is from S. On the other hand prevailing wind directions during summer and autumn are mainly from W and it shifts to WNW for some period, therefore dry deposition extends towards E of ISDEMIR.

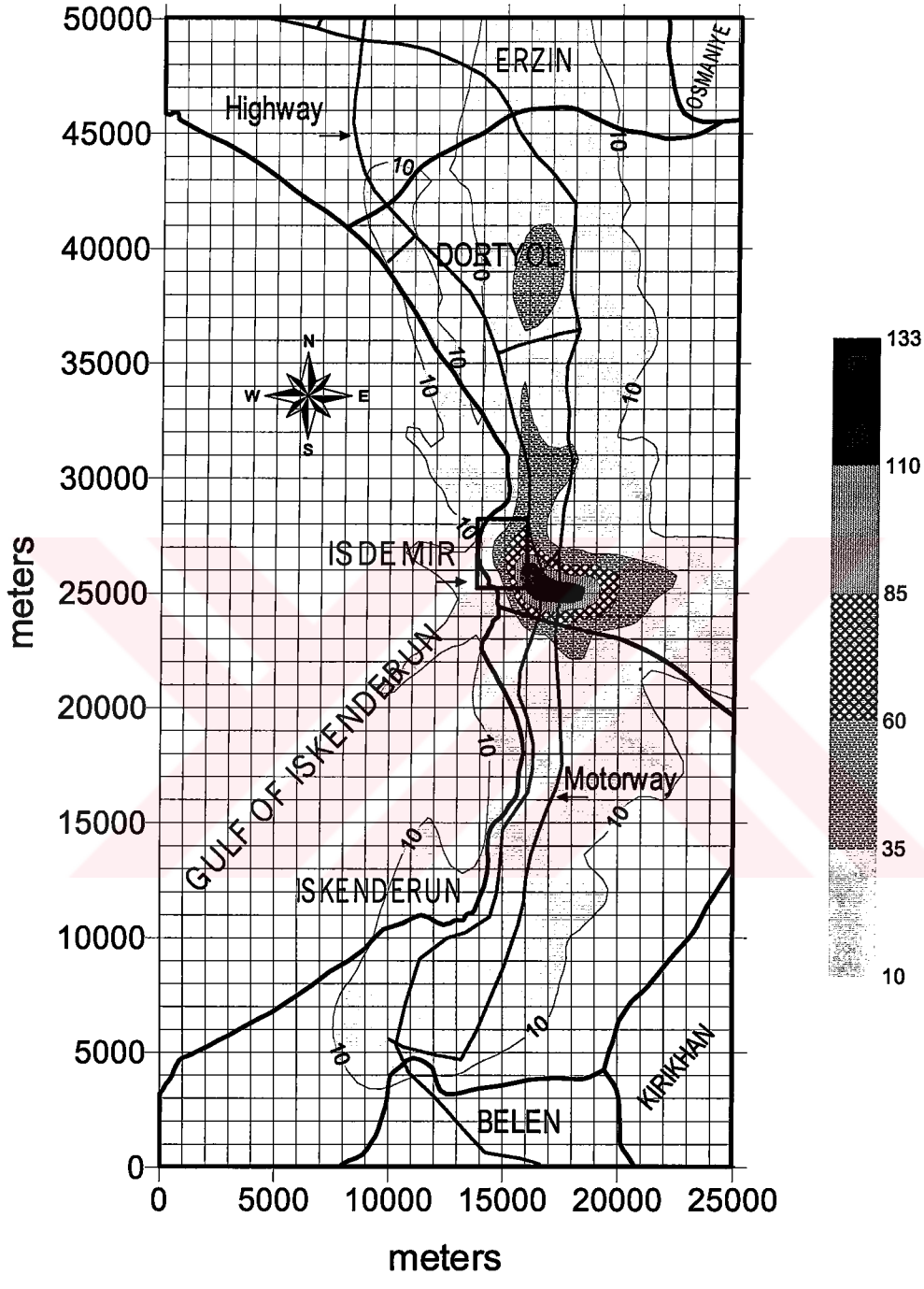

Figure 7.22 Annual deposition rate of PM (g/m^2-y) due to all sources

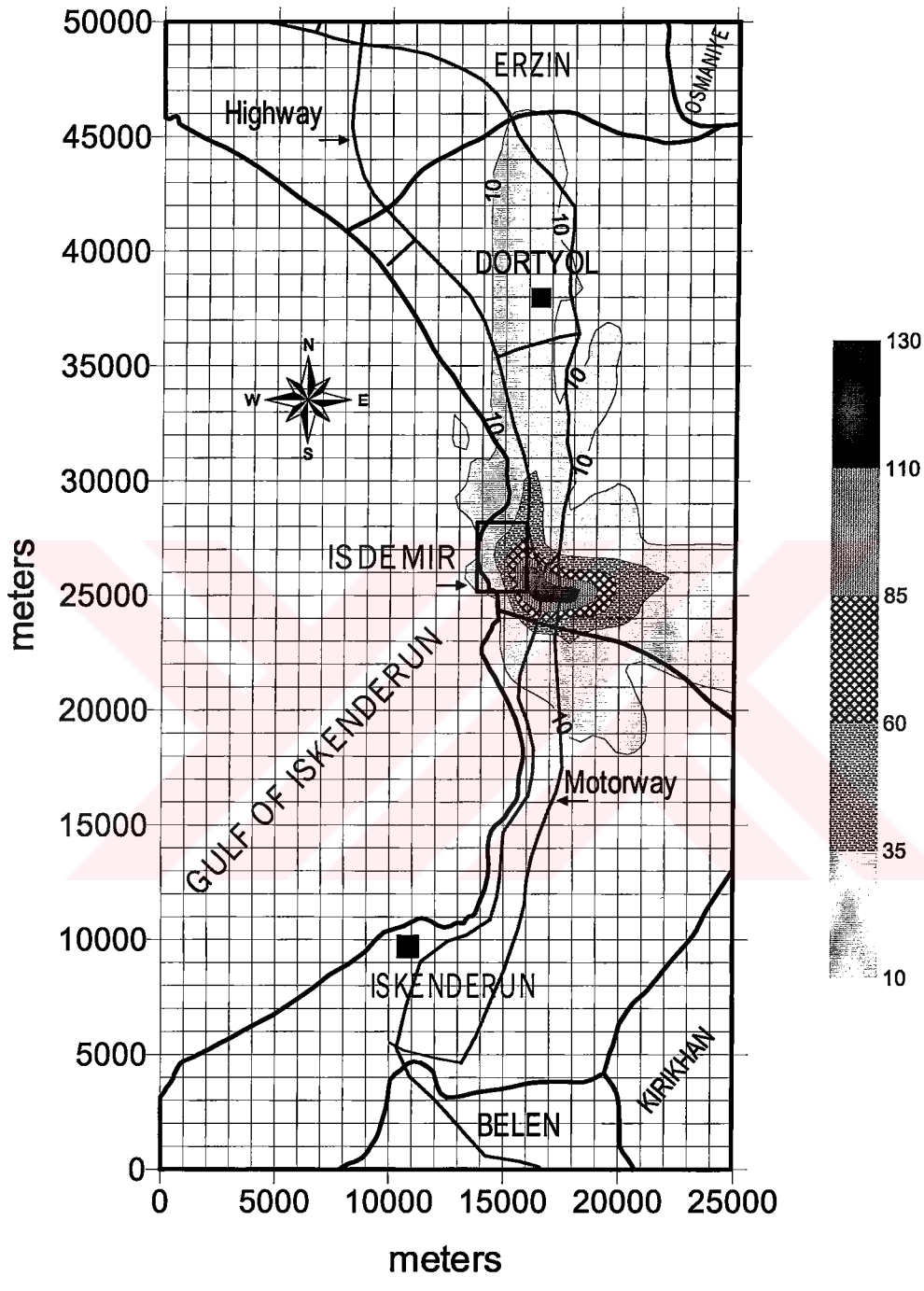

Figure 7.23 Annual deposition rate of PM (g/m^2-y) due to ISDEMIR

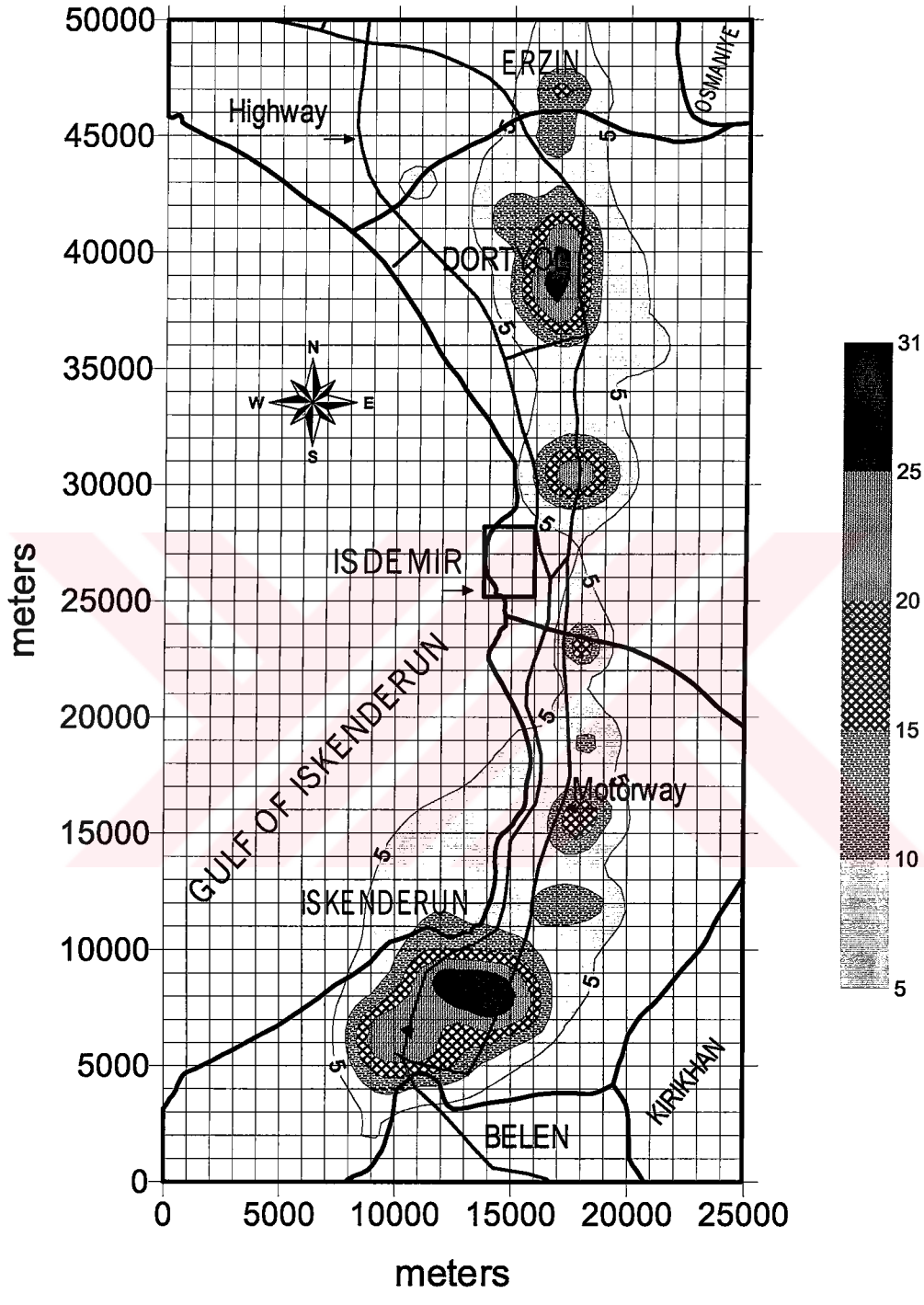

Figure 7.24 Annual deposition rate of PM (g/m^2-y) due to residential heating sources

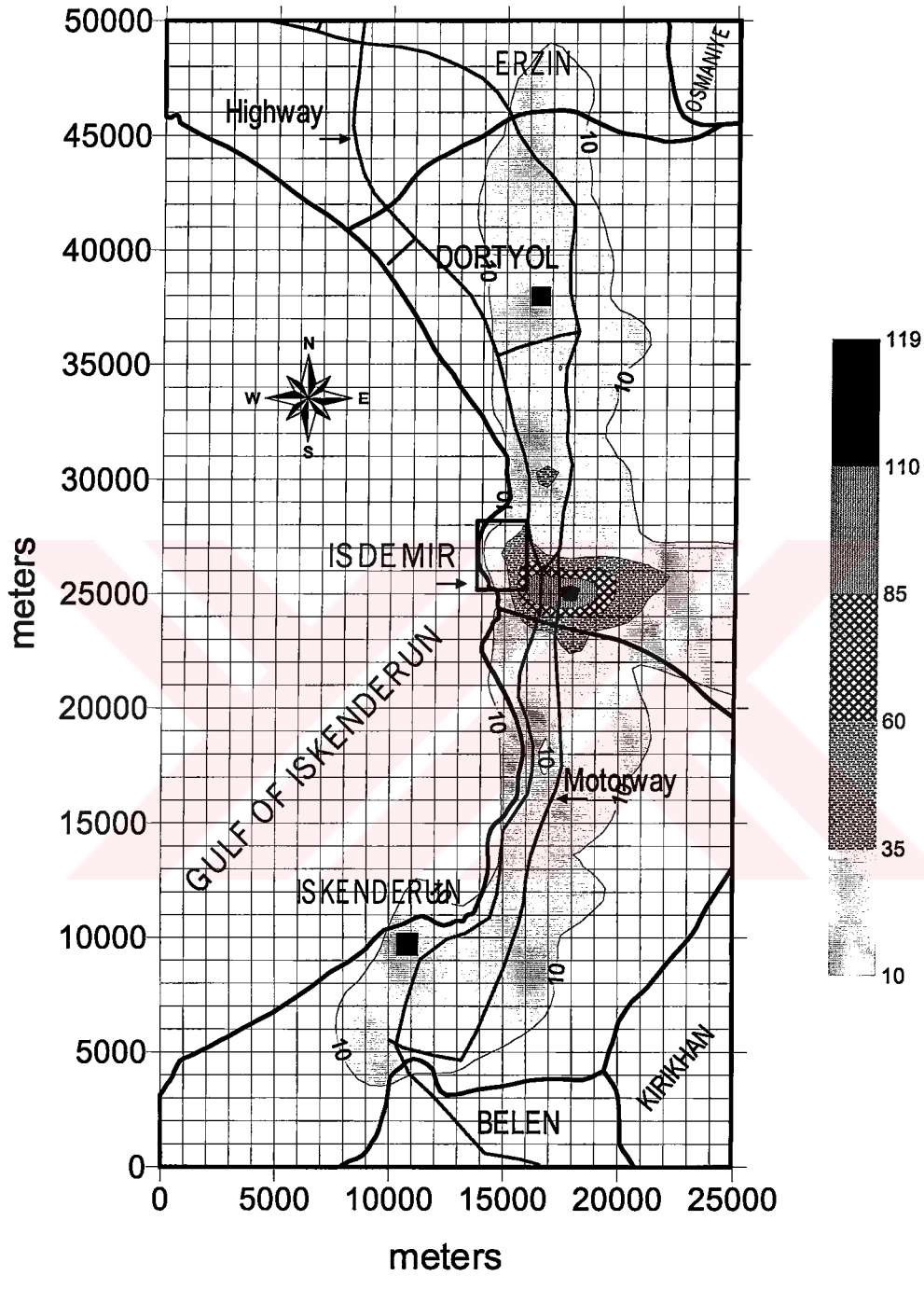

Figure 7.25 Annual dry deposition rate of PM (g/m^2-y) due to all sources

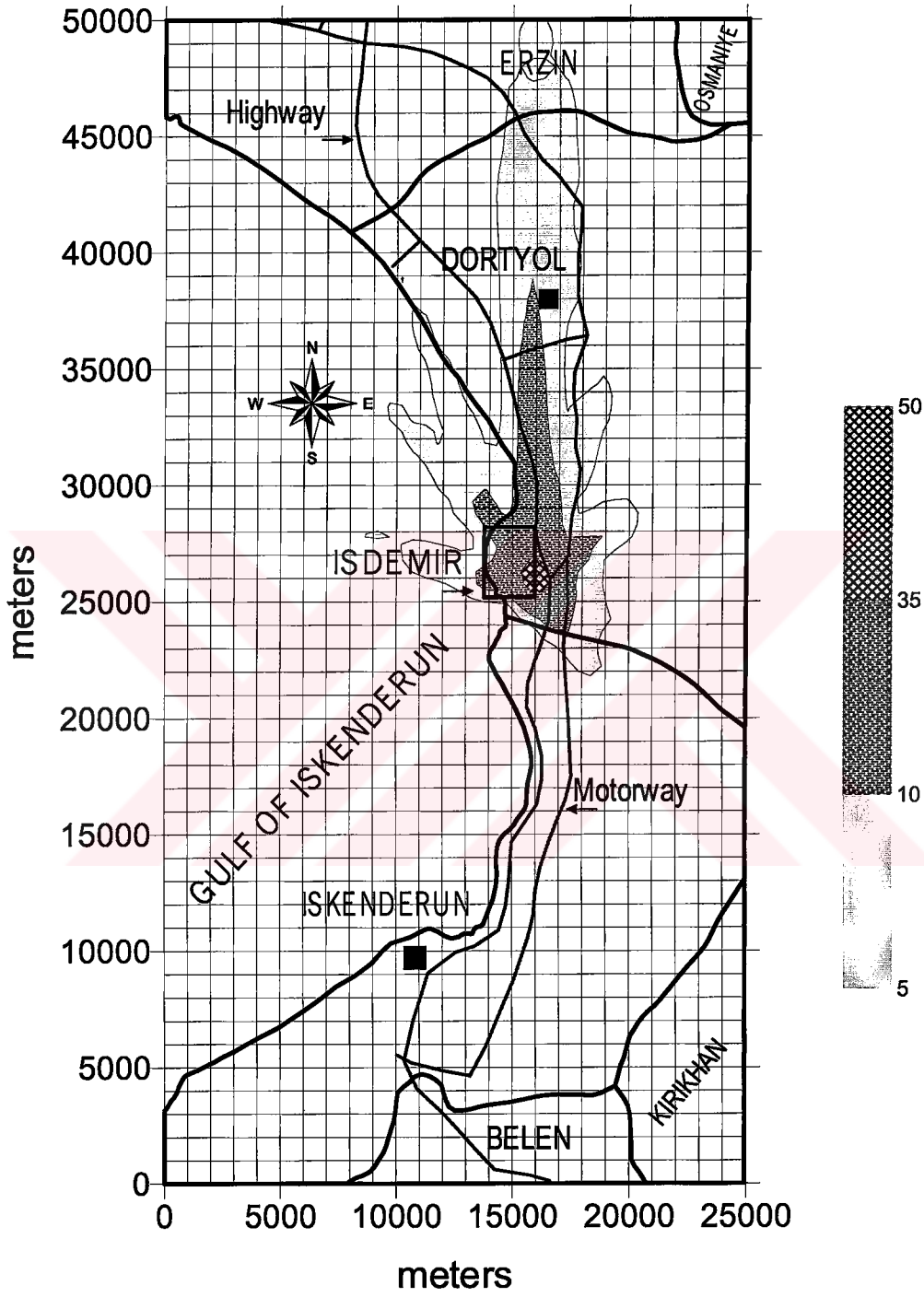

Figure 7.26 Annual wet deposition rate of PM (g/m^2-y) due to all sources

7.2 Modeling of SO_2

Results of dispersion modeling for SO_2 from several sources on annual, seasonal and daily basis are given in Figure 7.27 to 7.44.

7.2.1 Annual Dispersion of SO_2

The results of modeling calculation for the annual average ground level SO_2 concentrations in the study area are given in Figure 7.27 to 7.30. In almost everywhere in the study area, the annual average concentration of SO_2 seems to be between 10 to 50 $\mu g/m^3$. However, there are some regions where the concentration is higher than 50 $\mu g/m^3$, even reaching up to 140 $\mu g/m^3$. The long-term limit given in the TAQPR is 150 $\mu g/m^3$ in residential areas and 250 $\mu g/m^3$ in industrial areas. The concentrations reach, for example, up to 140 $\mu g/m^3$ in a very small area of about 2 km^2 to the ENE of ISDEMIR where altitude is 100 to 200 m above sea level. Near this location in the villages of Kozludere and Yenikoy annual average concentration of SO_2 is in the range of 70-100 $\mu g/m^3$. The effects of high SO_2 concentrations on the people living in these villages, on forest and other vegetation are not known. It will be interesting to make a study on this subject. Also, a region along the mountains where SO_2 concentration in the range of 50 to 70 $\mu g/m^3$ extends from the above mentioned villages up to Erzin from south to north. In the city of Iskenderun, minimum SO_2 concentration is from 10 to 50 $\mu g/m^3$. In the central and the eastern parts of the city SO_2 concentration rises to 50-70 $\mu g/m^3$. In a small area of about 3 km^2 in the eastern parts of Iskenderun SO_2 concentration reaches up to 70-100 $\mu g/m^3$.

In the northern parts of the area under investigation, almost all parts of the town of Dortyol have SO_2 concentration of 50-70 $\mu g/m^3$, which rises to 70-100 $\mu g/m^3$ in the central and eastern parts of the town. The annual prevailing wind directions are from W to NW and S. Therefore, the dispersion of SO_2 towards east and north of emission sources is quite normal.

Comparison of results from different source groups have shown that contributions of domestic heating in the annual average SO_2 concentrations at the city centers of Iskenderun, Payas and Dortyol were 98%, 85% and 73%, respectively as shown in Figure 7.27A.

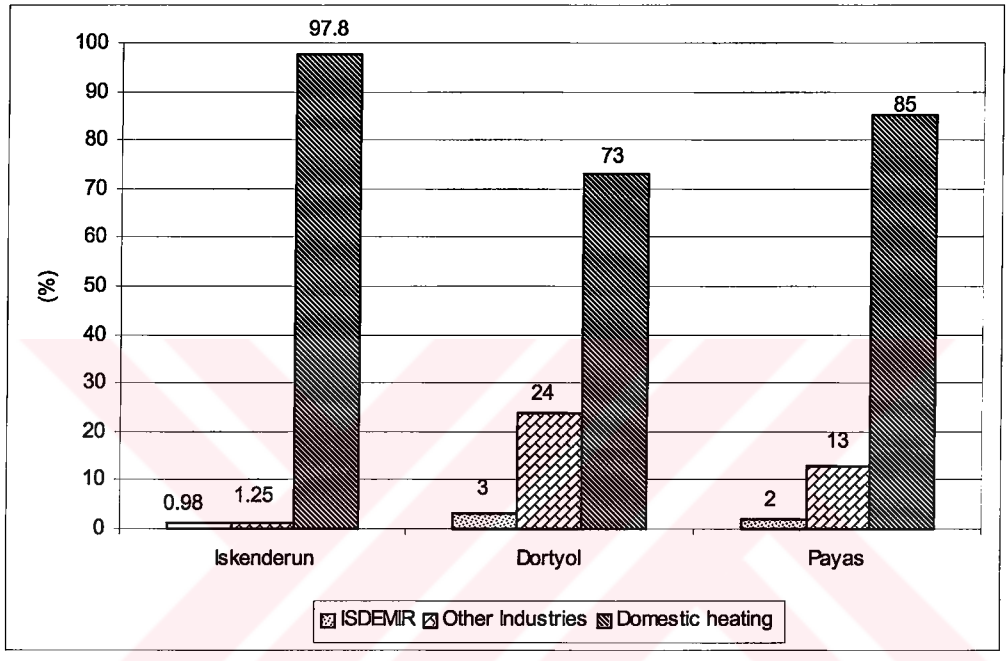

Figure 7.27A Contributions of several sources in the annual average SO_2 concentrations in Iskenderun, Dortyol and Payas.

Upon comparing the annual average SO_2 concentrations in Iskenderun, Payas and Dortyol with the limit of 50 $\mu g/m^3$ defined in WHO Guidelines and EC Regulation, it is seen from Figure 7.27 that in some parts of these cities, SO_2 concentrations exceed the WHO/EC limit. SO_2 concentrations in some places reach to a value that is twice the limit set by these regulations. However, SO_2 concentration is still below the limiting value in the TAQPR, which is under revision. The new limit value in revision is 100 $\mu g/m^3$. Even this suggested new limit is above the limits set by the WHO and EC Regulations. Therefore, SO_2 concentrations pose a danger for human health in many areas.

Figure 7.28 to 7.30 show contributions of several sources in the annual average SO_2 concentration in the study area. When only the SO_2 emissions of ISDEMIR are taken into consideration Figure 7.28 shows that ISDEMIR has negligible effect on annual average SO_2 concentration in the two major residential centers of Iskenderun and Dortyol. Further analysis revealed that ISDEMIR is responsible for only 1%, 2% and 3% of the annual average ground level concentrations of SO_2 at the city centers of Iskenderun, Payas and Dortyol, respectively. The stacks of ISDEMIR are quite tall providing a good dispersion and the dominant wind blowing from W and S takes the pollutants towards mountains and to the north of ISDEMIR.

Figure 7.29 shows the effect of other industries on annual average SO_2 concentration in the study area. As can be seen in this figure, the towns of Dortyol and Payas receive 10-50 $\mu g/m^3$ of SO_2 due to other industries located mostly in the south of these towns. It can be noted from Figure 7.29 and 7.30 that contribution of other industries in annual average ground level concentration of SO_2 is more than that of ISDEMIR, although annual SO_2 emissions from ISDEMIR are 83% of the total industrial SO_2 emissions. This is most probably because of taller stacks of ISDEMIR. Major SO_2 releasing stacks in ISDEMIR are from 100 to 187 m high. On the other hand stacks in all other industries are 20-25 m high from ground level. Therefore, the effect of taller stacks is seen in better dispersion of SO_2 from the stacks of ISDEMIR. Dispersion of SO_2 is investigated by detailed analysis using "discrete receptors". The receptor points were chosen at the city centers of the urban areas. This analysis revealed that the contributions of other industries in the annual average SO_2 concentrations at the city centers of Iskenderun, Payas and Dortyol are 1%, 13% and 24%, respectively. For the same locations ISDEMIR is responsible only for 1%, 2%, and 3% of the annual average SO_2 concentrations. These contributions are shown graphically in Figure 7.27A. Therefore, if some clean air plan is to be prepared for this area, due

considerations should be given to reduce SO_2 emissions from other industries as well, because these industries use fuel oil with 6% sulfur.

Figure 7.30 shows the annual average SO_2 concentrations resulting only due to residential heating sources. This figure shows that SO_2 concentration in the city of Iskenderun is mainly due to domestic heating activities. The maximum annual average SO_2 concentration reaches up to 100 $\mu g/m^3$ in Iskenderun, while it is up to 70 $\mu g/m^3$ in Dortyol. Coal is the major fuel used for domestic heating in the study area. The sulfur content of the coal is about 0.75 to 3.6% by weight. However, some dwellings use fuel oil for heating with a sulfur content of 1.5% by weight. Annual consumption of coal and fuel oil is 45000 tons and 4100 tons, respectively. In most of the buildings in the study area the stack heights are from 5 to 10 m. Therefore, this small release height results in poor dispersion of SO_2. It can be concluded that high concentrations of SO_2 in residential areas is due to the combined effect of high sulfur content of fuels and poor dispersion.

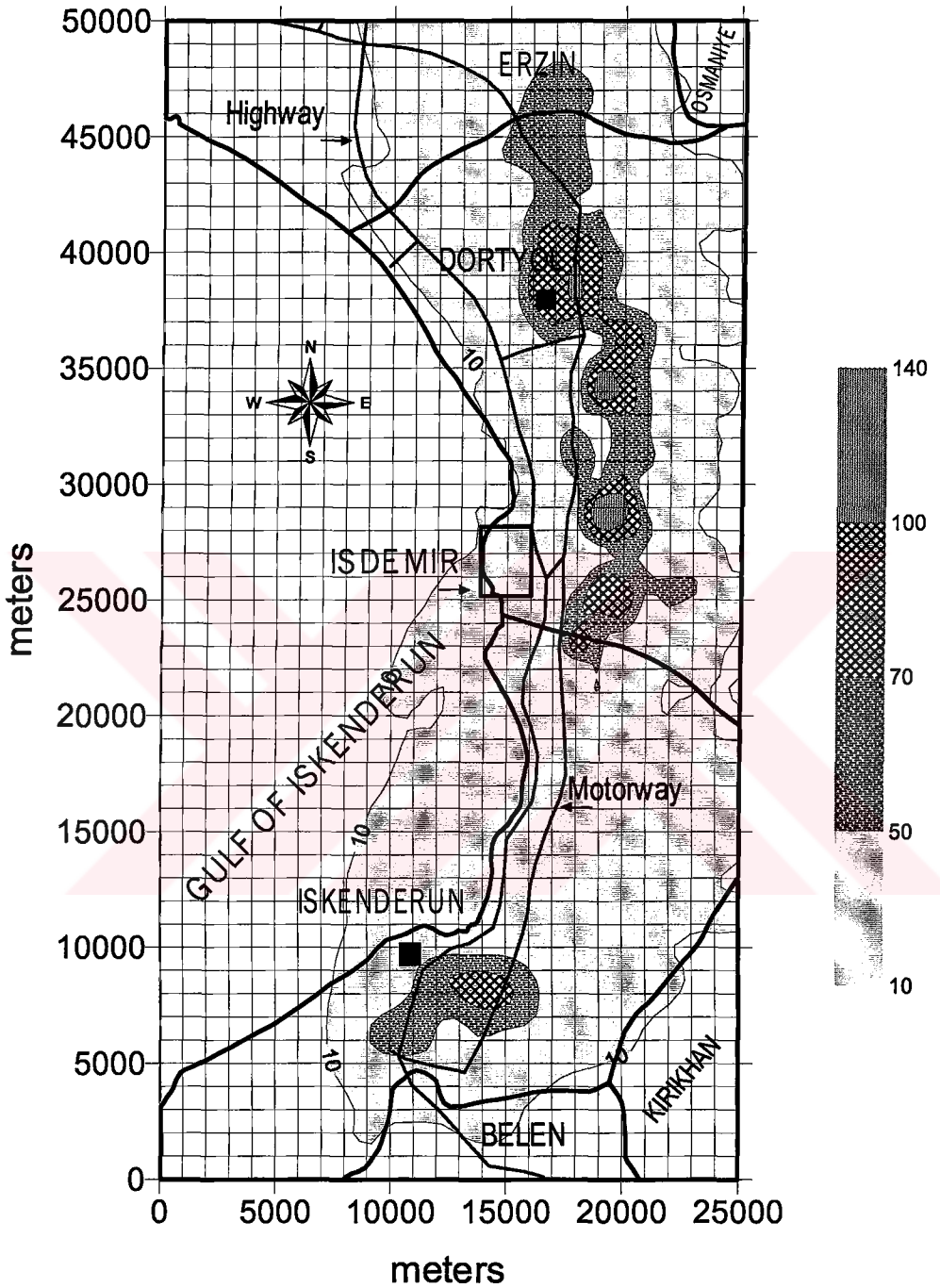

Figure 7.27 Annual average ground level concentrations ($\mu g/m^3$) of SO_2 due to all sources

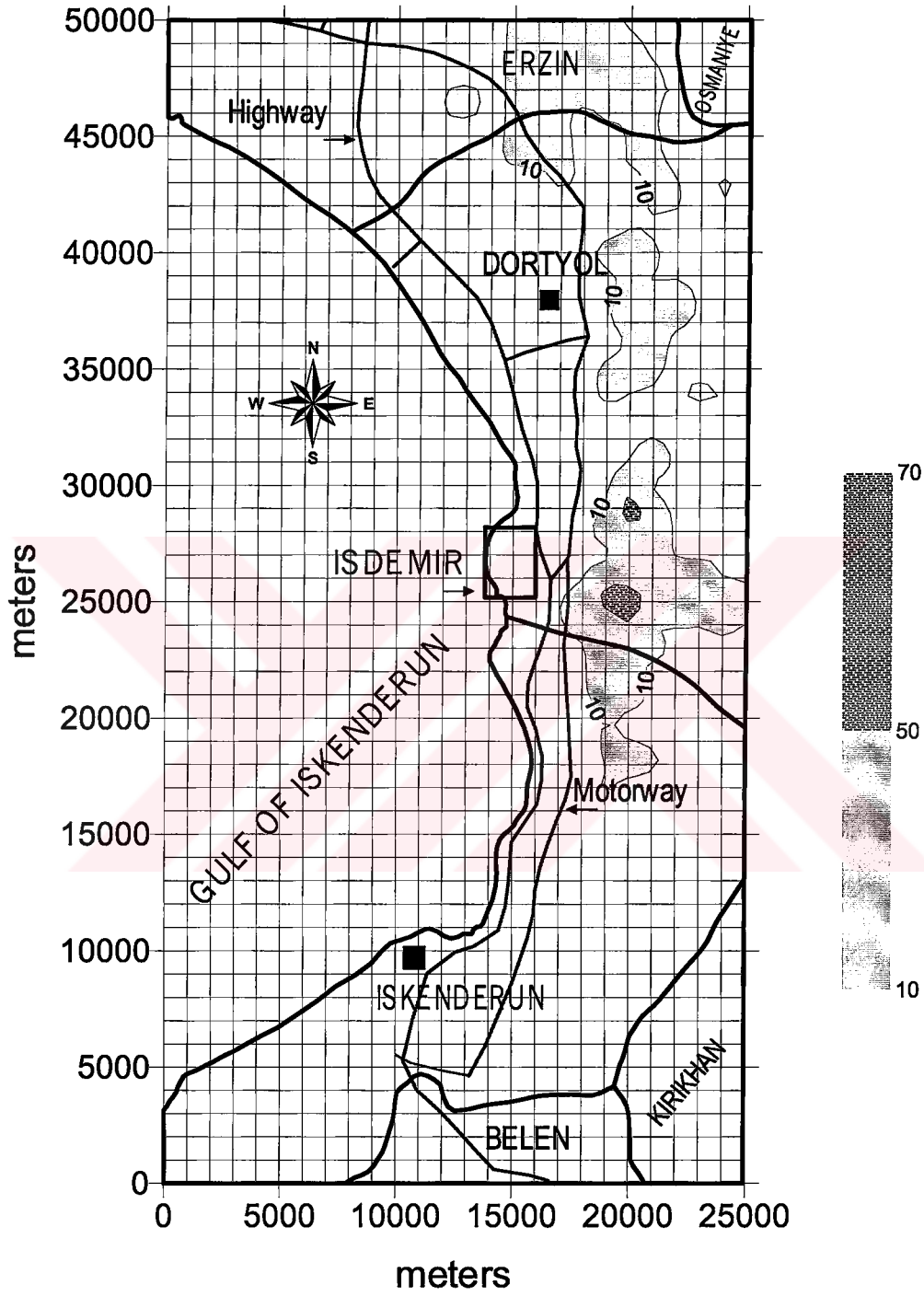

Figure 7.28 Annual average ground level concentrations ($\mu g/m^3$) of SO_2 due to ISDEMIR

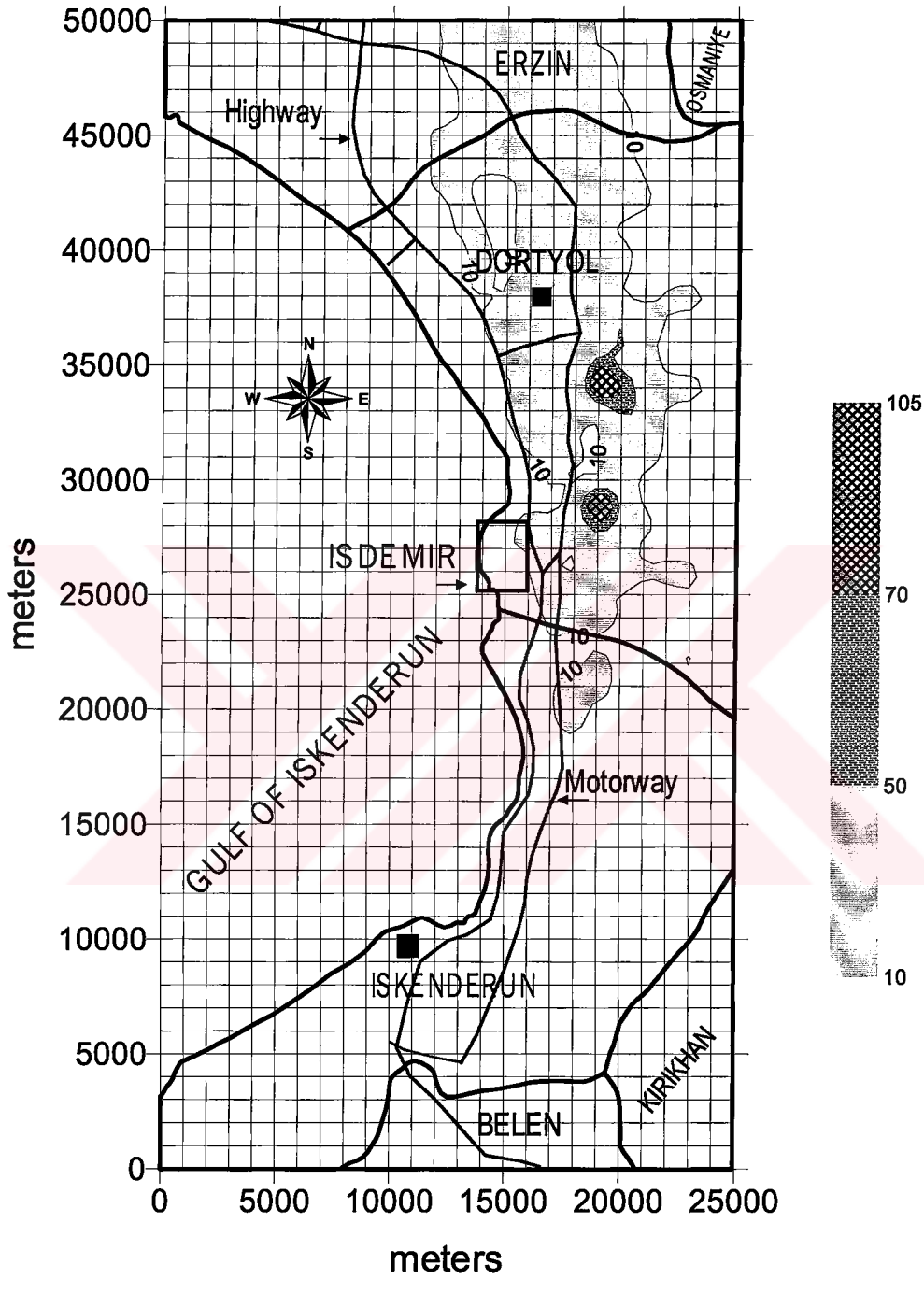

Figure 7.29 Annual average ground level concentrations (μg/m^3) of SO_2 due to other industries

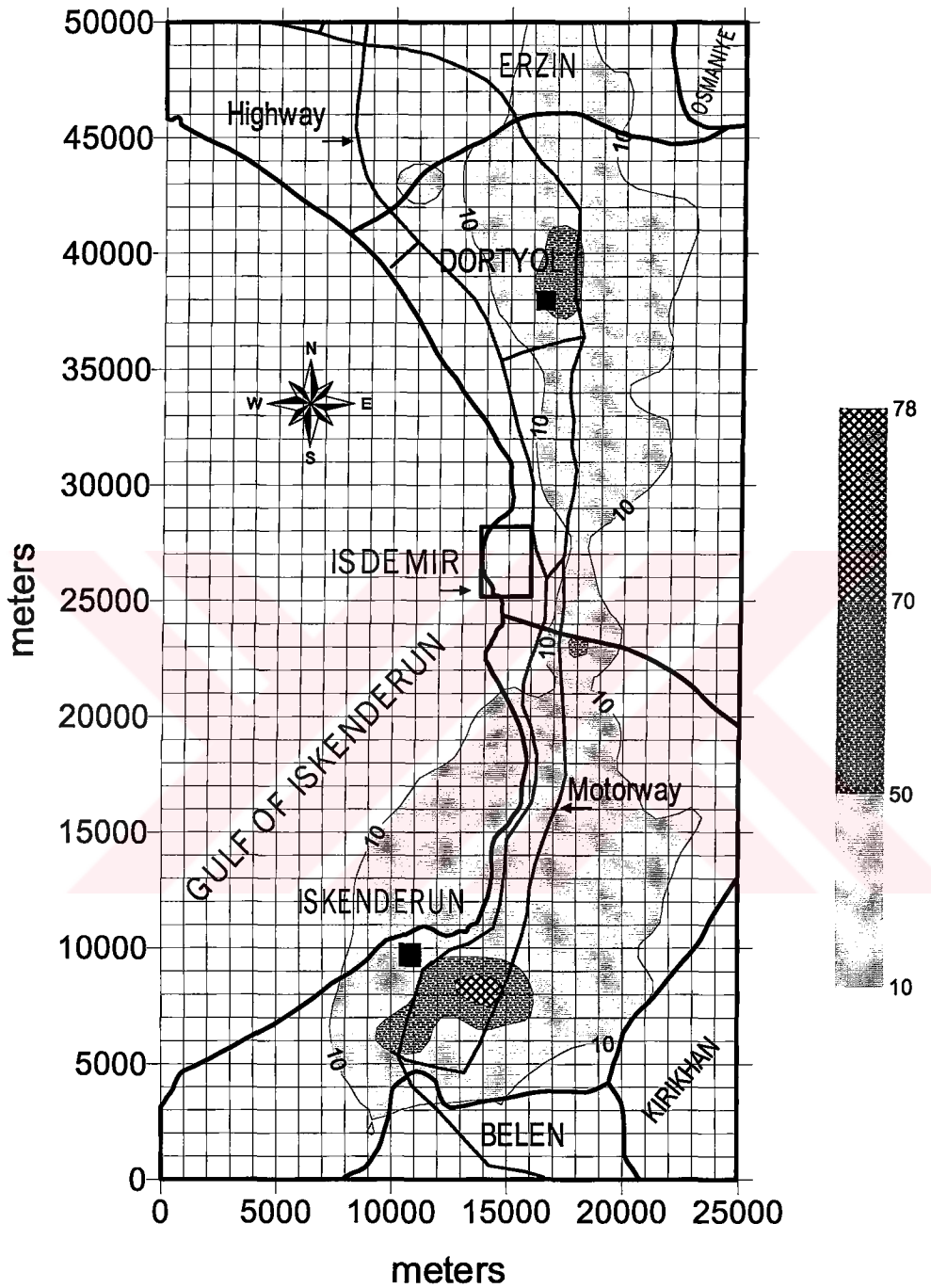

Figure 7.30. Annual average ground level concentrations ($\mu g/m^3$) of SO_2 due to domestic heating sources

7.2.2 Seasonal Dispersion of SO_2

Figure 7.31 shows winter average ground level concentrations of SO_2 where all sources are taken into consideration. The maximum concentration reached in the study area is 245 $\mu g/m^3$, which is just below the limit set by the TAQPR for winter. This maximum SO_2 concentration of 200-245 $\mu g/m^3$ occurs in the southeastern part of Iskenderun City, and in the central and northern parts of Dortyol for about 4 km^2 in each of the two population centers. During winter SO_2 concentration in almost all parts of Iskenderun City is above 50 $\mu g/m^3$, while in Dortyol it is above 100 $\mu g/m^3$. The reason for having higher SO_2 concentration in Dortyol is SO_2 emissions from other industries in addition to the emissions from residential heating in this town. Since the prevailing wind directions in winter are mainly from S, which shifts towards E for some time, therefore the dispersion of SO_2 takes place in the directions of N and NE of emission sources.

Figure 7.32 shows the winter average ground level concentrations of SO_2 only due to ISDEMIR. It is clear from the figure that ISDEMIR has almost negligible effect on SO_2 concentration in the major population centers in the study area. This is due to tall stacks of ISDEMIR as discussed in the previous section. Further analysis by running the model with discrete receptors showed that the contribution of ISDEMIR in winter average SO_2 concentrations at Iskenderun, Payas and Dortyol is 0.2%, 0.7% and 1%, respectively.

Figure 7.33 shows the winter average ground level concentrations of SO_2 only due to emissions from other industries. As seen in the figure, Dortyol and Payas receive a concentration of 10-50 $\mu g/m^3$ of SO_2 due to other industries during winter. This is due to shorter stack heights (20-25 m) in other industries than in ISDEMIR, and use of fuel oil with 6% by weight sulfur content. Moreover these industries are located in the south of residential areas of Dortyol and Payas in organized industrial estates, and during winter the prevailing wind direction is from S. Hence, residential areas of Dortyol and Payas are

vulnerable to emissions from other industries, especially during winter and spring when wind blows from S. Further analysis of results using discrete receptors revealed that the contribution of other industries in winter average SO_2 concentrations at Iskenderun, Payas and Dortyol was 0.2%, 4.7% and 5%, respectively.

Figure 7.34 shows the winter average ground level concentrations of SO_2 resulting only due to residential heating sources. As can be seen in the figure, SO_2 concentration over most of the study area is 10-50 $\mu g/m^3$. Higher concentrations of SO_2 are seen in the residential areas of Iskenderun, Dortyol and Payas. The maximum SO_2 concentration in Iskenderun City reaches up to 243 $\mu g/m^3$, that is very close to the limiting value of 250 $\mu g/m^3$ for winter set by the TAQPR, while in Dortyol it is up to 200 $\mu g/m^3$. These concentrations are almost the same values seen in Figure 7.31 where SO_2 concentrations are calculated by including all sources. Figure 7.34 shows that the sole contributor in SO_2 concentration in Iskenderun is the domestic heating, while in Dortyol it is not the sole but the major contributor. It was found in the detailed analysis with discrete receptors that domestic heating sources are responsible for 99.6%, 94.6% and 94% of winter average SO_2 concentrations at Iskenderun, Payas and Dortyol, respectively. The main reason for high SO_2 concentration in residential areas during winter is the burning of coal for domestic heating. In estimating the emissions due to domestic heating based on the information obtained from municipalities, it was assumed that 30% of coal used contain 3.6% sulfur, and the rest of the coal used contains 0.75% sulfur.

Figure 7.35 and 7.36 show the spring average ground level SO_2 concentrations due to all sources and contributions of other industries to the result. Of course, during the spring season there is no domestic heating. Therefore, these figures show that except some areas in the eastern and northern parts of Dortyol, the SO_2 concentration is between 10 and 15 $\mu g/m^3$. In spring SO_2 concentrations in the eastern and northern parts of Dortyol due to all sources rise to 50–80 $\mu g/m^3$, and due to other industries rise to 50-71 $\mu g/m^3$. This shows that high

concentration areas are mainly caused by emissions from the other industries in the spring season. The prevailing wind direction in spring is also from S like in winter, but wind speed is slower than it is in winter. Since wind speed was less than 3 m/s for most of the time. Therefore, dispersion of SO_2 especially from other industries was not good, which was the reason for slightly higher concentrations of SO_2 as compared to the ones during winter due to other industries in Dortyol

Figure 7.37 shows summer average ground level concentrations of SO_2 due to all sources and contributions of several sources to this distribution. This figure shows the dispersion of SO_2 towards eastern side of the study area; this is because of prevailing wind direction in summer is from W and WNW. The wind speed during summer is relatively higher than during winter and spring; it is more than 3 m/s for most of the time and is in the range of 5 to 10 m/s for about half of the time. The maximum SO_2 concentration of 100-120 $\mu g/m^3$ has been found towards NE and ESE of ISDEMIR in the mountains at altitudes of 200-500 m from sea level. Moreover the high concentration area in the ESE of ISDEMIR is because of its own emissions while the one in NE of ISDEMIR is mostly due to emissions from other industries.

Figure 7.38 and 7.39 show the autumn average ground level concentrations of SO_2 due to all sources and other industries. These figures show that SO_2 concentrations are relatively high as compared to concentrations in spring and summer seasons, and they are towards the eastern side of the study area. The dispersion of SO_2 in autumn is less than in other seasons. Probably the reasons for this poor dispersion would be:

1. Low wind speed, which was 1.5 to 3 m/s for most of the time.
2. Combined effect of prevailing wind directions from W and N and high mountains in the eastern side of sources.

In autumn the maximum average SO_2 concentration of 217 $\mu g/m^3$ was found towards NE of ISDEMIR in the mountains at an altitude of about 200 m as

shown in Figure 7.39. The villages of Yenikoy and Kozludere are located in this high concentration zone. Another high concentration zone formation is seen in the figure in the SE of Dortyol where concentration reaches up to 150 $\mu g/m^3$, and where the village of Karakese is located. Sincan, a village at about 3 km in the east of ISDEMIR at an altitude of 200-300 m, is located within the contours of 100 $\mu g/m^3$ of SO_2. Also the town of Karayılan, located at the base of mountains opposite to the residential area of ISDEMIR is found to be exposed to SO_2 concentrations of 10-100 $\mu g/m^3$ in autumn. All these villages are located at altitudes of 100 to 300m and they have a total population of 11,626 including the town of Karayilan. Therefore, the effect of SO_2 on human health and vegetation in these places seems to be in danger and it should be studied in detail.

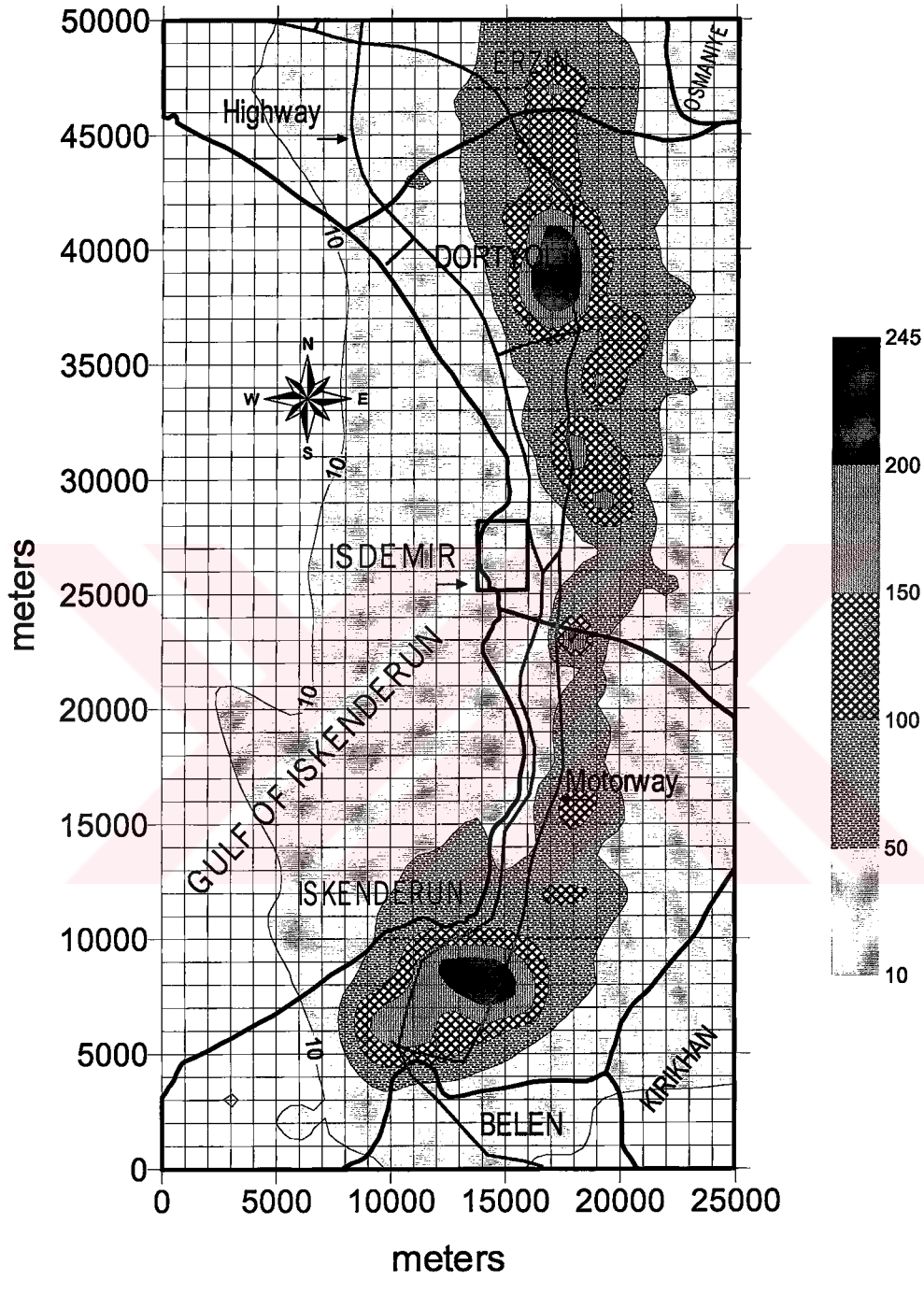

Figure 7.31 Winter average ground level concentrations ($\mu g/m^3$) of SO_2 due to all sources

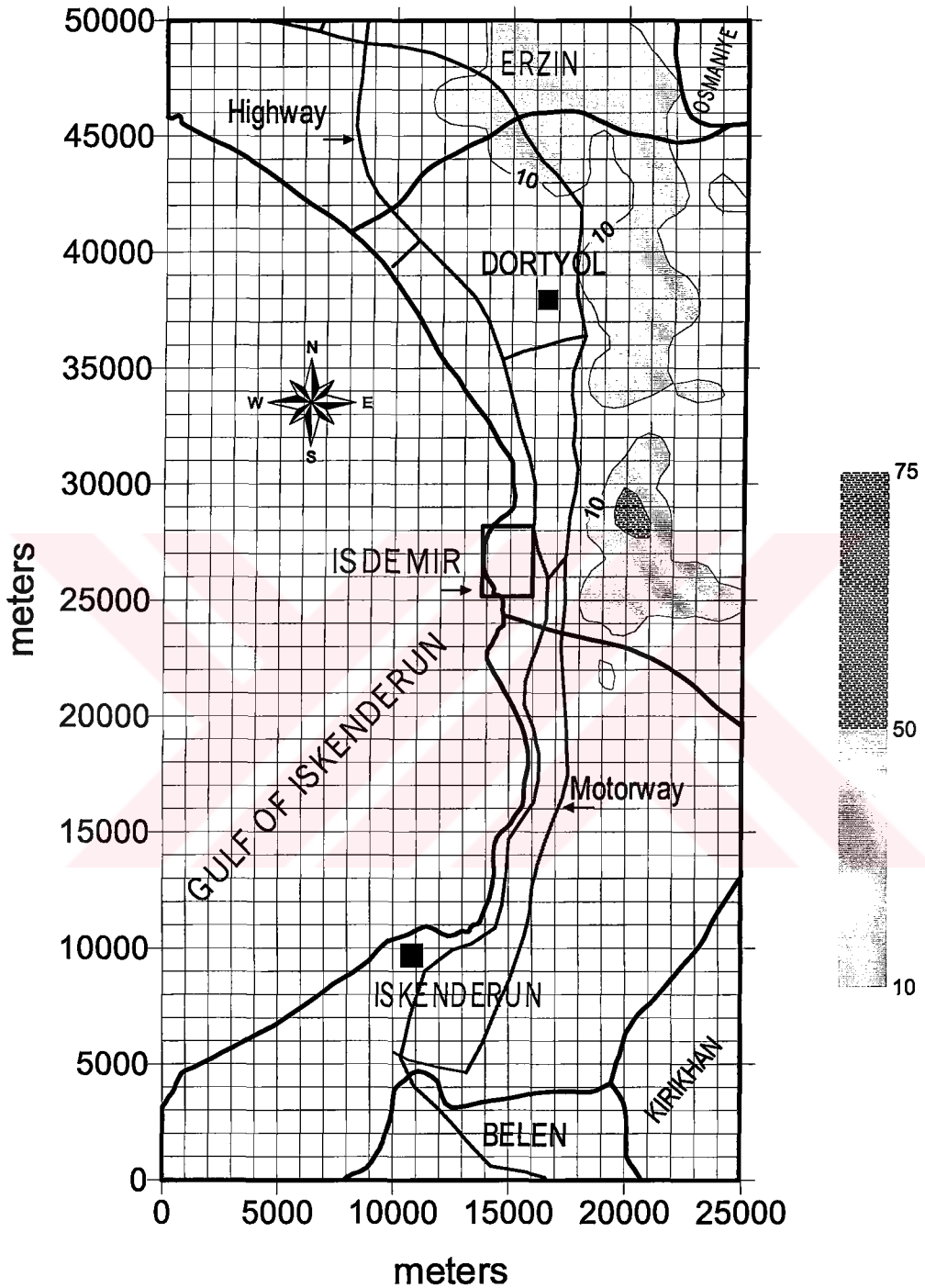

Figure 7.32. Winter average ground level concentrations ($\mu g/m^3$) of SO_2 due to ISDEMIR

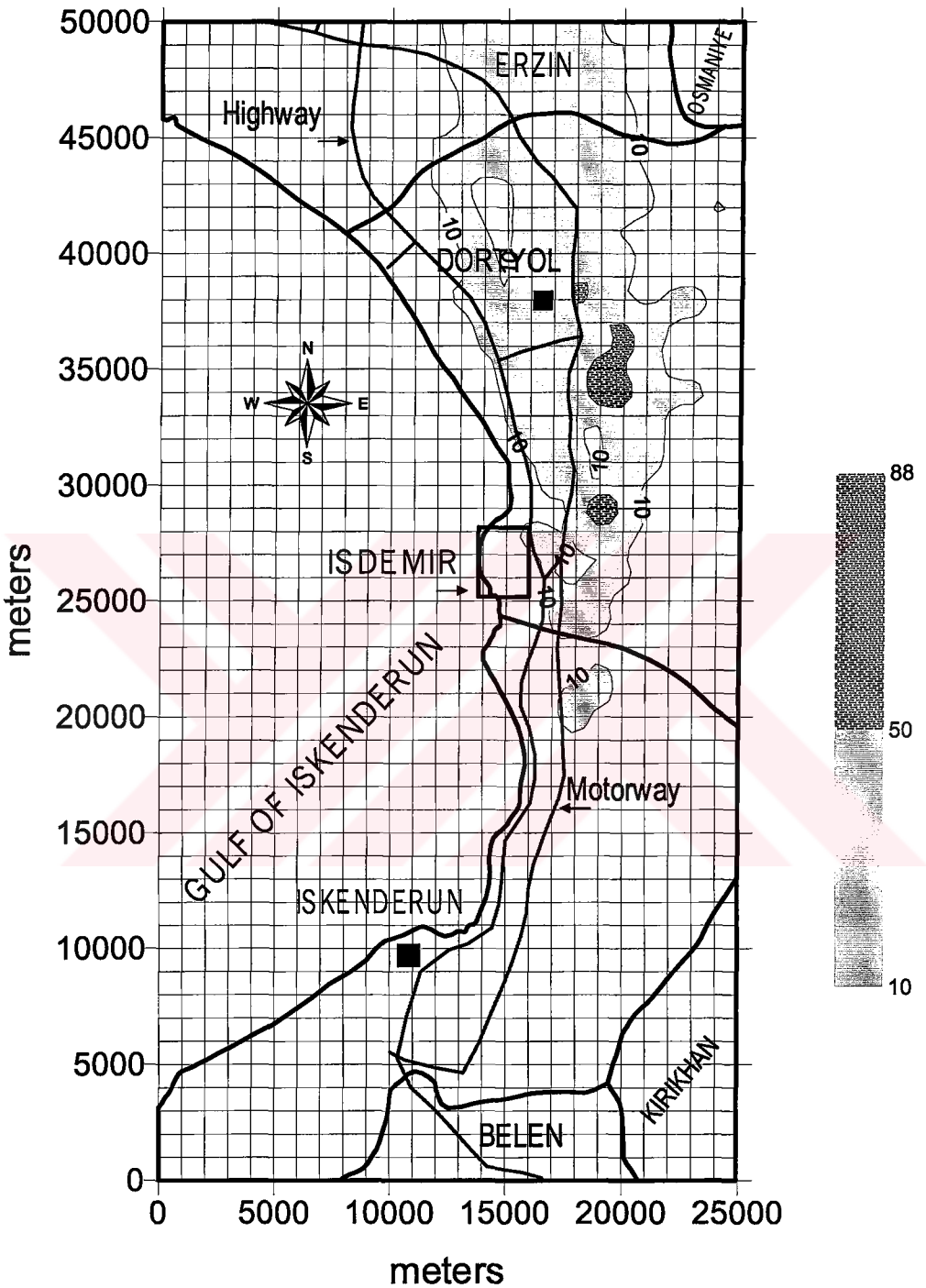

Figure 7.33. Winter average ground level concentrations ($\mu g/m^3$) of SO_2 due to other industries

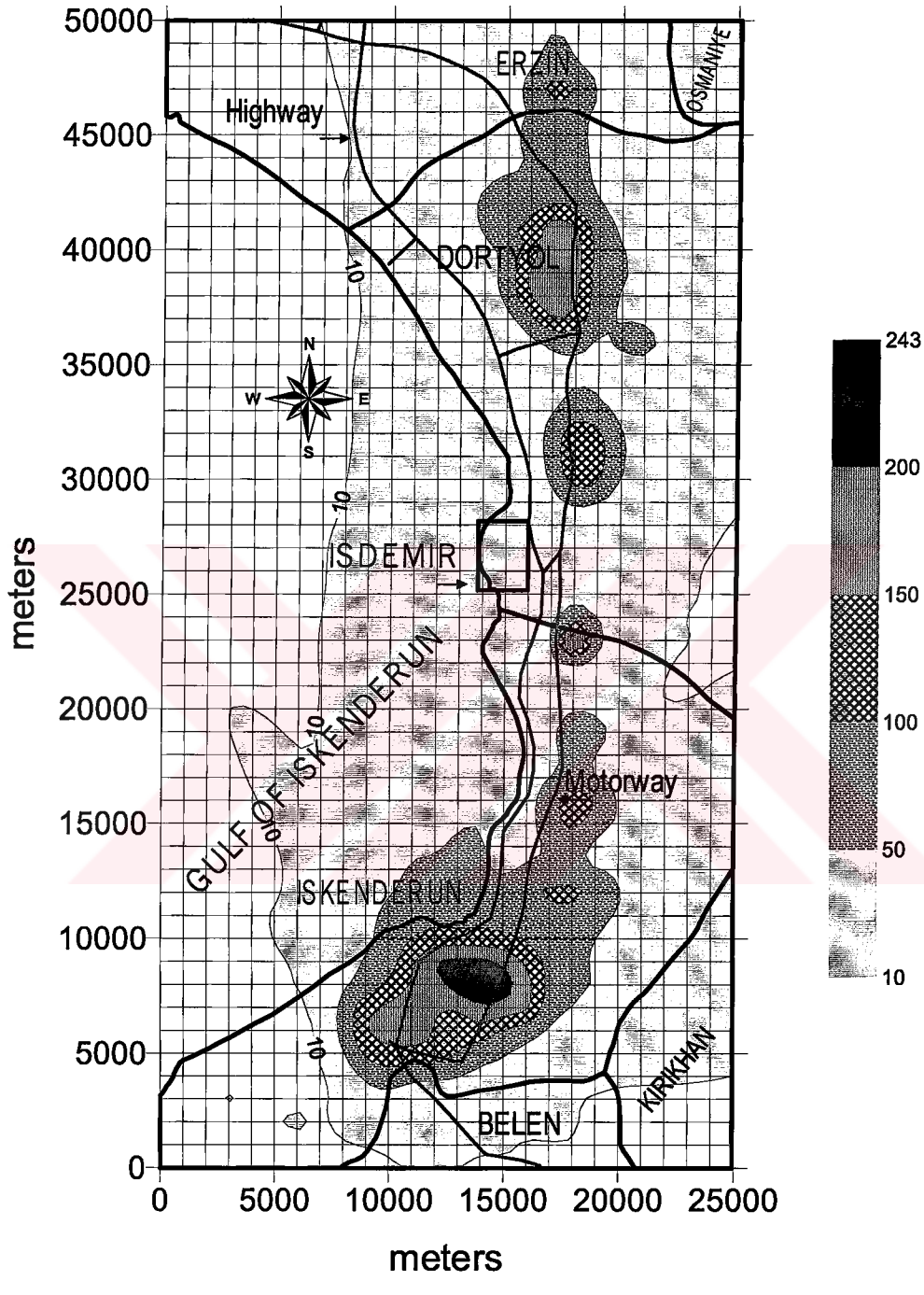

Figure 7.34 Winter average ground level concentrations ($\mu g/m^3$) of SO_2 due to domestic heating sources

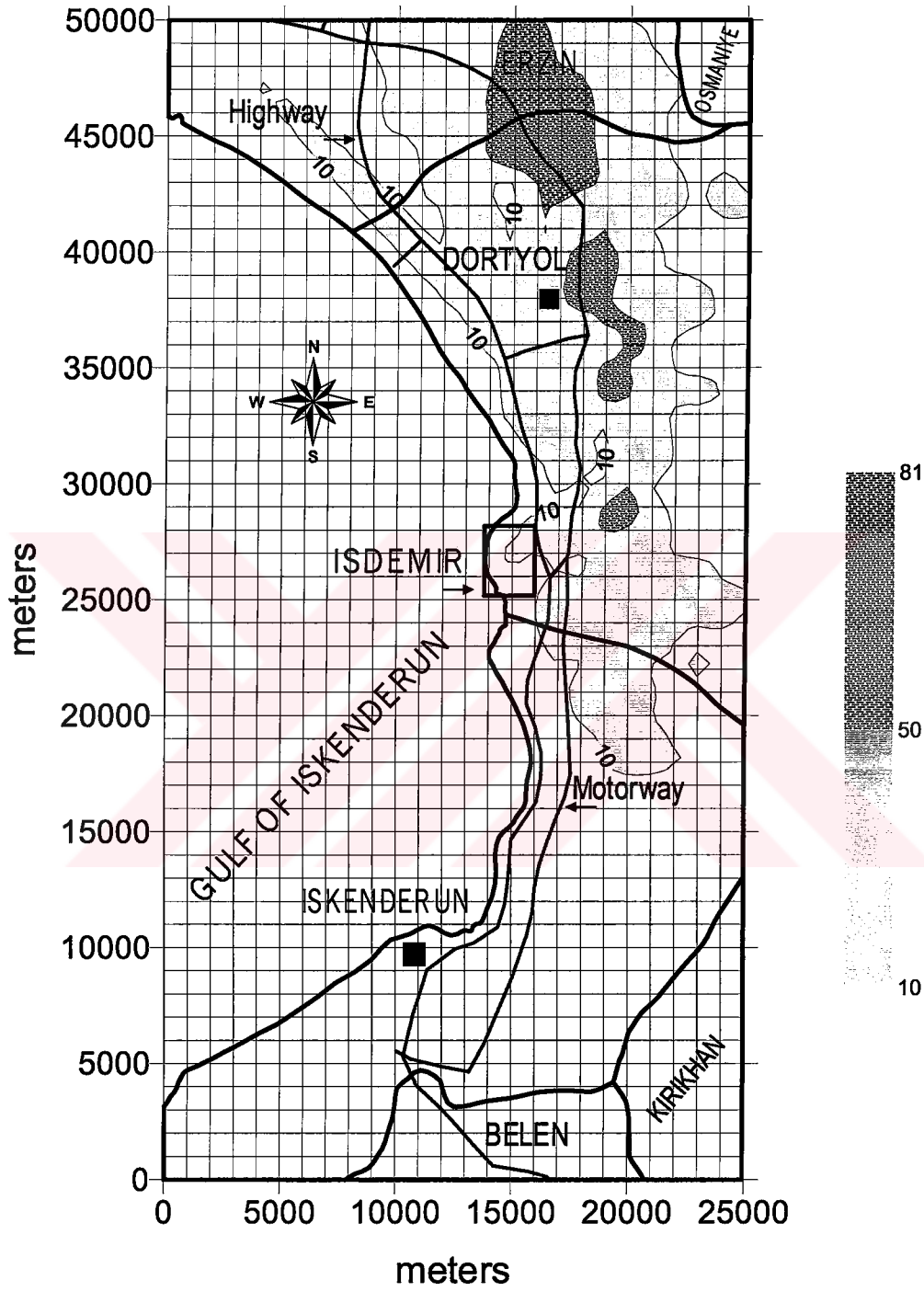

Figure 7.35 Spring average ground level concentrations ($\mu g/m^3$) of SO_2 due to all sources

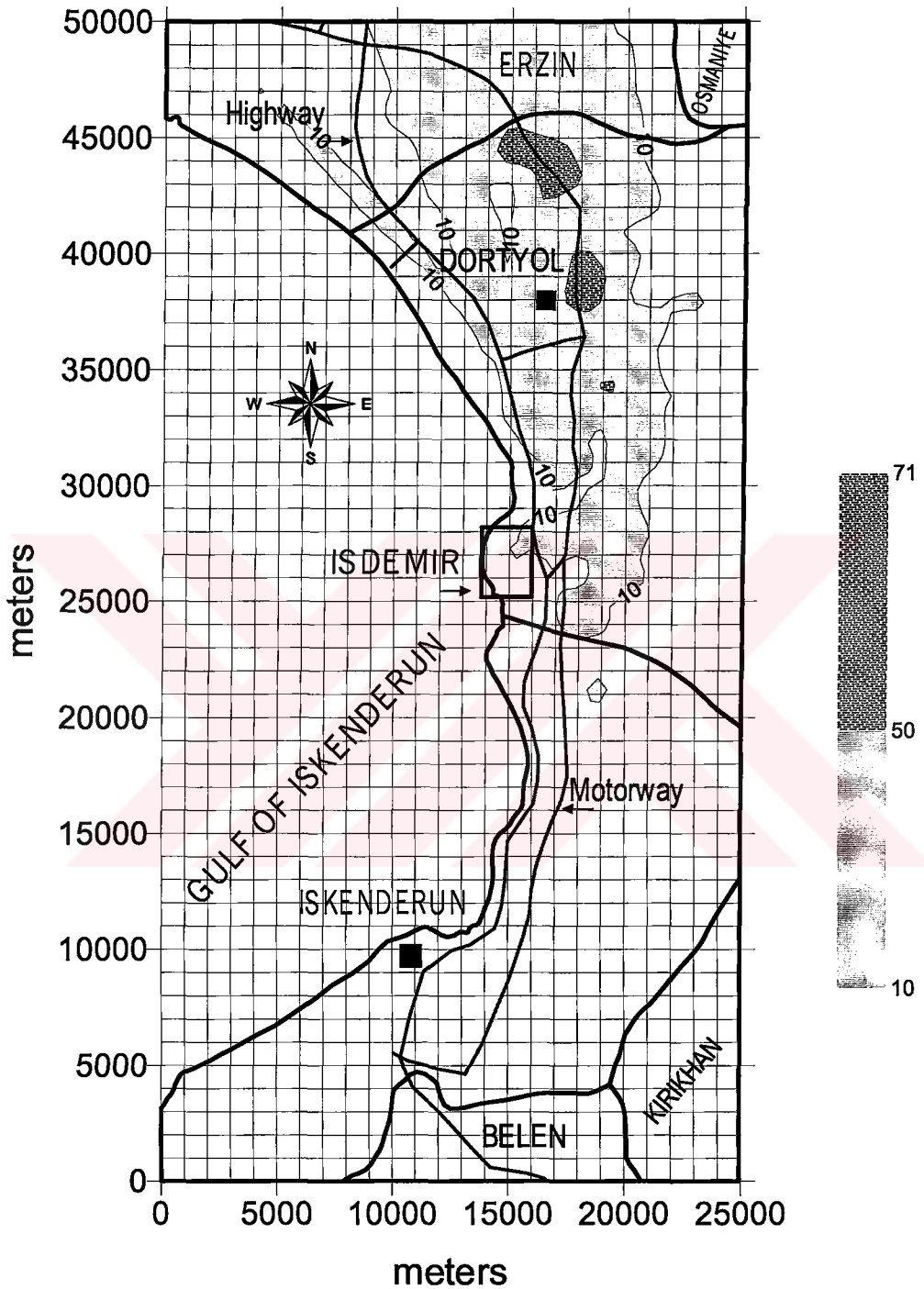

Figure 7.36 Spring average ground level concentrations ($\mu g/m^3$) of SO_2 due to other industries

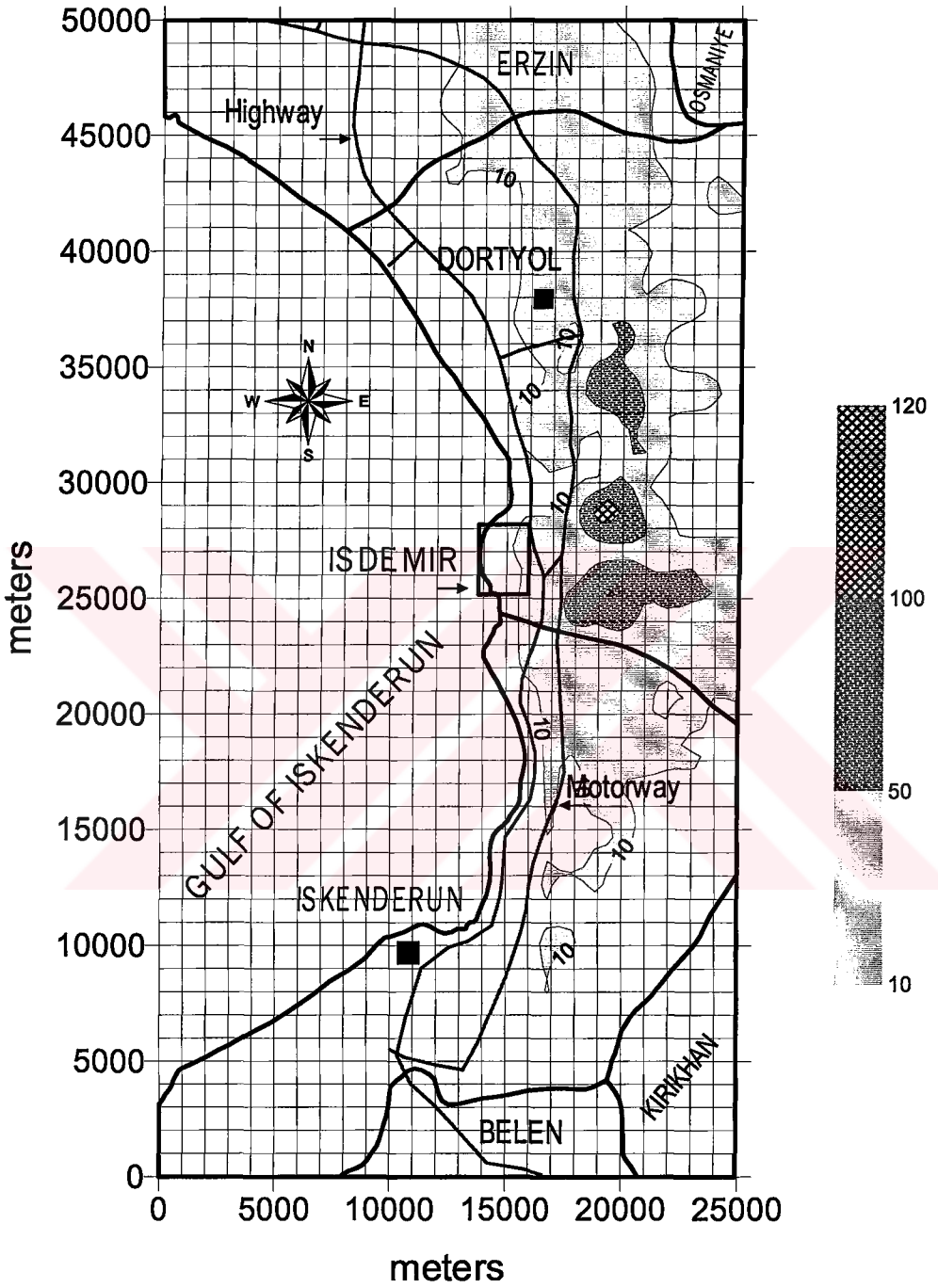

Figure 7.37 Summer average ground level concentrations ($\mu g/m^3$) of SO_2 due to all sources

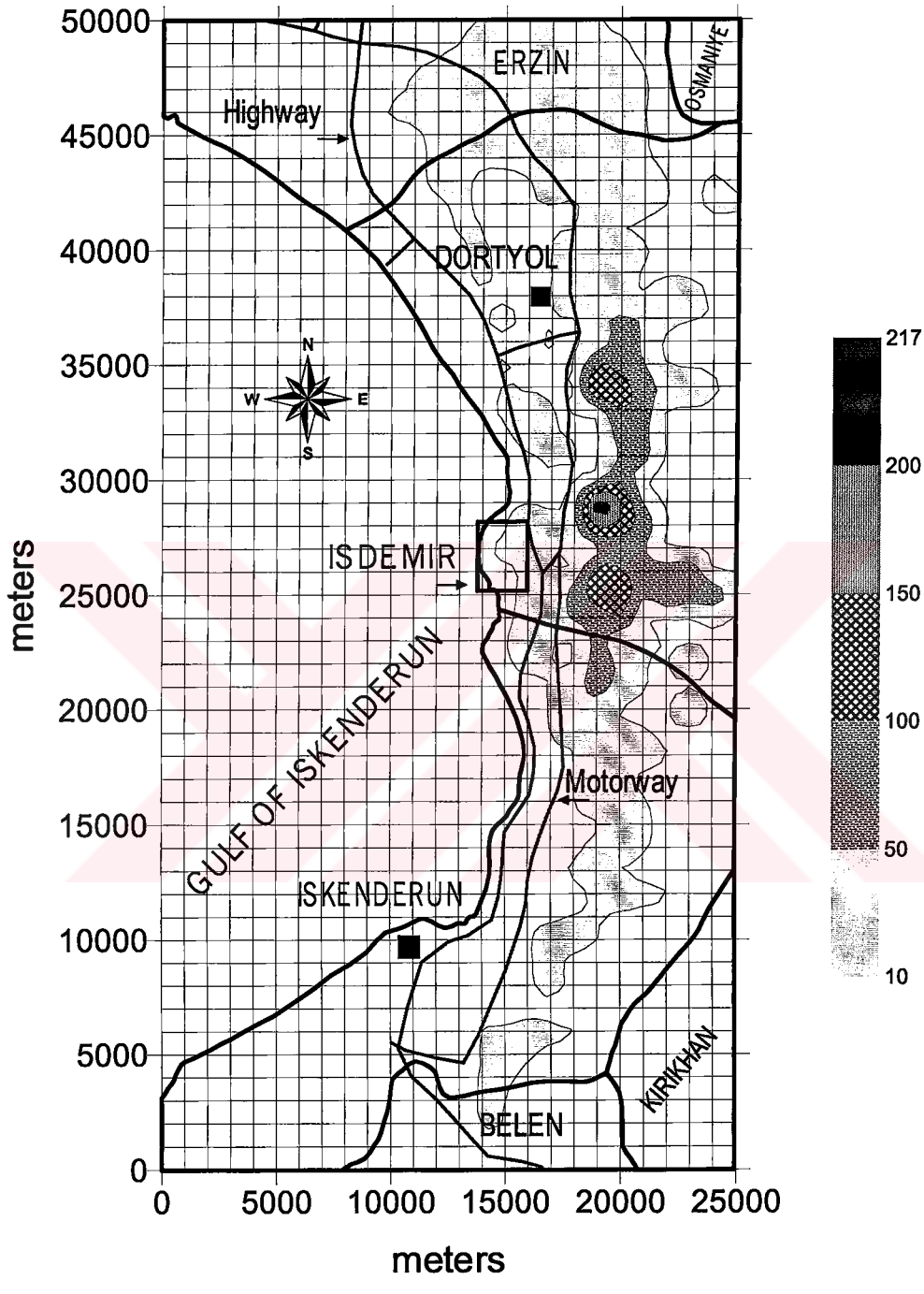

Figure 7.38. Autumn average ground level concentrations ($\mu g/m^3$) of SO_2 due to all sources

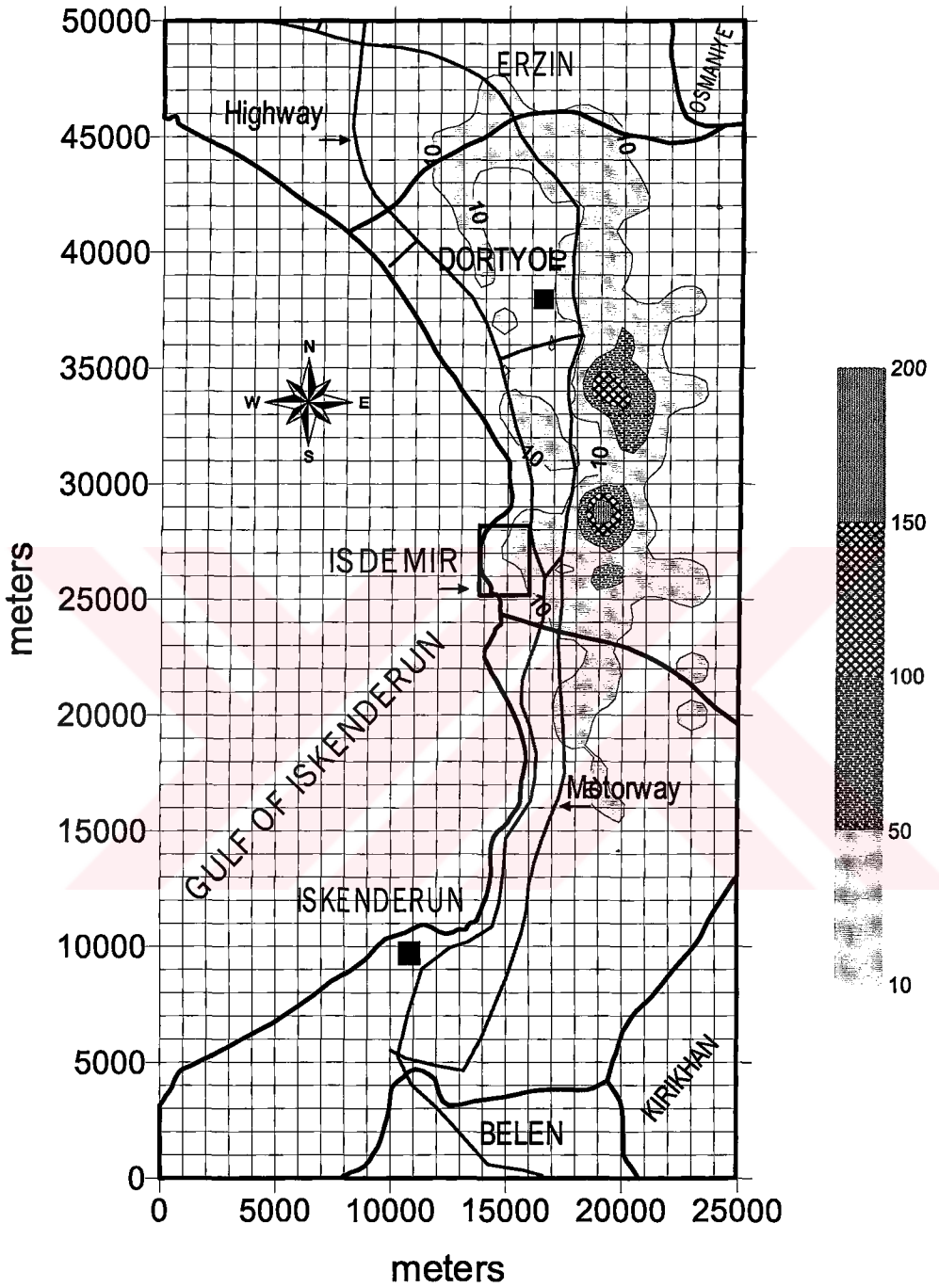

Figure 7.39 Autumn average ground level concentrations ($\mu g/m^3$) of SO_2 due to other industries

7.2.3 Short Term Dispersion of SO_2

Short-term dispersion of SO_2 was also studies for selected days from all seasons. These are the same days for which short-term dispersion of PM was studied. The short-term limit for SO_2 defined in the TAQPR is 400 $\mu g/m^3$. This limit is set to be 125 $\mu g/m^3$ in WHO Guidelines and EC Regulations.

There were 50 days during year 2001 when daily average SO_2 concentrations exceeded the limit of 400 $\mu g/m^3$ set by the TAQPR. The maximum concentration was seen near the town of Dortyol. Majority of the days exceeding the limit was during winter season when residential heating is done and the prevailing wind direction is from south. There were 19 days during the year 2001 when the daily average SO_2 concentrations exceeded the limit of 400 $\mu g/m^3$ in the city of Iskenderun. While such days were 26 and 15 for Dortyol and Payas, respectively. Moreover there were 89 days during year 2001 when the daily average (24-h average) concentrations of SO_2 exceeded the limit of 125 $\mu g/m^3$ set by WHO and EC.

Figure 7.40 shows daily average concentrations of SO_2 on January 18, 2001. As can be seen in the figure the maximum concentration of SO_2 reaches up to 650 $\mu g/m^3$ in the NE of ISDEMIR and in the southeastern parts of Iskenderun. Most parts of Iskenderun City are subjected to 10-250 $\mu g/m^3$ of SO_2 concentrations. Southern and eastern parts of Iskenderun as well as southern parts of Dortyol have SO_2 concentrations of 250-400 $\mu g/m^3$. The reasons for high concentrations of SO_2 in the urban areas on January 18, 2001 were SO_2 emissions from domestic heating sources and low wind speed. Figure 7.40 shows that most of the urban areas have 24-h average SO_2 concentrations on that day below the limit set by the TAQPR, but they exceed the WHO and EC Regulations limits of 125 $\mu g/m^3$. The short-term limit for SO_2 in the proposed revision of TAQPR is 250 $\mu g/m^3$.

Figure 7.41 shows daily average SO_2 concentrations on November 28, 2001. On that day the maximum SO_2 concentration reached to 610 $\mu g/m^3$ and the town of Dortyol was badly affected from this. That high concentration of SO_2 at Dortyol was due to the combined effects of SO_2 emissions mainly due to residential heating sources and other industries as well as due to very slow wind speed of less than 1.5 m/s blowing from south.

Figure 7.42, 7.43 and 7.44 shows 24-h average concentrations of SO_2 on selected days from spring, summer and autumn seasons of year 2001 when the SO_2 concentrations exceeded the short-term limits. As can be seen from these figures, none of the residential area was affected by these high SO_2 concentrations on those days, except some rural areas.

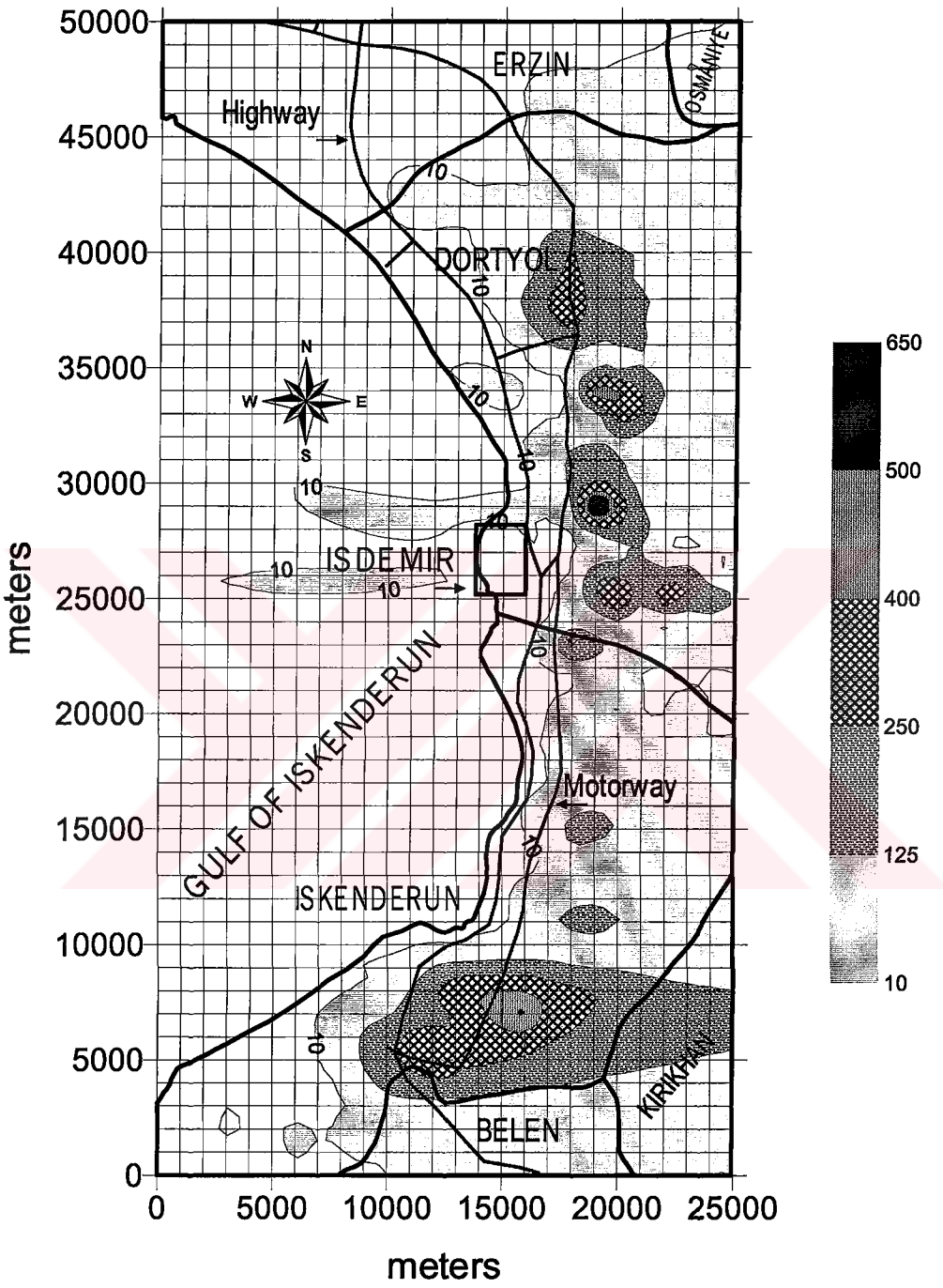

Figure 7.40 24-h average ground level concentrations ($\mu g/m^3$) of SO_2 due to all sources on January 18, 2001

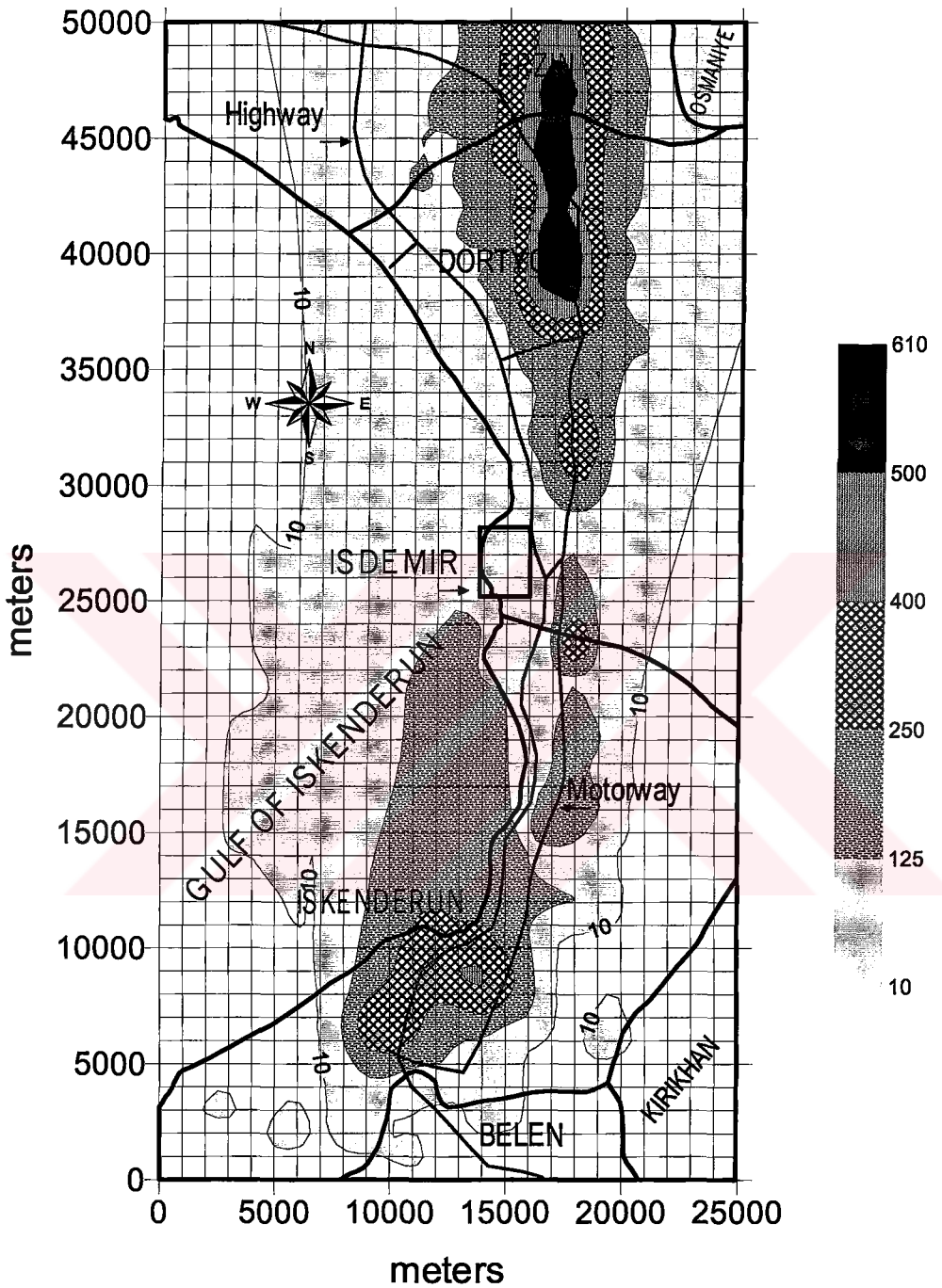

Figure 7.41 24-h average ground level concentrations ($\mu g/m^3$) of SO_2 due to all sources on November 28, 2001

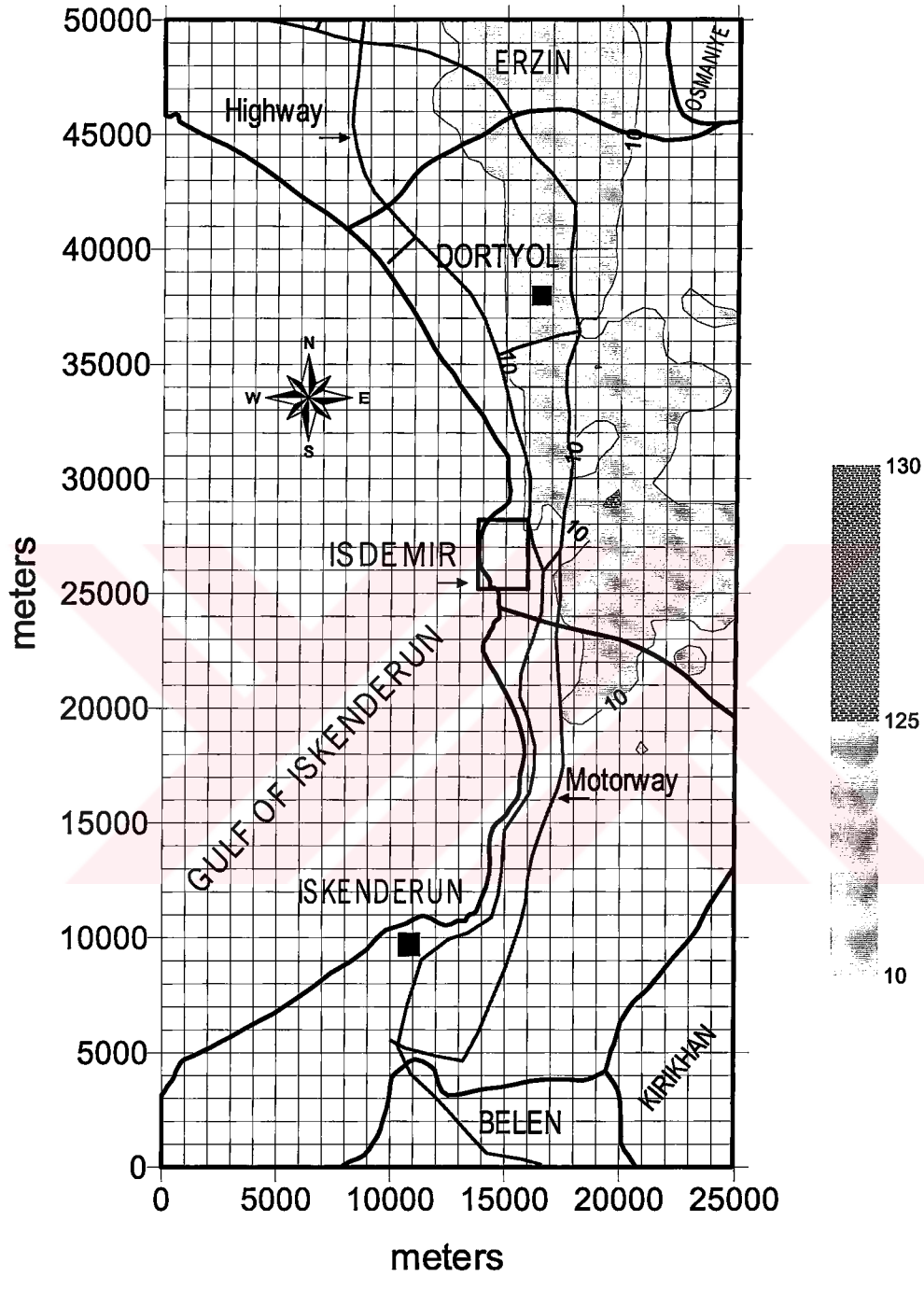

Figure 7.42 24-h average ground level concentrations ($\mu g/m^3$) of SO_2 due to all sources on April 23, 2001

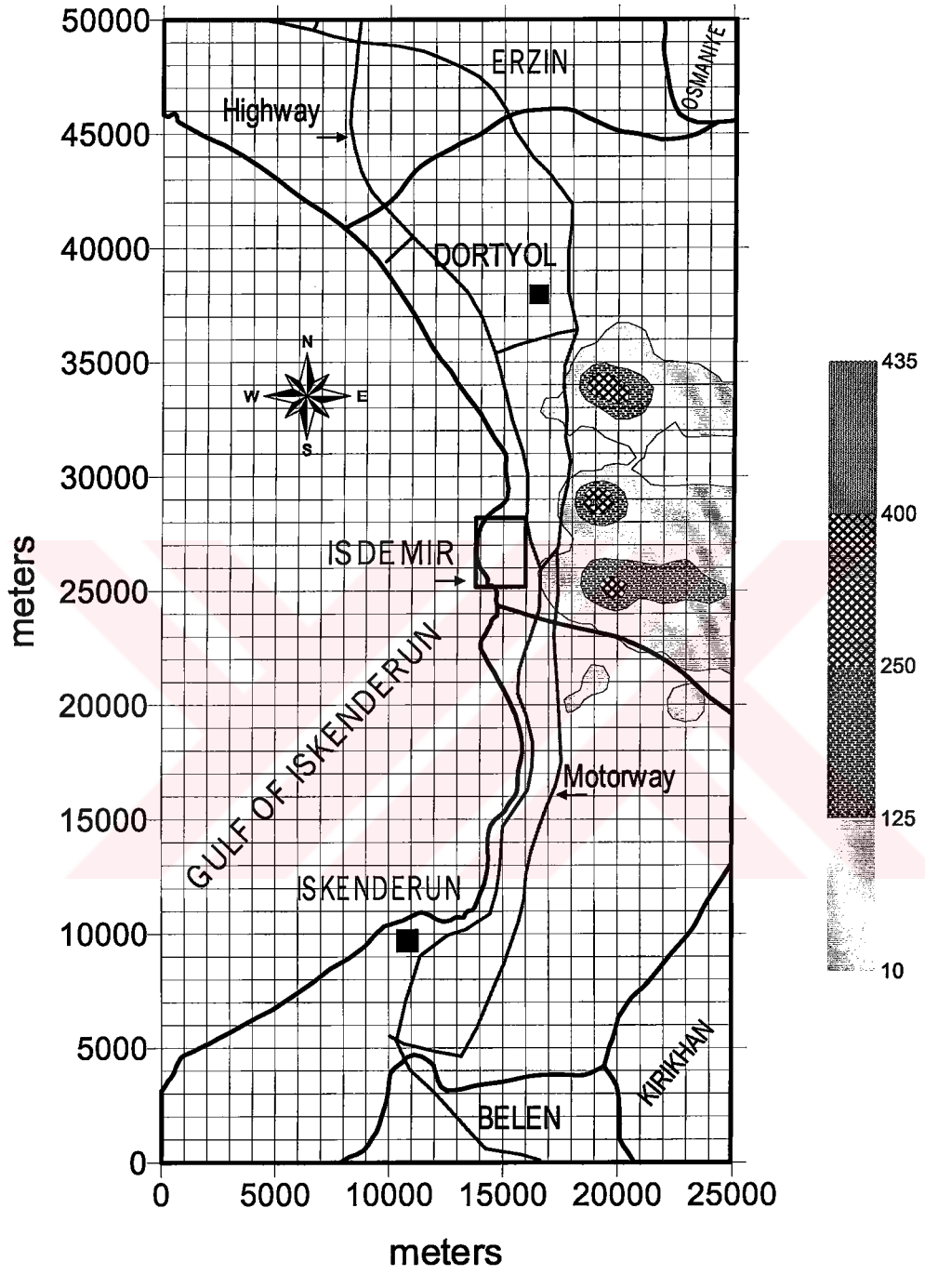

Figure 7.43 24-h average ground level concentrations ($\mu g/m^3$) of SO_2 due to all sources on July 31, 2001

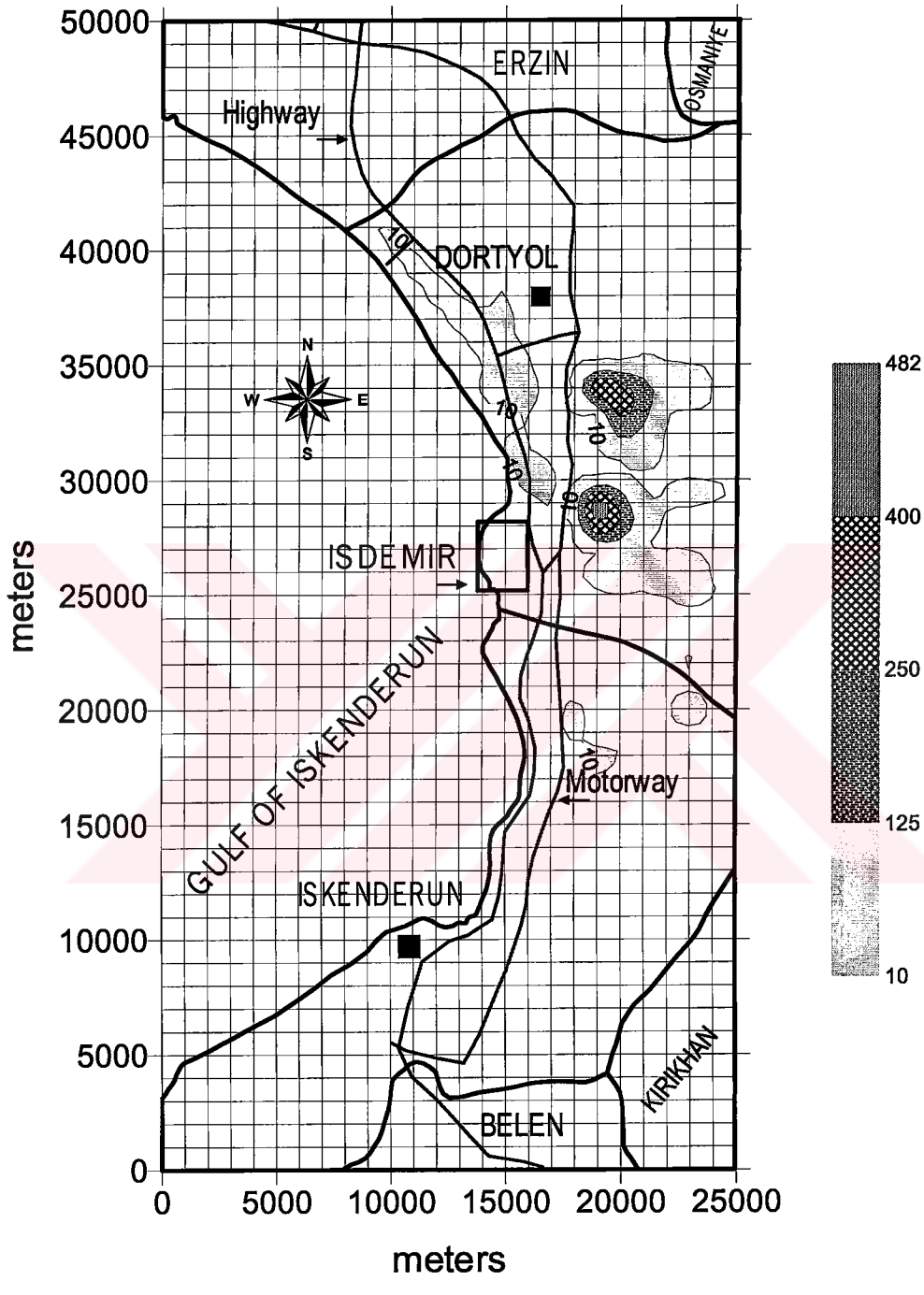

Figure 7.44 24-h average ground level concentrations ($\mu g/m^3$) of SO_2 due to all sources on October 19, 2001

7.2.4 Wet Deposition of SO_2

Figure 7.45 shows the annual wet deposition rate of SO_2 from all sources. The maximum wet deposition of 4 g/m^2-yr occurs on a very small area inside ISDEMIR near its eastern boundary. Area surrounding it is found to receive 2-3 g/m^2-yr of wet deposition of SO_2. As can be seen from the figure the area between ISDEMIR and Dortyol, about 14 km long and 2-3 km wide strip, receives a wet deposition of 1-2 g/m^2-yr of SO_2. On the other hand in the southern part of the study area, the wet deposition rate of SO_2 in Iskenderun is about 0.1-1 g/m^2-yr. The wet deposition rate is again 0.1-1 g/m^2-yr in most parts of the study area. Figure 7.46 shows wet deposition rates of SO_2 due to ISDEMIR, which emits 80% of the total SO_2 emissions in the study area. This figure shows that Dortyol receives 0.1-1 g/m^2-yr of SO_2 wet deposition due to ISDEMIR.

Since the wet deposition rate is small, acidification of soil or possibility of acid rain is not likely in the study area. A study conducted by Ornektekin et al. (2001) showed that pH of rainwater samples collected between January and May 2000 at Iskenderun, Payas and ISDEMIR were 7.08, 6.36 and 6.49, respectively. This shows that acidification of soil or acid rain is not a problem in the study area, because pH of collected rainwater samples is even more than 5.6, which is the pH of pure rainwater. Although large quantities of SO_2 are released from several sources in the study area, that may cause acidification problem, the rainwater samples did not show an acidic character according to Ornektekin's study. On the other hand considerable amounts of PM are also emitted to the atmosphere especially from ISDEMIR. This PM contains crustal elements like Al, Fe and Ca, among these elements especially Ca acts as a neutralizing agent. Soil of the study area is rich in $CaCO_3$, which was also found to be the main neutralizing agent (Ornektekin et al., 2001). Besides, considerable amounts of $CaCO_3$ are also transported to the eastern Mediterranean basin (where the study area is located) by Saharan dust (Al-Momani et al., 1995). It is expected that combined effect of transported,

anthropogenic and crustal $CaCO_3$ particles neutralize the acidic emissions from the study area and prevent acid rain.

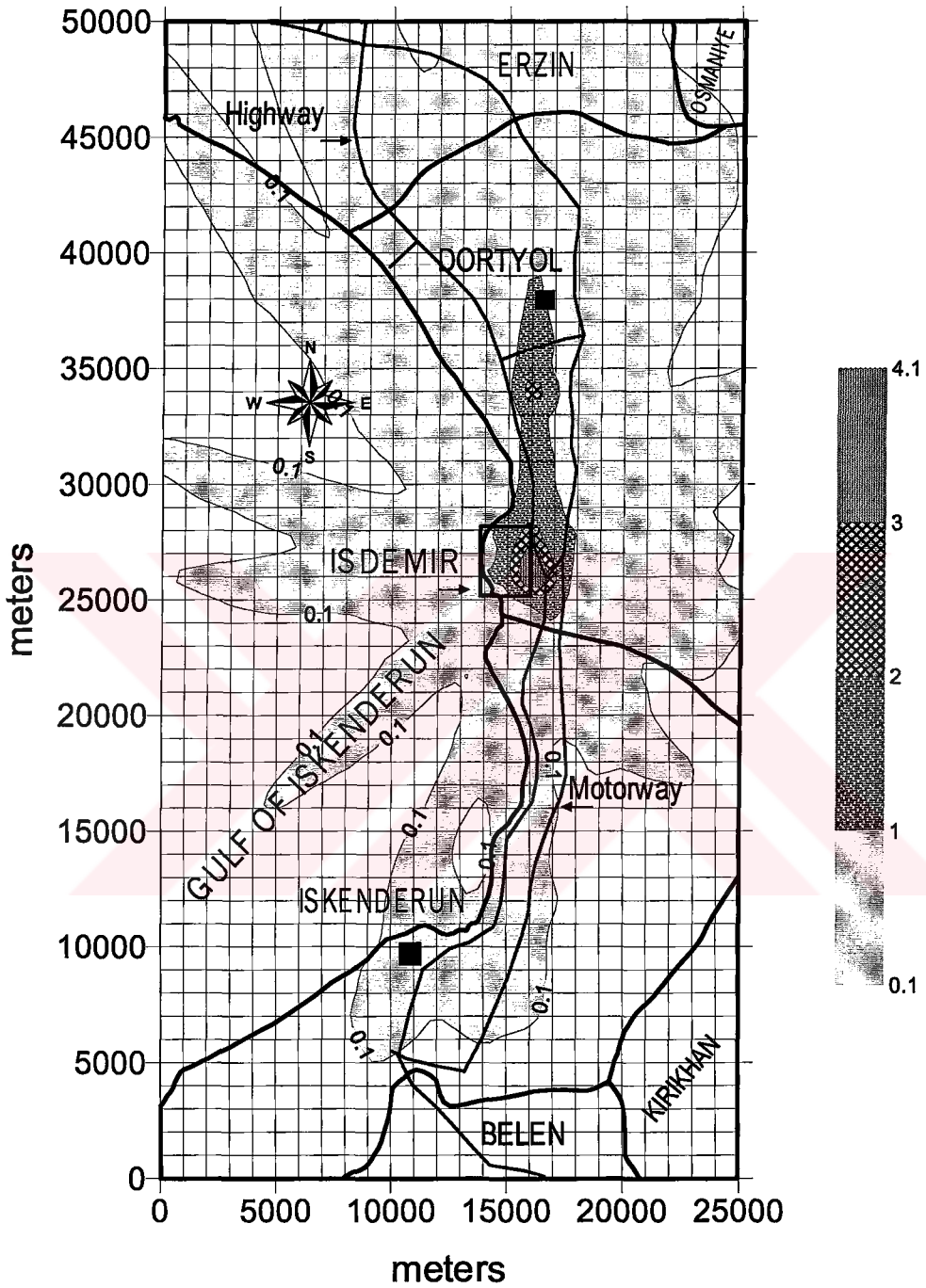

Figure 7.45. Annual wet deposition rate (g/m^2-yr) of SO_2 due to all sources

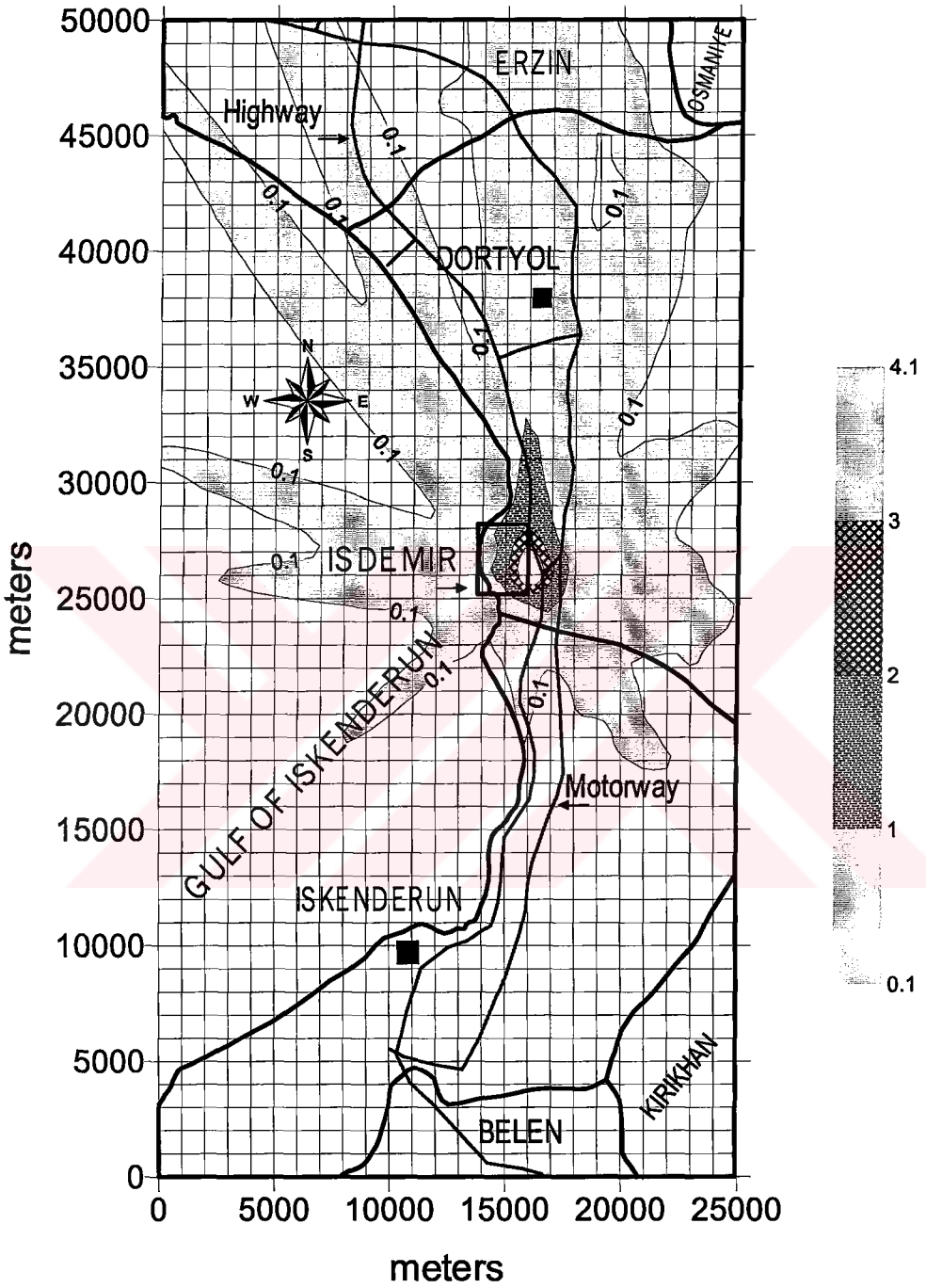

Figure 7.46. Annual wet deposition rate (g/m^2-yr) of SO_2 due to ISDEMIR

7.3 Modeling of NO_X

Results of dispersion modeling calculations for NO_X from all sources on annual, seasonal and daily basis are given in Figure 7.47 to 7.65.

7.3.1 Annual Dispersion of NO_X

The results for the annual dispersion of NO_X are shown in Figures 7.47 to 7.51. The annual average ground level concentrations of NO_X estimated by including all sources including traffic is shown in Figure 7.47. As can be seen from this figure, the annual average ground level concentration reaches up to 158 $\mu g/m^3$ at the city center of Iskenderun. The concentration in Iskenderun City lies mostly between 50-150 $\mu g/m^3$. In Dortyol and Payas maximum concentrations are 150 and 100 $\mu g/m^3$, respectively. The long-term limits for NO_2 and NO are defined as 100 and 200 $\mu g/m^3$, respectively, in the TAQPR. The major nitrogen oxide in the atmosphere is NO_2. The annual average ground level NO_2 concentrations exceed this limit at the locations mentioned above except Payas. Around these high concentration locations and along the highway and the motorway, there are some pockets where the NO_X concentration is about 100 $\mu g/m^3$. These regions are just at the limit set by the TAQPR for NO_2. The annual average concentrations of NO_X in almost all the study area, except the ones mentioned above, are from 10 to 50 $\mu g/m^3$. A very characteristic result is seen in Figure 7.47. As can be seen in the figure there is a belt of NO_X concentration areas along the highway and motorway where the concentration is between 10 and 40 $\mu g/m^3$. Although the limits of TAQPR are satisfied in most of the study area except in cities of Iskenderun and Dortyol, the NO_X concentrations are above the limits according to the EC Regulation and the WHO Guidelines. The long-term limits of NO_2 set by EC Regulation and WHO Guidelines are 50 and 40 $\mu g/m^3$, respectively.

Whenever the NO_2 concentration is high in the atmosphere there may be a possibility of photochemical smog formation along with NMVOC emissions.

This poses a danger to human health. Therefore, ozone and NO_2 measurements in the ambient air especially during summer season are advised for the study area.

The sources of NO_X emissions are industry, traffic and partly residential heating. The contributions of each source in the total annual NO_X emissions were 68%, 31% and 3%, respectively. According to the emissions measurements and the emission inventory it was found that 60% of the annual NO_X emissions in the study area were due to ISDEMIR. In order to find the contribution of ISDEMIR on the annual average ground level NO_X concentrations, the model has been run to see its effect separately. The results are shown in Figure 7.48 and 7.49. As it is clearly seen from the figures that the contribution of industry on the annual average NO_X concentrations is very little, up to 20 $\mu g/m^3$ in two small areas.

Figures 7.48 and 7.49 show the annual average NO_X concentrations due to ISDEMIR and other industries, respectively. The maximum NO_X concentrations due to ISDEMIR and other industries are 17 and 15 $\mu g/m^3$, respectively. Although ISDEMIR is the largest NO_X emitter in the area, its effect on the annual average ground level NO_X concentration is not much. This is most probably due to tall stacks of ISDEMIR and the wind condition, which ensures better dispersion of NO_X. The maximum NO_X concentration due to domestic heating was 5 $\mu g/m^3$, because of very low concentrations the map for domestic heating is not given here. These concentrations are well below the limits set by the TAQPR, EC Regulations and WHO Guidelines.

Figure 7.50 shows the annual average ground level concentration of NO_X due to the traffic on Iskenderun-Adana Highway and Motorway located in the study area. This figure shows that there are a number of pockets along these roads where NO_X concentration changes between 10 and 40 $\mu g/m^3$. The maximum NO_X concentration due to highway traffic was found to reach up to 55 $\mu g/m^3$ but only at three very small pockets adjacent to these inter-city roads. As can

be seen in Figures 7.48 and 7.49 the contribution of all other sources to the NO_X concentration at the ground level is very small, being between 5 and 10 $\mu g/m^3$. Only on very small area the concentration reaches up to 15 and 20 $\mu g/m^3$.

Figure 7.51 shows the annual average NO_X concentrations due to urban traffic at Iskenderun, Dortyol and Payas. The maximum NO_X concentration reached in the central parts of Iskenderun up to 150 $\mu g/m^3$. Generally a NO_X concentration of over 10 $\mu g/m^3$ prevails over almost in all of the urban areas in the study area, but central and eastern parts of Iskenderun City found to be subjected to a NO_X concentration of 40-100 $\mu g/m^3$, which is although below the limits set by the TAQPR, but exceeds the WHO Guidelines and EC limits. Only a small central part of Iskenderun has NO_X concentrations of 100-150 $\mu g/m^3$, which exceeds the TAQPR limits. In Dortyol and Payas the maximum NO_X concentration reaches up to 100 $\mu g/m^3$ which is below TAQPR limits, but exceeds WHO guide lines and EC Regulations limits. Therefore, the NO_X emissions form traffic are found to pose an air pollution problem in the urban areas.

Detailed analysis of the results given in figure 7.47 to 7.51 revealed that the contributions of traffic sources in the annual average NO_X concentrations at the city centers of Iskenderun, Payas and Dortyol were found to be 65%, 25% and 42%, respectively. The contributions of domestic heating in the same places were found to be 9%, 24% and 28%, respectively. Contributions of other industries in annual average NO_X concentration were seen at Payas and Dortyol, which were 3% and 9%, respectively. The share of ISDEMIR in the NO_X concentration was the least among all sources with 0.2%, 0.6% and 2.5% at city centers of Iskenderun, Payas and Dortyol, respectively. Highway traffic was responsible for 26%, 9% and 18% of annual NO_X concentrations at the city centers of Iskenderun, Payas and Dortyol, respectively. These results are shown graphically in Figure 7.51A.

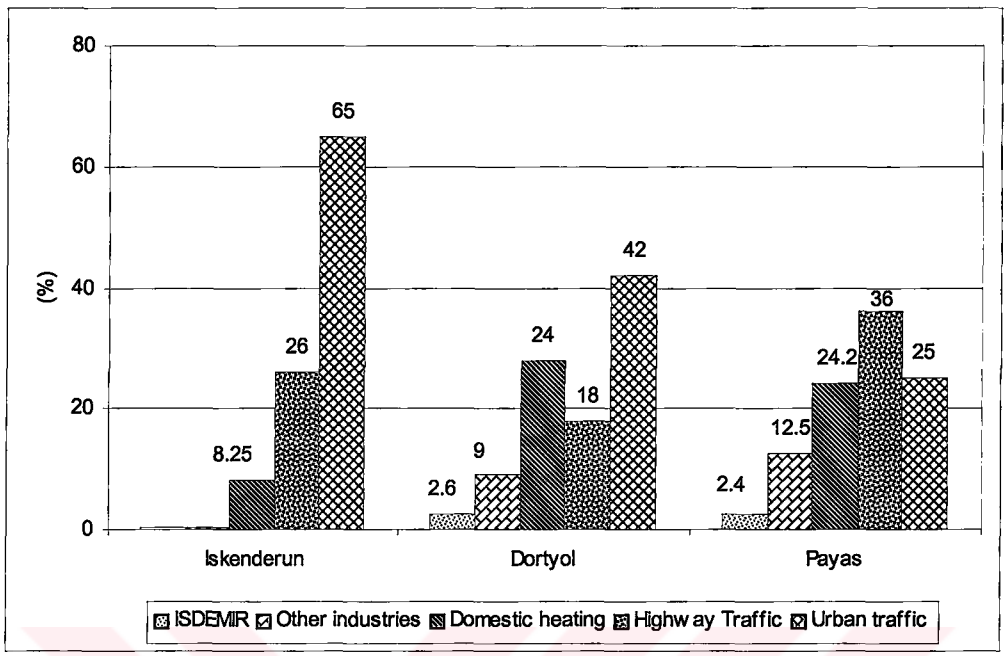

Figure 7.51A Contributions of several sources in the annual average NO_X concentrations in Iskenderun, Dortyol and Payas.

Although the contribution of traffic sources in the annual NO_X emissions is 31%, modeling results show that traffic sources are the major cause of NO_X concentration in the study area. This can be attributed to the tail pipe of vehicles being about only 40-100 cm high from the ground level. Therefore, NO_X emitted very close to the ground level cannot be dispersed properly and thus causing high ground level concentrations of NO_X.

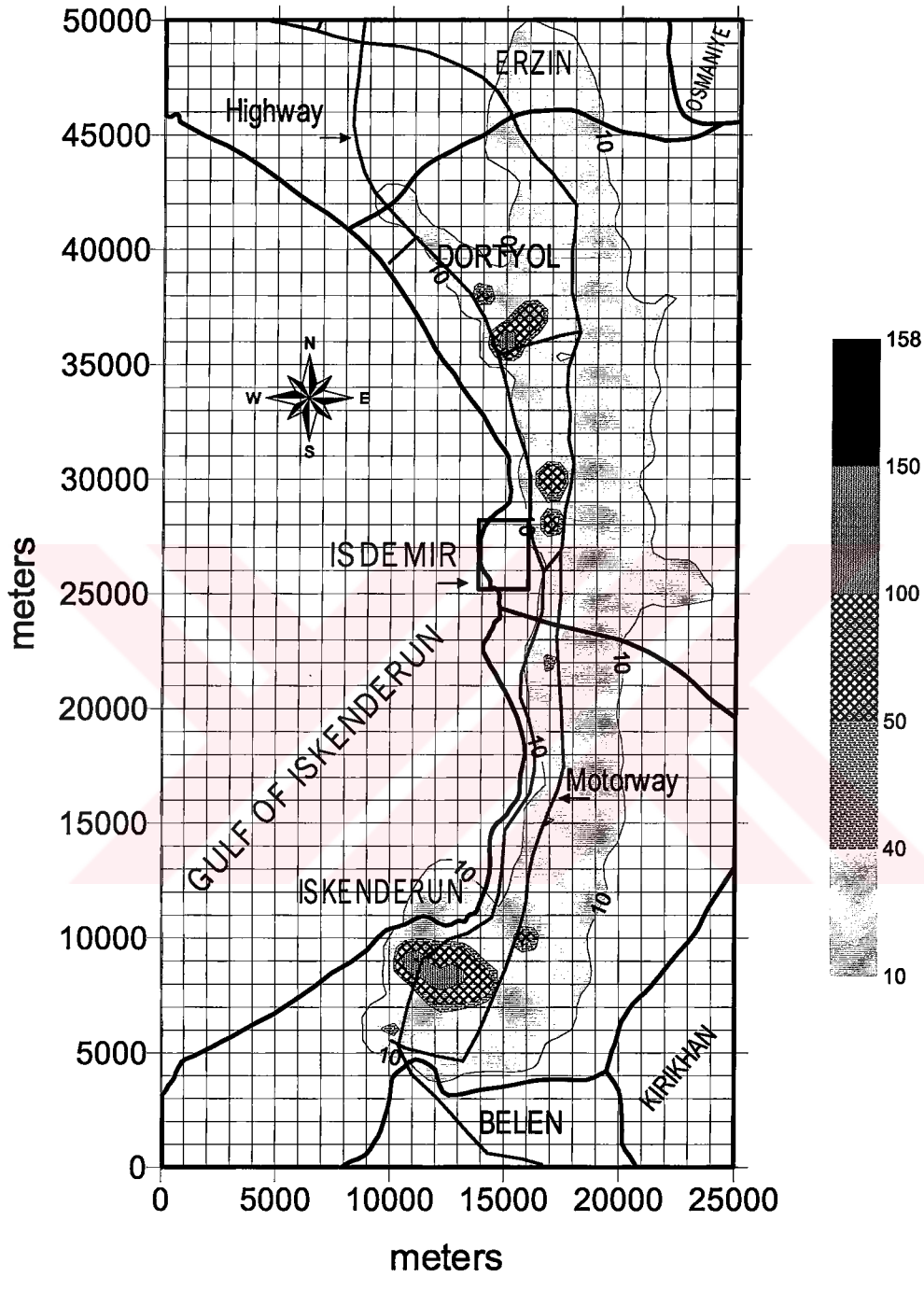

Figure 7.47 Annual average ground level concentrations ($\mu g/m^3$) of NO_X due to all sources

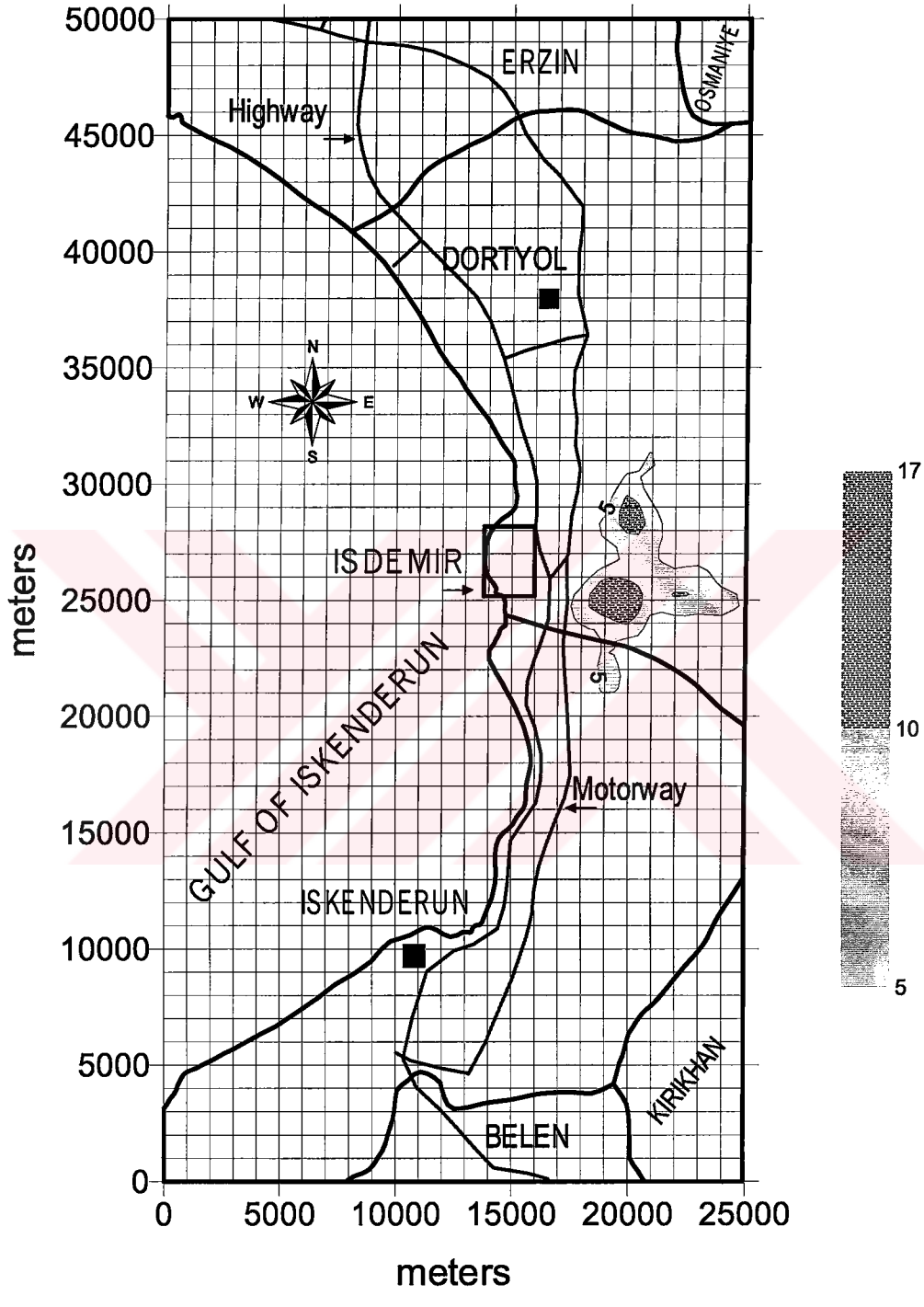

Figure 7.48 Annual average ground level concentrations ($\mu g/m^3$) of NO_X due to ISDEMIR

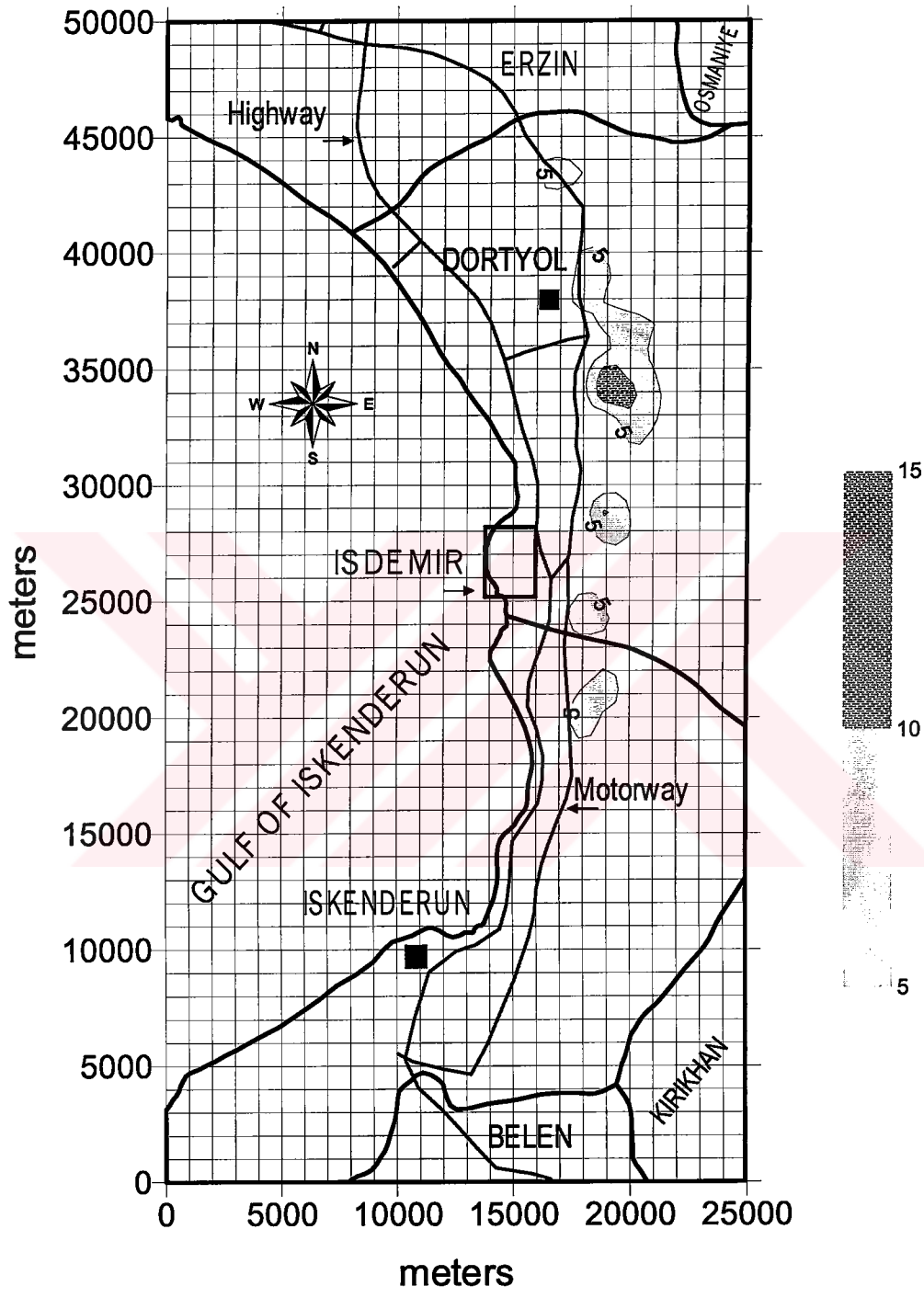

Figure 7.49 Annual average ground level concentrations ($\mu g/m^3$) of NO_X due to other industries

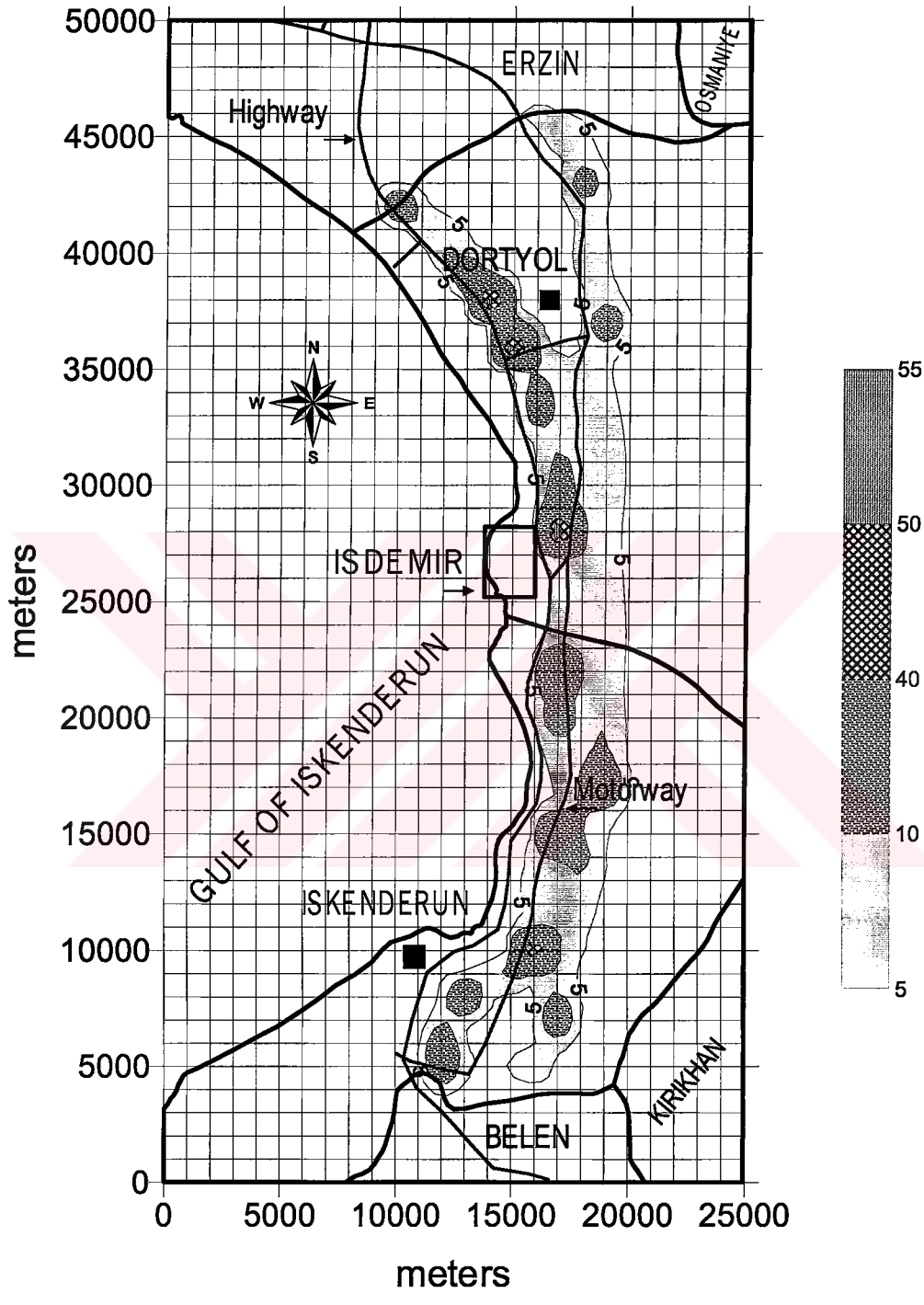

Figure 7.50 Annual average ground level concentrations ($\mu g/m^3$) of NO_X due to traffic sources on highways

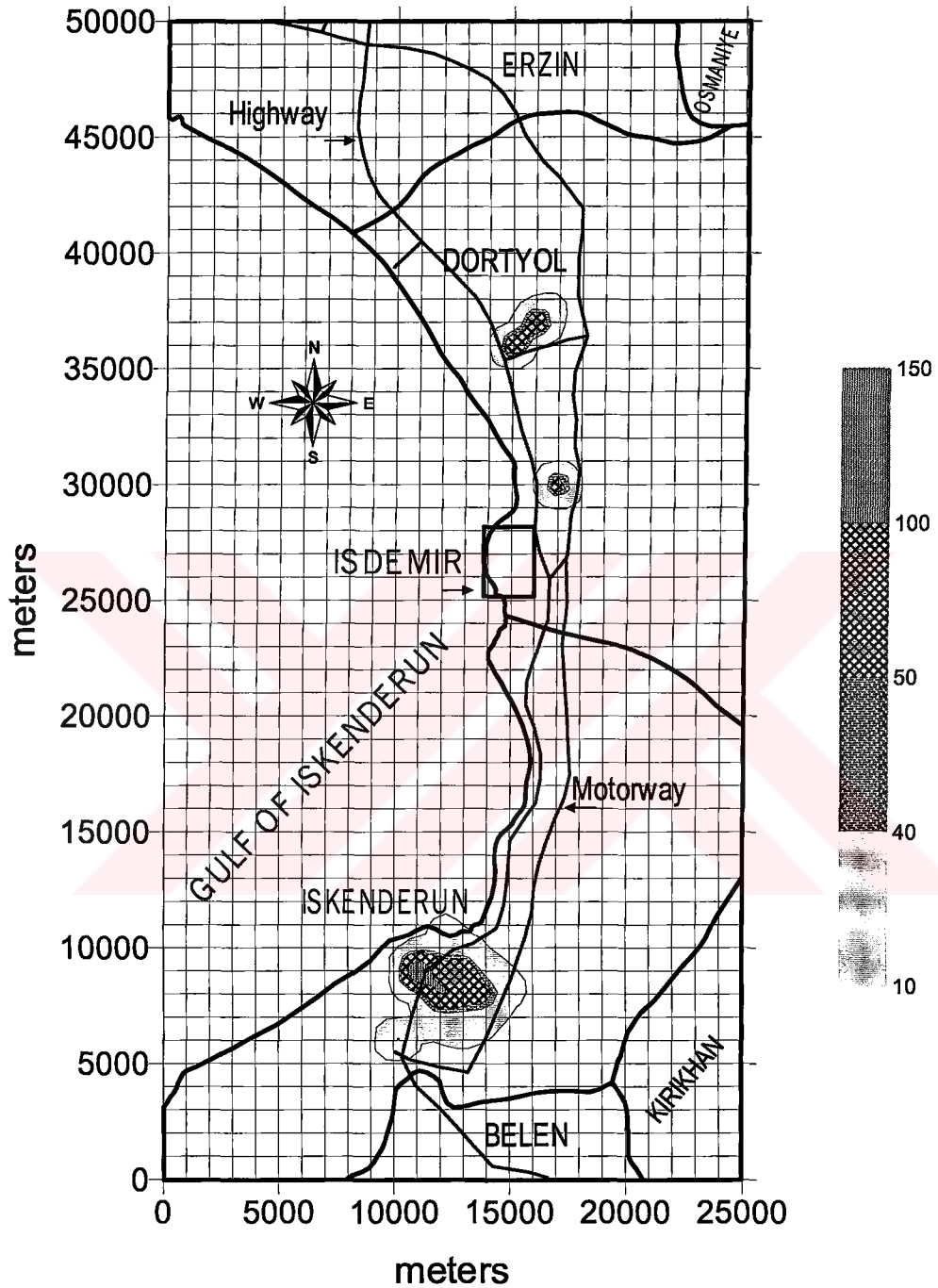

Figure 7.51 Annual average ground level concentrations ($\mu g/m^3$) of NO_X due to urban traffic sources

7.3.2 Seasonal Dispersion of NO_X

Figures 7.52 to 7.57 show the winter average ground level concentrations of NO_X due to all sources as well as contributions of several sources to it. As can be seen from these figures, the same trend seen in the annual average NO_X concentration is also prevailing for winter. A ground level NO_X concentration ranging from 40 to 160 $\mu g/m^3$ is seen during winter in the southeastern and eastern parts of Iskenderun city and up to 130 $\mu g/m^3$ in Dortyol, as shown in Figure 7.52. This result seems to be due to the combined effects of traffic sources and domestic heating. Again during winter the effects of ISDEMIR and other industries on the ground level concentrations of NO_X are very small. Figure 7.55 shows the winter average NO_X concentration due to domestic heating. Maximum concentration of up to 28 $\mu g/m^3$ is found in the southeast of Iskenderun and central parts of Dortyol. On the average NO_X concentration due to domestic heating in Iskenderun and Dortyol remain above 10 $\mu g/m^3$. With the results obtained from Figures 7.56 and 7.57, one can conclude that the traffic sources are responsible for winter average NO_X concentration in the study area with a maximum NO_X concentration reaching up to 142 $\mu g/m^3$.

Figures 7.58 to 7.60 show the spring, summer and autumn average ground level NO_X concentrations due to all sources. These figures show that traffic on inter-city and urban roads has the major responsibility for seasonal average NO_X concentration in the study area. As mentioned above, this is due to release of NO_X from vehicles in the traffic at a height that is very close to ground level. The effect of other sources on seasonal average ground level NO_X concentrations for the spring, summer and autumn has been found to be almost negligible.

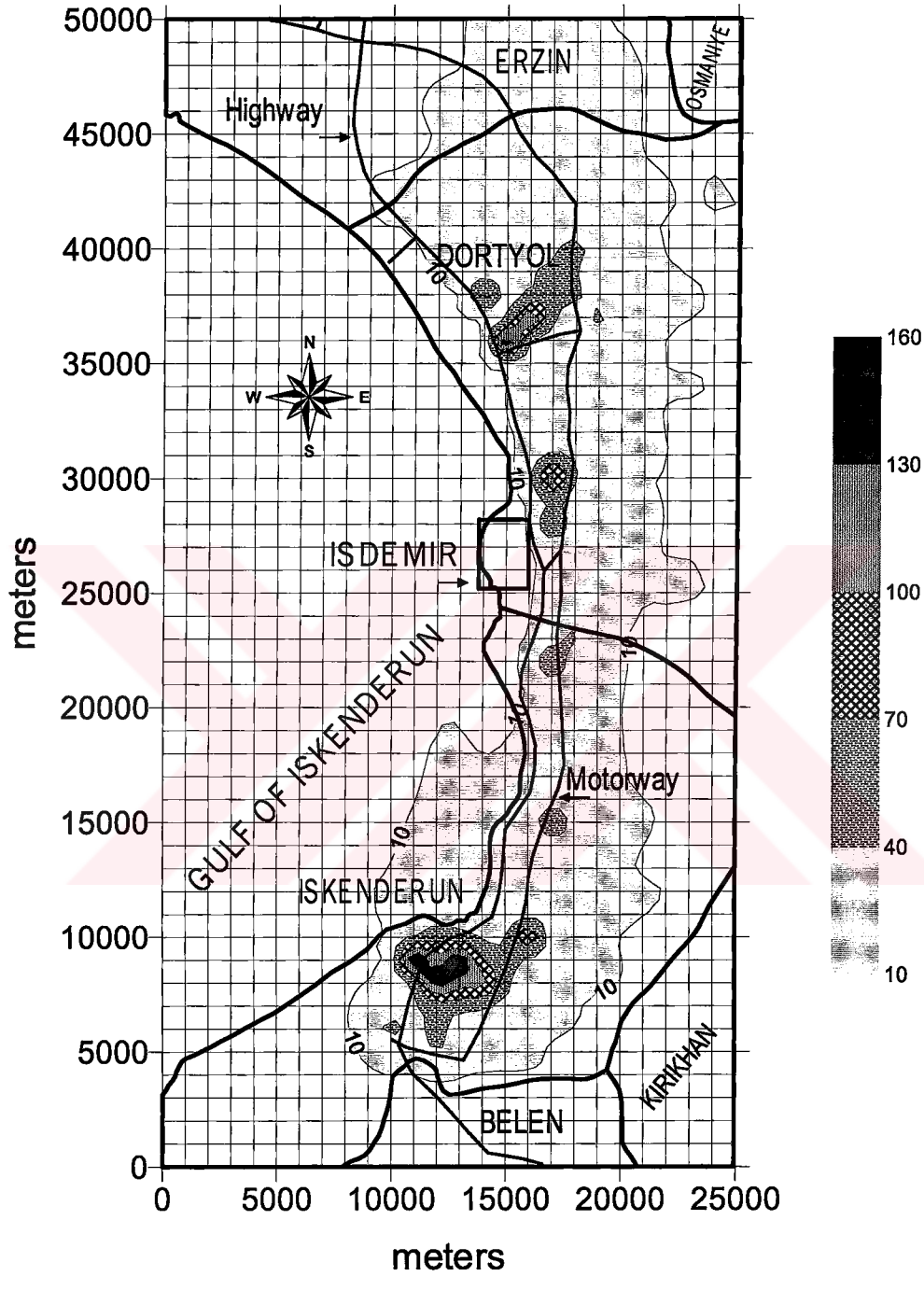

Figure 7.52 Winter average ground level concentrations ($\mu g/m^3$) of NO_X due to all sources

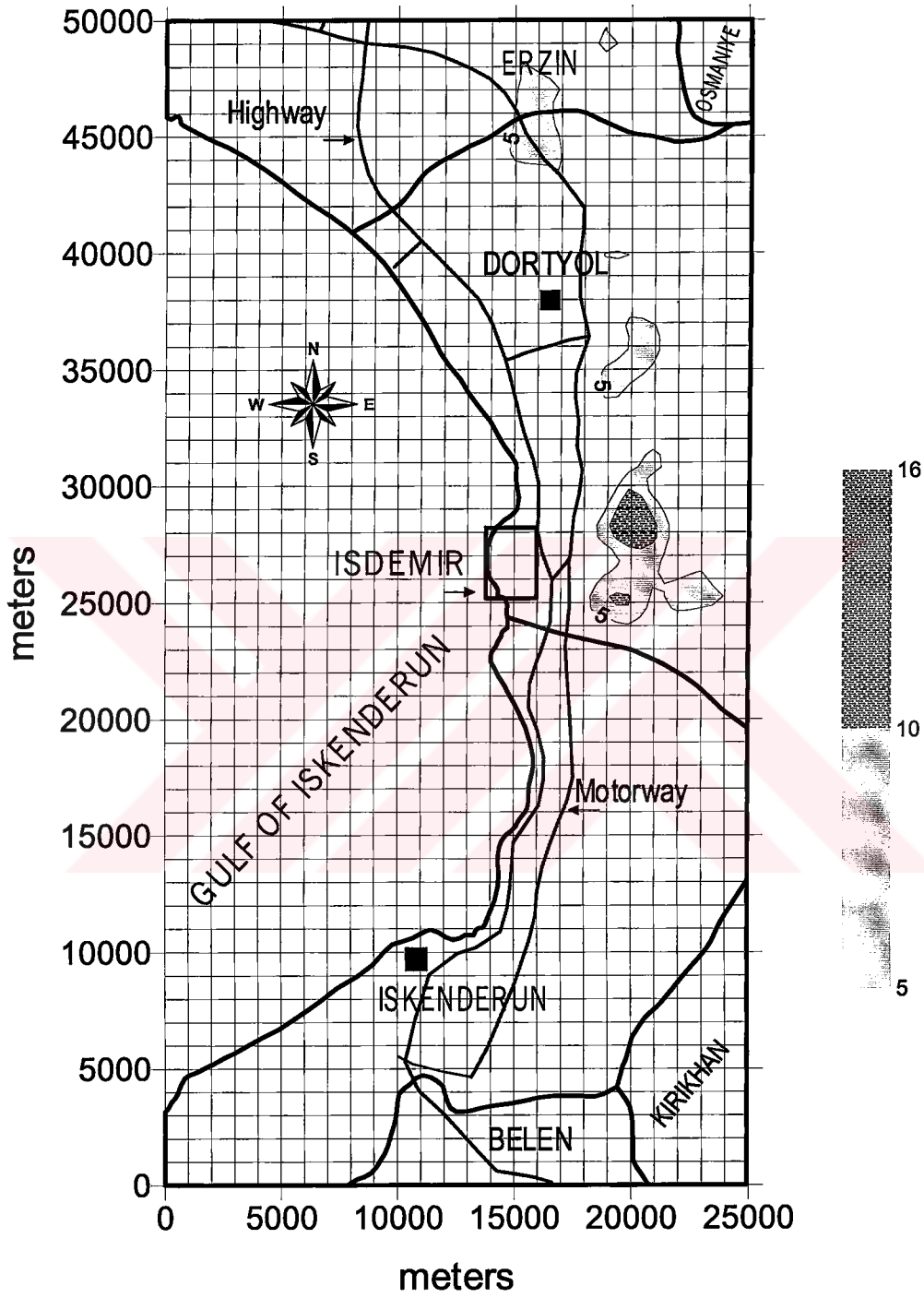

Figure 7.53 Winter average ground level concentrations ($\mu g/m^3$) of NO_X due to ISDEMIR

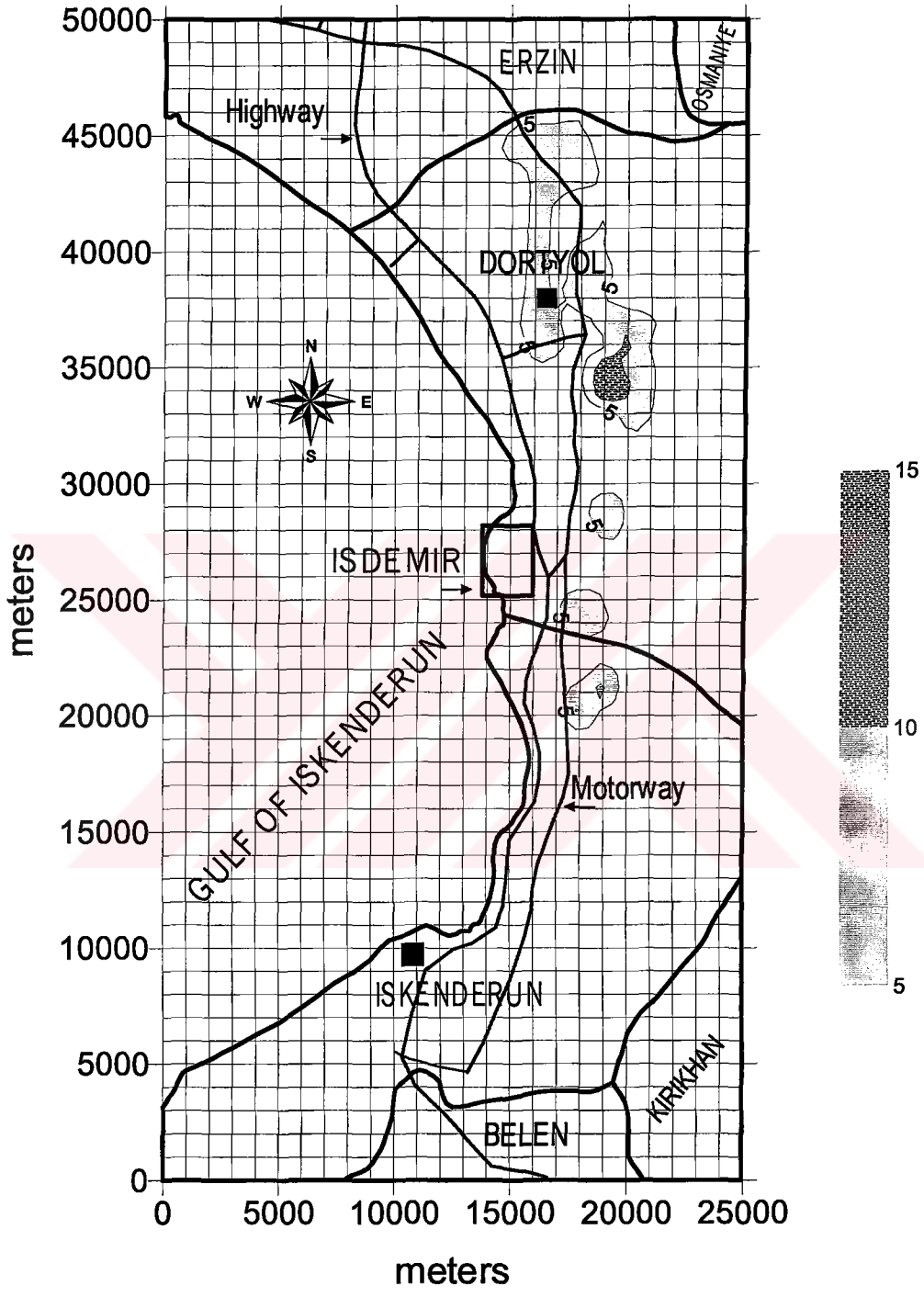

Figure 7.54 Winter average ground level concentrations ($\mu g/m^3$) of NO_X due to other industries

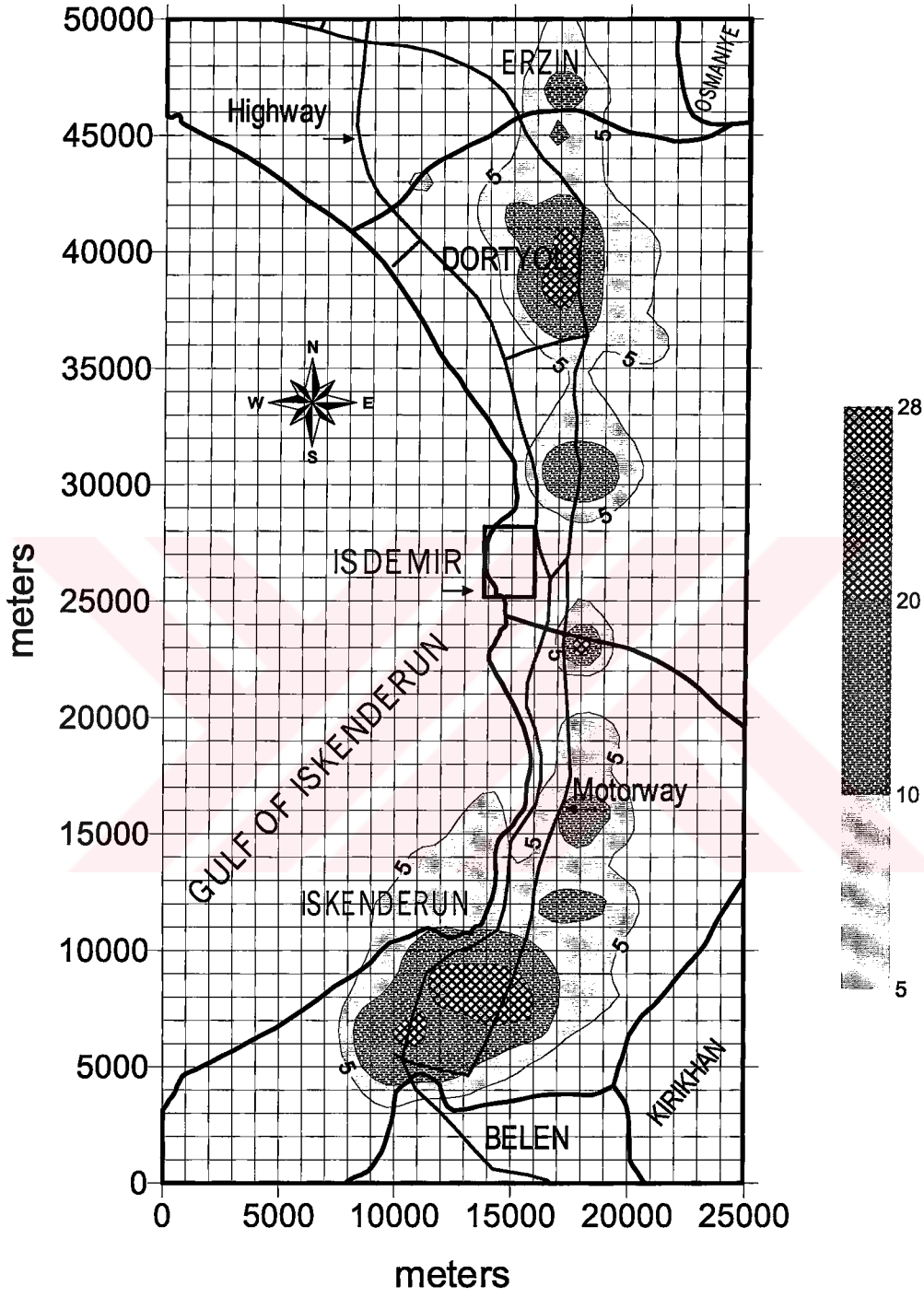

Figure 7.55 Winter average ground level concentrations ($\mu g/m^3$) of NO_X due to residential heating sources.

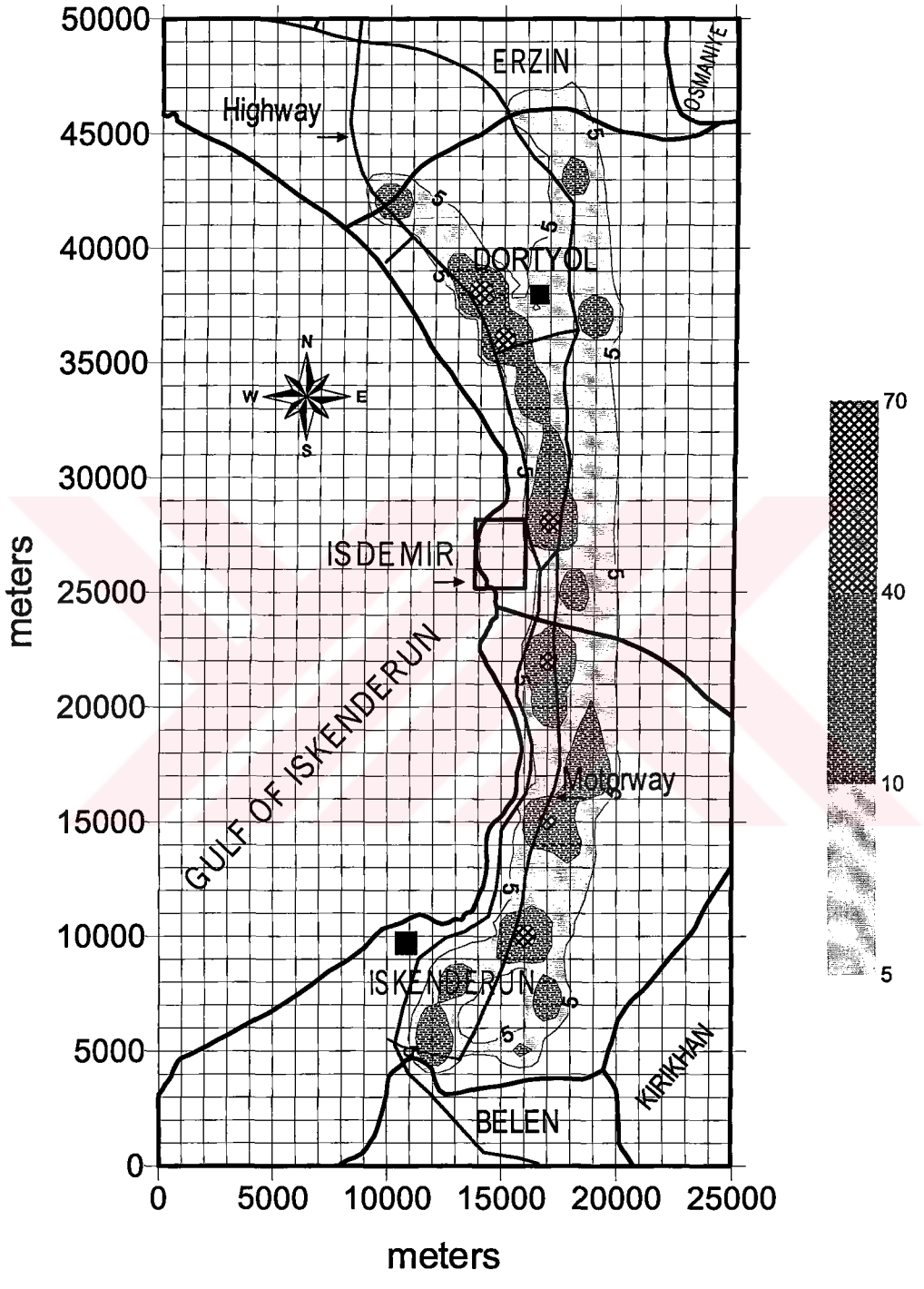

Figure 7.56. Winter average ground level concentrations ($\mu g/m^3$) of NO_X due to traffic sources on highways

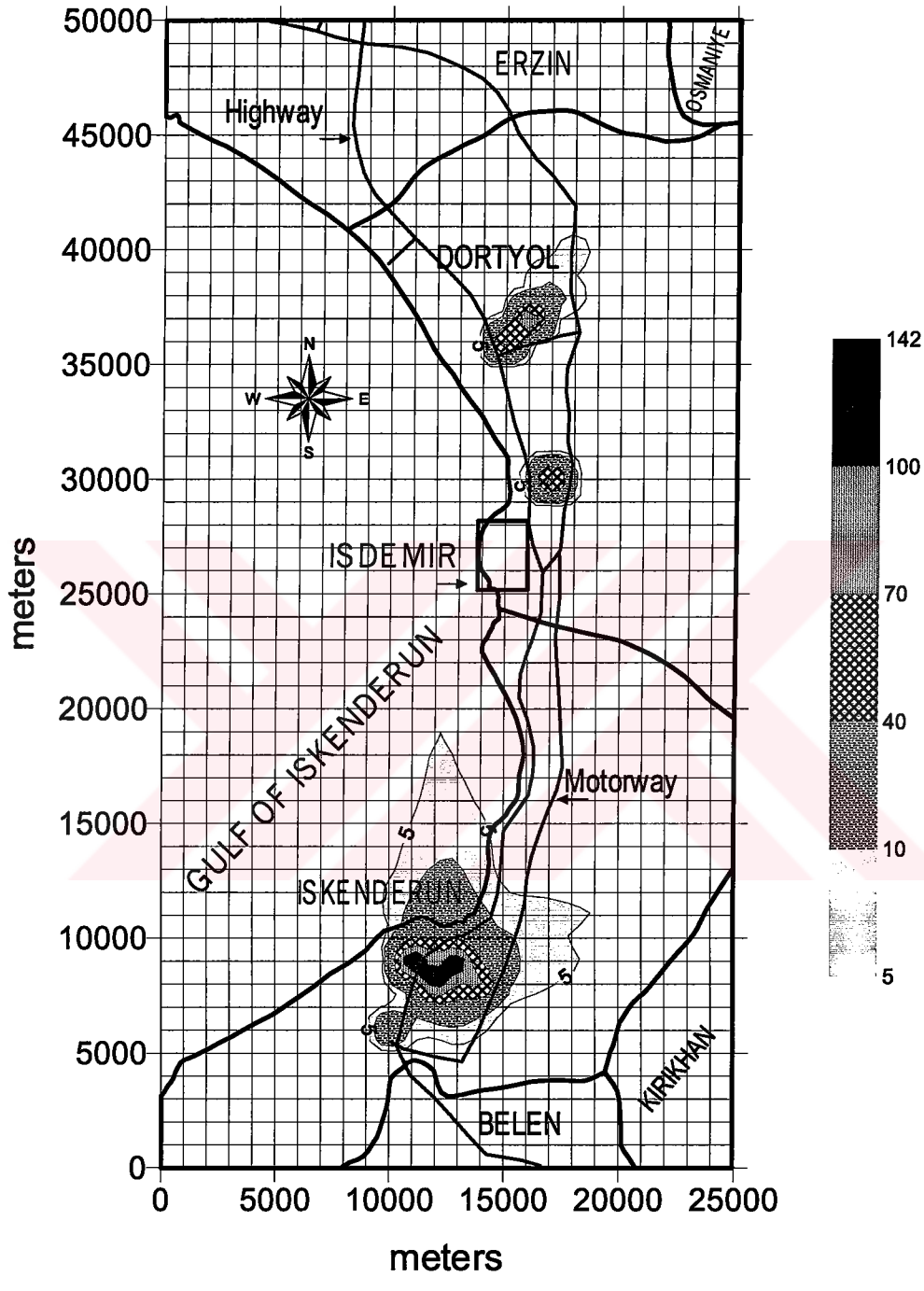

Figure 7.57. Winter average ground level concentrations ($\mu g/m^3$) of NO_X due to urban traffic sources

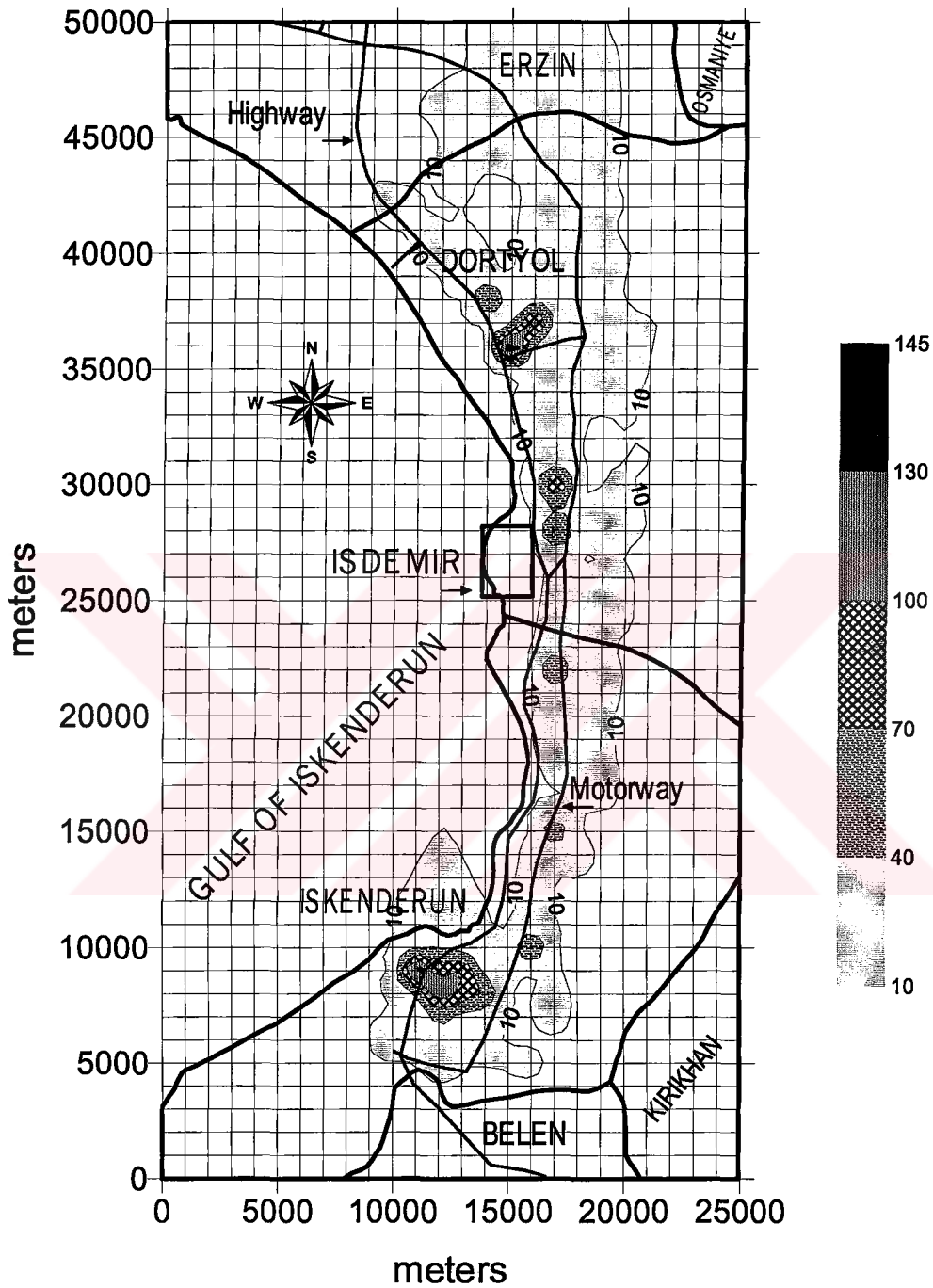

Figure7.58 Spring average ground level concentrations ($\mu g/m^3$) of NO_X due to all sources

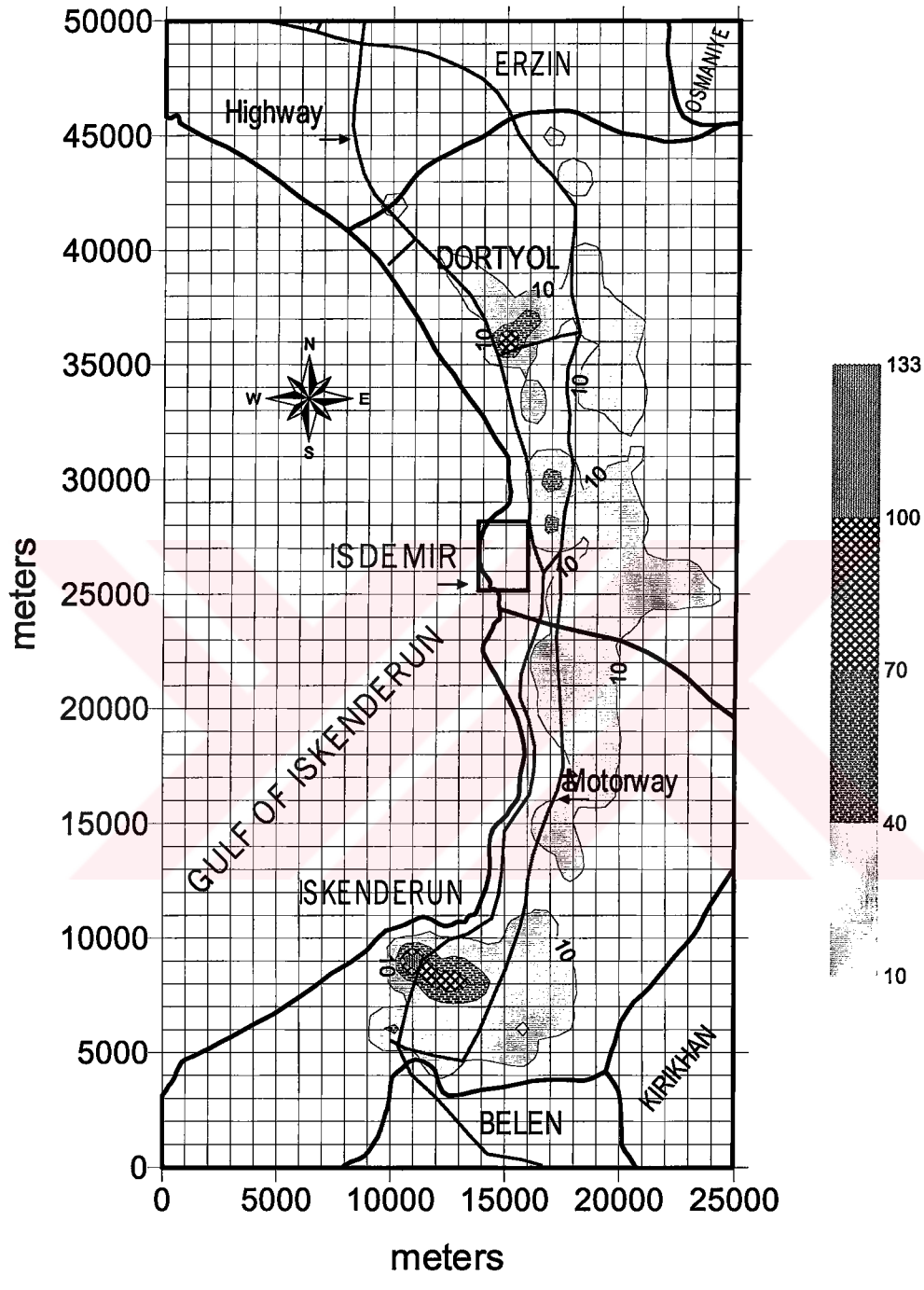

Figure 7.59 Summer average ground level concentration ($\mu g/m^3$) of NO_X due to all sources

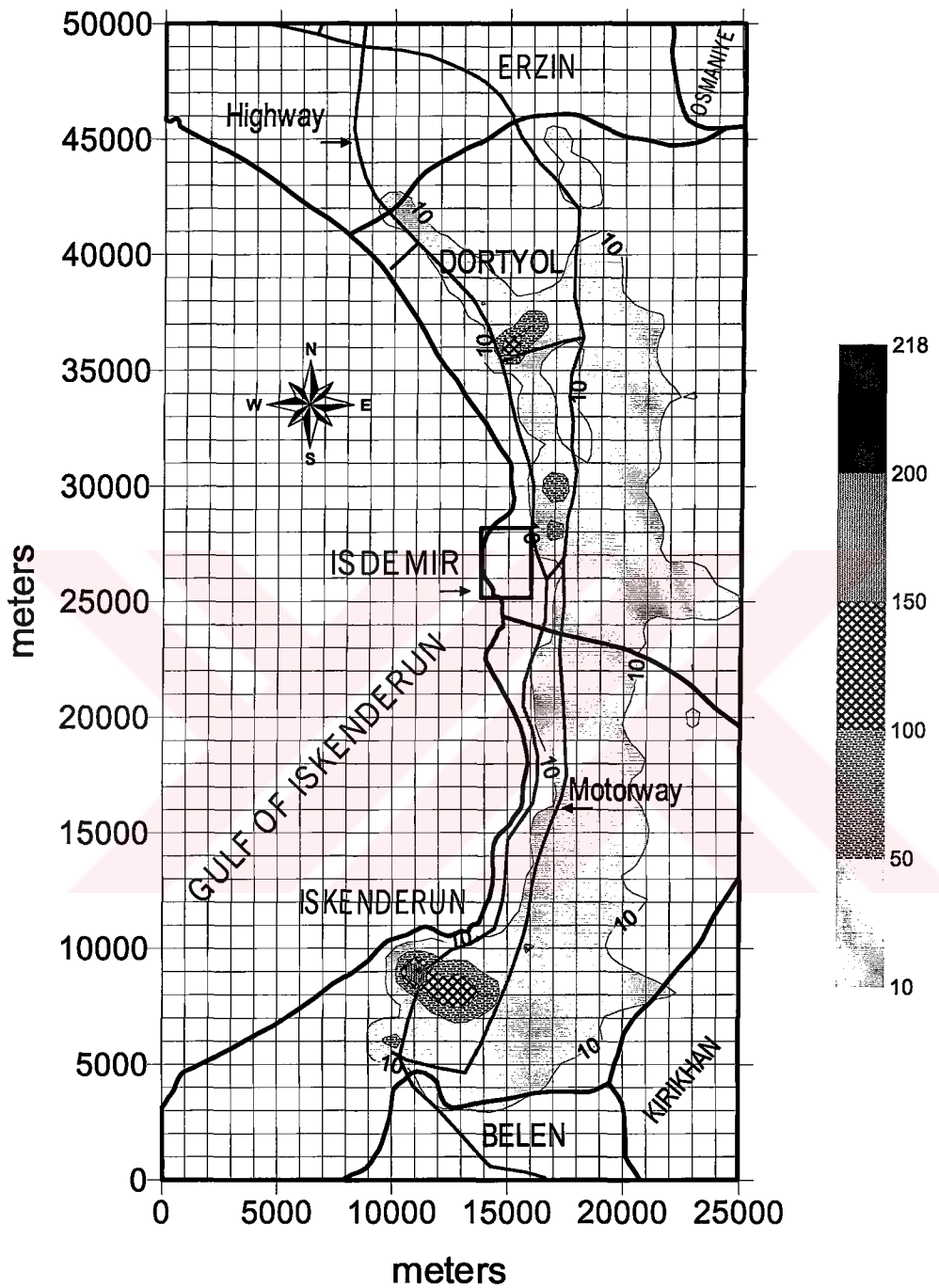

Figure 7.60. Autumn average ground level concentration ($\mu g/m^3$) of NO_X due to all sources

7.3.3 Short-Term Dispersion of NO_X

The short-term dispersion of NO_X was studied for selected days from all the seasons. Model was run for calculation of the daily average concentrations of NO_X for the same days for which short-term concentrations for PM and SO_2 were studied.

Results of model runs have shown that there were 28 days during the year 2001 when the daily average NO_X concentrations exceeded the short-term limit of 300 $\mu g/m^3$ defined in the TAQPR. All of these concentrations above the limit were found to be in the city of Iskenderun.

Figure 7.61 shows the daily average NO_X concentrations due to all sources on January 18, 2001. As can be seen in the figure the concentrations of NO_X are below 300 $\mu g/m^3$ in almost all of the study area. However, in a very small part of Iskenderun City it reaches up to 325 $\mu g/m^3$. The daily average concentrations of NO_X along the highway and motorway were from 10-100 $\mu g/m^3$ on that day. Figure 7.62 shows the daily average concentrations of NO_X due to all sources on November 18, 2001, as can be seen in the figure the short-term limit of TAQPR was not exceeded anywhere in the study area. The maximum NO_X concentration reached up to 290 $\mu g/m^3$ on that day.

Figure 7.63 to 7.65 shows daily average NO_X concentrations on selected days of spring, summer and autumn seasons, as can be seen from these figures the daily average concentrations of NO_X were relatively low and did not exceed the limit set by TAQPR.

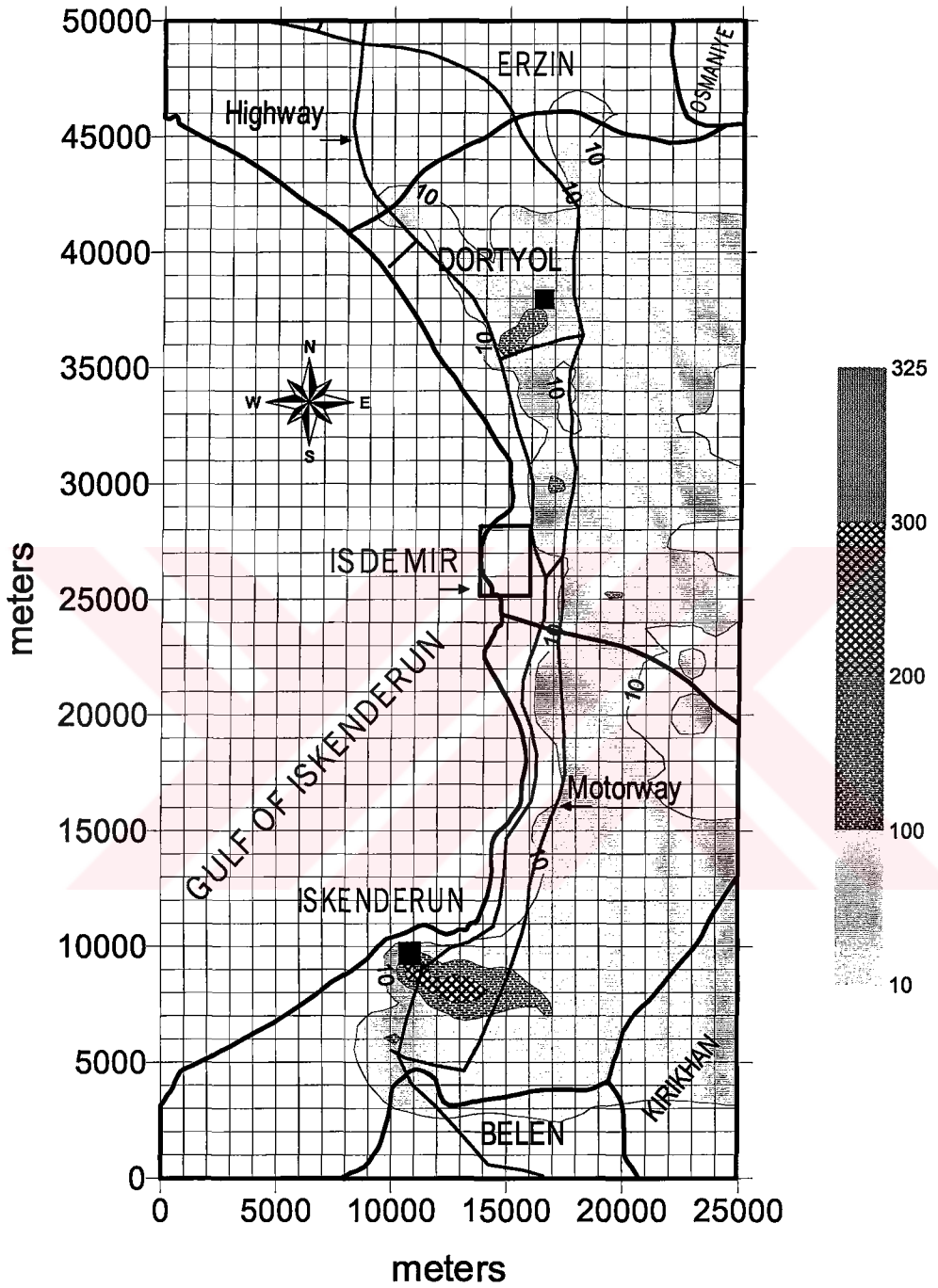

Figure 7.61 24-h average ground level concentrations ($\mu g/m^3$) of NO_X due to all sources on January 18, 2001

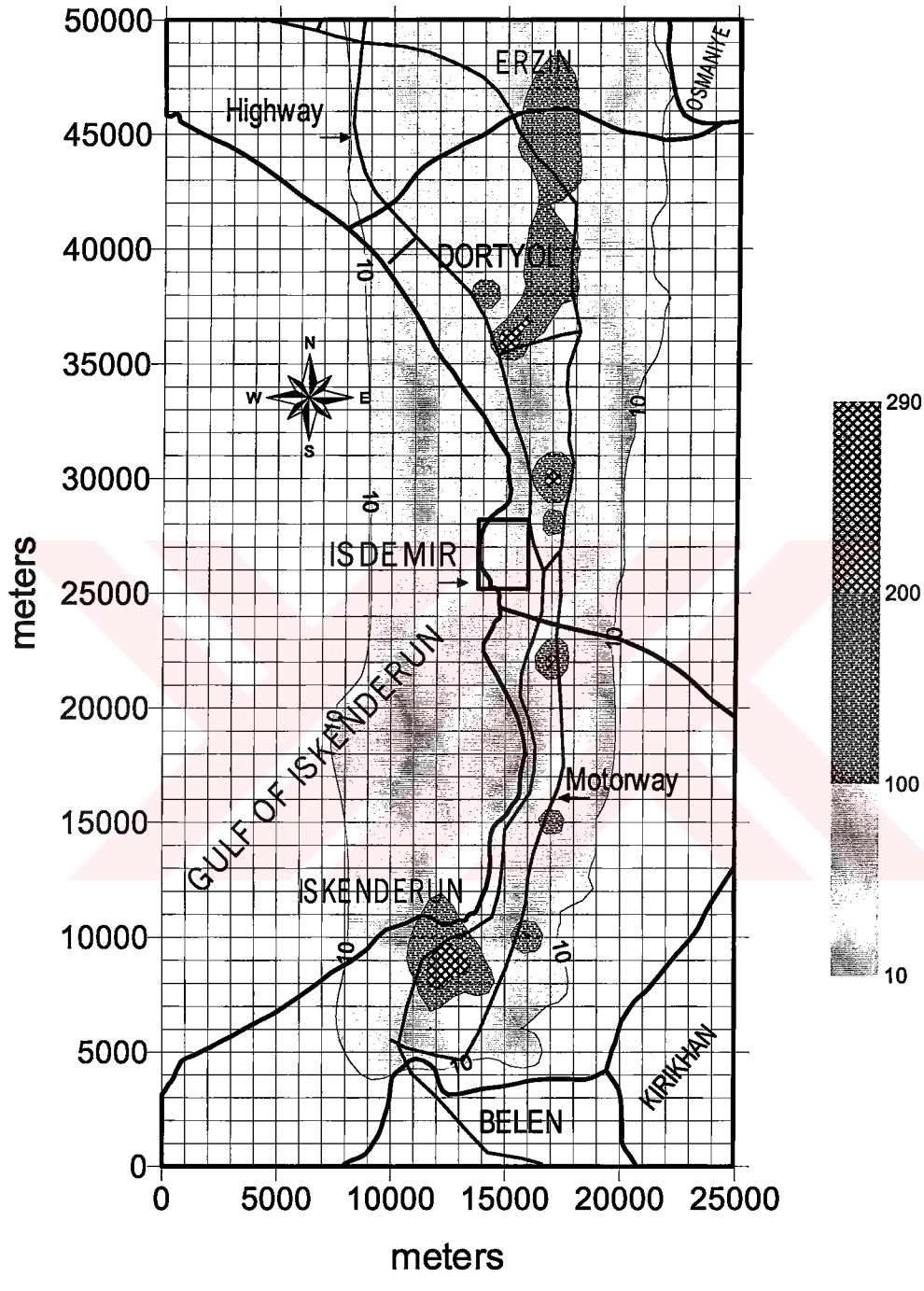

Figure 7.62 24-h average ground level concentrations ($\mu g/m^3$) of NO_X due to all sources on November 28, 2001

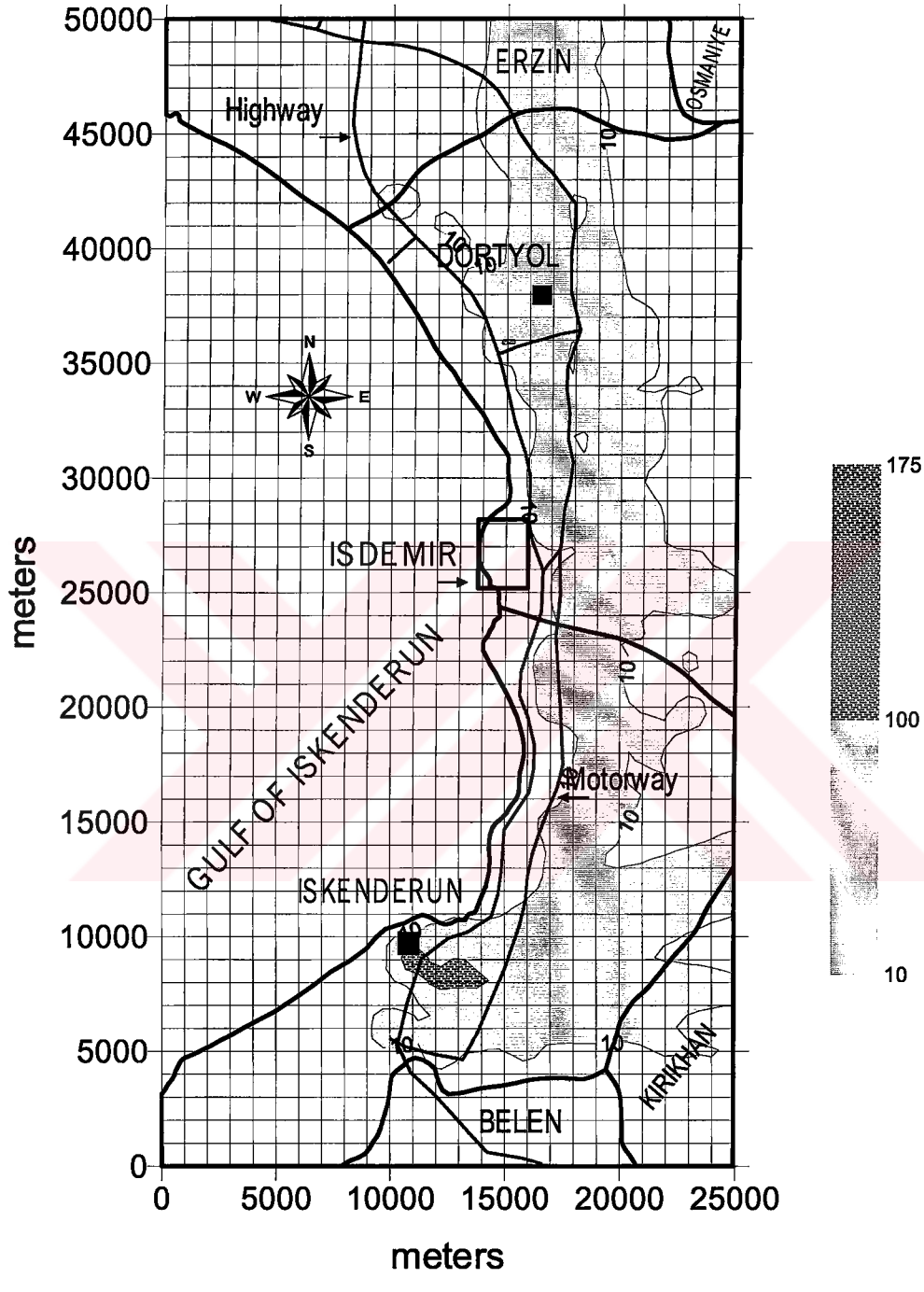

Figure 7.63 24-h average ground level concentrations ($\mu g/m^3$) of NO_X due to all sources on April 23, 2001

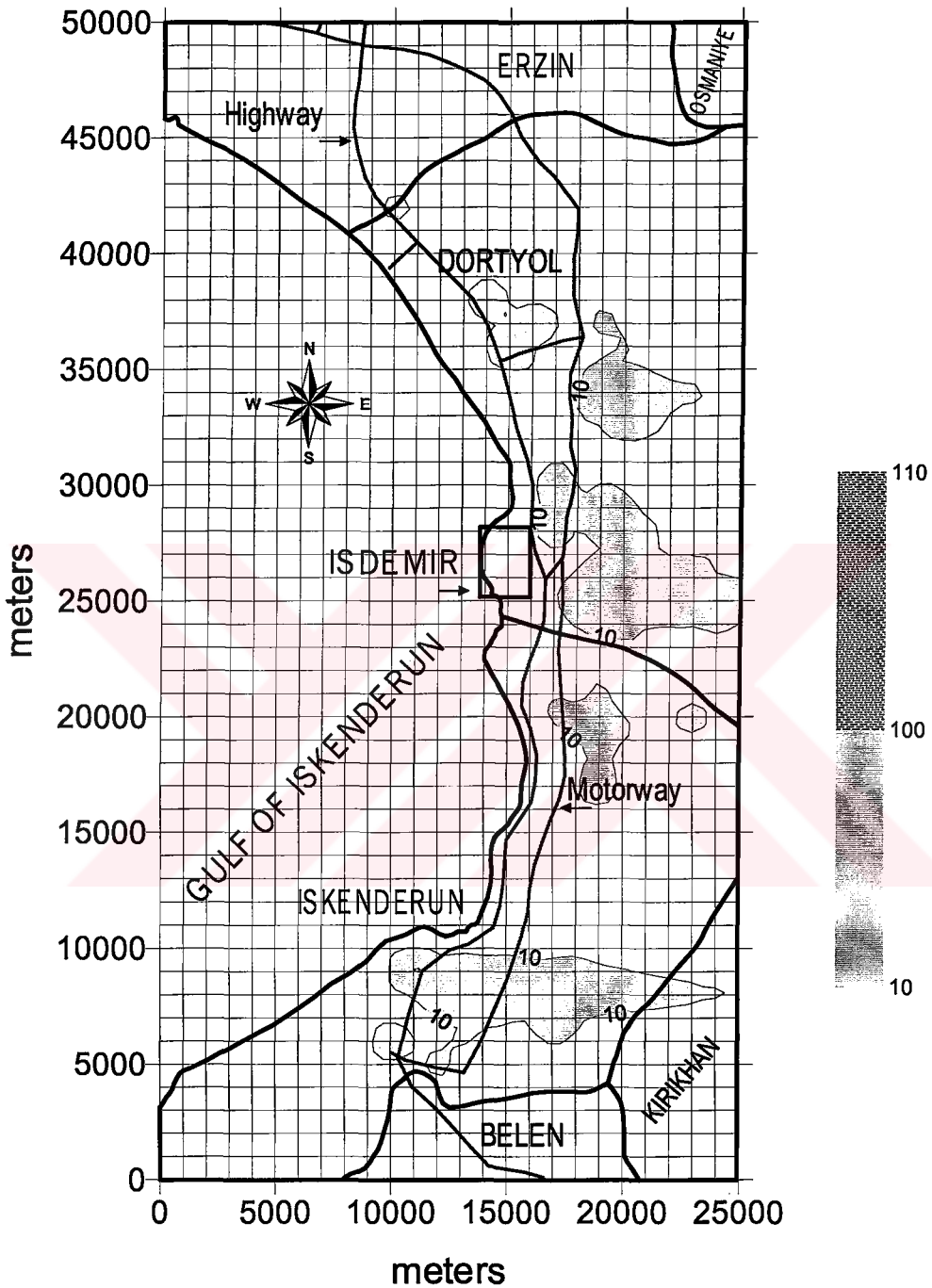

Figure 7.64 24-h average ground level concentrations ($\mu g/m^3$) of NO_X due to all sources on July 31, 2001

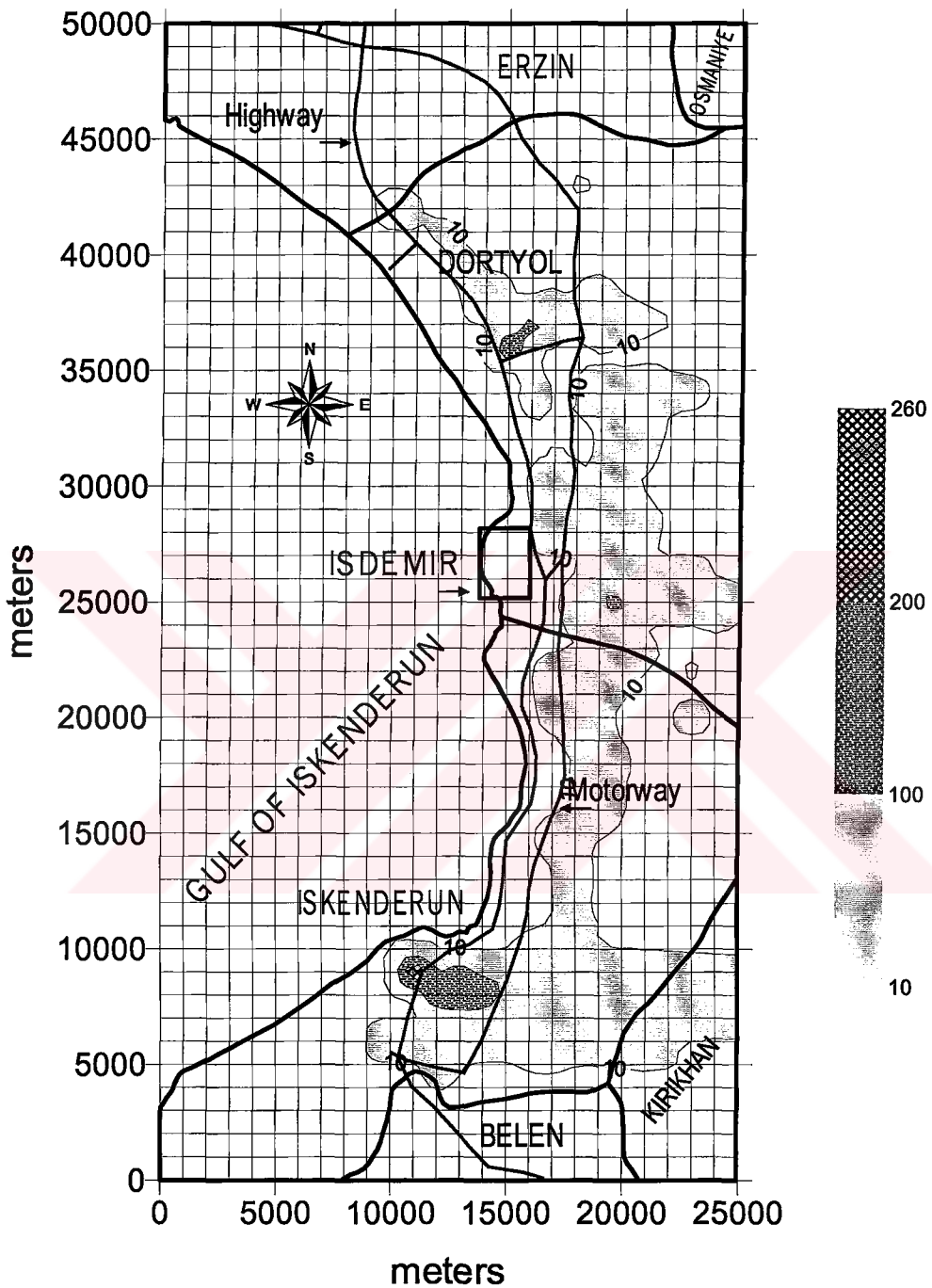

Figure 7.65 24-h average ground level concentrations ($\mu g/m^3$) of NO_X due to all sources on October 19, 2001

7.4 Modeling of CO

Results of dispersion modeling calculations of CO due to all sources on annual and seasonal basis are given in Figures 7.66 to 7.73.

7.4.1 Annual Dispersion of CO

As it is well known, CO is a product of incomplete combustion. From most of the combustion units CO is released in flue gases and concentration of CO in the flue gas is proportional to the combustion efficiency.

Figure 7.66 shows the annual average ground level concentrations of CO due to all sources. As can be seen from the figure, the CO concentrations have been found to reach up to1560 $\mu g/m^3$ at the city center of Iskenderun. The CO concentration towards ESE of ISDEMIR reaches up to 400 $\mu g/m^3$ in the mountains at an altitude of about 200-300 m, a location near the village of Sincan. The long-term limit set by the TAQPR is 10,000 $\mu g/m^3$, and the calculated CO concentrations from the dispersion model are very small as compared to this limit. WHO Air Quality Guidelines define the CO limit as 30,000 $\mu g/m^3$ and 10,000 $\mu g/m^3$ for 1-h and 8-h exposure times, respectively. However, they have not defined any value for the annual average CO concentration. The annual average CO concentration in most of the study area is found to be in the range of 10-100 $\mu g/m^3$ and in the urban areas in that region are more than 100 $\mu g/m^3$.

The contributions of several sources to the annual average ground level concentrations of CO are shown in Figure 7.66A. As can be seen from the figure urban traffic sources came out to be the major contributor to the CO concentrations in the urban areas of study region. The contributions of urban traffic at the city centers of Iskenderun, Dortyol and Payas were found to be 94%, 85% and 84%, respectively. This was followed by a contribution of 5% by domestic heating in the city of Iskenderun, while in Dortyol and Payas the

effect of CO emissions from ISDEMIR were also seen with contributions of 7.4% and 6.4% respectively.

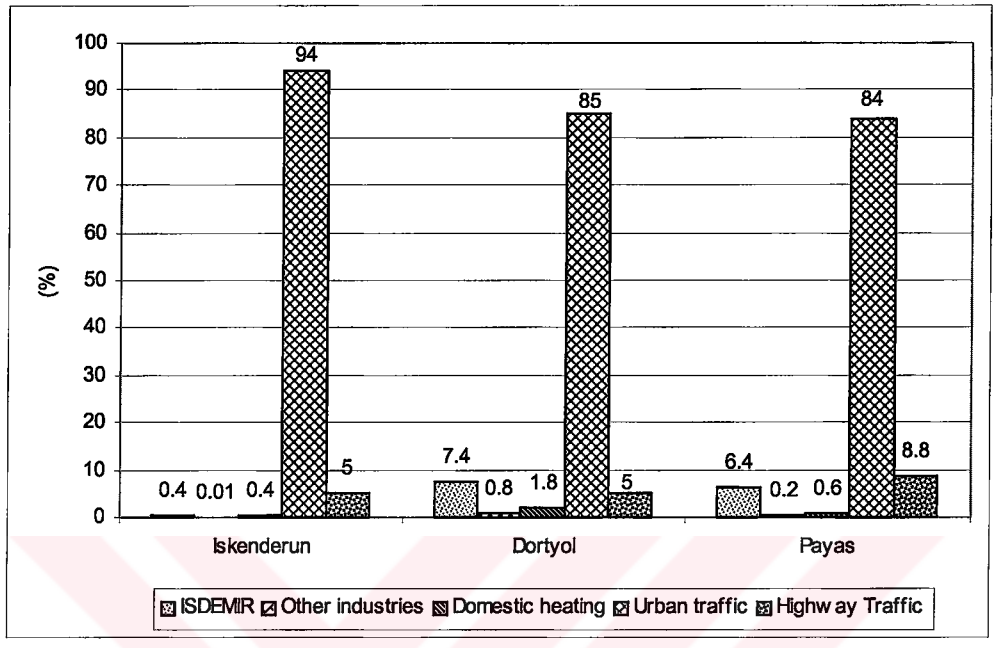

Figure 7.66A Contributions of several sources in the annual average CO concentrations in Iskenderun, Dortyol and Payas.

Figures 7.67 and 7.69 show the annual average CO concentrations due to ISDEMIR only and due to traffic sources, respectively. The maximum CO concentration due to ISDEMIR reaches up to 340 $\mu g/m^3$ in the ESE of ISDEMIR. The CO concentration around this area changes between 100 and 340 $\mu g/m^3$. Outside these areas and most parts of Dortyol was found to have a CO concentration of 10 to 100 $\mu g/m^3$ due to emissions of ISDEMIR.

Figure 7.68 shows annual average CO concentrations due to highway traffic. The maximum CO concentration was found to be 76 $\mu g/m^3$ at some small patches along the highways. However, CO concentrations along the highway and motorway are in the range of 10-40 $\mu g/m^3$.

Figure 7.69 shows annual average concentrations of CO due to traffic on urban roads. As can be seen from this figure the maximum concentration reaches up to 1540 $\mu g/m^3$ at the city center of Iskenderun. Upon comparing Figures 7.66 and 7.69, it can be concluded that almost all of the annual average CO concentrations in the study area and especially urban areas are due to traffic on urban roads.

Although the contribution of traffic sources in the total annual CO emissions in the study area is only 27%, however, due to very close to ground level release of exhaust gases from vehicles, the dispersion of CO could not take place effectively. The annual average ground level CO concentrations due to traffic along the motorway and the highway were found to be between 10 to 76 $\mu g/m^3$, while the concentration rises up to 1200 $\mu g/m^3$ in urban areas.

Although ISDEMIR is responsible for 72.5% of annual CO emissions in the study area, the effect of these emissions on the ground level CO concentrations is not much. Due to its tall stacks CO disperses effectively. Therefore, the contribution of CO in the annual average ground level concentrations is very small as compared to traffic sources.

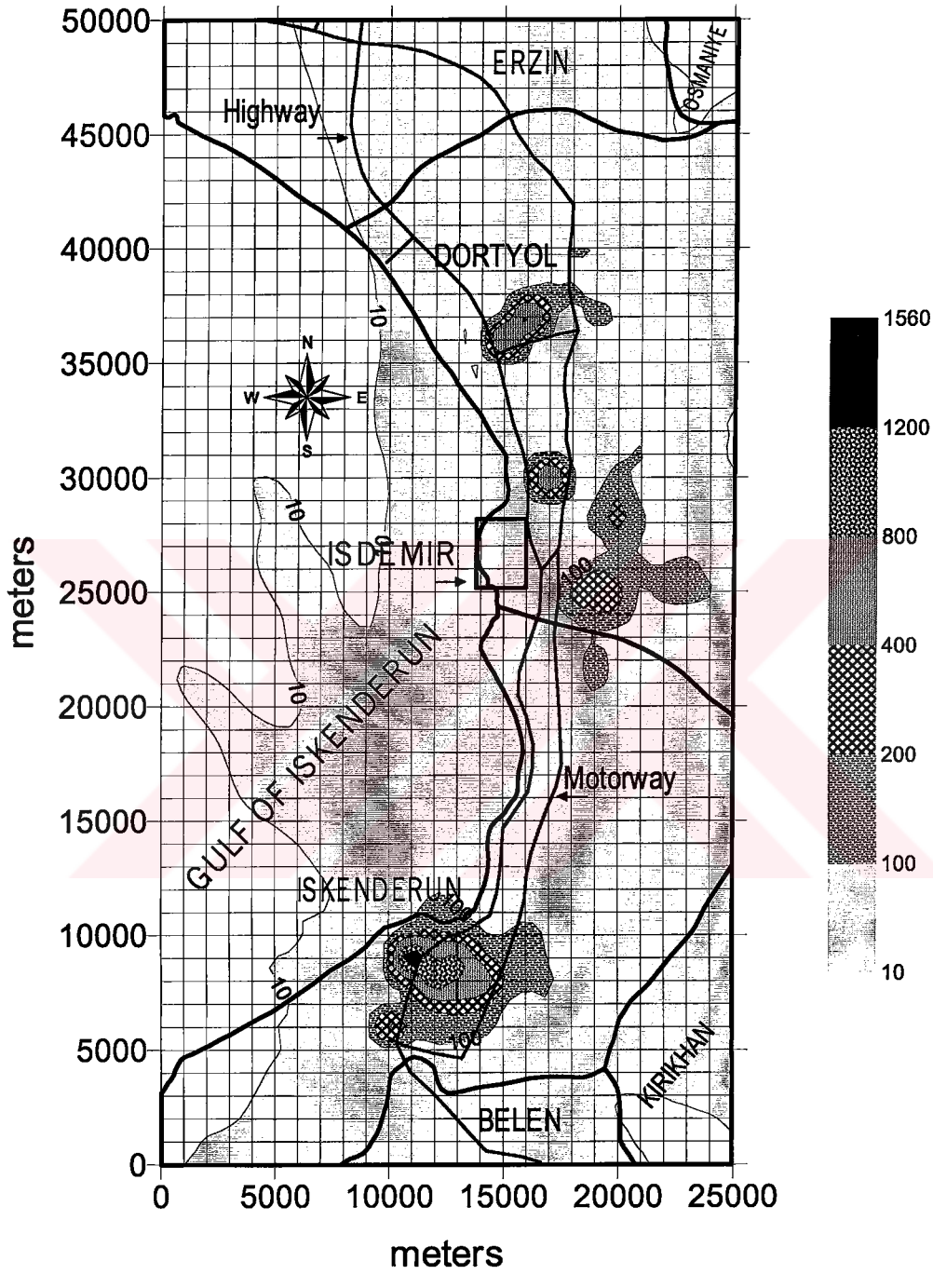

Figure 7.66 Annual average ground level concentrations (μg/m^3) of CO due to all sources

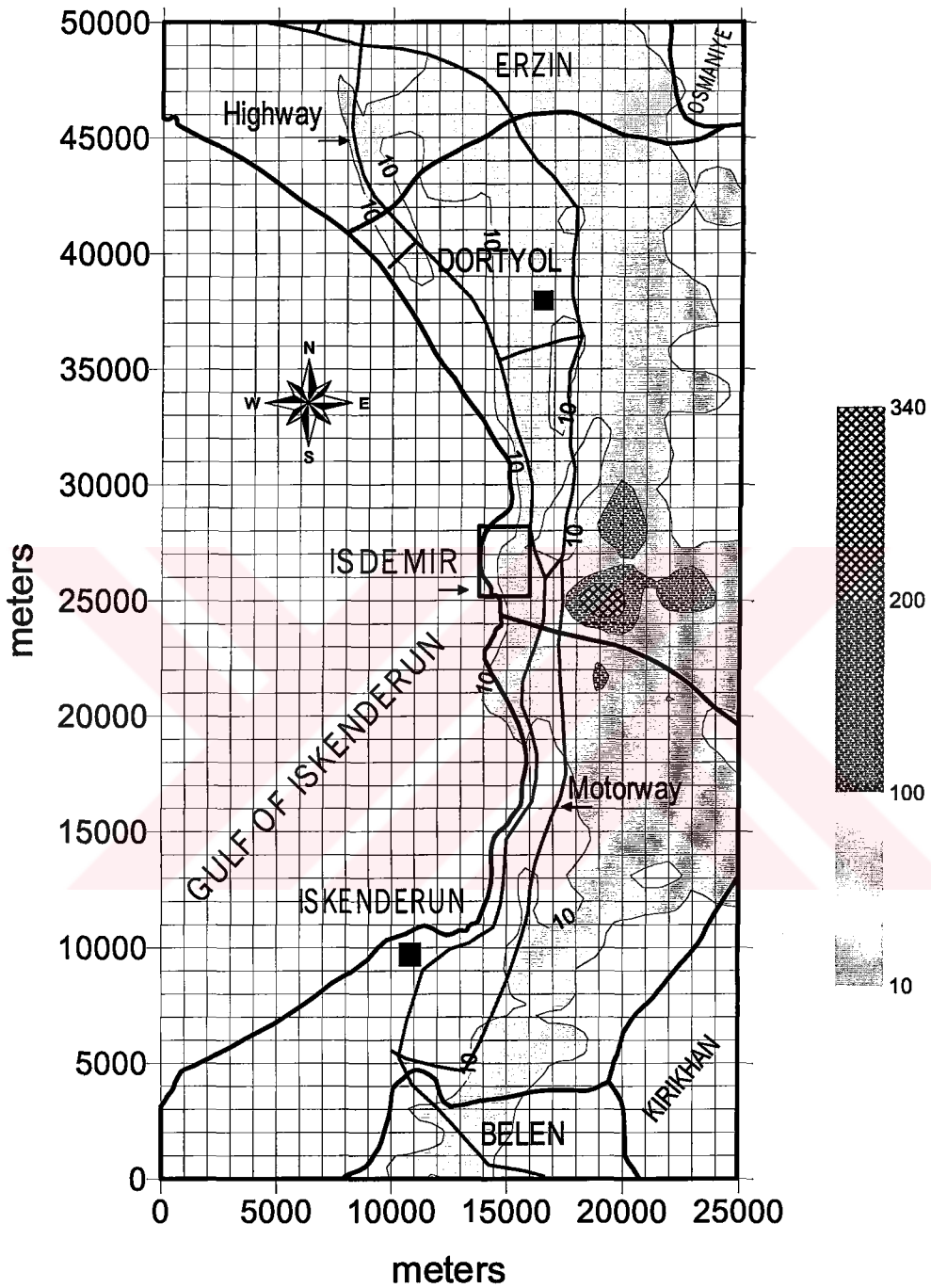

Figure 7.67 Annual average ground level concentrations ($\mu g/m^3$) of CO due to ISDEMIR

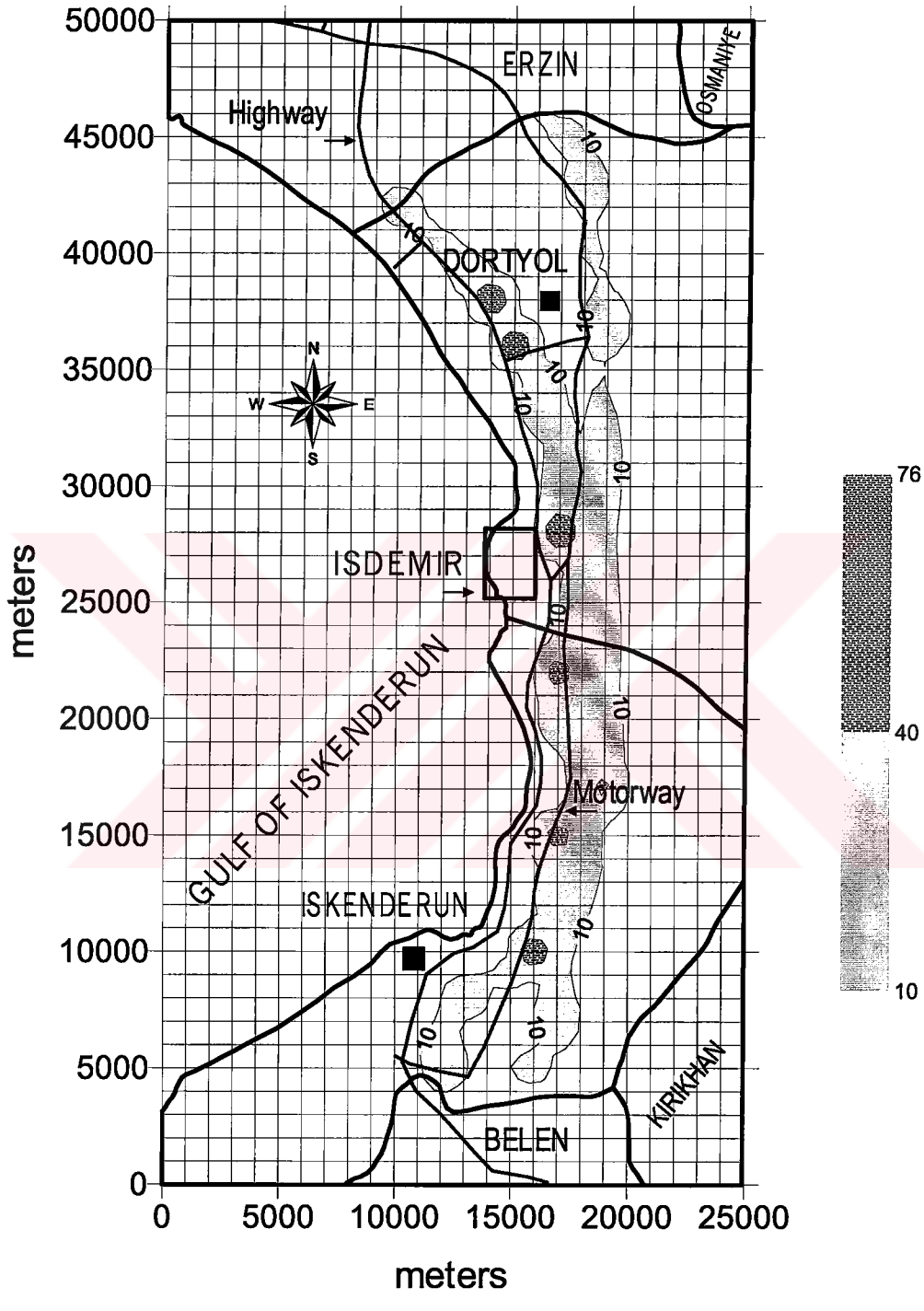

Figure 7.68 Annual average ground level concentrations ($\mu g/m^3$) of CO due to trafffic sources on highways

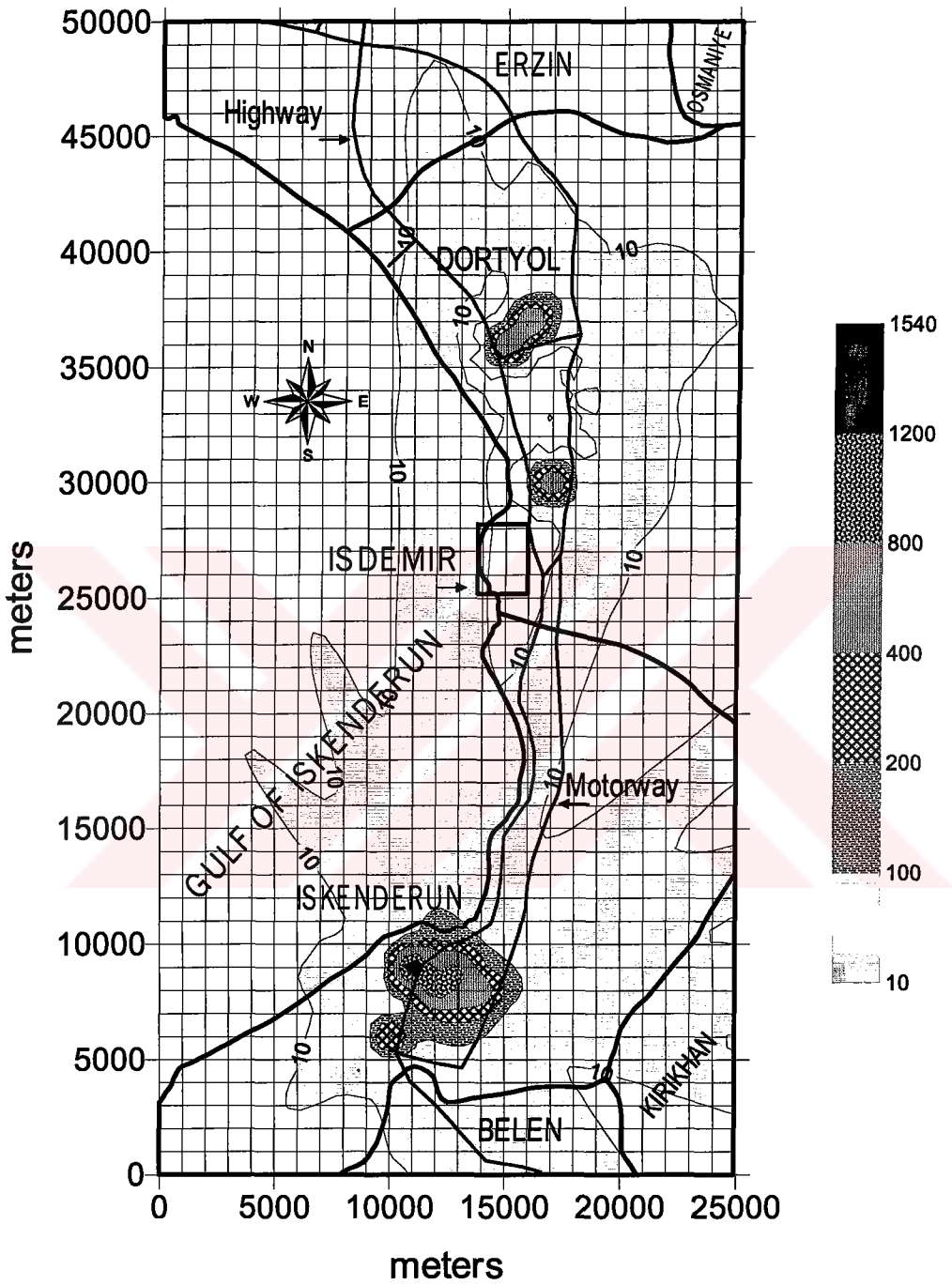

Figure 7.69 Annual average ground level concentrations ($\mu g/m^3$) of CO due to urban trafffic sources

7.4.2 Seasonal Dispersion of CO

Figures 7.70 to 7.73 show the winter average ground level concentrations of CO due to all sources as well as from several sources separately. Figure 7.70 shows that the maximum winter average CO concentration reaches up to 1475 $\mu g/m^3$ in the city center of Iskenderun. Almost all of the urban areas in this study have winter average CO concentrations more of than 200 $\mu g/m^3$. Figure 7.71 shows the winter average CO concentrations due to ISDEMIR, where the maximum concentration reaches up to 260 $\mu g/m^3$ towards ENE and ESE of ISDEMIR. During winter Dortyol and Payas are also subjected to 10-100 $\mu g/m^3$ of CO concentrations due to ISDEMIR.

Figure 7.72 shows the winter average CO concentrations due to traffic on highways. The concentrations along the highways are from 10-40 $\mu g/m^3$ with some small patches where concentration rises up to 95 $\mu g/m^3$. Figure 7.73 shows the winter average CO concentrations due to urban traffic. The maximum concentration reaches up to 1460 $\mu g/m^3$ in Iskenderun, while in Dortyol it reaches up to 1200 $\mu g/m^3$. All of the urban areas in this study are subjected to CO concentrations of more than 200 $\mu g/m^3$ during winter.

The model calculations were performed for the other seasons as well. The results from these calculations are very similar to the previous figures for CO, and the maximum concentration levels reach up to 1450 $\mu g/m^3$ in the city of Iskenderun. In most of the study area seasonal average CO concentrations remain in the range of 10-100 $\mu g/m^3$. In general, regardless of the season ground level CO concentrations are not much different from one season to another because of the fact that traffic sources are the basic cause of CO concentration in the study area.

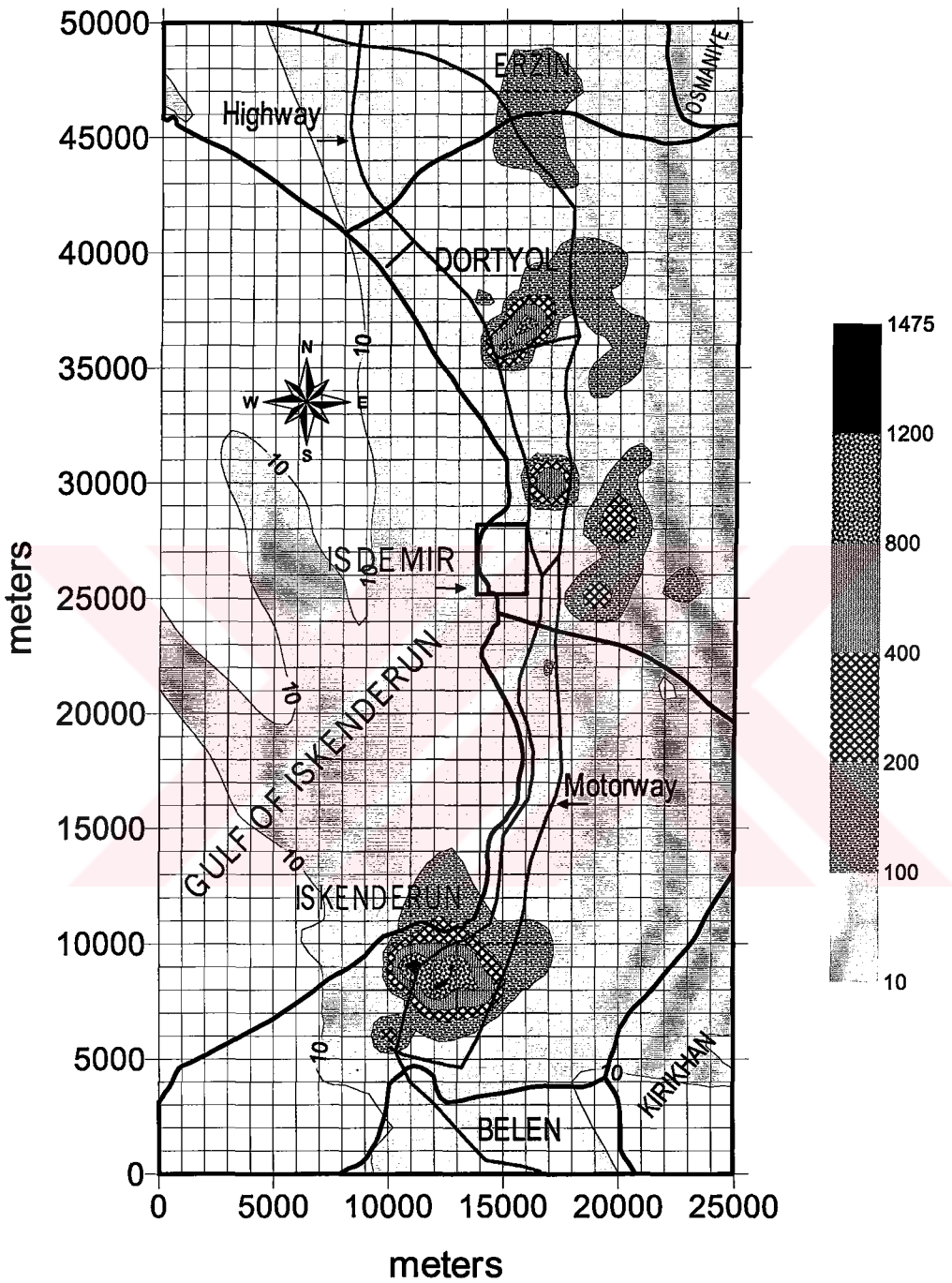

Figure 7.70 Winter average ground level concentrations ($\mu g/m^3$) of CO due to all sources

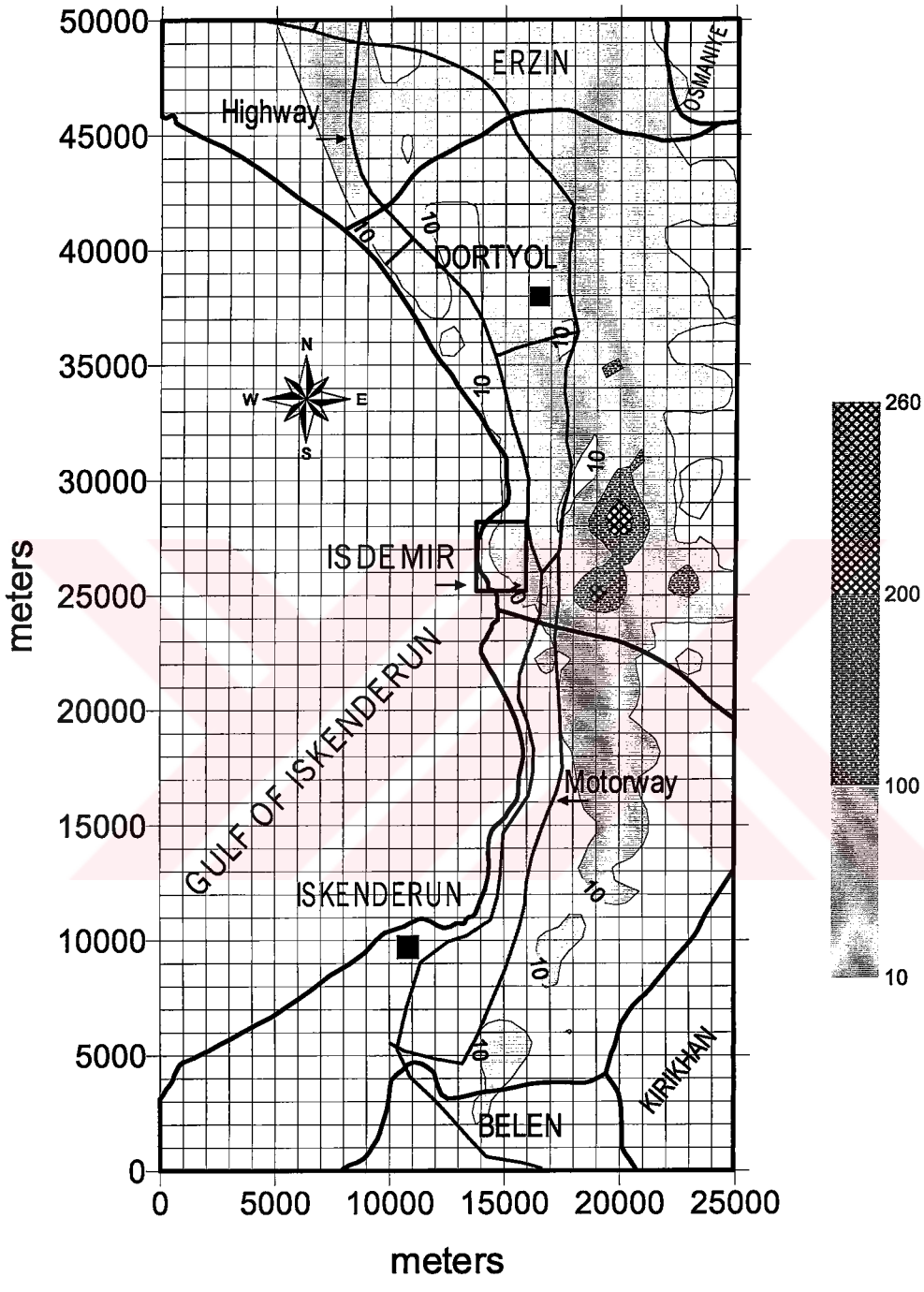

Figure 7.71 Winter average ground level concentration ($\mu g/m^3$) of CO due to ISDEMIR

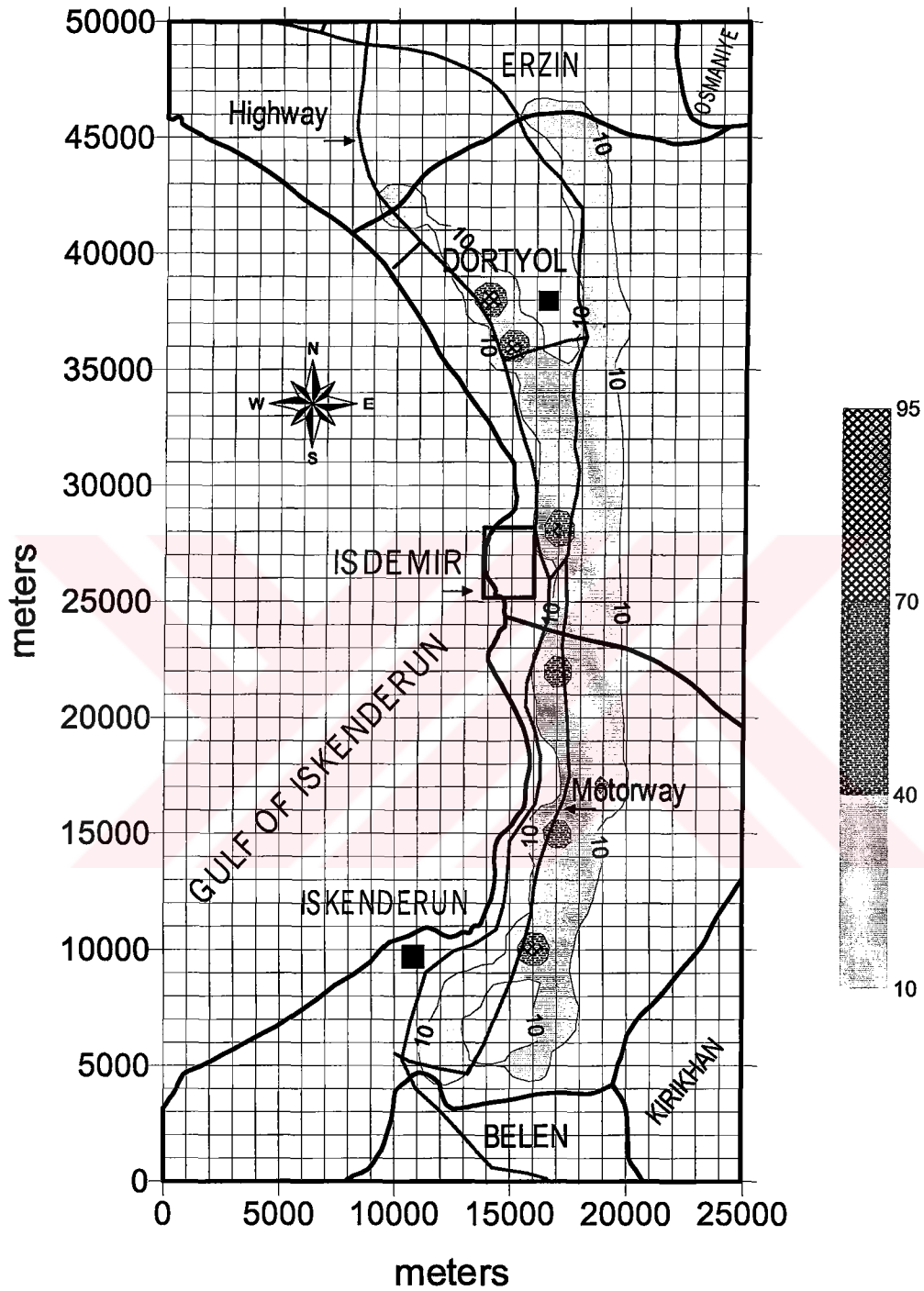

Figure 7.72 Winter average ground level concentration ($\mu g/m^3$) of CO due to trafffic sources on highways

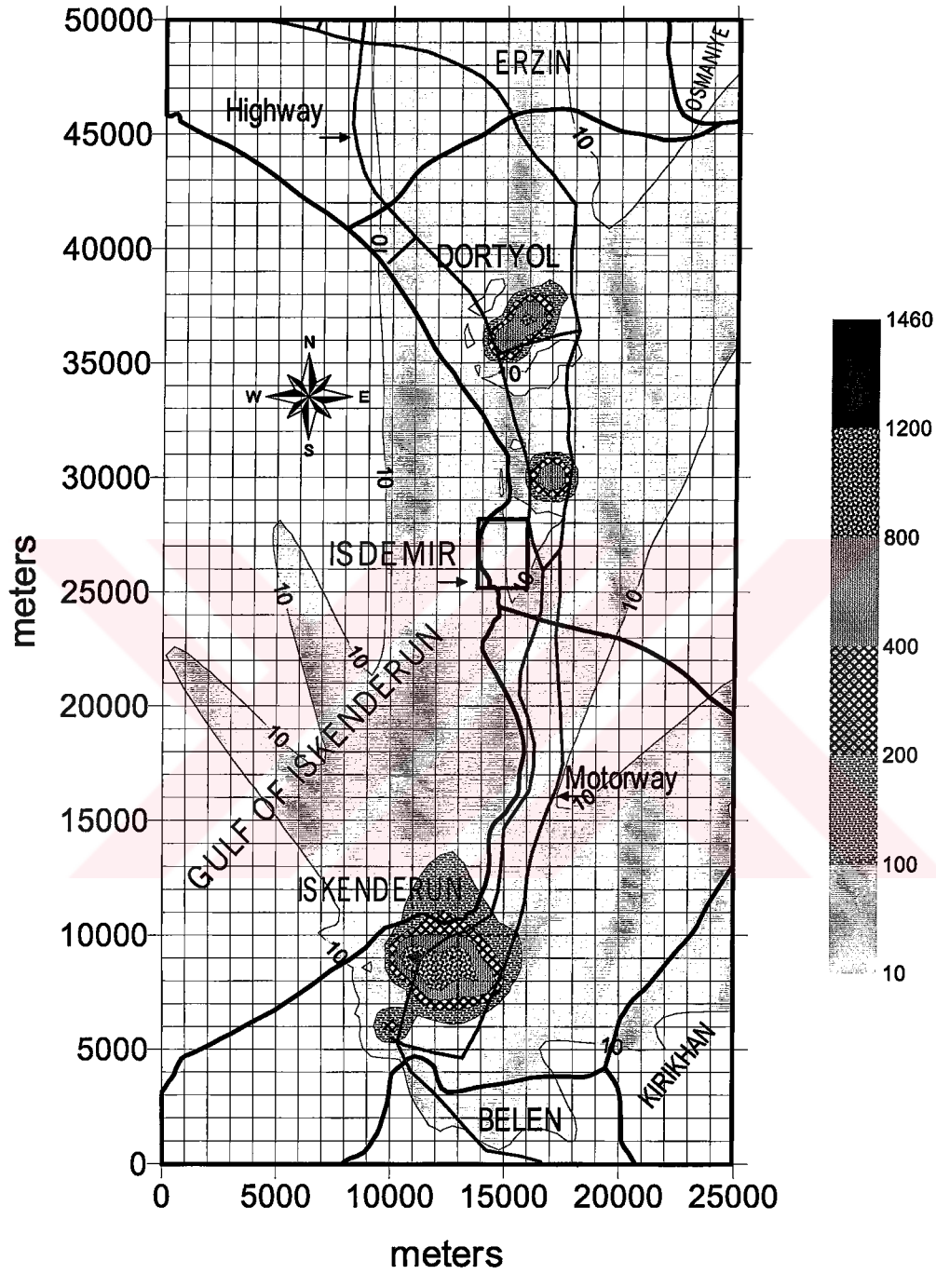

Figure 7.73 Winter average ground level concentration ($\mu g/m^3$) of CO due to urban trafffic sources

7.5 Model Performance Evaluation

The performance evaluation of a model is of great interest in any modeling study. This is a tool to check the correctness of the predictions made in the modeling study. The methods used to evaluate performance of pollution dispersion models described in Chapter 4, were used for checking the accuracy of predicted ground level pollution concentrations by ISCST3 model used in this study.

Unfortunately, there is only one air pollution monitoring station in the study area, which is located in the city of Iskenderun. Daily average ground level SO_2 and smoke concentrations are the only pollutants measured at this monitoring station, which is being operated under the control of the Ministry of Health, Government of Turkey. The data collected at the Ministry of Health offices are reported to the State Institute of Statistics. Since the smoke measurement cannot be identified as PM measurement. Therefore, only SO_2 results are considered for comparison with the model results. Daily average SO_2 concentrations data of this station was obtained from the State Institute of Statistics in Ankara for the year 2001. Measurement results were available only for the month of January. Since in the modeling calculations all input data used belonged to year 2001, therefore the model performance evaluation was done by comparing the measured data for January 2001 with the model predictions. For this purpose, the model was run specifically with January 2001 data to get the daily average SO_2 concentrations in the city of Iskenderun at the location of monitoring station, since only SO_2 concentrations were available for the monitoring station located in Iskenderun City. Statistical analysis was carried out for SO_2 using the observed as well as predicted daily average concentrations of SO_2. The results of statistical analysis are given in the following section SO_2.

The statistical parameters; index of agreement (d), total root mean square error $(RMST)_T$, linear regression coefficients (a,b) along with mean and standard

deviations (σ) for predicted and observed PM concentrations in Iskenderun were calculated to judge the performance of the model.

RMSE and d, which show the "error" and the "accuracy" involved in the predictions, mainly judge the evaluation of the model performance. The modeling results are regarded as "good" for a value of d close to 1 and a value of RMSE close to 0.

7.5.1 Model Performance in SO_2 Predictions

In order to evaluate the model performance in SO_2 predictions, the daily average predicted and observed ground level SO_2 concentrations for January 2001 were used. A comparison between the model predicted and observed daily average SO_2 concentrations is shown in Figure 7.74.

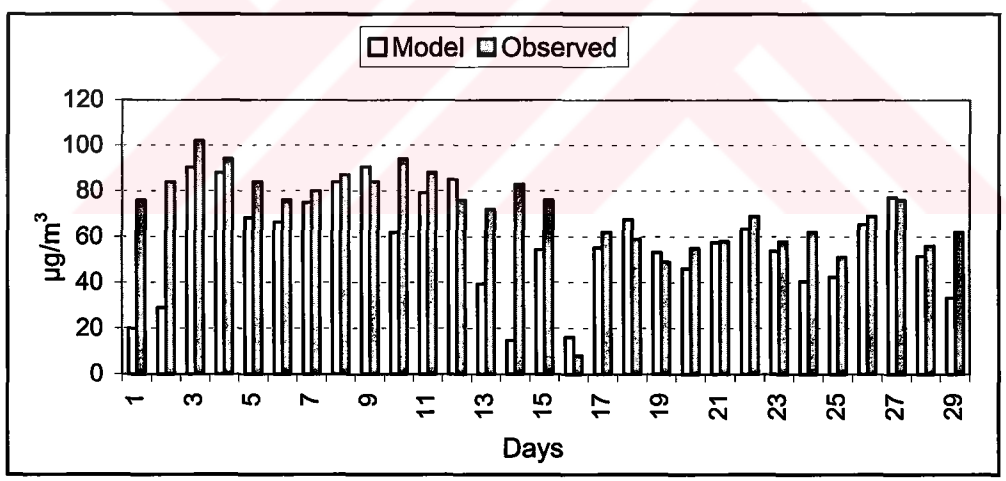

Figure 7.74 Comparison of ISCST3 predicted and observed ground level SO_2 concentrations in Iskenderun

The results of the statistical analysis for SO_2 and they indicate that the overall performance of the model is good. These results are presented in Table 7.3. As given in the table the value of index of agreement (d) is 0.67, which shows that the accuracy of model predictions was 67%. The model-predicted concentrations were smaller than the observed ones; thus the model under

predicted the concentrations. The relevant analysis of RMSE shows that there is a lower error in the model predictions. According to US EPA, the available evidence suggests that the variation in the observed and model predicted concentrations can be as much as ± 50 percent (US EPA, 2003). In this study as the model has predicted SO_2 concentrations with 67% accuracy, which is well within the often quoted factor-of-two accuracy for this kind of models.

The F-Test was also performed to see the significance of correlation between model-predicted and observed concentrations of SO_2. The calculated value of F ($F_{calculated}$) was found to be 11.114, while the tabulated value of F ($F_{Tabulated}$) was 4.21 at 1 and 27 degrees of freedom and at 5% level of significance. Since $F_{calculated} > F_{Tabulated}$ therefore, there is significant large positive correlation existing between the predicted and the observed concentrations of SO_2.

Table 7.3 Results of model performance evaluation for SO_2 concentrations ($\mu g/m^3$)

Parameter	SO_2
Observed mean (O)	71
Predicted mean (P)	58
Observed standard deviation (σ_o)	18
Predicted standard deviation (σ_p)	22
Correlation coefficient (r)	0.54
Systematic RMSE	15.26
Unsystematic RMSE	17.76
Total root mean square error ($RMSE_T$)	23.40
Index of agreement (d)*	0.67

* d is a unitless number

These methods of model evaluations have been used in several air pollution dispersion modeling studies all over the world. In a study in Jamshedpur India, which is rich is steel industries like the study area under consideration in this work, 68% accuracy in NO_X predictions by ISCST3 was reported (Sivacoumar et al., 2001). In a similar study in Izmir, Turkey the accuracy of ISCST3 prediction of SO_2 concentrations was found to be 72% (Elbir, 2002). The

comparison of the model accuracy found in this study with those in the previous studies show a good match.

In the modeling studies the differences between the observed and predicted concentrations may be due to:

- Errors in emission measurements and/or estimates from emission sources
- Assumptions used in the modeling study
- Accuracy of measurements at monitoring stations
- Locations of monitoring stations and changes in the local conditions.

CHAPTER 8

AIR QUALITY IMPROVEMENT SCENARIOS

The detailed analysis of air pollution dispersion calculations given in the previous chapter exposed certain sources that are responsible for deterioration of air quality in the study area, especially in the residential centers. For example, ISDEMIR, which is the largest emitter of pollutants in the study area, has adverse effects on the air quality especially in Payas and Dortyol. Although ISDEMIR is the biggest contributor in SO_2 emissions from the study area, the effect of other industries on SO_2 concentrations in Payas and Dortyol is far more than ISDEMIR. Moreover, the use of coal as a major fuel for domestic heating causes serious problems of PM and SO_2in the residential areas during winter.

Keeping all these factors under consideration, certain scenarios were designed and effects of these scenarios were studied to see the improvement in air quality of the study area. These scenarios are:

- Scenario # 1: PM and SO_2 emissions from ISDEMIR to be reduced below the limit set by the TAQPR
- Scenario # 2: Increase in the stack heights of other industries from 20-25m to 50m
- Scenario # 3: Replacement of high sulfur fuel oil with low sulfur fuel oil in other industries
- Scenario # 4: Use of natural gas instead of coal for domestic heating

8.1 Scenario # 1

This is a scenario in which PM and SO_2 emissions from ISDEMIR are controlled, and these emissions are kept below the limits set by the TAQPR. There is no change in the emissions from all other sources. Currently ISDEMIR is releasing 2400 kg/h of PM and 4146 kg/h of SO_2. The limits set by the TAQPR for emissions of PM and SO_2 from any industrial complex are 15 kg/h and 60 kg/h, respectively. It is assumed in this scenario that ISDEMIR releases 14 kg/h of PM and 58 kg/h of SO_2 into the atmosphere, which means that 99.4% and 98.6% reductions in PM and SO_2 emissions from ISDEMIR, respectively. The removal efficiency of 99.4% for PM is possible with efficient dust control systems like Electrostatic Precipitators (ESP) and bag house filters. However, 98.6% removal efficiency for SO_2 is hardly possible with the conventional control devices available in the market. For example, Flue Gas Desulfurization systems can give a removal efficiency of about 95%. Even if FGD systems are installed in ISDEMIR with 95% efficiency, still it will be releasing 207 kg/h of SO_2, which is again 3.5 times higher than the limit defined in the TAQPR. Therefore, if SO_2 emissions from ISDEMIR are to be controlled, the best strategy would be to use raw materials with low sulfur content and installation of FGD systems if needed along with the addition of $CaCO_3$ during sinter process, which is responsible for 32% of the SO_2 emissions from ISDEMIR.

Results of Modeling for PM

The results of the dispersion modeling calculations for PM in Scenario#1 on annual basis are given in Figure 8.1 to 8.4. This is a scenario in which it is assumed that ISDEMIR is releasing 14 kg/h instead of 2400 kg/h of PM, while there is no change in PM emissions from all other sources. Figure 8.1 shows that the annual average ground level concentrations of PM in the study area reaches up to a maximum value of 52 $\mu g/m^3$, which is found in the southeastern parts of Iskenderun city and in a very small part of Dortyol. This concentration is below the limits set by the EC Regulation and proposed revision of the

TAQPR, which are 80 and 100 $\mu g/m^3$, respectively. Annual average PM concentrations for the existing situation can be seen in Figure 7.3. The annual average ground level concentrations of PM due to ISDEMIR are shown in Figure 8.2. As can be seen from the figure, the highest PM concentration is even below 1 $\mu g/m^3$ in a very small area to the ESE of ISDEMIR. Moreover, it is clear from the Figure 8.2 that Dortyol and Payas receive a PM concentration of 0.1 to 0.5 $\mu g/m^3$, which is a negligible concentration. In the existing conditions of 2400 kg/h PM emissions from ISDEMIR, Dortyol and Payas are subjected to 10 to 40 $\mu g/m^3$ of annual average ground level PM concentration (Figure 7.4). Figures 8.1.and 8.2 show that the PM concentrations of up to 52 $\mu g/m^3$ are mainly due to domestic heating activities and urban traffic.

Figure 8.3 shows the annual deposition flux (combined effect of dry and wet depositions) of PM from all sources. The maximum deposition flux of PM was found to be 31 g/m^2-yr in Iskenderun and Dortyol. Figure 8.4 shows the annual total deposition flux from ISDEMIR only. It is clear from this figure that none of the residential area receives any PM deposition due to ISDEMIR. Therefore, the depositions seen in Figure 8.3 in Iskenderun and Dortyol are due to domestic heating.

It can be concluded from these figures that if the PM emissions from ISDEMIR are controlled then there will not be any problem of PM concentration at ground level in the study area, and the maximum concentration in the study area will be below the limiting values of PM defined in the EC Regulations and TAQPR. Moreover, controlling PM emissions from ISDEMIR below the limit set by the TAQPR there will be a dramatic reduction of 95% in the annual PM emissions from Iskenderun Region.

Results of Modeling for SO_2

The results of the dispersion modeling calculations of SO_2 for Scenario#1 are given in Figures 8.5 to 8.6. In Scenario#1 it was assumed that the SO_2

emissions from ISDEMIR are controlled, and ISDEMIR releases 58 kg/h of SO_2 instead of 4146 kg/h of SO_2. Figure 8.5 shows the annual average ground level SO_2 concentrations from all sources. Upon comparing this figure with Figure 7.27 (for which 4146 kg/h of SO_2 emissions from ISDEMIR were considered), it is seen that they are more or less identical except the high concentration area in the ESE of ISDEMIR has reduced in size. The ground level SO_2 concentrations in Iskenderun and Dortyol are almost the same. On the other hand, Figure 8.6 shows the annual average SO_2 concentrations due to ISDEMIR only. As can be seen in the figure, for Scenario#1 the ground level SO_2 concentrations due to ISDEMIR are negligible. Figure 7.28 and 8.6 can be seen for comparison between the ground level concentrations of SO_2 from ISDEMIR in the existing situation and in Scenario # 1, respectively. As can be seen from Figure 7.27 the annual average SO_2 concentrations due to ISDEMIR when the emissions are not controled, reach up to 70 $\mu g/m^3$, while in Scenario # 1 (Figure 8.6) the maximum annual average SO_2 concentrations due to ISDEMIR are 1.2 $\mu g/m^3$.

From the discussion above, it can be concluded from these figures that even if SO_2 emissions of ISDEMIR are controlled, it will not make any significant reduction in the ground level SO_2 concentrations. The sources responsible for high SO_2 concentrations at the ground level are domestic heating and other industrial sources. However, keeping SO_2 emissions from ISDEMIR below the TAQPR limit of 60 kg/h will lead to a reduction of about 80% in the total annual emissions of SO_2 from the Iskenderun Region.

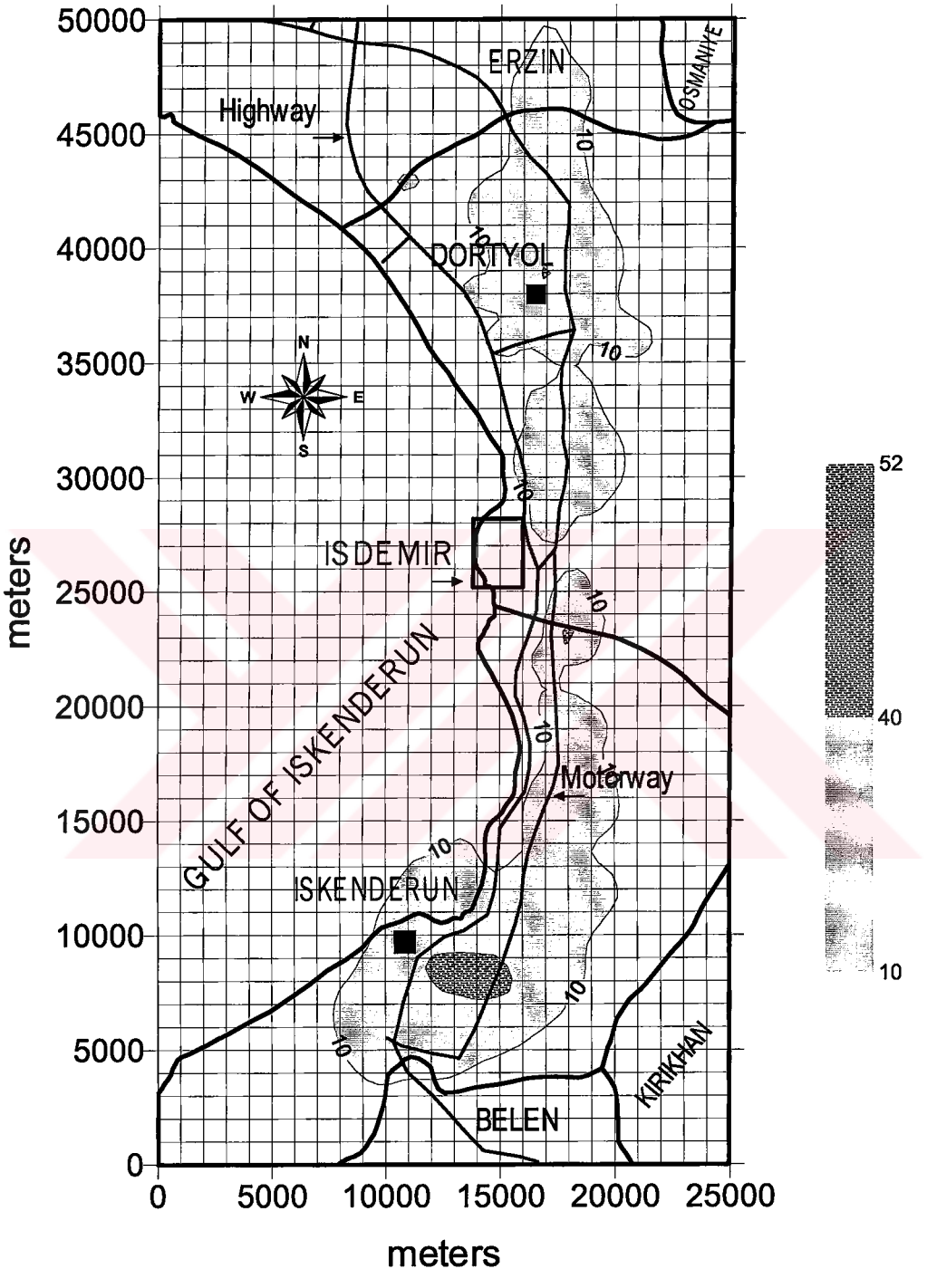

Figure 8.1 Annual average ground level PM concentrations due to all sources in Scenario # 1

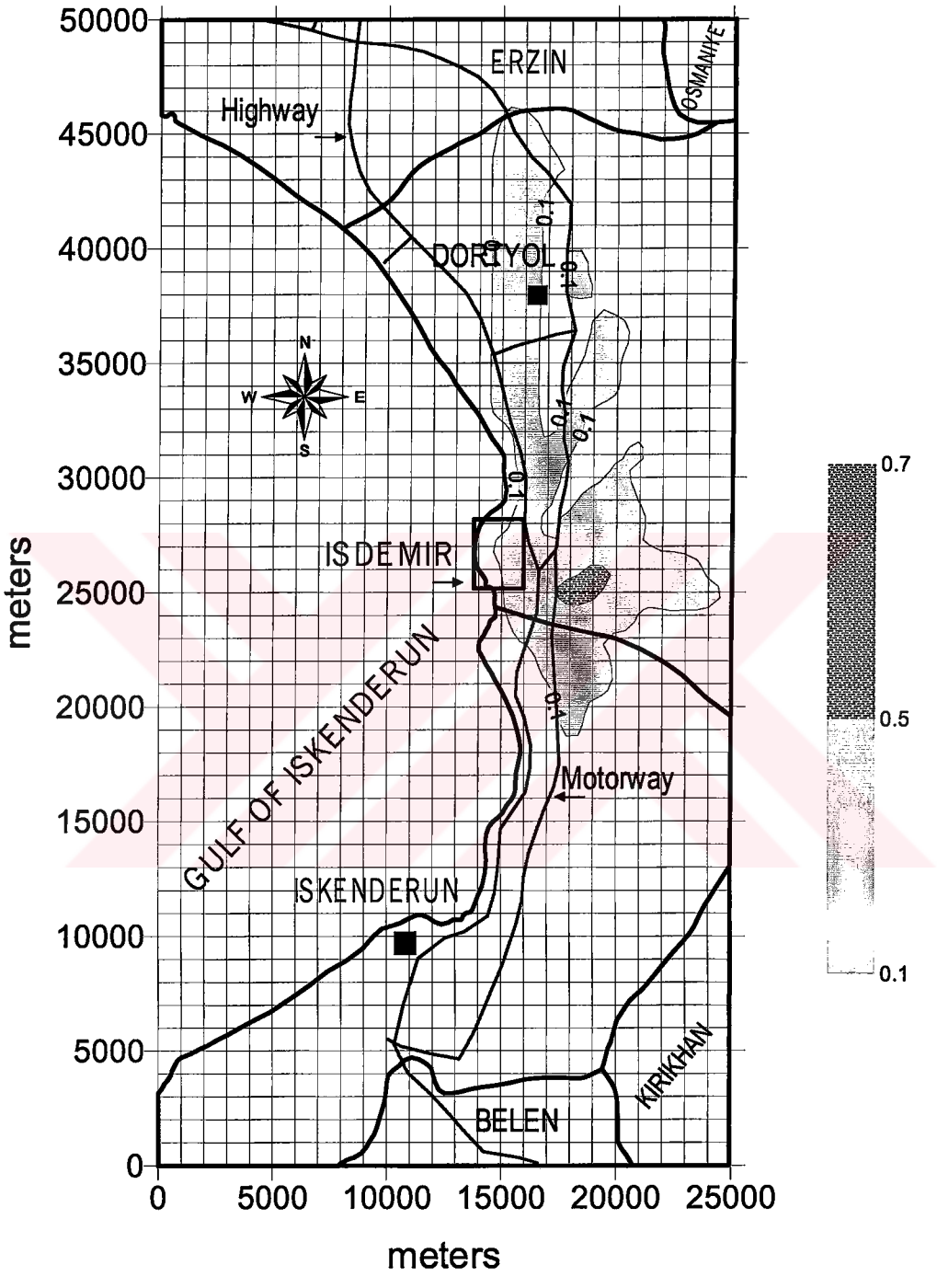

Figure 8.2 Annual average ground level PM concentrations due to ISDEMIR in Scenario # 1

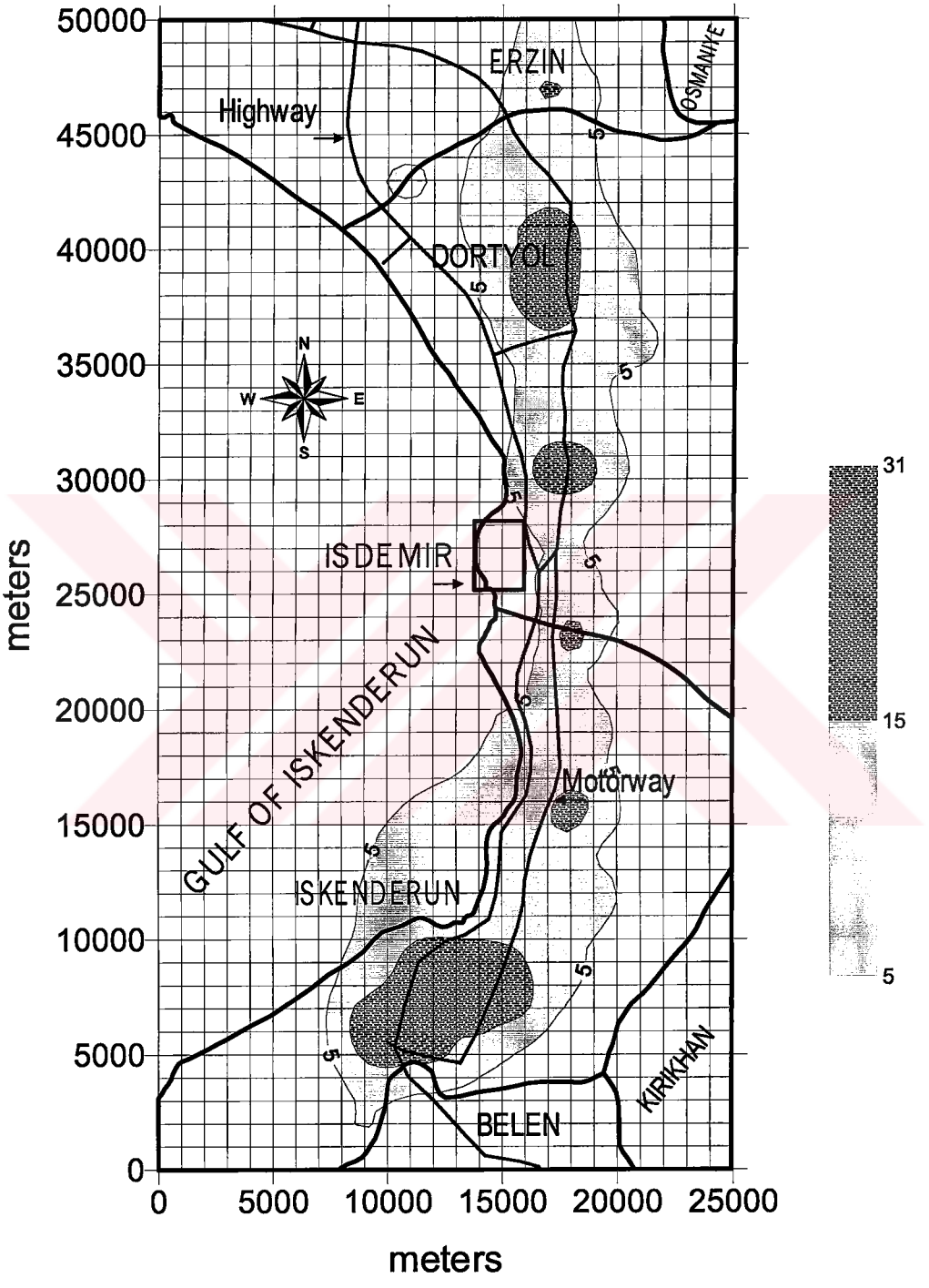

Figure 8.3 Annual average deposition rate (g/m^2-yr) of PM due to all sources in Scenario # 1

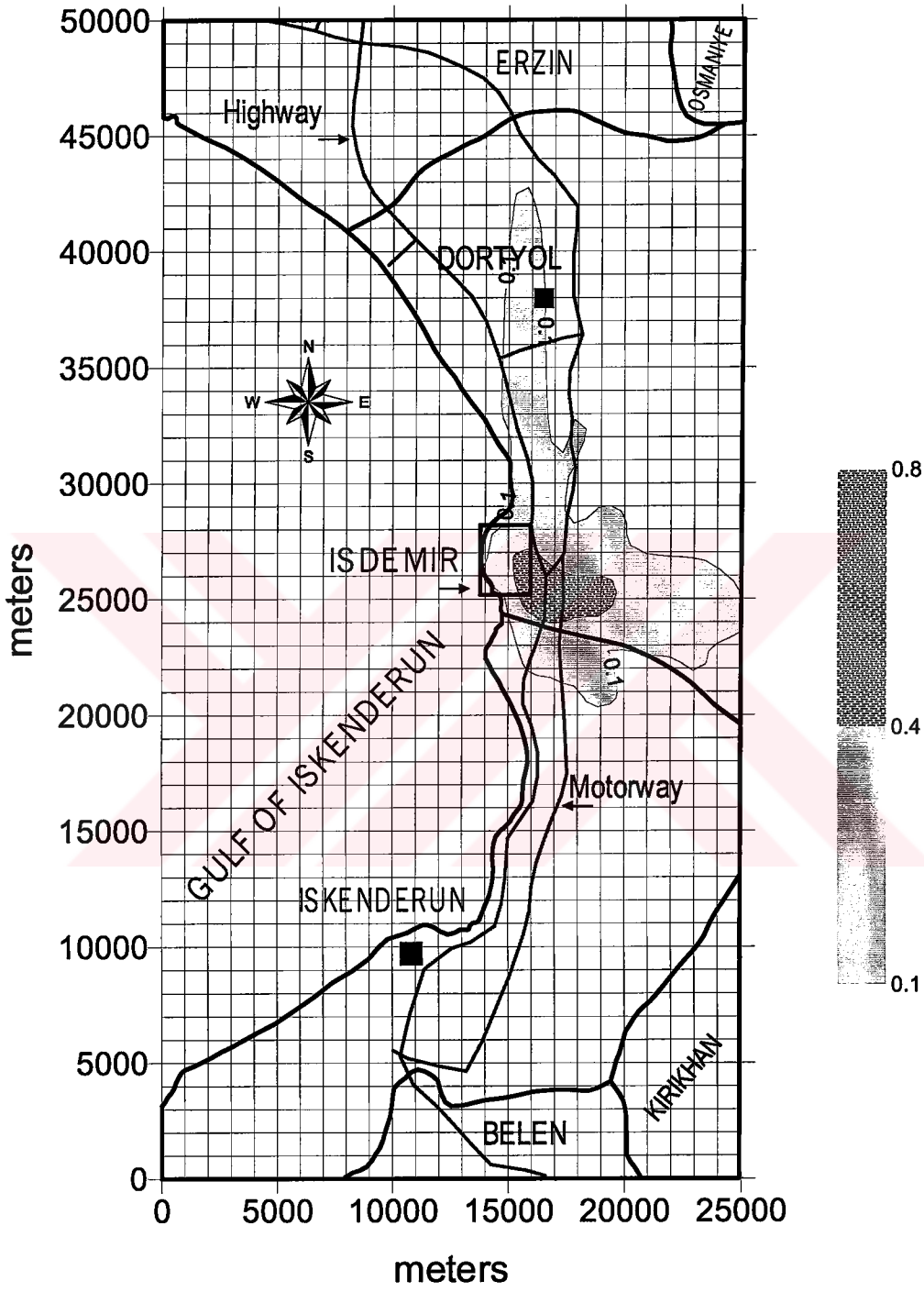

Figure 8.4 Annual average deposition rate (g/m^2-yr) of PM due to ISDEMIR in Scenario # 1

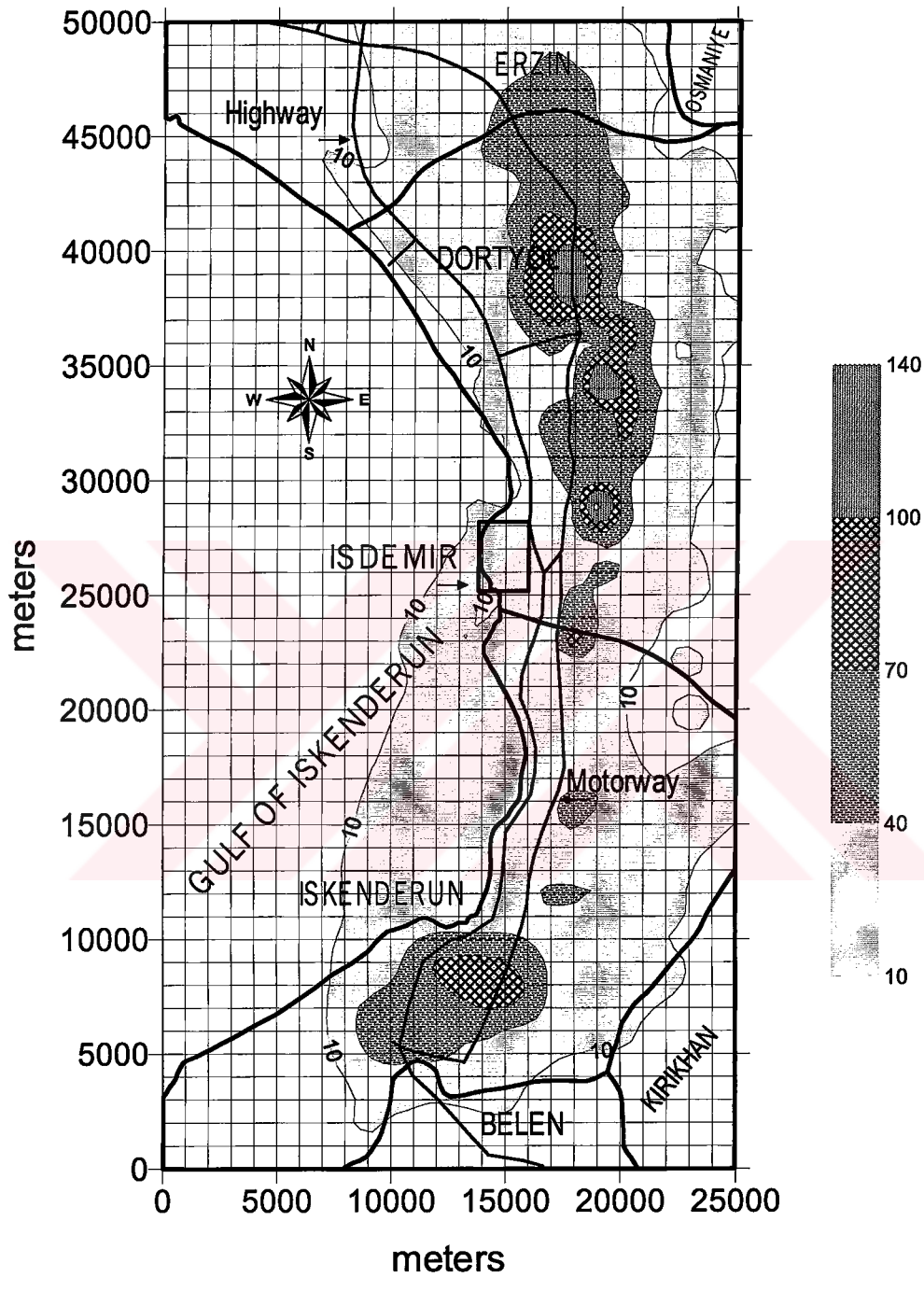

Figure 8.5 Annual average ground level concentrations of SO_2 due to all sources in Scenario # 1

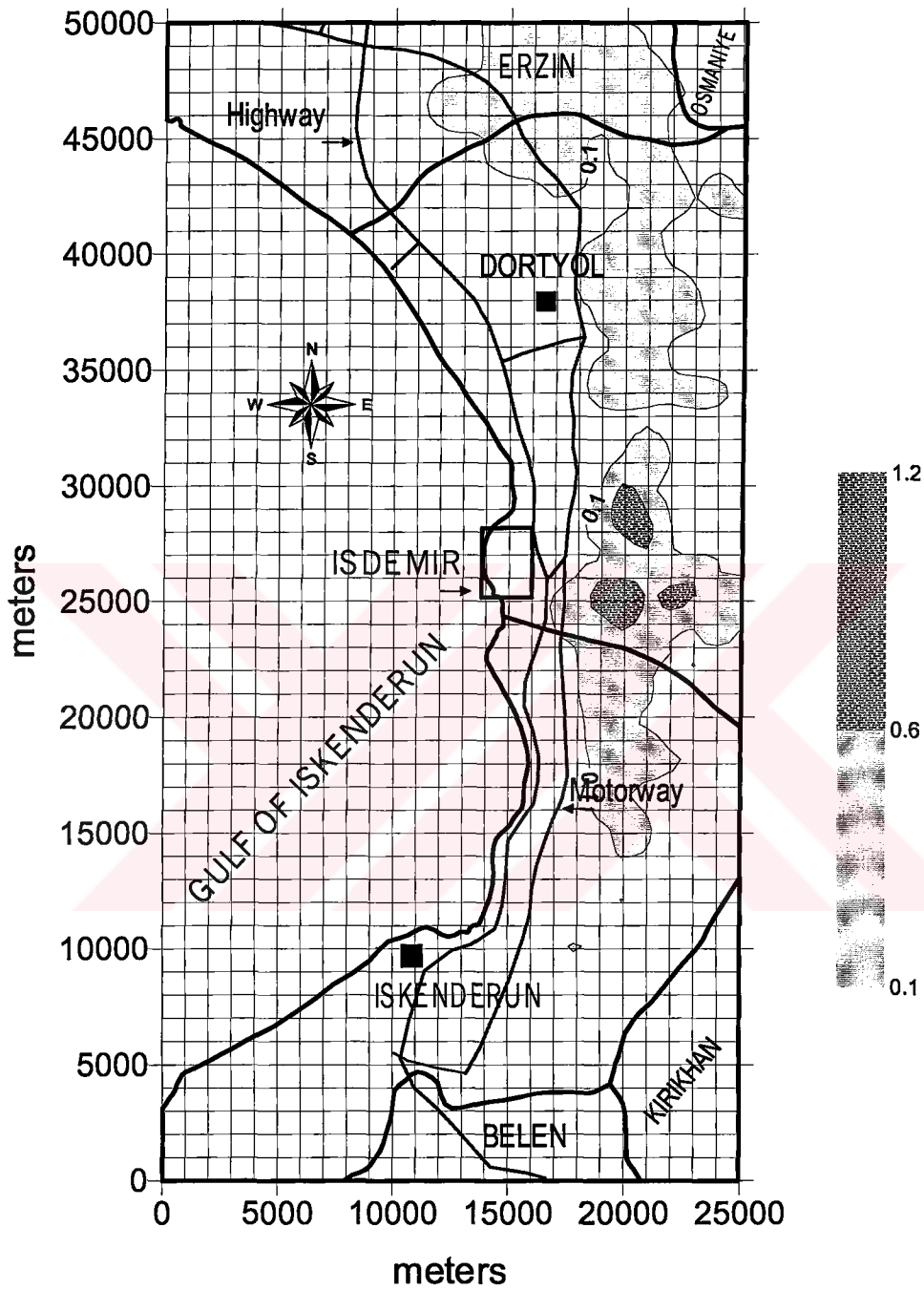

Figure 8.6 Annual average ground level concentrations of SO_2 due to ISDEMIR in Scenario # 1.

8.2 Scenario # 2

This is a scenario in which it is assumed that the stack heights in all other industries are raised from 20-25m to 50 m from ground level. It has already been discussed in the previous chapter that the total annual SO_2 emissions from other industries are almost five times less than that of ISDEMIR. However, the effect of other industries on the ground level SO_2 concentrations in Dortyol and Payas is more than that of ISDEMIR. The better dispersion of SO_2 emissions from ISDEMIR was attributed to its taller stacks. Therefore, it is decided in this scenario to study the effect of other industries with taller stacks on the ground level SO_2 concentrations.

It has been discussed earlier in Chapter 7 and in Figure 7.29, that other industries are responsible for the annual average ground level SO_2 concentrations of up to 50 $\mu g/m^3$ in Dortyol and Payas. Therefore, in this scenario the modeling calculations are performed only for other industries to see the changes on the ground level SO_2 concentrations due to taller stacks of other industries.

Figure 8.7 shows the annual average ground level concentrations of SO_2 from other industries in Scenario # 2. As can seen from this figure only the northern and eastern parts of Dortyol receive an SO_2 concentration of 10 to 50 $\mu g/m^3$, other parts of Dortyol and Payas are subjected to an SO_2 concentration of less than 10 $\mu g/m^3$. The maximum annual average SO_2 concentrations of up to 90 $\mu g/m^3$ are found towards the east of both the organized industrial estates of Dortyol and Payas. This dispersion trend is due to annual prevailing wind directions from W, WNW and from S. Upon comparing this figure with Figure 7.29 (which shows the annual average ground level concentration of SO_2 from other industries in the existing conditions), the effect of taller stacks can be seen in a better dispersion of SO_2. This resulted in the decrease of SO_2 concentrations in whole of Payas and in almost 70% of Dortyol from 50 $\mu g/m^3$ to less than 10 $\mu g/m^3$. This implies that there will be 80% reduction in the

existing annual average concentrations of SO_2 due to other industries in whole of Payas and most parts of Dortyol.

Figure 8.8 shows the winter average SO_2 concentrations for the Scenario # 2. This figure shows that most parts of Dortyol and some northern parts of Payas are still subjected to winter average SO_2 concentrations of 10-50 $\mu g/m^3$. The increase in stack heights of other industries has a positive effect on the ground level concentration of SO_2 during winter as they have reduced it from 50 $\mu g/m^3$ in western parts of Dortyol and Payas to less than 10 $\mu g/m^3$.

The results of Scenario # 2 can be summarized as; increasing the stack heights from 25 m to 50 m in other industries located in the organized industrial estates of Dortyol and Payas will decrease SO_2 concentrations due to other industries in these towns by 80%. The effect of this reduction on the overall annual average concentrations of SO_2 from all sources will be about 30% in these towns. But increasing stack heights in other industries does not significantly reduce the winter average ground level SO_2 concentrations in Dortyol and Payas.

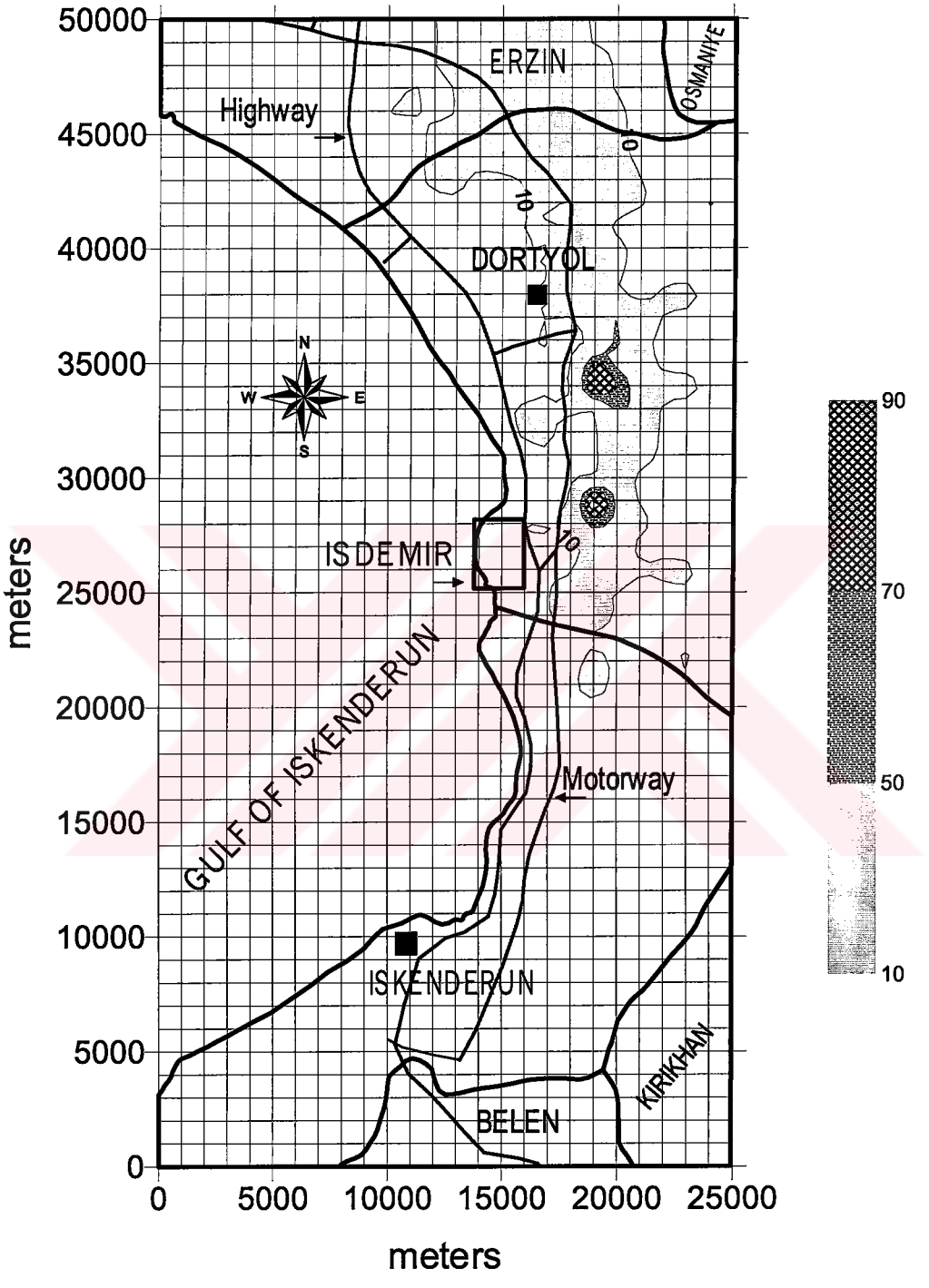

Figure 8.7 Annual average ground level concentrations of SO_2 due to other industries in scenario # 2

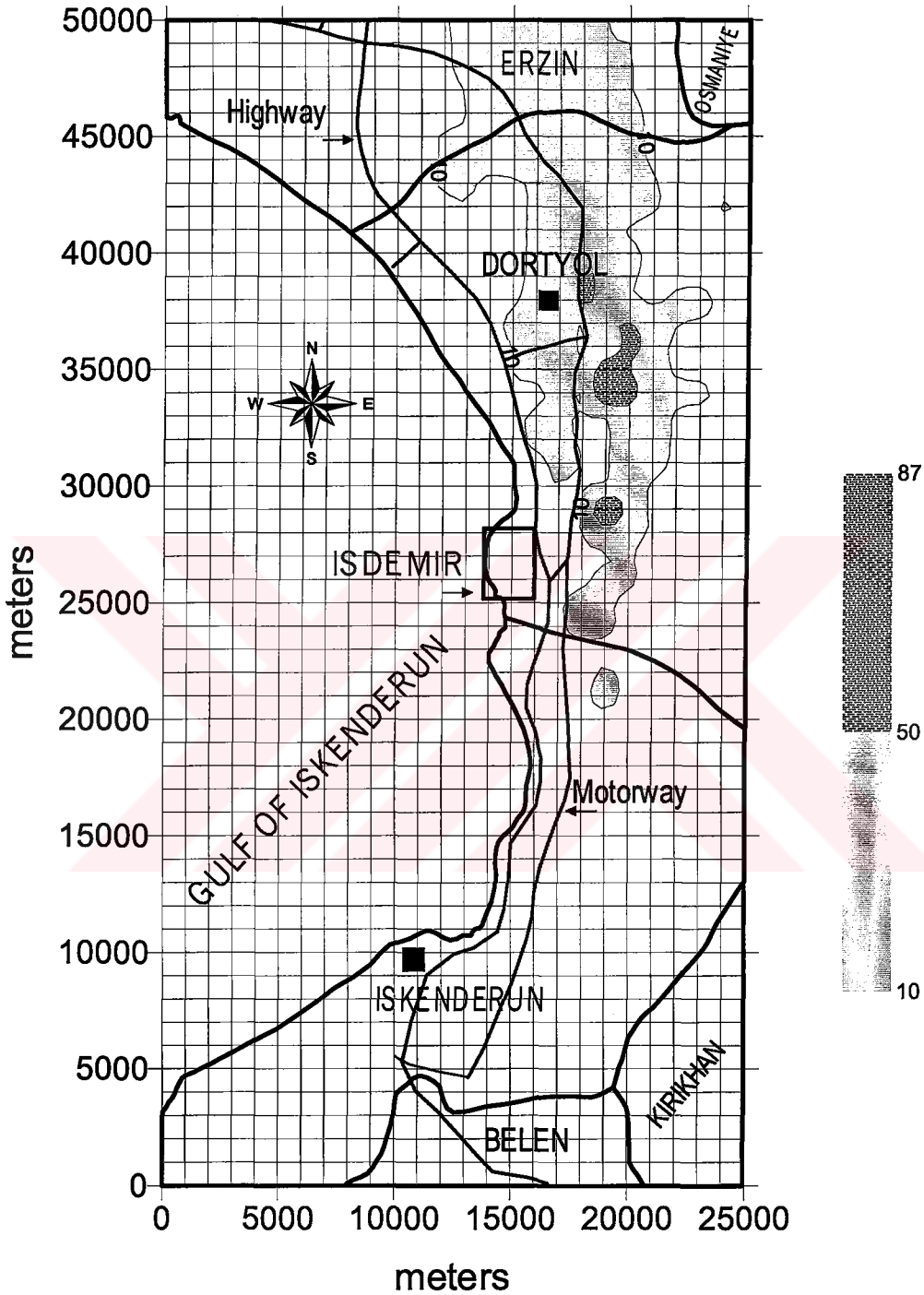

Figure 8.8 Winter average ground level concentrations of SO_2 due to other industries in scenario # 2

8.3 Scenario # 3

The Scenario # 3 is again related to SO_2 emissions from other industries. In this scenario the effect of replacing high sulfur fuel oil with the low sulfur fuel oil on SO_2 concentrations in the study area is studied. All of the steel industries in this study except ISDEMIR and Yazici Steel use fuel oil No.6 with a sulfur content of 6% by weight. This fuel oil is the cheapest among other fuels used in furnaces, and is supplied by TUPRAŞ from its oil refinery in Batman, Turkey. As a result of using high sulfur fuel oil the emissions of SO_2 from other industries were found to be 1764 kg/h (Table 6.6). As can be seen in Figure 7.29, Dortyol and Payas are subjected to annual average SO_2 concentrations of up to 50 $\mu g/m^3$ due to emissions from other industries.

In this scenario it was assumed that all of the steel industries using fuel oil with 6% by weight sulfur are shifted to fuel oil having 1.5% by weight sulfur. The modeling calculations for Scenario#3 are performed for other industries only, because of the same reasons that are described in Scenario # 2.

Figure 8.9 shows the annual average ground level concentrations of SO_2 from other industries for Scenario#3. As can be seen from the figure only a very small area in the eastern parts of Dortyol is receiving SO_2 concentrations of 10 to 34 $\mu g/m^3$, while the SO_2 concentrations in all other parts of Dortyol and Payas are below 10 $\mu g/m^3$.

Figure 8.10 shows the winter average SO_2 concentrations from other industries for Scenario # 3. This figure shows that the most parts of Dortyol and all of Payas are subjected to winter average SO_2 concentrations of less than 10 $\mu g/m^3$ except the eastern and southeastern part of Dortyol where the concentration goes up to 30 $\mu g/m^3$ due to westerly winds in wintertime.

It can be concluded from the results of the Scenario#3 that in other steel industries replacing the fuel oil with 6% sulfur with a fuel oil having a sulfur

content of 1.5%, will greatly improve the air quality in Dortyol and Payas. Comparing the results of Scenario # 2 and Scenario # 3 shows that the later has shown better results regarding the improvement of air quality in the towns of Dortyol and Payas. As the results of Scenario # 3 shows that almost all of the residential areas in these towns are receiving less than 10 $\mu g/m^3$ of annual average SO_2 concentrations due to other industries. In the existing conditions these towns are subject to an annual average SO_2 concentrations of up to 50 $\mu g/m^3$. Implementation of Scenario # 3 will cause a reduction of about 90% in the annual average ground level concentrations of SO_2 due to other industries in Dortyol and Payas. The overall effect of this reduction will lead to about 40% reduction in the annual average ground level concentrations of SO_2 due to all sources.

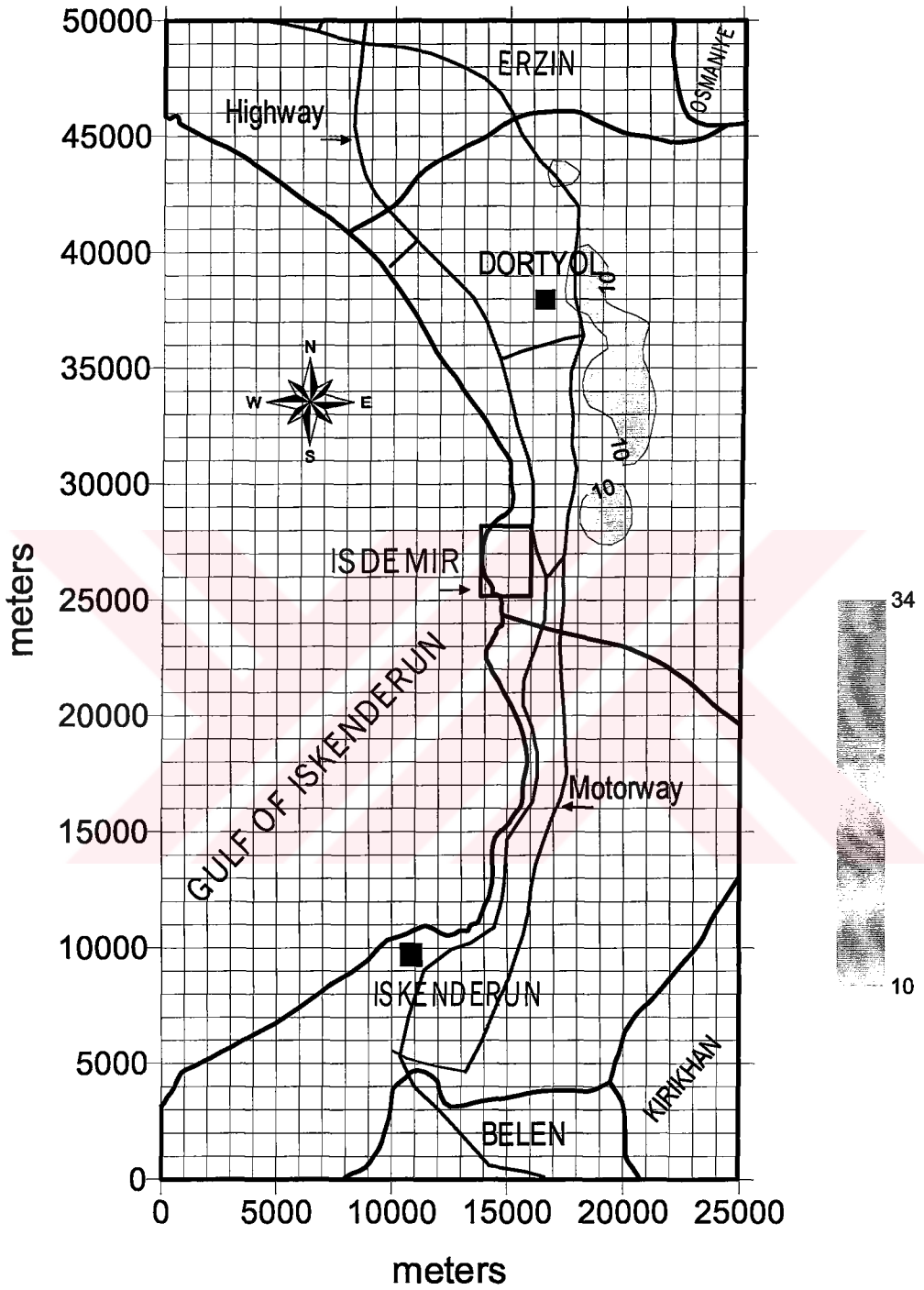

Figure 8.9 Annual average ground level concentrations of SO_2 due to other industries in scenario # 3

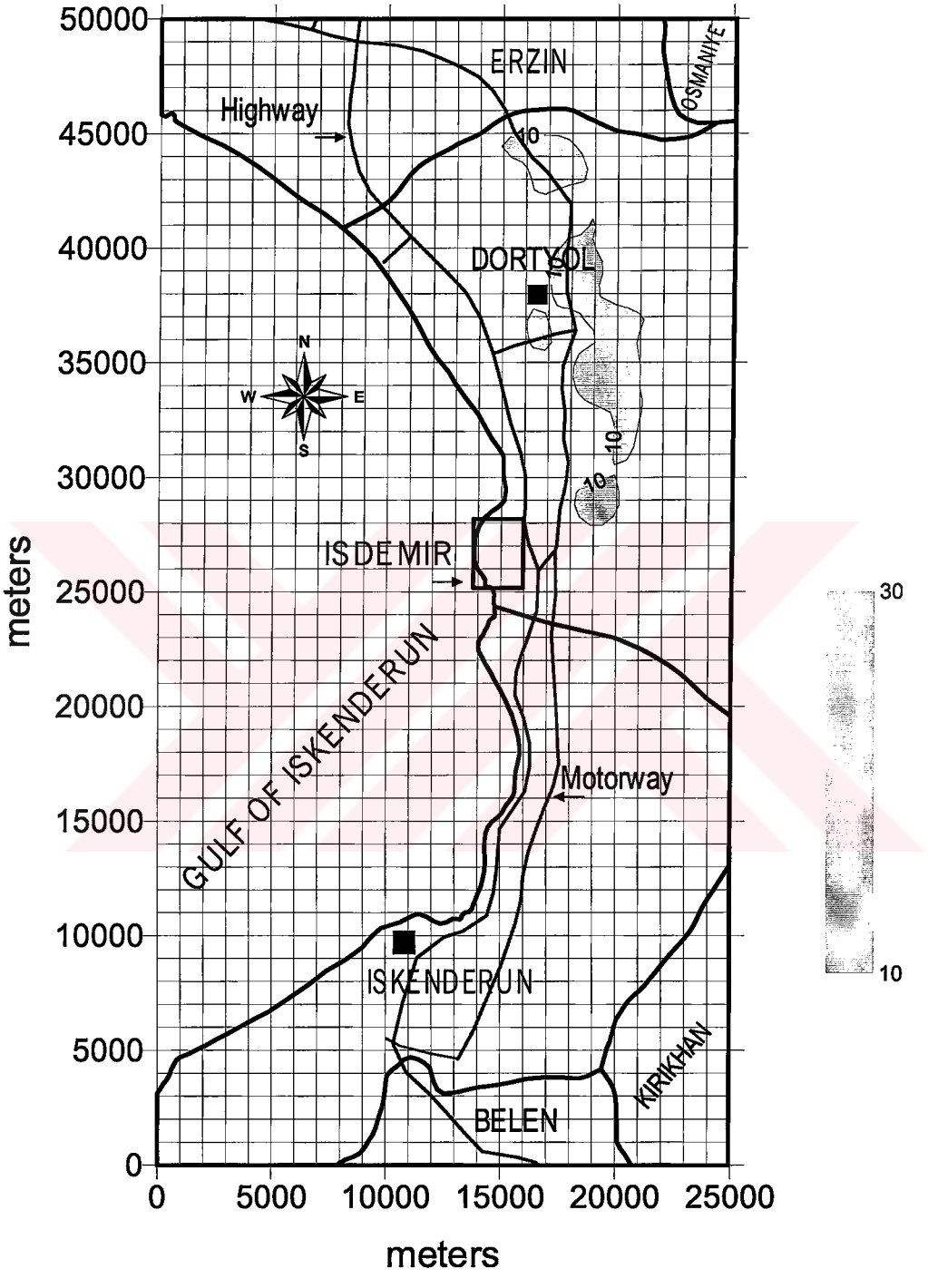

Figure 8.10 Winter average ground level concentrations of SO_2 due to other industries in scenario # 3

8.4 Scenario # 4

The Scenario # 4 is related to the domestic heating activities during winter. In the present conditions the major fuel used for domestic heating is coal. A small amount of fuel oil is also used for domestic heating in the urban areas of Iskenderun and Dortyol. It is assumed in this scenario that the entire domestic heating in the study area is shifted from coal to natural gas. According to the planning of BOTAS, the supply of natural gas in the study area will start in 2004.

As a result of using coal for domestic heating, the concentrations of PM and SO_2 in the study area are mainly due to burning of coal. Although the annual average PM concentrations in Iskenderun and Dortyol do not exceed the limiting concentration of PM (80 $\mu g/m^3$) defined by the EC Regulations, but they are close to this limit (Figure 7.3). Similarly the winter average PM concentrations at Iskenderun and Dortyol are below the limiting value of 200 $\mu g/m^3$ for PM set by the TAQPR (Figure 7.6).

In case of annual average ground level SO_2 concentrations, they are mainly due to domestic heating in Iskenderun (Figure 7.27 to 7.30), while in Dortyol they are due to the combined effects of domestic heating and other industries. The annual average SO_2 concentrations in these residential centers exceeded the limiting value of 50 $\mu g/m^3$ defined in the WHO guidelines and the EC Regulations. However, they are well below the existing and proposed revision limits of 150 and 100 $\mu g/m^3$, respectively for SO_2 in the TAQPR. The situation during winter in Iskenderun and Dortyol is even worse. Although the winter average concentrations of SO_2 do not exceed the limiting values set by the TAQPR, but reach the value of 243 $\mu g/m^3$ in some parts of Iskenderun city (Figure 7.34). Moreover, daily average concentrations of SO_2 exceeded the limit on 50 days during 2001. Therefore, in order to see the improvement in the air quality by changing the fuel type it was decided to study the scenario in which entire domestic heating is done by natural gas in the study area.

Since domestic heating is done only during winter, the dispersion modeling calculations are done only for winter season. Since sulfur and ash are not present in the natural gas, therefore there will not be any PM and SO_2 concentrations due to burning of natural gas. Hence the problems related to PM and SO_2 in the residential areas will be eliminated totally.

Figure 8.11 shows the winter average ground level NO_X concentrations from residential heating. As can be seen from this figure, that most parts of Iskenderun and Dortyol are subject to a NO_X concentration of more than 40 $\mu g/m^3$. In the central parts of Dortyol and eastern to southeastern parts of Iskenderun NO_X concentrations reaches up to 70-106 $\mu g/m^3$. This is **almost 3 to 4 times** more than the NO_X concentrations due to burning of coal (Figure 7.55). This high NO_X concentration can be attributed to the higher flame temperature of natural gas as compared to coal, which leads to the formation of thermal NO_X.

Figure 8.12 shows the winter average ground level CO concentrations from residential areas for the Scenario # 4. As can be seen from this figure, most parts of Iskenderun and Dortyol the CO concentrations range between 100 and 212 $\mu g/m^3$. Rural areas in this scenario are subjected to CO concentrations of 10-100 $\mu g/m^3$.

It can be concluded from the results of the Scenario # 4 that by using natural gas as a fuel for domestic heating instead of coal, the air quality can be improved dramatically in the residential centers of the study area, as there will be no emissions of PM and SO_2. However, NO_X concentrations will be elevated.

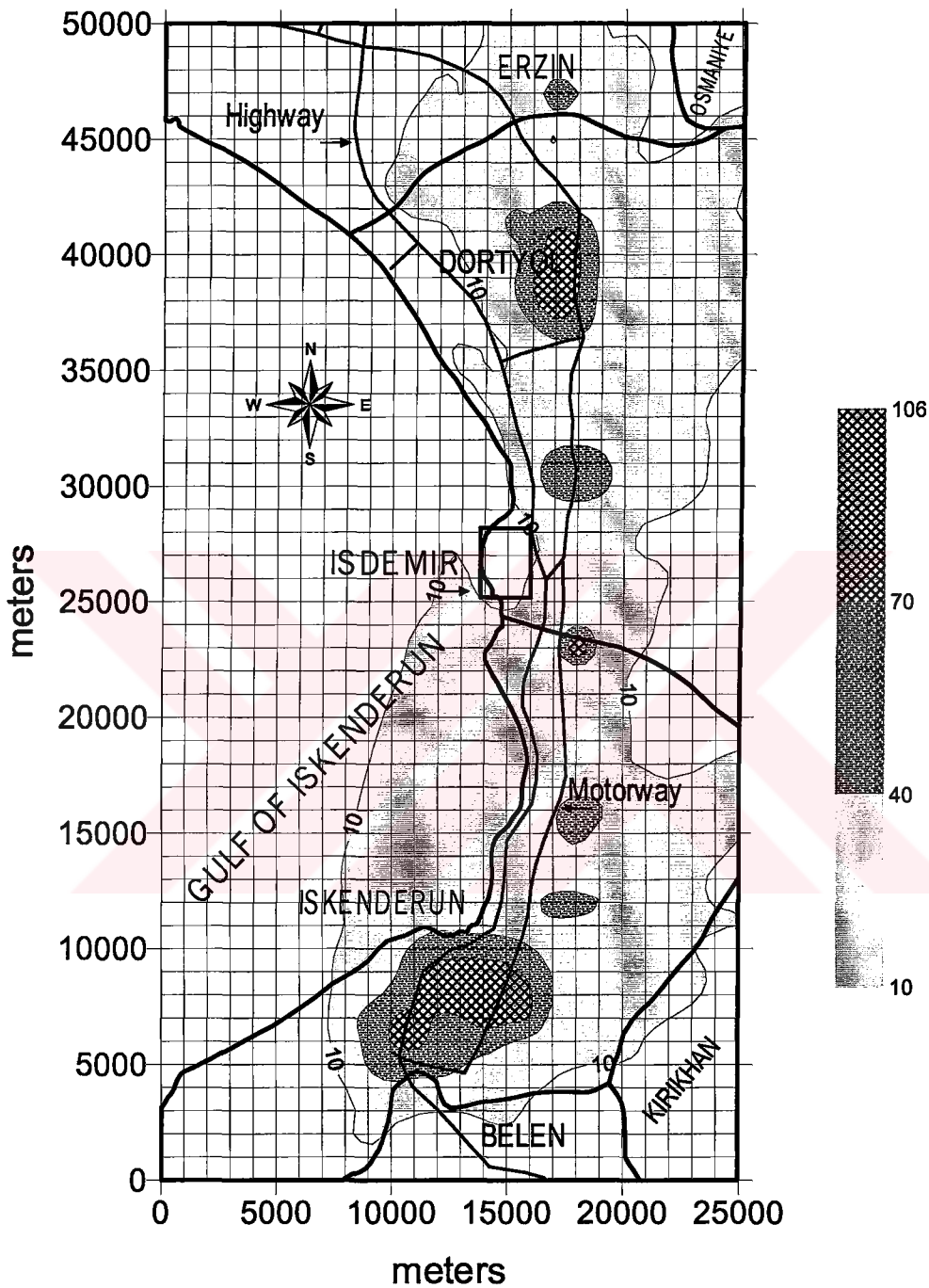

Figure 8.11 Winter average ground level concentrations of NO_X due to residential heating by natural gas in scenario # 4

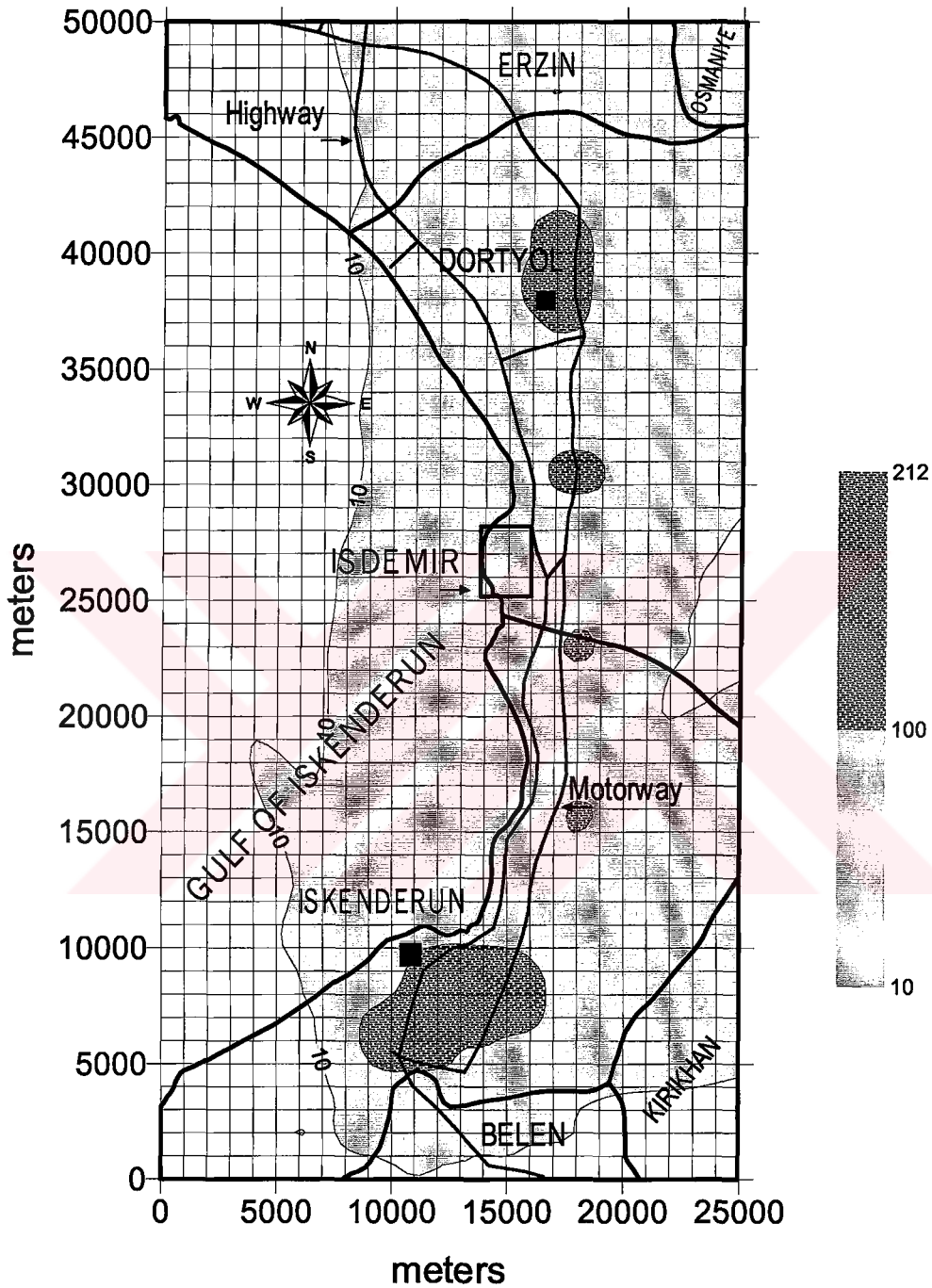

Figure 8.12 Winter average ground level concentrations of CO due to residential heating by natural gas in scenario # 4

8.5 Economics of Air Quality Improvement Scenarios

An economic analysis has been performed for all of the air quality improvement scenarios described earlier in this chapter. The results of economic analyses are given in Table 8.1 and 8.2, details and calculations of these analyses are given at Appendix C. Table 8.1 summarizes the costs associated with the control of PM and SO_2 emissions from ISDEMIR. Costs have been estimated for PM control by fabric filters and ESPs depending upon their applicability in several units of ISDEMIR. For the control of SO_2 emissions these different types of FGD systems have been evaluated and cost estimates are worked out.

The total annual average PM control costs are found to be 2,659,580 US$/year, the details are given in Table 8.1. These costs include annual initial investment (assuming 30 years of operational life and straight-line depreciation applicable), as well as annual operating costs. The initial investment for Bag-house Filter System was found to be 1,849,065 US$, and the price of filter bags was worked out to be 92,453 US$ (Table C.1 given in Appendix C). The life of filter bags is considered as two years.

Thus, the total initial investment for fabric filter system (Bag-house Filters) will be = 1,849,065 + 92,453 = 1,941,518 US$.

The initial investment cost of ESPs for ISDEMIR was found to be 37,425,000 US$.

Therefore, the initial investment required for the installation of PM control systems at ISDEMIR will be :

= Initial investment on Fabric Filters + Initial Investment on ESPs

= 1,941,518 + 37,425,000 = 39,366,518 US$

As can be seen in Table 8.1 the annual average costs (initial investment + operational) of FGD systems are found to be much higher than that of PM control systems. Wet limestone scrubber proved to be the most expensive option with 21.73 million US$/year of cost estimate, followed by wet lime scrubber at a cost of 12.98 million US$/year and dry lime injection system with about 4.75 million US$/year.

Total initial investment on FGD Systems for the capacity required by ISDEMIR was found to be:

- Limestone wet scrubbers = 100 million US$
- Lime wet scrubbers = 55 million US$
- Dry lime injection system = 15 million US$

As summarized in Table 8.1 the combination of fabric filters, ESPs and dry lime injection systems seems to be the most economical choice for the control of PM and SO_2 emissions from ISDEMIR. This option requires an expenditure of about 7,393,200 US$/year. The other two options are twice and more than three times more expensive as compared to the dry lime injection FGD system.

Table 8.2 shows the summary of economic analyses for Scenarios # 2, 3 and 4. As can be seen in the table all of the "other industries" need to spend 50,000 US$/ year collectively to slightly improve air quality in Dortyol and Payas.

In case of Scenario # 3 all "other industries" will have to spend collectively 6.9 million US$/year to replace high-sulfur fuel oil with the low-sulfur content fuel oil. This will greatly improve the air quality in Dortyol and Payas.

In Scenario # 4 each dwelling in the study area needs to spend 255 US$/year to shift residential heating from coal and fuel oil to natural gas. This will dramatically improve the air quality in all of the residential areas in Iskenderun Region by total elimination of PM and SO_2 emissions.

Table 8.1 Summary of economic analyses and effects on air quality for Scenario # 1

Pollutants/ Conditions	Emission Control Techniques	Average cost of emissions control systems (US$/year)	Effect on air quality	Average cost of pollution control (US$/year)		
				PM + Wet limestone	PM + Wet lime	PM + Dry lime
PM emissions from ISDEMIR reduced from 2400 kg/h to below 15 kg/h	Fabric Filter	518,945	Reduction in the annual average ground level PM concentrations in whole of the Iskenderun Region from up to 127 $\mu g/m^3$ to less than 52 $\mu g/m^3$ i-e, below EC Regulation and TAQPR limits.	**24,389,580**	**15,639,580**	**7,393,200**
	ESP	2,140,635				
	Sub total	2,659,580				
SO_2 emissions from ISDEMIR reduced from 4146 kg/h to below 60 kg/h	Wet limestone scrubber	21,730,000	Almost negligible effect on the annual average ground level concentrations of SO_2 in the Iskenderun Region, because tall stacks of ISDEMIR ensure effective dispersion of SO_2 emissions even without any emission control system.			
	Wet lime scrubber	12,980,000				
	Dry lime injection	4,733,620				

Table 8.2 Summary of economic analysis and effects on air quality for Scenario # 2- 4

Case	Conditions	Effect on air quality	Total Cost (US$/year)
Scenario # 2	Increasing the stack heights in other industries from 25 m to 50 m.	A slight reduction in the annual average ground level concentrations in Dortyol and Payas	50,000
Scenario # 3	Change of Fuel Oil No. 6 (having 6% by wt. sulfur) with Domestic Fuel Oil (with 1.5 % by wt. sulfur) in all of the re-rolling mills in Iskenderun Region	Reduction in annual average ground level concentration of SO_2 due to other industries, from 50μg/m^3 to below 10 μg/m^3 in Dortyol and Payas	6,901,508
Scenario # 4	Entire domestic heating in the Iskenderun Region is shifted from coal to natural gas	Total elimination of PM and SO_2 due to domestic heating, which is the largest contributor in ground level PM and SO_2 concentrations in the residential centers of Iskenderun Region	255 US$/year per dwelling

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

All sources namely the industrial, domestic heating and traffic in urban areas as well as the traffic on inter-city roads are included in the emission inventory and dispersion modeling study. All industrial emissions except NMVOC were determined by emission measurements at source, NMVOC emissions calculated by using CORINAIR emission factors. Emissions from domestic heating and traffic sources were also calculated by using CORINAIR emission factors.

The emission inventory, which has been prepared for the first time for Iskenderun Region, has shown some important results. The total annual emissions from Iskenderun Region are found to be:

- 19,951 tons of PM
- 40,833 tons of SO_2
- 10,764 tons of NO_X
- 109,938 tons of CO and
- 5,665 tons of NMVOC.

Industrial sector was found to be the major contributor in total emissions from Iskenderun region, industries were responsible for:

- 96% of total PM
- 97% of total SO_2

- 68% of total NO_X and
- 73% of total CO
- 4% of total NMVOC

Among industries ISDEMIR is the single largest source of emissions

The share of domestic heating in total annual emissions was not found to be high. The highest percentage is for PM, being 3.5% of the total emissions.

In the total annual emissions from the Iskenderun region the traffic sources were responsible for:

- 0.76% of PM
- 31% of NO_X
- 27% of CO and
- 94% of NMVOC

The results of the dispersion modeling showed that the Iskenderun City, the largest residential area in the region, was the least affected by industrial emissions. Domestic heating activities were found to be the basic cause of PM concentrations in the residential areas. Moreover, contribution of domestic heating sources in the annual average PM concentrations at city centers were:

- 97% in Iskenderun
- 82% in Dortyol and
- 87% in Payas

During winter because of domestic heating, mainly by coal, the average PM concentrations reach up to 150 $\mu g/m^3$ in Iskenderun and up to 130 $\mu g/m^3$ in Dortyol which are below the limit of TAQPR.

The maximum annual average ground level PM concentration of was found in the areas towards ESE of ISDEMIR, which was below the limit set in TAQPR but above the EC limit.

The maximum PM deposition was found to occur near the southeast corner of the property of ISDEMIR. Dry deposition was responsible for 89% while wet deposition accounted for 11% of the total PM depositions.

Annual average ground level SO_2 concentrations in some parts of Iskenderun and Dortyol reaches up to 100 and 140 $\mu g/m^3$, respectively. While in northeastern parts of Payas it reaches up to 70 $\mu g/m^3$. They do not exceed the TAQPR limit but exceeded WHO/EC limits. **Domestic heating activities** accounted for SO_2 concentrations of:

- 98% in Iskenderun
- 85% in Dortyol
- 73% in Payas

Although ISDEMIR's share is 80% in total annual SO_2 emissions from Iskenderun Region, but the contribution of **other industries** in the annual average ground level concentrations of SO_2 is more than that of ISDEMIR. The contribution of other industries in the annual average SO_2 concentrations at city centers of:

- Iskenderun was 1%
- Payas was 13%
- Dortyol was 24%,

However, ISDEMIR was responsible for the annual average SO_2 concentrations of 1%, 2% and 3% in Iskenderun, Payas and Dortyol, respectively.

During **winter**, SO_2 concentrations in almost all of Iskenderun City and Payas were above 70 $\mu g/m^3$ while in Dortyol it was above 100 $\mu g/m^3$. The average SO_2 concentration in the southeastern parts of Iskenderun and central and northern parts of Dortyol reached up to 245 $\mu g/m^3$, which is just below the limit of TAQPR.

The maximum wet deposition of SO_2 of 4.1 g/m^2-y occurs on a very small area inside ISDEMIR near its eastern boundary. The wet deposition rate of 0.1-1 g/m^2-y that is quite small, prevails over the most parts of the study area. Based on the literature it has been concluded that there is no acid rain problem in the study area.

The maximum ground level concentration of NO_X was found to be 158 $\mu g/m^3$ in Iskenderun and Dortyol, which is above the TAQPR as well as WHO/EC limits. These NO_X concentrations were mainly due to urban traffic.

The results of modeling study showed that annual and seasonal average ground level concentrations of CO are well below the limits set in the TAQPR. The maximum annual average ground level concentration of CO was found to be 1560 $\mu g/m^3$.

Model simulations have shown that on certain days during 2001, the 24-h average concentrations of PM, SO_2 and NO_X exceeded the limits set in the TAQPR as follows:

- PM concentrations exceeded on 22 days
- SO_2 concentrations exceeded on 50 days
- NO_X concentrations exceeded on 28 days

Moreover, there were 89 days during year 2001 when 24-h average ground level SO_2 concentrations exceeded WHO/EC limits of 125 $\mu g/m^3$.

The performance of ISCST3 Model was evaluated by comparing the concentrations predicted by the model and observed concentrations of SO_2 at the air quality monitoring station present in Iskenderun City. The overall accuracy of SO_2 concentrations predicted by the model was found to be 67%. However, the model under predicted the SO_2 concentrations.

The results of four air quality improvement scenarios for the study area are as follows:

- Scenario # 1 has shown that by keeping PM emissions from ISDEMIR below the limit set by the TAQPR will eliminate the problem of ground level PM concentration. Another interesting result from Scenario # 1 is that controlling SO_2 emissions from ISDEMIR will not cause any significant reduction in the ground level concentrations of SO_2. However, SO_2 emissions from ISDEMIR need to be controlled in order to comply with the TAQPR. Moreover, implementing scenario # 1 will cause 95% and 80% reductions in the total emissions of PM and SO_2, respectively from Iskenderun region.

- Scenario # 2 shows that increasing stack heights of "other industries" from 25 m to 50 m will cause an overall reduction of about 30% in the annual average concentrations of SO_2 in Dortyol and Payas.

- Scenario # 3 has shown that other steel industries should be shifted to low sulfur fuel oil in order to improve the air quality in Dortyol and Payas by an overall reduction of about 40% in the annual average ground level concentrations of SO_2.

- The results of Scenario # 4 show that if domestic heating is shifted to natural gas from coal and fuel oil, there will be a dramatic improvement in the ground level concentrations of PM and SO_2. However, ground level concentrations of NO_X will increase.

As an overall conclusion, the industrial sector was found to be responsible for the annual average pollutant concentrations, however domestic heating and urban traffic was the dominant cause of the ground level concentrations of pollutants in the urban areas

9.2 General Recommendations

The dry deposition of SO_2 and NO_X could not be studied, due to lack of some additional meteorological data (vegetation leaf index). Therefore, upon availability of complete meteorological data dry deposition of gases can be studied.

Traffic counts in urban areas are found to be an important data missing in this study. Therefore, it is strongly recommended that these counts should be made. Replacing the assumed urban traffic counts with the actual count data will refine the emission inventory as well as modeling results of this study.

The impacts of air pollution on human health, vegetation and animals in this region should be studied especially in the mountainous region in the East of ISDEMIR at different altitudes. Inclusion of other pollutants such as ozone, PM_{10} and heavy metals in the study will help to understand better the air pollution problems and their effect in the Iskenderun Region.

The study of heavy metals and PM_{10} present in the emissions especially from ISDEMIR would be of great interest, because presence of heavy metals in PM emissions from ISDEMIR is unavoidable as iron ores are major raw material in this industry.

Although the share of ISDEMIR in the annual SO_2 emissions from the study area was 80%, its effect on the ground level SO_2 concentrations was very small. However, the emissions from ISDEMIR exceed the emission limits given in the standards. Therefore, these emissions should be controlled by using proper emission control technologies.

There is a high probability of photochemical smog formation in the region. Therefore, it is strongly suggested to measure the O_3 and NO_2 concentrations in the atmosphere in addition to PM, SO_2, and NMVOC.

9.3 Suggestions for the Clean Air Plan

Major sources of emissions in Iskenderun Region have been identified in this study. Based on outcomes of this study a comprehensive **clean air plan** should be developed by local authorities for Iskenderun region. The clean air plan can be developed on the basis of the results of this study. The following needs due attention during preparation of the clean air plan:

- Periodic updates of the emission inventory on regular basis to have up to date knowledge about amount of emissions from this region.
- Development of emission control plans for industries releasing pollutants above the limits specified in the TAQPR (MOE, 1986), such as ISDEMIR and re-rolling mills, and even the emission limits of EC should be considered since Turkey is a candidate country for the EU.
- To reduce emissions from re-rolling mills, two scenarios have been studied. In the 1st case, the heights of stacks were increased from the existing ones to 50 m for all re-rolling mills. In the 2nd case fuel oil having 6% sulfur was replaced with fuel oil of 1.5% sulfur content. The later scenario has given better results by showing about 90% decrease in ground level concentration of SO_2 due to these industries. Authorities may choose any one of these two options. Moreover, other options can also be studied using the modeling system used in this study.
- The emissions of PM from ISDEMIR are 160 times higher than the limit defined in TAQPR; a scenario was studied assuming that PM emissions from ISDEMIR are below the limit. The results of this scenario show about 59% reduction in the ground level concentrations of PM due to ISDEMIR. It is, therefore, suggested that in the clean air plan due attention should be given to control PM emissions from ISDEMIR.
- Before giving permission to setup any new industrial unit, its impacts should be studied. This can be accomplished very easily and without much effort by using the air quality modeling system developed in this study.

- Efforts should be directed towards shifting the industries to cleaner fuels such as natural gas instead of fuel oil or controlling their emissions. Natural gas will be available for use in the Iskenderun region in 2004 (BOTAŞ, 2002).
- The air pollution monitoring station operating in Iskenderun is not enough to give a clear picture of pollution levels in that city. This monitoring station is located in the northern part of the Iskenderun city, which is closer to sea and in a relatively cleaner place. The best places to set up monitoring stations in Iskenderun are in central and southeastern parts of the city, as the maximum ground level concentrations predicted by the modeling calculations were in those areas.
- Air pollution monitoring stations should be setup in Dortyol and Payas to record the daily average ground level pollutant concentrations. These are also the most polluted residential areas in Iskenderun region, which are subject to emissions from industrial sources.
- NO_2, O_3, and NMVOC should also be included as new parameters for the monitoring stations in the area.

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http://www.undp.org
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APPENDIX A

Gaussian Dispersion Model

There are several models available for predicting the concentrations downwind of a single source, but most of them are numerical methods. However, under a set of simplifying assumptions, the analytical closed form solution can be obtained. The first formulation for the steady state concentration downwind from a continuous point source was presented by Sutton and further developed by Pasquill (1962) and Gifford. (1971). This solution is commonly known as the Gaussian Plume Model. The concentration distribution perpendicular to the plume axis is assumed to be Gaussian. The plume travels with a uniform wind velocity (u) downwind from the source (Murali, 1995).

The contaminated gas stream (normally called a plume) is shown rising from the smokestack and then leveling off to travel in the x direction and spreading in the y and z directions as it travels.

Such plumes normally rise a considerable distance above the smokestack because they are emitted at temperatures higher than atmospheric and with a vertical velocity. For Gaussian plume calculations the plume is assumed to be emitted from a point with coordinates 0, 0, H, where H is called the effective stack height, which is the sum of the physical stack height h and the plume rise.

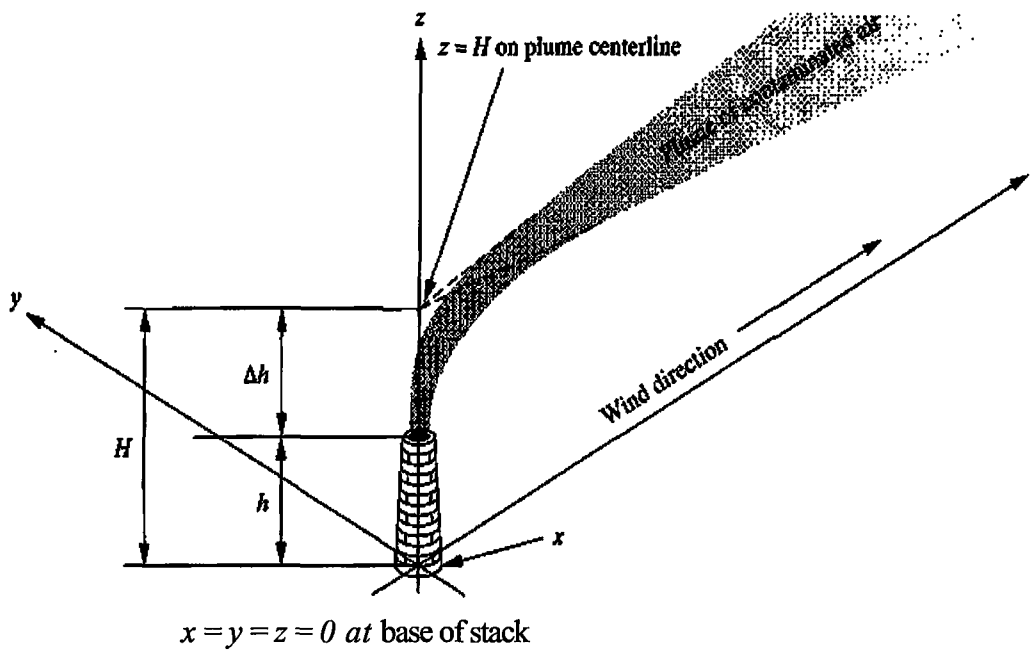

Figure A.1. Explanation of Gaussian Dispersion Parameters

Assumptions for Gaussian Dispersion Model

1. The plume has a Gaussian distribution in both horizontal and vertical planes with σ_y and σ_z as the standard deviations of the concentrations of the plume in horizontal crosswind and vertical directions respectively.

2. The mean speed affecting the plume is u, which is the wind speed at the source level i.e. at the point where dispersion starts.

3. Uniform and continuous emission of Q g/sec of pollutant takes place.

4. Diffusion of pollutant in 'x' direction is negligible compared to diffusion in crosswind direction. This is true if emission is continuous and if wind speed is more than 1m/sec.

5. Total reflection of the plume takes place at the earth's surface i.e. there is no deposition or reaction on the pollutants at the surface. Also the pollutants are inert and passive so that there is no gravity fallout and there are no atmospheric chemical reactions.

6. Parameters governing the diffusion of the pollutant do not change in space and time i.e. steady-state conditions prevail.

7. The terrain underlying the plume is flat.

The Gaussian Model equation is given by:

$$C(x,y,z) = \frac{Q}{2\pi\sigma_y\sigma_z u} Exp.\left[-\frac{y^2}{2\sigma_y{}^2}\right].\left\{Exp.\left(-\frac{(z-H)^2}{2\sigma_z{}^2}\right) + Exp.\left(-\frac{(z+H)^2}{2\sigma_z{}^2}\right)\right\}$$

Where

C (x,y,z) = Concentration of pollutant at location x,y,z in g/m3.

Q = Pollutant emission rate at source in g/sec.

u = Horizontal wind speed at the source at stack height in m/sec

H = Effective stack height in m.

H = h +Δh

h = Physical height of stack (m)

Δh = Plume rise (m)

σ_y, σ_z = Standard deviations of the concentration of pollutant at x in the horizontal cross wind and vertical directions respectively.

And z = height of receptor above ground level

Dispersion Coefficients (σy, σz):

Dispersion coefficients (σy, σz) are defined as parameters, which describe the growth of the dimensions of a Gaussian plume as a function of travel distance or travel time and atmospheric stability. They also depend on the source height and the surface roughness. For estimating the concentration downwind resulting from a continuous plume, the values of dispersion coefficients σy, σz and wind

speed are necessary besides the physical data such as coordinates x, y and z, emission rate Q, effective height H etc. In fact, dispersion coefficients are standard deviations of plume concentration distribution in the crosswind (σy) and vertical (σz) directions, σy and σz are a function of downwind position x as well as the atmospheric stability condition. Many experimental measurements in the atmosphere have led to the evaluation and correlation of σ_y and σ_z. There are several sets of charts for estimating the values of these two parameters. Most commonly used method for estimation of plume dispersion coefficients is the empirical method proposed by Pasquill (1962) and later modified and described by Turner (1970).

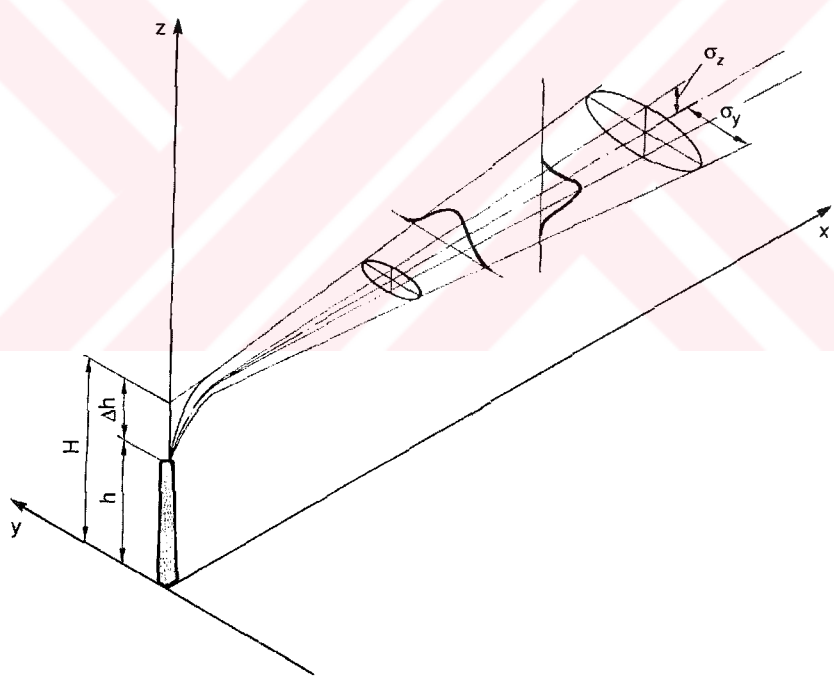

Figure A.2. Gaussian Dispersion.

Limitations of Gaussian Dispersion Model

- It does not consider the existence of various stability layers at different heights in the atmosphere.

- It does not consider the change in stability characteristics with time.
- It does not consider the terrain characteristics such as terrain roughness, existence of mountains and valleys, distribution of land and water masses.
- It does not consider the existence of free convection regions and strong wind shears like change of wind directions and change of wind speed with height.
- It ignores stack down wash.
- Dry and wet depositions of pollutants are ignored.
- Considers pollutants as non-reactive.
- No absorption/adsorption of pollutants by soil is considered when it reaches the ground level.

APPENDIX B

B.1 Emissions from ISDEMIR

Table B.1 Emissions from stacks of ISDEMIR

Stack Name	Stack Code	PM (Kg/h)	SO_2 (Kg/h)	NOx (Kg/h)	CO (Kg/h)
COKE AND BY PRODUCTS					
Breaking and mixing unit No.2	CBU-BM1	20.1			
Breaking and mixing unit No.2	CBU-BM2	1.73			
Breaking and mixing unit No.2	CBU-BM3	35.7			
Breaking and mixing unit No.2	CBU-BM4	25			
Breaking and mixing unit No.2	CBU-BM5	13			
Breaking and mixing unit No.2	CBU-BM6	2.2			
Breaking and mixing unit No.2	CBU-BM7	6.28			
Breaking and mixing unit No.2	CBU-BM8	2.89			
Breaking and mixing unit No.2	CBU-BM9	1.76			
Breaking and mixing unit No.2	CBU-BM10	0.443			
Breaking and mixing unit No.2	CBU-BM11	2.46			
Breaking and mixing unit No.2	CBU-BM12	5.64			
Dry Cooling unit	CBU-DC1	18.9	0	2.06	2.1
Dry Cooling filter unit	CBU-DCF1	0.474			
Coke battery No. 1	CBU-CB1	15.17	101.78	42.53	327.6
Coke battery No. 2	CBU-CB2	5.5	131.3	36.1	424.8
Coke battery No. 3	CBU-CB3	2.76	47.24	14.47	226.3
Coke battery No. 4	CBU-CB4	17.18	60.93	14.21	283.8
Sub Total		***177.187***	***341.25***	***109.37***	***1264.6***
SINTERING UNIT					
Sintering Stack	SU-S1	540	1308	129	4043
Sinter ESP stack	SU-SESP1	63.1			
Unit No. 159	SU-U159	0.567			
Unit No. 170	SU-U170	9.59			
Unit No. 184	SU-U184	138			
Unit No. 191	SU-U191	1.51			
Slurry prep. and drying Unit1	SU-SPD1	3.39		0.0972	
Slurry prep and drying Unit2	SU-SPD2	1.64			
Sub Total		***757.797***	***1308***	***129.0972***	***4043***
BLAST FURNACE					
Furnace stack 1	BF-F1	0.663		2.53	196
Furnace stack 2	BF-F2	2.11		13.1	2580

Stack Name	Stack Code	PM (Kg/h)	SO_2 (Kg/h)	NOx (Kg/h)	CO (Kg/h)
Furnace stack 3	BF-F3	0.943		30.3	1410
Ventilation stack 1	BF-V1	423			
Ventilation stack 2	BF-V2	31.7			
Ventilation stack 3	BF-V3	43.1			
Ventilation stack 4	BF-V4	10.2			
SO_2 Reduction Filter stack	BF-SO_2R1	0.152		0.115	5.54
Sub Total		***511.868***		***46.045***	***4191.54***
STEEL MAKING PLANT					
Converter gas cleaning Stack	SM-CGC1	2.66		10.1	21.4
Chemical dust filter stack	SM-CDF1	0.472			
Electrical shop dust filter stack	SM-ESDF1	0.214			
lime oven No.1	SM-LO1	1.27		0.259	94.7
lime oven No.2	SM-LO2	0.824		0.233	67
lime oven No.3	SM-LO3	1.81		0.227	75.9
lime oven No.4	SM-LO4	1.85		0.182	75.5
lime oven No.5	SM-LO5	7.21		0.264	81.6
lime oven No.6	SM-LO6	5.09		0.663	133
Lime unit dust filter	SM-LDF1	1.07			
Lime unit dust filter	SM-LDF2	0.138			
Mixer dust filter No.1	SM-MDF1	1.9			
Mixer dust filter No.1	SM-MDF2	4.82			
Mixer dust filter No.2	SM-MDF3	15.1			
Mixer dust filter No.2	SM-MDF4	19.4			
Sub Total		***63.828***		***11.928***	***549.1***
Re-rolling Mills					
Steel bars unit TAV furnace 1	FU-TAV1	48.4	202.9	24.4	
Steel bars unit TAV furnace 2	FU-TAV2	24.6	127.3	24.6	
Steel bars unit TAV furnace 3	FU-TAV3	3	83.2	11.72	
Light profile bars furnace	FU-LPF1	16.3	32	24.1	
Medium profile bars furnace	FU-MPF1	2.77		6.08	
Construction steel bars furnace	FU-CSF1	6.51	45.7	4.84	
Sub Total		***101.58***	***491.1***	***95.74***	
ENERGY PRODUCTION FACILITY					
Energy production stack	EPF-EP1	787.9	2005.5	427.3	
Sub Total		***787.9***	***2005.5***	***427.3***	
PRODUCTION WORKSHOP					
Production Workshop Furnace	PW-PWF	0.287		0.291	0.859
Sub Total		***0.287***		***0.291***	***0.859***
GRAND TOTAL		**2400**	**4146**	**820**	**10049**

B.2 Stack Dimensions and Pollutants in Stack Gases of ISDEMIR

Table B.2 Characteristics of stacks of ISDEMIR

No.	Name of Stack	Stack No.	Height (m)	Lower internal diameter (m)	Upper Internal Diameter (m)	Pollutant
	Coke and By products Unit					
1	Breaking and mixing unit No.2	426/74	22.8	1.25	1.25	PM
2	Breaking and mixing unit No.2	426/75	22.8	1.25	1.25	PM
3	Breaking and mixing unit No.2	427/78	38	1.25	1.25	PM
4	Breaking and mixing unit No.2	427/79	38	1.25	1.25	PM
5	Breaking and mixing unit No.2	428/81	27	1	1	PM
6	Breaking and mixing unit No.2	428/82	27	1	1	PM
7	Breaking and mixing unit No.2	428/83	27	1.4	1.4	PM
8	Breaking and mixing unit No.2	428/84	27	1.4	1.4	PM
9	Breaking and mixing unit No.2	429/101	35	0.8	0.8	PM
10	Breaking and mixing unit No.2	429/102	35	0.6	0.6	PM
11	Breaking and mixing unit No.2	429/104	35	0.6	0.6	PM
12	Breaking and mixing unit No.2	434	35	0.6	0.6	PM
13	Dry Cooling unit		35	1	1	PM,Flue gas
14	Dry Cooling filter unit		30	1	1	PM
15	Coke battery No. 1		100	6.4	6.4	PM,Flue gas
16	Coke battery No. 2		100	6.4	6.4	PM,Flue gas
17	Coke battery No. 3		100	6.4	6.4	PM,Flue gas
18	Coke battery No. 4		100	6.4	6.4	PM,Flue gas
	Sinter Unit					
19	Sintering Stack		187	15	7	PM,Flue gas
	Sintering Stack canal 1					PM,Flue gas
	Sintering Stack canal 2					PM,Flue gas
	Sintering Stack canal 3					PM,Flue gas
	Sintering Stack canal 4					
20	Sinter ESP stack		50	10	5	PM
	Sinter ESP stack canal 1					PM
	Sinter ESP stack canal 2					PM
	Sinter ESP stack canal 3					PM
	Sinter ESP stack canal 4					PM
	Sinter ESP stack canal 5					PM
21	Unit No. 159		40	2.2	2.2	PM
22	Unit No. 170		40	2.5	2.5	PM
23	Unit No. 184		40	1.7	1.7	PM
24	Unit No. 191		30	1.2	1.2	PM

No.	Name of Stack	Stack No.	Height (m)	Lower internal diameter (m)	Upper Internal Diameter (m)	Pollutant
25	Slurry preparation & drying	unit 1	30	1.2	1.2	PM, Flue gas
26	Slurry preparation & drying	unit 2	30	1.2	1.2	PM, Flue gas
	Blast Furnaces					
27	Furnace stack 1		65	6	3	PM, Flue gas
28	Furnace stack 2		65	6	3	PM, Flue gas
29	Furnace stack 3		65	6	3.9	PM, Flue gas
30	Ventilation stack 1		55	6	4	PM
31	Ventilation stack 2		55	6	4	PM
32	Ventilation stack 3		50	6	4	PM
33	Ventilation stack 4	167-168	50	3	1.4	PM
34	SO_2 Reduction Filter stack		40	2.5	1.1	PM,Flue gas
	Steel Making Plant					
35	Converter gas cleaning Stack		70	3.6	3.6	PM, Flue gas
36	Chemical dust filter stack		25	0.8	0.8	PM
37	Electrical shop dust filter stk.		25	0.8	0.8	PM
38	lime oven No.1		40	0.82	0.82	PM, Flue gas
39	lime oven No.2		40	0.82	0.82	PM, Flue gas
40	lime oven No.3		40	0.82	0.82	PM, Flue gas
41	lime oven No.3		40	0.82	0.82	PM, Flue gas
42	lime oven No.4		40	0.82	0.82	PM, Flue gas
43	lime oven No.5		40	0.82	0.82	PM, Flue gas
44	lime oven No.6		40	0.82	0.82	PM, Flue gas
45	Lime unit dust filter	N-37	10	0.7	0.7	PM
46	Lime unit dust filter	N-9	10	0.8	0.8	PM
47	Mixer dust filter No.1	exhaust 1	40	0.8	0.8	PM
48	Mixer dust filter No.1	exhaust 2	40	0.8	0.8	PM
49	Mixer dust filter No.2	exhaust 1	40	0.8	0.8	PM
50	Mixer dust filter No.2	exhaust 2	40	0.8	0.8	PM
	Re-rolling Mills					
51	Steel bars unit TAV furnc. 1		80	7.4	3.5	PM, Flue gas
52	Steel bars unit TAV furnc.2		80	7.4	3.5	PM, Flue gas
53	Steel bars unit TAV furnc. 3		80	7.4	3.5	PM, Flue gas
54	Light profile bars furnace		80	10.4	4.2	PM, Flue gas
55	Medium profile bars furnace		80	7.4	4	PM, Flue gas
56	Construction steel bars furn.		80	7.4	4	PM, Flue gas
	Energy Production Facility					
21	Energy production stack		150	20	5.1	PM, Flue gas
	Energy production stack 1/1					PM, Flue gas
	Energy production stack 1/2					PM, Flue gas
	Energy production stack 2/1					PM, Flue gas
	Energy production stack 2/2					PM, Flue gas
	Energy production stack 3/1					PM, Flue gas
	Energy production stack 3/2					PM, Flue gas

No.	Name of Stack	Stack No.	Height (m)	Lower internal diameter (m)	Upper Internal Diameter (m)	Pollutant
	Energy production stack 4/1					PM, Flue gas
	Energy production stack 4/2					PM, Flue gas
	Energy production stack 5/1					PM, Flue gas
	Energy production stack 5/2					PM, Flue gas
	Production Workshop					
58	Production workshop furnace		30	1.5	1.5	PM, Flue gas

B.3 Emissions from Other Industries

Table B.3 Emissions from stacks of other industries

No.	Stack Code	PM (kg/hr)	SO_2 (kg/hr)	NO_X (kg/hr)	CO (kg/hr)
1	YAZICI1	2.58			
2	YAZICI2	0.88			
3	YAZICI3	0.8			
4	YAZICI4	0.83	1.35	5.14	
5	YAZICI5			0.12	0.008
6	YAZICI6		0.09	0.13	0.009
YAZICI SUB TOTAL		***5.09***	***1.44***	***5.39***	***0.017***
7	NUR1	3.4	515	15	20
8	KOC1	0.8	161	11	1.4
9	ATAKAS1	2.15	347	62	0.3
10	PAY1	0.104	13.5	2.78	0.25
11	ILHAN1	1.6	368	43	
12	YOLB1	0.8	51	2.2	0.07
13	YOLB2	0.7	97	2.9	0.83
14	TOSYALI	1.5	210	65	9
15	OYSA1	0.525			
16	OYSA2	1.056			
17	OYSA3	0.412			
18	OYSA4	0.091		0.334	4.97
19	OYSA5	0.041			
20	OYSA6	0.11			
21	OYSA7	0.046			
22	OYSA8	0.081			
23	OYSA9	0.153			
24	OYSA10	0.012			
25	OYSA11	0.009			
26	OYSA12	0.059			
OYSA SUB TOTAL		**2.595**		**0.334**	**4.97**
Total		**18.739**	**1763.9**	**209.854**	**36.837**

APPENDIX C

ECONOMIC ANALYSES OF AIR QUALITY IMPROVEMENT SCENARIOS

There are four different scenarios studied in this project that may improve the air quality in the Iskenderun Region to a great extent. Economic analyses of these scenarios are given in this section.

C.1 Economic Analysis for Scenario # 1

In this scenario it was assumed that PM and SO_2 emissions from ISDEMIR are controlled and the emissions are below limits set by the TAQPR. Currently ISDEMIR is emitting 2,400 kg/h of PM and 4146 kg/h of SO_2, while the limits are 15 kg/h and 60 kg/h, respectively. Layout of several units in ISDEMIR and location of major stacks are shown in Figure C.1.

Assumptions

- Price of electricity = 106,000 TL/kWh (as of December 2002), this is equivalent to 0.068 US$/kWh (as of 11.12.2002), the price of electricity is considered as 0.07 US$/kWh to adjust the small fluctuations in the exchange rates and price of electricity.

- Exchange rate of TL to US$ is 1,550,000 TL/US$
- Fans, motors and ducts are already present and being operated in ISDEMIR therefore, their initial and operating costs are not included in this economic analysis.
- Lime ovens are being operated in ISDEMIR; they will be used to produce lime from limestone if needed for emission control systems.
- These assumptions are valid for all calculations in this section

A. PM Control from ISDEMIR

In order to control the PM emissions from ISDEMIR, basic design calculations for dust control systems have been performed and costs associated with them are estimated using the data available in literature as well as information collected from local vendors and TEAS (Turkish Electricity Generation Agency), who have these systems installed at various power plants in Turkey.

Two dust control systems, namely, Fabric Filters and Electrostatic Precipitators (ESP's) have been considered in this study to control PM emissions from ISDEMIR. The reasons for considering only these two systems are:

- Very high removal efficiency (up to 99.9 %), (for ISDEMIR 99.4% removal of PM is required)
- Ability to remove very small particles from gas
- Ability to handle large quantities of gas
- Low pressure drop as compared to scrubbers and cyclones
- Low power requirements
- Wide range of operating temperatures

A.1 Fabric Filters for ISDEMIR

Fabric filters have been considered for the control of PM emissions from several units of ISDEMIR where temperature of the stack gas was reasonably low or was near to ambient temperature. This is important in fabric filters because the fabrics used for bags that can operate at high temperatures are at least 5 times more expensive than the fabrics for low temperature operations (Set Cement Plant, Ankara, 2002). This not only increases the capital cost but also the maintenance cost, as the life of fabric filter bags is 2-4 years. Moreover, fabric filters are also designed for the units where CO in the stack gas was more than 0.4% by volume, beyond which ESP is not used due to safety reasons. Pulse jet type of fabric filters have been designed in this study keeping in view their relatively smaller size (because of higher gas to cloth ratio) and continuous operation (due to online cleaning).

Design calculations for fabric filter of dry cooling stack (cbu-dc1) in coke and by products unit:

- Gas to cloth (G/C) ratio: 2.44 m^3/m^2-min (Heinson, 1999)
- Gas flow rate = Q = 68,597 m^3/h = 1,143 m^3/min
- Fabric required for filter = A = Q/(G/C) =

  = (1,143 m^3/mi)/(2.44 m^3/m^2-min) = 468 m^2

5 % additional fabric is considered as a factor of safety, therefore the:

- Total fabric required is = 468 x 1.05 = 492 m^2

The price of bag-house is 70 Euro per sq. m of fabric required for filtration (Set Cement Plant, Ankara, 2002). Since the prices of Euro and U.S. Dollar are almost the same, therefore all the cost estimations are given in U.S. Dollars.

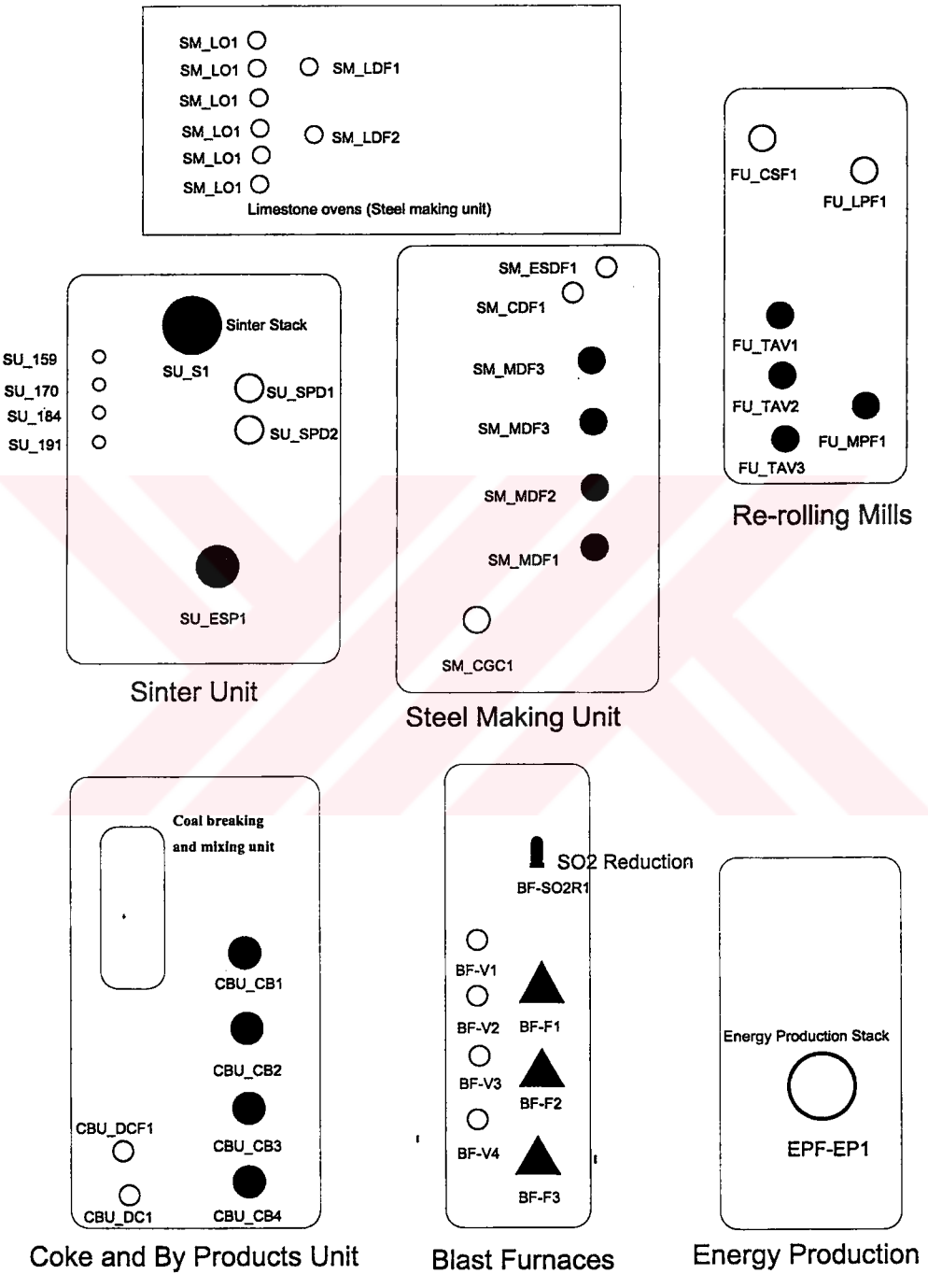

Figure C.1 Layout of several units in ISDEMIR

- Price of Baghouse with accessories = 492 x 70 = 34,439 US$
- Cost of bag is 3.5 Euro per sq. m of fabric (Set Cement Plant, Ankara, 2002).
- Price of bags = 492 x 3.5 = 1,722 US$
- Capital investment for baghouse filter = 34,439 + 1,722 = 36,161 US$

The maximum pressure drop in baghouse is up to 254 mm H_2O (Handbook of Env. Eng, 1999). All of the units in ISDEMIR are equipped with fans and motors for removing exhaust gases through stacks. It has been assumed that all of these existing motors and fans and are adequate enough to coupe this pressure drops in baghouses. Therefore, no new motor or fan is considered in the investment cost of PM control equipment.

Based on the information taken from local vendor, the quantity of pressurized air required for the periodic cleaning of fabric filters is 1 m^3/min for a gas flow rate of 35,000 m^3/h. The amount of energy required to produce 1 m^3/min of pressurized air is 0.15 kWh. Using the same information, and for 8000 h/year of operation, cost of electricity to produce pressurized air is calculated as:

- Energy required to produce pressurized air for one year of operation =

  = (1 m^3/min x 68597m^3/h /35000 m^3/h)*(8000 h x 60 min/h x 0.15 kWh/m^3)

  = 141,114 kWh/year

  Cost of electricity = 0.07 US$/kWh
- The cost of electricity for producing pressurized air =

  = 141,114 kWh x 0.07 US$/kWh

  = 9878 US$/year

Similar calculations have been performed for several stacks in ISDEMIR, and the results are presented in Table C.1. As can be seen from table the total initial investment for fabric filters in ISDEMIR is 1,941,518 US$. As a part of operating expenses the annual cost of electricity for the production of pressurized air is 407,982 US$. The cost of electricity for fans and motors are not considered here, because they are already installed and being operated in ISDEMIR. The fabric filters need to be changed every 2 years, therefore, US$ 46,227 (US$ 92,453/2) can be considered as a part of maintenance cost.

The total initial cost of baghouse filters (without bags) is 1,849,065 US$, if the life of the baghouse filter is considered as 30 years, and a straight-line depreciation is assumed then the annual fixed investment cost for baghouse filters is:

- Annual investment cost = 1,849,065 US$/30 y = 61,636 US$/y

Annual maintenance cost for baghouse filters @ 5% of initial investment is:

- Annual maintenance cost = 61,636 US$* 0.05 = 3,068 US$ ~ 3,100 US$/y

Annual cost of operation = Cost of (Bags + Electricity + Maintenance)

= 46,227 + 407,982 + 3100 = 457,309 US$/year

Annual average cost of PM emissions control at ISDEMIR by fabric filters =

Annual initial investment + annual cost of operation

= 61, 636 + 457,309

= 518,945 US$ ~ 519,000 US$/year

Table C.1 Design data and costs of fabric filters for ISDEMIR

Stack Code	PM (kg/h)	T_{gas} (°C)	Q_{gas} (m^3/h)	PM (mg/m^3)	PM limit (mg/m^3) (TAQPR)	Gas to cloth Ratio (m/min)	Area of Fabric (m^2)	Price of Filter housing (US$)	Price of bags (US$)	Total Price (US$)	Electricity used for pressurized air (kWh/y)	Cost of Elect. (US$/y)
Coke and By products												
CBU-DC1	18.9	27	68597	275	150	2.44	492	34,439	1,722	36,161	141,114	9,878
Sinter												
SU-S1	540	102	1576064	343	150	2	13,791	965,339	48,267	1,013,606	3,242,189	226,953
SU-SESP1	63.1	64	362980	174	150	2	3,176	222,325	11,116	233,442	746,702	52,269
SU-U170	9.59	15	65928	145.8	150	2	577	40,381	2,019	42,400	135,623	9,494
SU-U184	138	16	103232	1319	150	2	903	63,230	3,161	66,391	212,363	14,865
SU-SPD1	3.39	66	29262	116	-	2	256	17,923	896	18,819	60,196	4,214
Steel Making												
SM-CGC1	2.66	53	487970	5.4	200	1.52	5,618	393,265	19,663	412,929	1,003,824	70,268
SM-LO5	7.21	248	9207	783	200							
SM-LO6	5.09	137	13728	370	200	1.52	264	18,484	924	19,408	47,181	3,303
SM-MDF2	4.82	26	79287	61	100	1.52	913	63,899	3,195	67,094	163,105	11,417
SM-MDF3	15.1	29	33112	390	100	1.52	425	29,780	1,489	31,269	76,013	5,321
Total								**1,849,065**	**92,453**	**1,941,518**	**5,828,309**	**407,982**

A.2 ESPs for ISDEMIR

Electrostatic precipitators have been considered for the units of ISDEMIR where the temperature of stack gas was relatively high (more than 200 ° C), and CO in the gas was less than 0.4%. This is the limit for activation of alarm in ESP, and the ESP is shut down to avoid any explosion. ESPs can handle flow rate of the flue gas up to 110,000 m^3/min and temperature of up to 400 ° C. Pressure drop in ESP is generally less than 12.7 mm H_2O. The residence time of gas in the ESP is from 2 to 10 seconds. ESPs can collect particles of diameter from 0.01 μm to 1000 μm with removal efficiency reaching up to 99.99%. Power requirement of ESP is up to 17.5 W per m^3/min (Handbook of Environmental Engineering, 1999).

Design calculations FOR coke battery stack 1(CBU-CB1)

The Deutsch-Andersen equation is used for the basic design of ESPs (De Nevers, 1999) for ISDEMIR.

$$\eta = 1 - e^{-w\,(A/Q)}$$

Where: η = collection efficiency of the precipitator

e = base of the natural logarithm

w = migration velocity also called as drift velocity (m/s)

A = the effective collecting plate area of the precipitator (m^2)

Q = gas flow rate through the precipitator (m^3/s)

The aim of PM control for ISDEMIR is to bring its PM emissions from 2,400 kg/h down to 14 kg/h, below the limit of 15 kg/h set by the TAQPR. In order to achieve a target of 14 kg/h emissions, a collection efficiency of 99.42% is required. The ESPs in this study have been designed based on a collection efficiency of 99.5%, which is an achievable efficiency with ESP.

The other important parameter in the design of ESP is the migration velocity, the velocity of particles with which they approach the collecting plates. The migration velocity depends on the particle sizes, their resistivity and strengths of charging and collecting electric fields. Researchers and vendors have measured migration velocities for PM from different industrial processes; relevant migration velocities taken from literature have been used in design of ESPs in this study. Some measured drift velocities in different industrial processes are given in Table C.2.

Table C.2 Typical values of drift velocities in industrial practices (De Nevers, 1999)

Application	Drift Velocity (cm/s)
Pulverized coal (fly ash)	10.1-13.4
Utility fly ash	4.0-20.4
Pulp and paper mills	6.4-9.5
Cement (wet process)	10.1-11.3
Cement (dry process)	6.4- 7.0
Gypsum	15.8-19.5
Smelter	1.8
Open-hearth furnace	4.9-5.8
Blast furnace	6.1-14.0
Flash roaster	7.6
Cupola furnace	3.0-3.7

In this particular case the drift velocity has been taken as 4 cm/s because the particles present in the coke battery flue gas are close to the particles of utility fly ash as both are the remainings of very fine coal particles:

$$w = 4 \text{ cm/s} = 0.04 \text{ m/s}$$

Other input data for the design of ESP for coke battery stack1 is given in Table C.3

Rearranging the Deutsch-Andersen equation for effective plate area, one obtain the following equation:

$$A = (-Q/w)* \ln (1- \eta)$$

By substituting the relevant values into this equation:

$$A = \{(- 29{,}6726 \text{ m}^3/\text{h})/(3600 \text{ s/h} *0.04 \text{ m/s})\} * [\ln(1-0.995)]$$

$$= 10{,}918 \text{ m}^2$$

The effective collection plate area of ESP for Coke Battery No.1 will be 10,918 m^2, to estimate the price of this ESP, a plate area vs. price curve given in the EPA OAQPS Cost Control Manual (EPA, 1996) has been used.

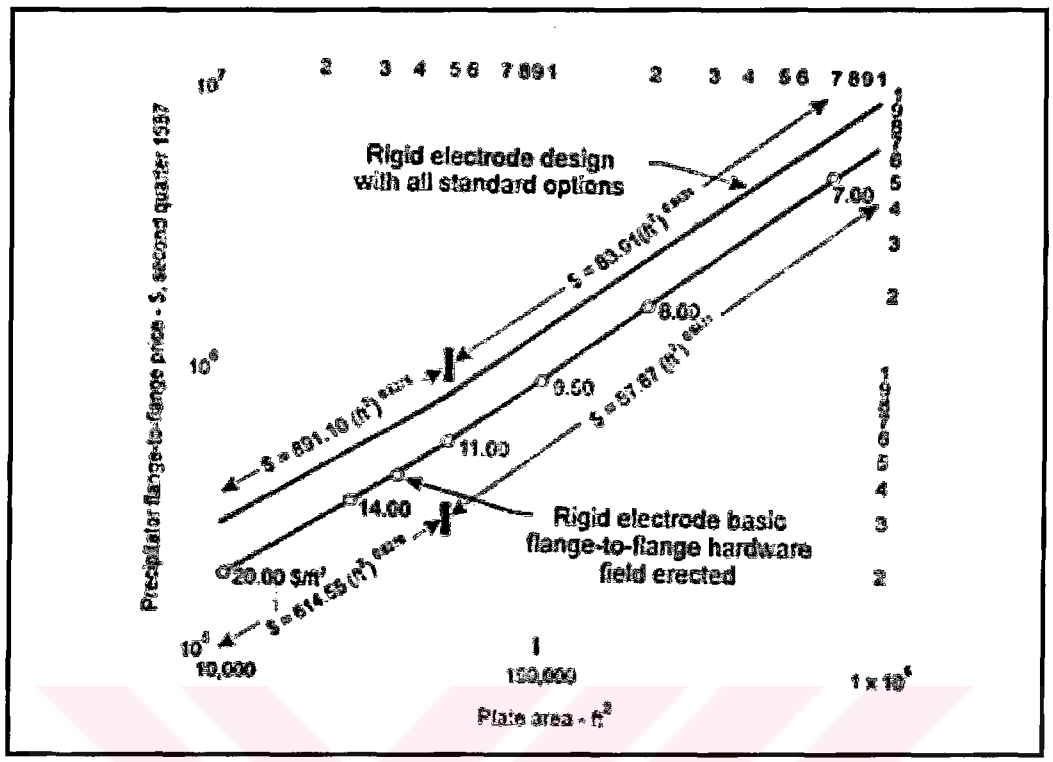

Figure C.2 Dry-type rigid electrode ESP flange-to-flange purchase price versus plate area (US EPA, 1996)

According to the curve given above in Figure C.2:

- The price of this ESP = 1,800,000 US$

This is a price of ESP equipped with inlet and outlet nozzles, diffuser plates, hopper auxiliaries, structural supports and insulation. The price of ESP learned from Set Cement Plant, Ankara, is very close to the price estimated in this study. That cement factory in Ankara has purchased an ESP for 847,830 US$, which can clean 125,000 Nm^3/h of flue gas. The price of the same ESP was found to be 850,000 US$ in our calculation if estimated by using the plate area vs. price curve given above.

There are some other direct costs involved with the purchase of ESP. Those are instrumentation, freight, sales tax, ductwork, erection and installation of

equipment, foundation, insulation etc. All together they are about 50 % of the equipment cost (ESP). Since the motors and fans are already installed and being operated in all units of ISDEMIR, it is assumed that they can be used to serve the ESP as well.

Therefore:

- Total cost for ESP = 1.5 x 1,800,000 US$ = 2,700,000 US$

Electricity required for the operation of ESP is 17.5 W per m^3/min of the treated gas (Handbook of Env. Eng., 1999).

- Annual electricity requirement for ESP of the Coke Battery No1. =

  = {(296,726 m^3/h) /60 min/h} *(0.0175 kW/m^3/min) * (8000 h)

  = 692,361 kWh

Price of electricity = 0.07 US$/kWh

- Annual cost of electricity = (692,361 kWh) * (0.07 US$/kWh)

  = 48,465 US$/year

Similar calculations have been done for several units in ISDEMIR where ESPs are considered to be installed (a total of 15 ESPs). The results of these calculations are presented in Table C.3. As given in the table the total capital cost of setting up electrostatic precipitators are 37,425,000 US$. If the life of an ESP is considered as 30 years, and a straight-line depreciation is used, the annual initial investment for ESPs comes out to be 1,247,500 US$/y. As given in Table C.3, the annual cost of electricity for all of the ESPs in ISDEMIR is 851,135 US$/y.

The total initial investment for ESPs only without accessories, etc. is estimated to be 24,950,000 US$ as given Table C.3. Annual maintenance cost for ESPs @ 5% of initial investment can be estimated as:

- Annual maintenance cost = (24,950,000US$/30 y) * 0.05

  = 41,584~ 42,000 US$/year

- *Annual cost of operation = Cost of (Electricity + Maintenance)*

  = 851,135 + 42,000 = 893,135 US$/year

- *The annual average cost of PM emissions control by ESPs in ISDEMIR = Annual initial investment + Cost of operation*

  = 1,247,500 + 893,135 = 2,140,635 US$

Annual average cost of PM emissions control from ISDEMIR = Annual cost for baghouse filters + Annual cost for ESPs

= 518,945 US$ + 2,140,635 US$

= 2,659,580 US$/year

Total Initial Investment needed for PM control systems at ISDEMIR =

Initial investment on Baghouse Filters + Price of bags

+ Initial investment on ESPs

= 1,849,065 + 92,453 + 37,425,000 = 39,366,518 US$

Table C.3 Design data and costs of ESPs for ISDEMIR

Stack Code	PM (kg/h)	CO (%)	T_{gas} (^{o} C)	Q_{gas} (Nm^3/h)	PM (mg/m^3)	PM limit (mg/m^3) (TAQPR)	Drift vel.(w) (m/s)	Plate area of ESP (m^2)	Price of ESP only ($)	Total Price (ESP, freight, etc.) ($)	Electricity Required (kWh/year)	Elect. Cost (US$/y)
Coke and By Products												
CBU-CB1	15.17	0.16	228	296,726	51.14	200	0.04	10,918	1,800,000	2,700,000	692,361	48,465
CBU-CB2	5.5	0.20	241	320,853	17.26	200	0.04	11,805	2,000,000	3,000,000	748,657	52,406
CBU-CB3	2.76	0.20	261	174,329	15.81	200	0.04	6,414	1,200,000	1,800,000	406,768	28,474
CBU-CB4	17.18	0.19	215	218,652	79	200	0.04	8,045	1,350,000	2,025,000	510,188	35,713
Blast Furnaces												
BF-V1	423		25	545,636	766	30	0.1	8,030	1,350,000	2,025,000	1,273,151	89,121
BF-V2	31.7		30	495,181	64	30	0.1	7,288	1,300,000	1,950,000	1,155,422	80,880
BF-V3	43.1		24	688,166	65	30	0.1	10,128	1,500,000	2,250,000	1,605,721	112,400
BF-V4	10.2		26	87,832	116.4	30	0.1	1,293	300,000	450,000	204,941	14,346
Re-Rolling Mills												
FU-TAV1	48.4		228	86,279	561	150	0.03	4,233	700,000	1,050,000	201,318	14,092
FU-TAV2	24.6		272	104,437	236	150	0.03	5,124	850,000	1,275,000	243,686	17,058
FU-TAV3	3		232	44,467	68	150	0.03	2,181	500,000	750,000	103,756	7,263
FU-LPF1	16.3		128	225,410	72	150	0.03	11,058	1,800,000	2,700,000	525,957	36,817
FU-MPF1	2.77		121	114,314	25	150	0.03	5,608	950,000	1,425,000	266,733	18,671
FU-CSF1	6.51		163	106,326	65	150	0.03	5,216	850,000	1,275,000	248,094	17,367
Energy Production												
EPF-EP1	787.9		250	1,702,421	463	200	0.03	83,518	8,500,000	12,750,000	3,972,316	278,062
Total									**24,950,000**	**37,425,000**	**12,159,068**	**851,135**

B. SO_2 Control for ISDEMIR

The emissions of SO_2 from ISDEMIR are 4146 kg/h from several units as has been given in Chapter 6 (Table 6.1). The limit of SO_2 emissions from any industrial facility as set by TAQPR is 60 kg/h. Therefore SO_2 emissions form ISDEMIR are 69 times more than the limit. These emissions need to be controlled. The stack gases in ISDEMIR containing SO_2 are regarded as Lean-Gases because the amounts of SO_2 in these gases are below 0.05%. There are several options to reduce SO_2 emissions from lean gases, such as, limestone wet scrubbing, use of raw materials and fuels having low sulfur content, dry injection of CaO or $CaCO_3$ in the furnace etc.

FGD Design for ISDEMIR

B.1 Limestone Wet Scrubber for ISDEMIR

Design calculations for limestone wet scrubber (FGD) system for ISDEMIR are done and presented in the following section.

Following are the units in ISDEMIR that are releasing SO_2 in the atmosphere:

1. Coke and by-products unit (341 kg/h).
2. Sinter unit (1308 kg/h).
3. Re-rolling mills (491 kg/h).
4. Energy production facility (2005 kg/h).

Since the SO_2 releasing stacks in these units are located far from each other, only one FGD plant to control all SO_2 emissions form ISDEMIR is not possible. Moreover, the total volume of stack gases from all of these stacks is very large, and it will not be possible to handle those gases with only one FGD plant. Therefore, 4 separate FGD plants (one for each unit) can be a better strategy for control of SO_2 emissions from ISDEMIR and this strategy ha been adopted in these calculations.

Limestone wet scrubber for coke and by products unit

There are 4 stacks of coke batteries in this unit that are responsible for SO_2 emissions of 341 kg/h.

Design Calculations

In a limestone-wet scrubber the removal of SO_2 gas is carried out according to the following reactions:

$$CaCO_3 + SO_2 + 2H_2O \longrightarrow CaSO_3.2H_2O + CO_2 \ldots.(1)$$

$$CaSO_3.2H_2O + 1/2O_2 \longrightarrow CaSO_4.2H_2O \ldots\ldots\ldots (2)$$

The overall reaction is

$$CaCO_3 + SO_2 + 2H_2O + 1/2O_2 \longrightarrow CaSO_4.2H_2O + CO_2 \ldots..(3)$$

- Total stack gas flow rate (from 4 stacks) = 1,010,960 Nm^3/h
- Average SO_2 concentration of combined stack gas = 337 mg/Nm^3
- Load of SO_2 in the flue gas = 1,010,960 Nm^3/h * 337 mg/Nm^3 * 10^{-6} kg/mg

  = 341 kg/h = 341 kg/h * 1/(64 kg/kmole of SO_2)

  = 5.39 kmole/h

Generally the efficiency of limestone-wet scrubbers is 96%, the same is assumed for the plant in consideration.

- The amount of SO_2 that can be removed by the FGD plant = 5.39 kmole/h * 0.96

  = 5.174 kmole/h
- Amount of SO_2 remaining in the clean gas = (5.39-5.174) kmole/h * 64 kg/kmole

  = 13.82 kg/h

According to reaction given in equation 3, one mole of limestone is required to remove one mole of SO_2. Therefore, 100% pure limestone needed to remove SO_2 from stack gas is calculated as:

- Limestone consumption = 5.39 kmole/h * 100 kg/kmole of $CaCO_3$
  = 539 kg/h

As a factor of safety 10% excess $CaCO_3$ is considered, moreover 100% pure limestone is difficult to find in the market, in this study its purity is assumed to be 80%. Therefore, after taking into account these parameters the quantity of limestone required is calculated as:

- Total quantity of limestone required = (539 kg/h x 1.10)/0.80
  = 741 kg/h
  = 0.74 ton/h

The design calculations for all four units of ISDEMIR are done similarly as described above for coke and by products unit. The results of these calculations are presented in Table 8.4

Table 8.4 summarizes the basic designs for FGD plants for several units of ISDEMIR. As given in the Table 8.4, 8.84 ton/h $CaCO_3$ is needed to remove 3979 kg/h of SO_2 from stack gases in ISDEMIR. After removal of SO_2 from the raw flue gases, the clean gases will again be loaded with 166 kg/h of SO_2, which will eventually be released to the atmosphere. These SO_2 emissions are above the limit of 60 kg/h as defined in the TAQPR. In order to bring the SO_2 emissions down to 60 kg/h from ISDEMIR, FGD plants need to operate with 98.6% removal efficiency, which is very difficult to achieve. Another solution for reduction of SO_2 emissions from ISDEMIR is to use natural gas as fuel instead of fuel oil in the furnaces of Re-rolling Mills. This will eliminate 491 kg/h of SO_2 emissions from Re-rolling Mills as well as one FGD Plant. Natural gas supply will be available in the study area in 2004 (BOTAŞ,2002).

Table C.4 Design data and results of calculations for wet limestone scrubbing FGD plants for ISDEMIR

Units	Power (MW)	Flow rate of flue gas (Nm^3/h)	SO_2 in raw flue gas			Removal efficiency (%)	SO_2 in clean flue gas		Limestone required (ton/h)
			Conc. (mg/Nm^3)	Conc. Limit (mg/Nm^3)	Load (kg/h)		Concentration (mg/Nm^3)	Load (kg/h)	
Coke and by products	279	1,019,960	853 (at 3% O_2)	200 (at 3% O_2)	341	96	34 (at 3% O_2)	13.82	0.74
Sinter	78	1,576,064	6946 (at 5% O_2)	2000 (at 5% O_2)	1308	96	285 (at 5% O_2)	53.76	2.8
Re-rolling mills	233	566,919	5694 (at 3% O_2)	1700 (at 3% O_2)	491	96	140 (at 3% O_2)	19.84	1.0
Energy production	800	1,702,421	3837 (at 3% O_2)	1000 (at 3% O_2)	2005	96	86 (at 3% O_2)	78.72	4.3
Total		**4,936,364**			**4145**			**166**	**8.84**

Estimation of price for SO_2 removal from ISDEMIR by limestone wet scrubbers

Capital Investment

In order to estimate the initial capital investment required for the installation of FGD plants in ISDEMIR, necessary information were obtained from TEAŞ as they have installed FGD Systems at several power plants in Turkey. For example, three FGD units have been installed at a price of 77.8 million US$ at Yatağan Power Plant. These FGD systems can process raw flue gas flow rates between 670,000 and 1,450,000 Nm^3/h. Since the flow rates of raw flue gases in several units of ISDEMIR are close to or within this range, if the similar FGD plants are decided to be installed at ISDEMIR then it will cost around 100 million US$ for four units. But if the furnaces of Re-rolling Mills will be heated by natural gas, then three FGD units in ISDEMIR will be required, which will cost about the same as in the case of Yatağan Power Plant.

Operational Costs

Operational costs include expenditures on electricity, limestone, salaries of staff and miscellaneous expenses. Based on the information obtained from TEAŞ, each FGD plant consumes 7 to 10 MW of electricity. There will be four FGD plants in ISDEMIR, assuming that each of them will use 8 MW of electricity (same as Cayirhan power plant near Ankara), then they will use 32 MW of electricity in total. Assuming 8000 hours of operation in an year, the cost of electricity is calculated as:

- Electricity consumed annually = 32 MW *1,000 kW/MW * 8000 h
  = 256,000,000 kWh

- Cost of Electricity = 0.07 US$/kWh * 256,000,000 kWh
  = 17.92 million US$

- Annual consumption of limestone = 8.84 ton/h * 8000 h/year
  = 70720 ton/year
- Price of limestone = 5,800,000 TL/ton (ISDEMIR, 2003)
- Cost of limestone = 70720 ton/year * 5,800,000 TL/ton
  = 410.2 billion TL
- Cost of limestone (in US$)= 410.2 billion TL /(1,550,000 TL/US$)
  = 264,630 US$

Assuming 10 people will work in each of the FGD plant, therefore, total 40 worker will be working at FGD plants in ISDEMIR. Assuming that salary of each worker is 500 million TL per month.

- Salaries of staff = 40 x 12 x 500,000,000 TL
  = 240 billion TL = 154,838 US$
- Annual miscellaneous expenditure/Maintenance = 50,000 US$
- Total cost of operation = Cost of (Electricity + limestone + salaries + miscellaneous costs)
  = 17,920,000 + 264,630 + 154,838 + 50,000

Total cost of operation = 18,389,468 US$/year

The initial investment for four wet limestone FGD plants in ISDEMIR is estimated to be 100 million US$. If the operational life of these plants is considered to be 30 years, and a straight-line depreciation is used, then the annual initial investment would be:

- Annual capital cost for FGD plants in ISDEMIR = 100,000,000/30
  = 3.34 million US$

Annual average expenditure for SO_2 removal by limestone wet scrubbers = annual capital cost + annual cost of operation

= 3.34 + 18.39 = 21.73 million US$.

These calculations show that the cost of electricity is the greatest among all expenditures for the control of SO_2 by limestone-wet scrubbers in ISDEMIR. If required electricity is supplied from ISDEMIR's own power plant (capacity 220 MWe), then the cost of electricity can be substantially reduced.
The above analysis has shown that limestone scrubbers are not a feasible option for the control of SO_2 in ISDEMIR, because:

It cannot reduce SO_2 emissions below the limit set by the TAQPR
It is very expensive

There are some other options to remove SO_2 from flue gases, such as lime scrubbing and dry lime injection, etc.

B. 2 Wet Lime Scrubbing

In wet scrubbing, lime is added to water and the resulting slurry is sprayed into a scrubber tower. The gas to be cleaned enters from the bottom of this tower and flows upward through the shower of lime slurry. The sulfur dioxide is absorbed into the spray and then precipitated as wet calcium sulfite. The sulfite can be converted to gypsum by oxidation.

Lime scrubbing systems can achieve 99% SO_2 removal, while even new state-of-the-art limestone systems are designed to achieve only 96% removal. The relatively higher removal efficiency of lime-scrubber is because, lime is chemically more reactive as compared to limestone and its typical surface areas are from 15 to 40 m^2/g. Limestone systems achieve 96% removal by showering a large volume of slurry into the gas, typically at least 15 liters of slurry per cubic meter of gas. On the other hand, lime systems require a much smaller volume of slurry only 3 to 5 liters of slurry per cubic meter of gas to achieve 96% SO_2 removal. Therefore, the size as well as the number of equipment required for scrubber is reduced significantly. The number of pumps required to

recycle lime slurry is less than that required for limestone slurry. Eventually, this reduces capital, operational and maintenance costs of SO_2 removal system. As stated in the previous section that, in order to reduce the SO_2 emissions from ISDEMIR below the TAQPR limit of 60 kg/h a removal efficiency of 98.6% is required. This can be achieved by lime wet scrubbing system as it can remove up to 99% of the SO_2 from flue gas.

Process of SO_2 removal by lime wet scrubbers

In a lime-wet scrubber the removal of SO_2 is carried out according to the following reactions:

$$CaCO_3 + \text{Heat} \longrightarrow CaO + CO_2 \quad \text{.....(4)}$$

$$CaO + H_2O \longrightarrow Ca(OH)_2 \quad \text{.....(5)}$$

$$Ca(OH)_2 + SO_2 + \tfrac{1}{2} O_2 \longrightarrow CaSO_4 + H_2O \quad \text{..... (6)}$$

According to reactions 4 to 6, it can be noted that one mole of $CaCO_3$ is required to generate one mole of lime (CaO), and one mole of lime is needed to have one mole of hydrated lime ($Ca(OH)_2$), which then reacts with one mole of SO_2 to remove it from the flue gas.

Capital Cost

Because limestone scrubbers require a much larger volume of slurry to be showered into the flue gas than for lime scrubbers, limestone scrubbers are much larger and more costly than lime scrubbers. Savings in equipment cost from using lime are substantial. Assuming that the initial cost of lime scrubbers is 55% of the limestone scrubbers, the initial investment for lime scrubbing system for ISDEMIR would be 55 % of the initial investment for four limestone scrubbers for ISDEMIR.

- Initial investment for four lime scrubbers for ISDEMIR =
  = 0.55 x initial investment of limestone scrubber
  = 0.55 x 100 million US$ = 55 million US$

Operational Costs

Since lime is expensive as compared to limestone, which will increase the cost of operation. There are six lime ovens already working in ISDEMIR, out of theses three ovens are operated generally to meet the lime requirements of ISDEMIR. Two are kept at standby and the remaining one may be on maintenance. These can be used to produce lime from limestone for wet scrubbing. The lime ovens of ISDEMIR use coke gas as fuel. Coke gas is basically used as fuel at the energy production facility in ISDEMIR. The deficiency of coke gas if any, is made up by using pitch and fuel oil. Therefore, the coke gas used to produce lime will have to be made up by purchasing additional fuel oil. At ISDEMIR on average 1200 kcal of heat is used to produce one kg of lime. Thus 1,200,000 kcal (5016 MJ) of heat is needed to produce one tone of lime. The amount of heat required for the production of one tone of lime is 4.25 million BTU, which is equivalent to 4441 MJ (R. Norris, 1977). The calculations given below are based on 5016 MJ/ton of heat requirement. The limestone consumption calculated in the limestone wet scrubber design in the previous section can be taken as limestone requirement for the production of lime, because reaction 4 given above shows that one mole of limestone is required to produce one mole of lime.

Amount of limestone to be converted to lime = 8.84 ton/h
Heat required to produce lime = 5016 MJ/ton
Amount of coke gas needed to produce 5016 MJ of heat =
= 5016MJ x 1/(16.34 MJ/m^3) = 307 m^3
Therefore 307 m^3 of coke gas is consumed to produce one tone of lime.
Hourly consumption of coke gas = 8.84 ton/h x 307 m^3/ton = 2714 m^3/h

Assuming that there will be 8000 hours of annual operation:

Annual consumption of coke gas = 2714 m^3/h x 8000 h = 21,712,000 m^3

Fuel oil equivalent of 21,712,000 m^3 of coke gas:

Heat generated by 21,712,000 m^3 of coke gas = 21,712,000 m^3 x 16.34 MJ/m^3

= 354,774,080 MJ

Fuel oil equivalent = 354,774,080 MJ x 1/(41,000 MJ/ton) = 8653 ton

Price of fuel oil = 200 US$/ton (ISDEMIR, 2003)

Price of fuel used for lime production = 8653 ton x 200 US$/ton

= 1,730,600 US$

Cost of limestone = 264,630 US$ (the same as in case of limestone wet scrubbers)

Cost of lime = Cost of (limestone + fuel)

= 264,630 + 1,730,600 = 1,995,230 US$

Power consumption for the lime process is significantly lower than for the limestone-based process. The lime process uses about 0.8-1.3% of a power station's gross generation versus about 1.5-2.5% for a limestone-gypsum process (http://www.lime.org). Therefore, the electricity consumption for lime scrubbers of ISDEMIR can be assumed as 50% of the limestone scrubbers. The Electricity consumption for limestone scrubbers was estimated to be 256,000,000 kWh/year.

- Electricity consumption for 4 lime scrubbers = 0.50 x 256,000,000 kWh/year

  = 128,000,000 kWh/year
- Price of electricity = 0.07 $/kWh
- Cost of electricity = 0.07 $/kWh x 128,000,000 kWh/year

  = 8,960,000 US$/Year

Again assuming that same number of staff with same salaries will be working on lime wet scrubbers as was assumed for lime stone wet scrubbers, which was assumed to 40 for four wet limestone FGD units.

- Salaries of staff = 154,838 US$/year
- Annual miscellaneous expenses/maintenance = 30,000 US$

Annual cost of SO_2 removal with lime wet scrubbers

Total cost of operation = Costs of (Electricity + lime + salaries + misc.)

= 8,960,000 + 1,995,230 + 154,838 + 30,000

- Total cost of operation = 11,140,068 US$/year

The initial investment for four wet lime scrubbing FGD plants is estimated to be 55 million US$. If the operational life of these plants is considered to be 30 years and a straight-line depreciation is used, then the annual initial investment would be:

- Capital cost for four wet lime scrubbers = 55,000,000/30

= 1.84 million US$/year

Annual average expenditure for SO_2 removal = capital cost + cost of operation

= 1.84 + 11.14 = 12.98 million US$/year

It can be concluded from the above calculations that, an annual expenditure of 12.98 million US$ is required to reduce SO_2 emissions from ISDEMIR below the limit (60 kg/h) set by TAQPR. In this case both the limits set for concentrations (in mg/m^3, given in Table C.4) in stack gases as well as pollution load limit for SO_2 are satisfied.

B.3 Dry Lime Scrubbing

The solids handling and wet sludge disposal are the two major problems with wet scrubbing FGD systems. To avoid these problems another system of SO_2 removal from flue gas is used, which is called dry scrubbing. In this system dry alkaline particles (generally limestone or lime) are injected into the gas stream, where they react with the gas to remove SO_2. The reaction products ($CaSO_3$ and $CaSO_4$) are collected at dust control systems (ESP or fabric filters), that must be installed at downstream of the injection points. The efficiency of these systems can reach up to 90% (De Nevers, 1995).

The dry scrubbing systems are significantly cheaper as compared to wet scrubbing systems, because of minimal initial investments and small operating costs. The powdered lime (dry scrubbing reagent) can be injected either into the furnace or in the ducts containing flue gas. If the reagent is injected in ducts then importance should be given to the gas temperature in the ducts. Higher removal efficiencies can be achieved at gas temperatures between 600 to 800 $^{\circ}$ C (De Nevers, 1995). The mean residence time should not be shorter than 1-2 second within reaction temperature range. In dry injection systems the quantities of reagent needed to react with SO_2, i.e., Ca/S ratio 2 to 4 times of the stoichiometric requirement of reagent. This is recommended to ensure contact between SO_2 gas molecules and reagent particles. Due to minimization of the energy used for grinding and the maximization of the specific surface, the mean particle size of calcium hydroxide is recommended to be 5 μm (Breihofer, 1991).

The design data for the dry scrubber for ISDEMIR is given in Table C.5. Since these systems have relatively low efficiencies, therefore the SO_2 pollution load (in kg SO_2/h) from ISDEMIR cannot be reduced below the limit set by TAQPR. However, the SO_2 concentrations in the stack gases can be reduced below the concentration limits set by the TAQPR. In order to satisfy concentration limits, the removal efficiencies of 71 to 77 % are required as given in Table C.4. These

removal efficiencies can be achieved by dry injection of lime (CaO) or hydrated lime ($Ca(OH)_2$) in the ducts at points close to the furnace exit where the gas temperatures are sufficiently high. The reaction product of lime and SO_2 will be $CaSO_3$ and $CaSO_4$, which will be collected in the ESPs or baghouse filters downstream of the injection points. It is assumed that the dust collection systems designed for ISDEMIR in the previous sections are capable of capturing this reaction product along with PM already present in the flue gases.

Initial Investment

The investment for dry injection system mainly consists of

- Dosing and injection system
- Flue gas ducts and fans
- Dust control system

Since ducts, fans and dust control systems for ISDEMIR are already either present or have been designed in this study, therefore the initial investment will be needed for dosing and injection system. The injection of reagent will be done in the ducts of every unit from where SO_2 is being released. Flue gases from several stacks in every unit will not be combined in this case, therefore dosing and injection system will be needed for every SO_2 emitting unit.

A price vs. capacity (MWe) curve given in Figure C.3, has been developed for German vendors (Breihofer, 1991), which is used to estimate the price of dry injection systems for ISDEMIR.

This curve is developed for power plants according their generation capacities (MWe), the initial investment estimate is given in million DM (German Mark). The power of several units in ISDEMIR is given in Table C.5, which is 1390 MW_{th} from all units. The power of all units of ISDEMIR (1390 MW_{th}) can be

converted to MWe by assuming a 30% power conversion efficiency from thermal to electric power.

Electric power equivalent of total power from all units of ISDEMIR:

$= 1390\ MW_{th} * 0.30 = 417\ MWe$

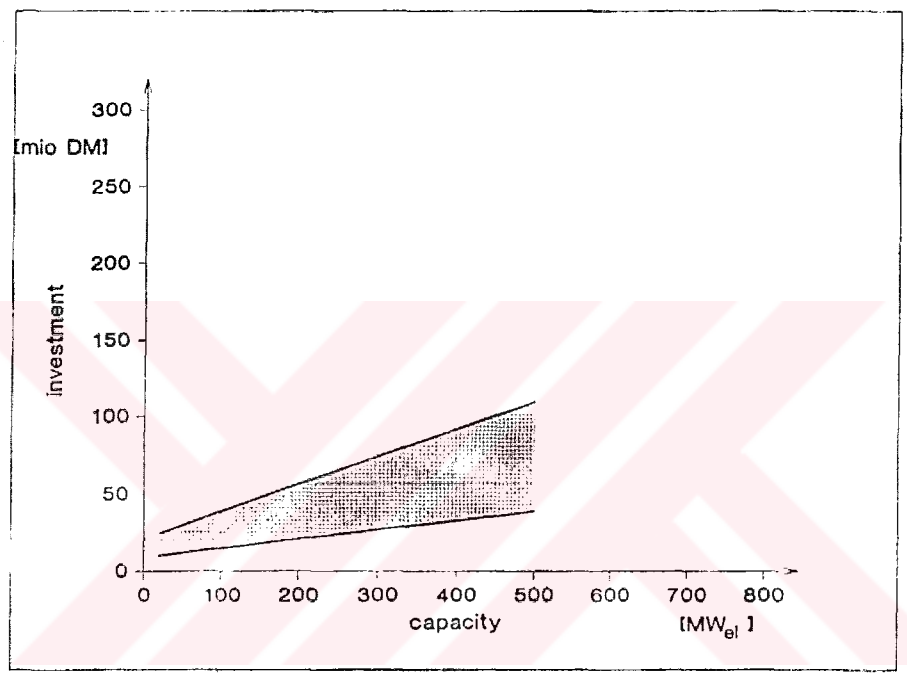

Figure C.3 Initial investment estimation curve for German vendors

The estimated initial investment on dry lime injection FGD systems for ISDEMIR can be read from the curve given in Figure C.3 as 50 million DM (approximately 30 million US$). This estimated cost includes the initial investment on ducts, fans and dust control systems along with cost of dry lime dosing and injection system. Since ducts, fans and dust control systems either exits or has already been taken into account in the previous section, therefore, for ISDEMIR the initial investment cost only for dry lime dosing and injection system is needed to be estimated. It is assumed that 50% of the initial

investment (30 million US$) estimated above goes for ducts, fans and dust control systems. Therefore, initial investment needed for dosing and injection systems for ISDEMIR will be:

= 0.5 * 30, 000,000 US$ = 15, 000,000 US$

If the life of dry injection system is considered as 30 years, and a straight-line depreciation is used, then the annual initial investment cost will be:

- Annual initial investment cost = 15,000,000 million US$/30year

  = 500,000 US$/year

Table C.5 Design data for dry scrubbing system for ISDEMIR

Units	Power (MW_{th})	Flow rate of flue gas (Nm^3/h)	SO_2 conc. on raw flue gas (mg/Nm^3)	Conc. limit set by TAQPR (mg/Nm^3)	Req. η needed to meet limit
Coke and by products	279	1,019,960	853 (at 3% O2)	200 (at 3% O2)	77%
Sinter	78	1,576,064	6946 (at 5% O2)	2000 (at 5% O2)	71%
Re-rolling mills	233	566,919	5694 (at 3% O2)	1700 (at 3% O2)	70%
Energy production	800	1,702,421	3837 (at 3% O2)	1000 (at 3% O2)	74%
Total	**1390**	**4,936,364**			

Cost of Operation

The cost of operation includes expenditures on lime (reagent) and electricity consumption.

Lime Requirement

Since the amount SO_2 in the gas is the same for all of the design calculations in this study, therefore the stoichiometric requirement of limestone as given in Table 8.4 is also valid for dry injection system. However, in dry injection systems the Ca/S ratio of 2-4 is recommended by researchers and companies ((Breihofer, 1991). A Ca/S ratio of 2 is used for the dry injection system for ISDEMIR, therefore, the amount of limestone required will be double of the requirement for wet systems. The limestone requirement for SO_2 removal from ISDEMIR was calculated to be 8.84 ton/h, and hence it is 17.68 ~ 18 ton/h (8.84 ton/h x 2) for the dry injection system.

In dry lime injection systems the removal of SO_2 is carried out according to the following reactions:

$$CaCO_3 + \text{Heat} \longrightarrow CaO + CO_2 \quad \text{.....(4)}$$

$$CaO + H_2O \longrightarrow Ca(OH)_2\ (\text{dry}) \quad \text{.....(5)}$$

$$Ca(OH)_2 + SO_2 + \tfrac{1}{2}\,O_2 \longrightarrow CaSO_4 + H_2O\ (g) \quad \text{..... (6)}$$

As can be seen from reactions 4 to 6 one mole of $CaCO_3$ is required to produce one mole of CaO and $Ca(OH)_2$. Lime will be produced in lime ovens already operational in ISDEMIR. Assuming 8000 h/year of operation at ISDEMIR, the cost of limestone will be:

- Amount of limestone required = 18 ton/h x 8000 h/year
  = 144,000 ton/year
- Price of limestone = 5,800,000 TL/ton
- Cost of limestone = 5,800,000 TL/ton x 144,000 ton/year
  = 835 billion TL = 538,838 US$/year ~ 538,900 US$/year
- The fuel required to produce lime will be double of the amount of fuel used in wet lime system = 8653 ton/year x 2 = 17306 ton/year

Price of fuel = 200 US$/ton

- Annual cost of fuel = 17306 ton/year x 200 US$/ton = 3,461,200 US$/year
- Cost of lime = Cost of (limestone + fuel)
  = 538,900 + 3,461,200 = 4,000,100 US$/year

Cost of Electricity

The power consumption to operate dry injection scrubbing system is estimated to be 1 kW/MWe of power generation (Breihofer, 1991). All of the units of ISDEMIR are not power generation plants. There is one 220MWe power plant is ISDEMIR, rest of the units are related to processing of iron and steel. The thermal power capacities of several units in ISDEMIR are given in Table C.5. If the conversion efficiency from thermal to electric power is assumed to be 30%, then the total electric power equivalent of all the units in ISDEMIR is:

- Electric power equivalent of ISDEMIR = total thermal power x 0.3
  = 1390 MW_{th} x 0.3
  = 417 MWe

Total power required for dry injection system = 1 kW/MWe x 417 MWe
= 417 kW

Assuming 8000 h/year of operation in ISDEMIR, the annual requirement of electricity would be:

- Electricity consumption = 417 kW x 8000 h/year = 333,6000 kWh/year
- Price of electricity = 0.07 US$/kWh
- Cost of electricity = (0.07 US$/kWh) x (333,6000 kWh/year)
  = 233,520 US$/year

Total annual cost of operation = Cost of (Lime + Electricity)
= 4,000,100 + 233,520 = 4,233,620 US$/year

Total Cost of Dry lime Injection System

Annual average cost of Dry Lime Injection System for ISDEMIR =

= Annual initial investment + Annual cost of operation

= 500,000 + 4,233,620 = 4,733,620 US$

C.2 Economic Analysis for Scenario # 2

In this scenario the effects of increasing stack heights from 20-25 m to 50 m on the air quality in the study area were studied. In order to increase the stack heights, the existing stacks of the re-rolling mills operating in the Iskenderun region are assumed to be discarded and new stacks will be required to built. All of these stacks are made of steel sheets with a diameter of about 2-m at ground level, which gradually decreases as the stack ascends, and at the top of stack the diameter reduces to 1 m. In order to increase the stack heights to 50 m, the diameter of the stacks at ground level will be required to be increased. However, the fans and motors used to discharge flue gases from stacks will also be replaced with more powerful ones. This will bring additional burden on the re-rolling mills in Iskenderun Region.

According to Ozek Industry in Ankara (a company involved in the construction and installation of stacks) the initial investment to increase the stack heights from 25 m to 50 m and replacing fans and motors will be about US$ 25,000 on average for a re-rolling mill (private communications with Ozek, 2003). There are eight operating re-rolling steel mills in the Iskenderun Region. Therefore, a total initial investment of 200,000 US$ will be required. The life of these stacks will be about 20 years, annual maintenance of stacks, motors and fans is assumed to be around 5,000 US$/y for each re-rolling mill.

Thus the total cost associated with this scenario will be = 25,000 + (5000 x 20)

= 125,000 US$ per re-rolling mill for 20 years

Assuming a straight-line depreciation, the annual average initial investment for all of the re-rolling mills would be = 25,000 US$ x 8 x 1/20year = 10,000 US$

Annual average maintenance cost = 5000 US$/year x 8 = 40,000 US$/year

Annual average cost associated with Scenario # 2 = 10,000 + 40,000

= 50,000 US$/year

C.3 Economic Analysis for Scenario # 3

In the Scenario # 3, fuel oil No.6 with 6% sulfur by wt. was replaced with a fuel oil having 1.5% sulfur by wt., and the effects of this change on the air quality were studied. The results showed that use of fuel oil with 1.5% sulfur greatly improved the air quality in Dortyol and Payas by showing a reduction in ground level SO_2 concentrations. The implementation of this scenario can be regarded as the easiest one among all other options, because no process or equipment change or new installation is required in this case. The only burden on re-rolling mills will be the price difference between the Fuel oil No.6 and the Domestic Fuel oil, which has 1.5% sulfur by wt.

Annual fuel oil consumption data was obtained from all of the operating re-rolling mills in the study area and is presented in Table C.6. In order to calculate the economic burden on the re-rolling mills with change of fuel, the annual expenditures on fuel oil by several industries are analyzed and presented in Table C.6. The current prices of Domestic Fuel Oil and Fuel Oil No.6 including sales tax are 665,529 TL/kg and 367,636 TL/kg, respectively. The exchange rate of currency from TL to US$ is taken as 1,550,000 TL/US$ (the existing exchange rate).

As given in Table C.6 the replacement of Fuel Oil No. 6 with Domestic Fuel Oil will cost an additional 6.9 million US$ annually to the re-rolling mills.

Table C.6 Economic analysis for replacement of Fuel Oil No.6 with Domestic Fuel Oil

Industry	Annual fuel oil consumption (tons)	Annual cost of Fuel Oil No.6 (Million TL)	Annual cost of Domestic Fuel Oil (Million TL)	Annual cost difference (Million TL)	Annual cost difference (US$)
Nursan	6,750	2,481,543	4,492,321	2,010,778	1,297,276
Koc	6,750	2,481,543	4,492,321	2,010,778	1,297,276
Atakas Sahin	6,750	2,481,543	4,492,321	2,010,778	1,297,276
Pay	3,240	1,191,141	2,156,314	965,173	622,692
Ilhanlar	4,860	1,786,711	3,234,471	1,447,760	934,039
Yolbulan A	2,700	992,617	1,796,928	804,311	518,910
Yolbulan B	2,160	794,094	1,437,543	643,449	415,128
Tosyali	2,700	992,617	1,796,928	804,311	518,910
Total	**35,910**	**13,201,809**	**23,899,146**	**10,697,338**	**6,901,508**

C.4 Economic Analysis for Scenario # 4

In Scenario # 4 it was assumed that entire domestic heating in the study area has shifted from coal to natural gas, which will be available for use in 2004 (BOTAS, 2002). Currently coal is the major fuel used for domestic heating. There are four months (November to February) in which heating is done. Each dwelling uses about one ton of coal for heating in winter season. Heating value of the most widely used coal in the Iskenderun Region is 26,750 kJ/kg (6400 kcal/kg), which is used in the calculations.

- The heat generated by one ton coal = 26,750 kJ/kg x 10^3 kg/ton

  = 26,750 x10^3 kJ/ton = 26,750 MJ/ton

The existing price of coal is 199 million TL (December 2002). Therefore, each dwelling spends about 200 million TL (129 US$) for domestic heating in a winter season.

If natural gas were to be used as fuel for domestic heating and assuming that same amount of heat will be needed to heat up the dwelling, the equivalent amount of gas needed to produce 26,750 MJ of heat (the heating value of 1 ton coal) can be calculated as:

- The calorific value of natural gas = 36 MJ/Nm^3
- Amount of gas required for heating per winter season for each dwelling = (26,750 MJ)/(36 MJ/Nm^3) = 743 Nm^3

According to BOTAS (the gas distribution company in Turkey), natural gas is provided at 15 °C and at a pressure of 1.01325 bar, which is taken as standard (S) condition in this case. Moreover gas price is also given per m^3 at the above mentioned temperature and pressure.

- Amount of gas = 743 Nm^3 * (273 +15)/273 = 784 m^3 at 15 °C
  = 784 Sm^3

Each dwelling will consume 784 m^3 of natural gas for domestic heating in a winter season.

- Price of natural gas (inclusive of sales tax and as of December, 2002) = 377,600 TL/Sm^3
- Cost of heating for one dwelling per winter = 784 m^3 x 377,600 TL/m^3 at 15 °C
  = 296 million TL = 191 US$

The operating costs of domestic heating with coal and natural gas for one dwelling is 199 MTL (million Turkish Lira) (129 US$) and 296 MTL (191 US$), respectively. For entire winter season domestic heating with natural gas is 62 US$ (15.5 US$ per month) more expensive regarding the operating costs,

but its striking benefit is the total elimination of SO_2 and PM from residential areas, which are the major pollutants causing respiratory diseases in human beings.

In order to shift from coal to natural gas, households have to have some initial investment for piping in the building, cost of connection and gas heating systems. The existing prices of gas heating systems are about 1 x 10^9 TL (Demir Dokum, December 2002). This domestic heating system is adequate to heat a house having 150-m^2 living area.

- Price of gas heating system = 1,000,000,000 TL
- Installation and piping = 200,000,000 TL
- Total cost of heating system = 1,200,000,000 TL = 1.2 billion TL
- Life of heating system = 15 years
- Annual initial investment = 1.2 billion TL/15 year = 80 MTL/year
- Annual maintenance cost = 20 MTL
- **Total annual cost of heating by natural gas per dwelling =**

= Initial investment + maintenance cost + cost of gas

= 80 MTL + 20 MTL + 296 MTL = 396 MTL

= 255 US$

The cost of heating by natural gas taking into account initial investment, maintenance and operating expenses is 396 MTL (255 US$), which is almost double of the cost of heating by coal.

Table1 C.7 and C.8 show the summary of effects of scenarios on air quality and prices associated with them.

Table C.7 Summary of economic analyses and effects on air quality for Scenario # 1

Pollutants/ Conditions	Emission Control Techniques	Average cost of emissions control systems (US$/year	Effect on air quality	Average cost of pollution control (US$/year)		
				PM + Wet limestone	PM + Wet lime	PM + Dry lime
PM emissions from ISDEMIR reduced from 2400 kg/h to below 15 kg/h	Fabric Filter	518,945	Reduction in the annual average ground level PM concentrations in whole of the Iskenderun Region from up to 127 $\mu g/m^3$ to less than 52 $\mu g/m^3$ i-e, below EC Regulation and TAQPR limits.	**24,389,580**	**15,639,580**	**7,393,200**
	ESP	2,140,635				
	Sub total	2,659,580				
SO_2 emissions from ISDEMIR reduced from 4146 kg/h to below 60 kg/h	Wet limestone scrubber	21,730,000	Almost negligible effect on the annual average ground level concentrations of SO_2 in the Iskenderun Region, because tall stacks of ISDEMIR ensure effective dispersion of SO_2 emissions even without any emission control system.			
	Wet lime scrubber	12,980,000				
	Dry lime injection	4,733,620				

Table C.8 Summary of economic analyses and effects on air quality for Scenario # 2- 4

Case	Conditions	Effect on air quality	Total Cost (US$/year)
Scenario # 2	Increasing the stack heights in other industries from 25 m to 50 m.	A slight reduction in the annual average ground level concentrations in Dortyol and Payas	50,000
Scenario # 3	Change of Fuel Oil No. 6 (having 6% by wt. sulfur) with Domestic Fuel Oil (with 1.5 % by wt. sulfur) in all of the re-rolling mills in Iskenderun Region	Reduction in annual average ground level concentration of SO_2 due to other industries, from 50µg/m^3 to below 10 µg/m^3 in Dortyol and Payas	6,901,508
Scenario # 4	Entire domestic heating in the Iskenderun Region is shifted from coal to natural gas	Total elimination of PM and SO_2 due to domestic heating, which is the largest contributor in ground level PM and SO_2 concentrations in the residential centers of Iskenderun Region	255 US$/year per dwelling

Vita

Muhammad Tahir Chaudhary was born in Faisalabad, Pakistan on June 18, 1967. He received his B.Sc. degree in Agricultural Engineering from the University of Agriculture in Faisalabad, Pakistan in 1988. The Government of Pakistan in 1990 awarded him a Fellowship for a Postgraduate Diploma in Computer Systems. He joined Pakistan Atomic Energy Commission in Islamabad as an Assistant Engineer in July 1991 and was promoted as Senior Engineer in December 1995. He worked there until February 1997. He completed his M.Sc.(Hons.) in Agricultural Engineering in 1994 from the University of Agriculture, Faisalabad. He was awarded with University Merit Scholarship during M.S. studies. In February 1997 upon winning the Cultural Exchange Scholarship from the Governments of Pakistan and Turkey, he moved to Ankara, Turkey for Ph.D. studies at the Middle East Technical University, Department of Environmental Engineering. TUBITAK also awarded him a partial scholarship during his Ph.D. studies in Turkey. His areas of interest are industrial air pollution control and air quality modeling.