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DEVELOPMENT OF A GIS BASED DECISION SUPPORT SYSTEM FOR URBAN AIR QUALITY MANAGEMENT IN THE CITY OF İSTANBUL

LAYMAN REPORT

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İSTANBUL

DEVELOPMENT OF A GIS BASED DECISION SUPPORT SYSTEM FOR URBAN AIR QUALITY MANAGEMENT IN THE CITY OF İSTANBUL

BENEFICIARY	**Istanbul Metropolitan Municipality**
TYPE OF ORGANISATION	**Local Autohority**
PARTNER	**Dokuz Eylul University**
PROJECT MANAGER	**Tolga ELBİR, Ph.D**
TOTAL BUDGET	**314.535 €**
LIFE CONTRIBUTION	**160.295 €**
YEAR OF FINANCE	**2006**
DURATION	**01.02.2007 – 31.01.2009**
COMMISSION REFERENCE	**LIFE06-TCY/TR/000283**
PREOJECT WEB SITE	http://www.ibb.gov.tr/airqualistanbul

1. INTRODUCTION

Air pollution in an urban area is a relatively more difficult problem to control than water or land contamination. Continuous emissions of pollutants into the atmosphere from natural and anthropogenic sources, atmospheric dispersion and transformation of pollutants, and their transport over long distances are the major factors which make air quality management problematic.

A legal framework is needed to provide a context for urban air quality management. While there are many possible models, one example is suggested by WHO (WHO, 2000). The first step of this model is the development of goals and policies. When goals and policies have been developed, the next stage is the development of a strategy or a plan. Fig. 1 summarizes the stages involved in the development of an air quality management strategy. It also involves the development of an emission inventory. The monitoring of both meteorological conditions and air pollutant concentrations also ocur normally, as these data are required by models used to estimate air quality, and to validate the model output. Air quality standards and model outputs or measurements are considered in devising emission control tactics aimed at achieving the air quality standards. The tactics need to be enforced, and if the standards are achieved, they need continued enforcement. If the standards are not achieved after a reasonable period of time, the emission control tactics may need to be revised.

A geographical information system (GIS), the heart of an air quality management system is a management support tool that permits the decision maker to view and analyze spatial information at speeds and in ways that were never possible in the past.

At present, computer based decision support systems for urban air quality management are applied in major cities around the world. The application of decision support systems is an opportunity for improving air quality planning in the largest cities. These decision support systems generally encompass air quality monitoring, emission inventories, air quality modeling, air quality mapping and air quality impact assessment of various control strategies in support of evaluation of action plans by using information to the public about past and present air quality levels. The basic idea of decision support systems is to improve the decision making process for policy makers by providing a professional tool to assist air quality planning.

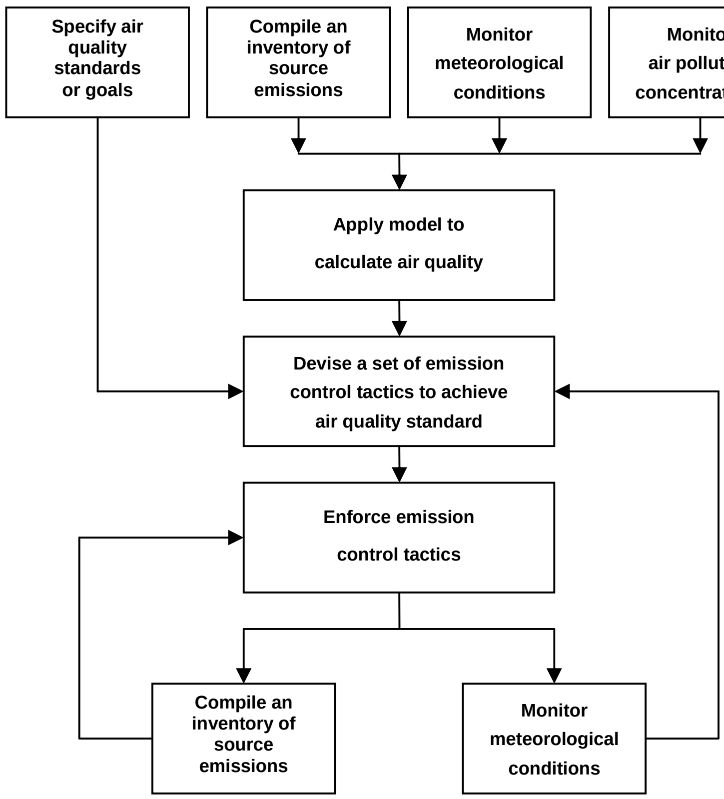


Figure 1. Stages involved in the development of an air quality management strategy (WHO, 2000)

Decision support systems used for urban air quality management are not routinely applied in Turkey. Present studies in Turkey often have a low spatial resolution and do not take full advantage of GIS and administrative databases. Larger cities in Turkey like Istanbul should develop their own decision support systems or adapt their data to an available system like the system developed in Europe.

This project focuses on the determination of air quality in the city of Istanbul and use of a GIS based decision making system developed for urban air quality management in Istanbul. Preparation of a comprehensive emission inventory and air quality modeling are the main themes of this research.

2. Summary of the Project and Objective

The project "Development of a GIS Based Decision Support System for Urban Air Quality Management in the City of Istanbul" was performed within the frame of the LIFE Third Countries Programme for the term February 1, 2007- January 31, 2009. The project was carried out by the cooperation of Istanbul Metropolitan Municipality (IMM) in the position of beneficiary and Dokuz Eylul University (DEU) in the position of partner.

The objective of this study is to develop a computerized decision support system for the management of the air quality of a big metropolis city as the first deal in Turkey. The basic goals of the study are to prepare a detailed emission inventory by reaching to the most important pollution resources in the city, to create the maps of air pollution in the city on based of a GIS by using a professional air quality dispersion modeling and finally to plan the corrective actions to improve the air quality in the city.

The project involved following tasks;

Task 1 (Organization): Initial meetings were arranged between the partners for the coordination. The project was announced to public. Project offices were established.

Task 2 (Data Collection): All necessary data for preparation of emission inventory and air quality modelling studies were collected. These are mainly pollutant source information (industry, domestic heating and traffic), ambient air observation, meteorological and topographical data.

Task 3 (Training): Technical trips were carried out in several major European cities which have been using similar air quality management systems. These trips aimed to discuss how other big European cities were managing their decision support systems and adapt to Istanbul's model.

Task 4 (Technical Studies): A comprehensive emission inventory indicating the sources of different air pollutants in the city were prepared. A dispersion model were used to translate emissions under given meteorological conditions into ambient air quality levels. Scenarios for air pollution abatement were evaluated.

Task 5 (Management): This task involved the implementation of new air quality management policies for Istanbul and reporting the final project report to EC.

3. The Results Achieved

Task 1 (Organization)

- ✓ Project offices were established in Istanbul and in Izmir. These offices are located in the buildings where IMM Department of Environment Protection and Control and DEU Department of Environmental Engineering. Following the establishment of those offices, the meetings were held with the participants from the EC authorities, project partners and other organizations in order to publicize the project.

- ✓ Both hardcopy and electronic version of the project brochure were prepared. Two thousands hardcopies of the brochures were printed and distributed to the related institutions.

- ✓ The project website, http://www.ibb.gov.tr/airqualistanbul, was prepared. The website provides general information on the air pollution, project methodology, objective of the project, expected results and links of the legal regulations.

Task 2 (Data Collection)

For preparation of the emission inventory;

- ✓ Industrial data (the name, address, capacity, production information, energy requirement, working hours, number of employees, stack information) was obtained for 1025 industrial plants.

- ✓ Data on the domesting heating (population and use of fuel (coal or natural gas) of the buildings) was obtained.

- ✓ Traffic data (number, sort and counting of the vehicles, city highway network) was obtained.

- ✓ Digital topographical data was obtained from IMM's Department of Information Technology Directorate of Geographical Information System.

- ✓ Hourly meteorological data (wind speed, wind direction, temperature, humidity, etc..) was obtained from Republic of Turkey Ministry of Environment and Forestry General Directorate of State Meteorology Affairs and IMM AKOM.

Task 3 (Training)

- ✓ Four major metropolitan cities (Stockholm, Paris, Marseille and St.Petersburg), which have being successfully used their own decision support systems for urban air quality management, were visited. These cities were selected after the investigations and communications with many major administrative institutions for a long time in Europe. After getting positive responses from three distinguished organizations, the tours were held. During the tours; seminars, presentations, demonstrations, meetings and discussions with the local administrators of the cities visited were held to render the air quality management system developed for the city of Istanbul to have an acceptable background.

Task 4 (Technical Studies)

Emission Inventory

- ✓ Emission factors were taken from CORINAIR (CITEPA, 1992) and US Environmental Protection Agency (USEPA) source emission factors catalogues (USEPA, 1995). The emission factors used for different pollutant source activities are summarized in Tables 1-3.

Table 1. Emission factors used to calculate industrial emissions

Fuel type	PM	SO_2	NO_X	VOC	CO
	kg/m^3 a) - kg/tons b)	g/GJ			
Lignite	3.4*A b)	20000*(S/H)*(1-r)	150	30	16
Fuel oil	1.12*S+0.37 a)	490*S	140	15	15
Motorine	1.12*S+0.37 a)	490*S	100	15	12
LPG	0.07 b)	-	88	2.5	13
Wood	4.4 b)	-	200	400	1504
Biomass	not available	-	280	4	30
Natural gas	-	-	100	5	13

A: ash content (%), S: sulfur content (%), H: heating value (MJ/kg)

Table 2. Assumptions used for emission calculations

Fuel type	Heating Value (MJ/kg)	Sulfur (%)	Ash (%)	Density (t/m^3)
Fuel oil	41.0	3.0	-	0.96
Lignite	12.1	1.5	21.5	-
LPG	45.4	-	-	0.55
Wood	16.0	-	-	-
Biomass	9.5	-	-	-
Natural gas	41.5	-	-	-

Table 3. Emission factors used to calculate residential heating emissions

	PM	SO_2	NO_X	VOC	CO
Lignite (kg/tons)	4.89	10.89	1.33	5.86	55.69
Fuel oil (kg/tons)	0.15	5.74	2.79	0.64	1.89
Wood (kg/tons)	8.62	0.25	0.92	11.47	65.72
Natural gas (kg/m^3)	0.02	0.02	1.85	0.34	1.01

A: ash content (%), S: sulfur content (%), H: heating value (MJ/kg)

- ✓ In order to determine the air pollutant emissions from major pollutant sources, a local emission inventory was prepared with 1-hour temporal and 1-km spatial resolution within an area of 170 km by 85 km centered at the metropolitan area of Istanbul.

- ✓ In a systematic way, the emission sources are broadly categorized as point, line and area sources, covering industrial, vehicular and residential sources respectively. Five major pollutants censisting of particulate matter (PM_{10}), sulfurdioxide (SO_2), carbonmonoxide (CO), non-methane volatile organic compounds (NMVOCs) and nitrogen oxides (NO_X) emitted through these sources were identified. The data on emissions from industries, fuel consumption for vehicles and domestic activities along with respective emission factors provide the emission inventory presented in Table 4.

Table 4.*Total and sectoral emissions in the study area, t/y*

	Emissions (t/y)				
	PM_{10}	**SO_2**	**NO_X**	**NMVOC**	**CO**
Industry	7,630	58,468	9,394	117	1,714
Residential heating	13,631	10,983	7,014	18,351	123,510
Traffic	5,200	1,016	138,000	38,500	270,000
TOTAL	26,461	70,467	154,408	56,968	395,224

Air Quality Modelling

- ✓ To calculate the dispersion of substances from pollutant sources, a dispersion model calls the California Puff model (CALPUFF) (Scire et al., 2000) based on Gaussian diffusion was used in this system. CALPUFF is a Lagrangian puff model and a multi–layer, gridded non–steady–state puff dispersion model that can simulate the effects of temporally and spatially varying meteorological conditions on pollutant transport, removal of pollutants by dry and wet deposition processes, and transformation of pollutants through chemical reactions.

- ✓ In order to provide meteorology input data, MM5 meteorological model was used in the project. The MM5 (short for Fifth-Generation NCAR/Penn State Mesoscale Model) is a regional mesoscale model used for creating weather forecasts and climate projections. It is maintained by Penn State University and the National Center for Atmospheric Research. Meteorological modeling studies by MM5 were done for different periods which show the air pollution episodes occured in Istanbul during the year of 2007.

✓ In order to illustrate the air quality in detail in Istanbul, the maps were prepared and discussed for the following periods:
  - Annual
  - Winter season
  - Summer season
  - Episodes (high pollution incidences continuing for two or three days)

Some of these maps are illustrated in the following figures.

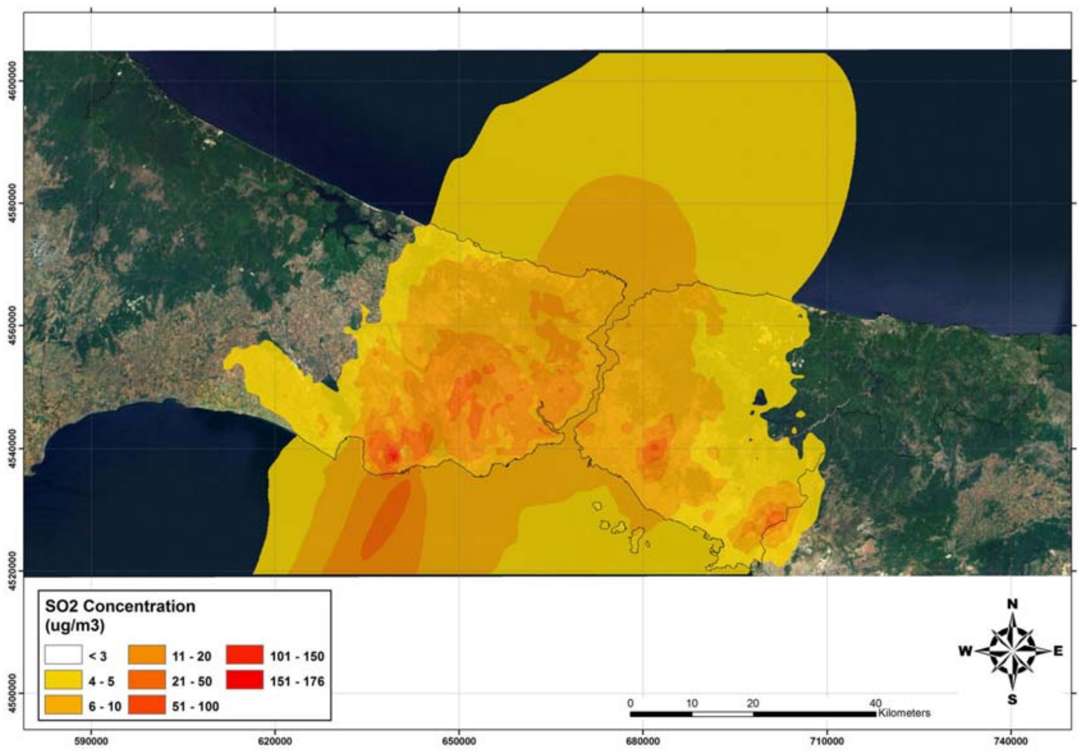


Fig.2. *Annual average SO_2 concentrations (all sources), $\mu g/m^3$*

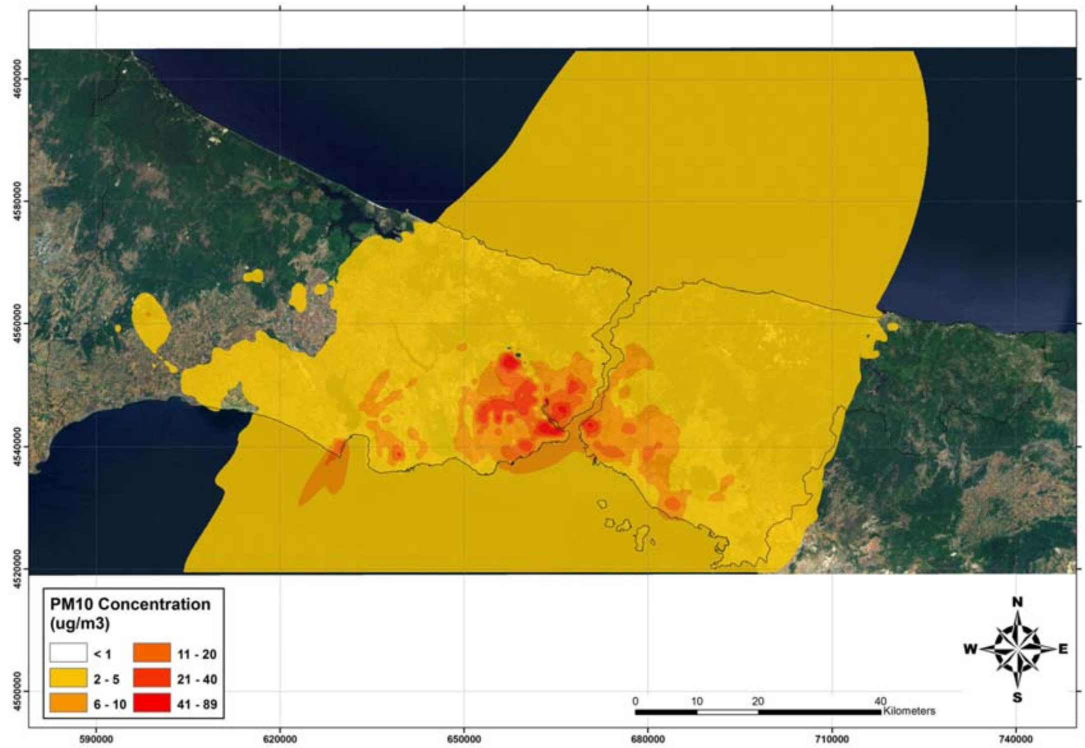


Fig.3. *Annual average PM_{10} concentrations (all sources), µg/m^3*

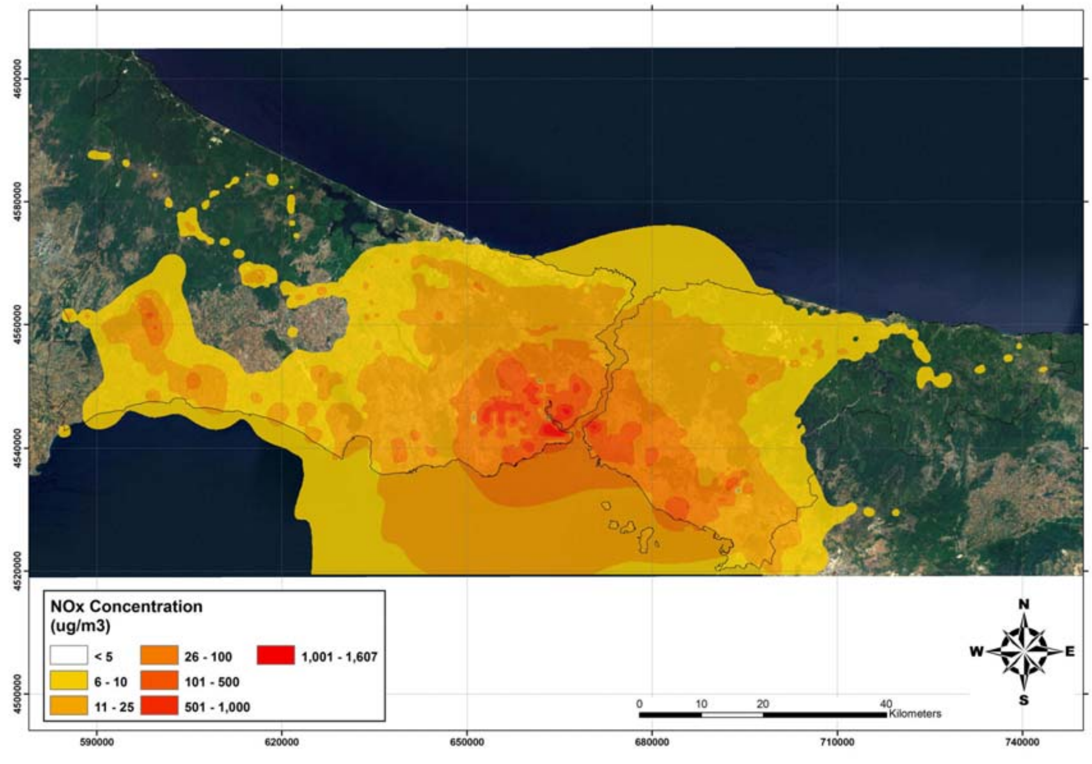


Fig.4. *Annual average NO_X concentrations (all sources), µg/m^3*

Statistical Analysis for Model Evaluations

- ✓ The level of representativeness of the model predictions was determined by comparing them with observed air quality data. For this, model predictions were evaluated by comparing them to the observed concentrations from ten ambient air quality stations. Mainly two methods were used: root of the mean square error (RMSE) and an index of agreement (d).

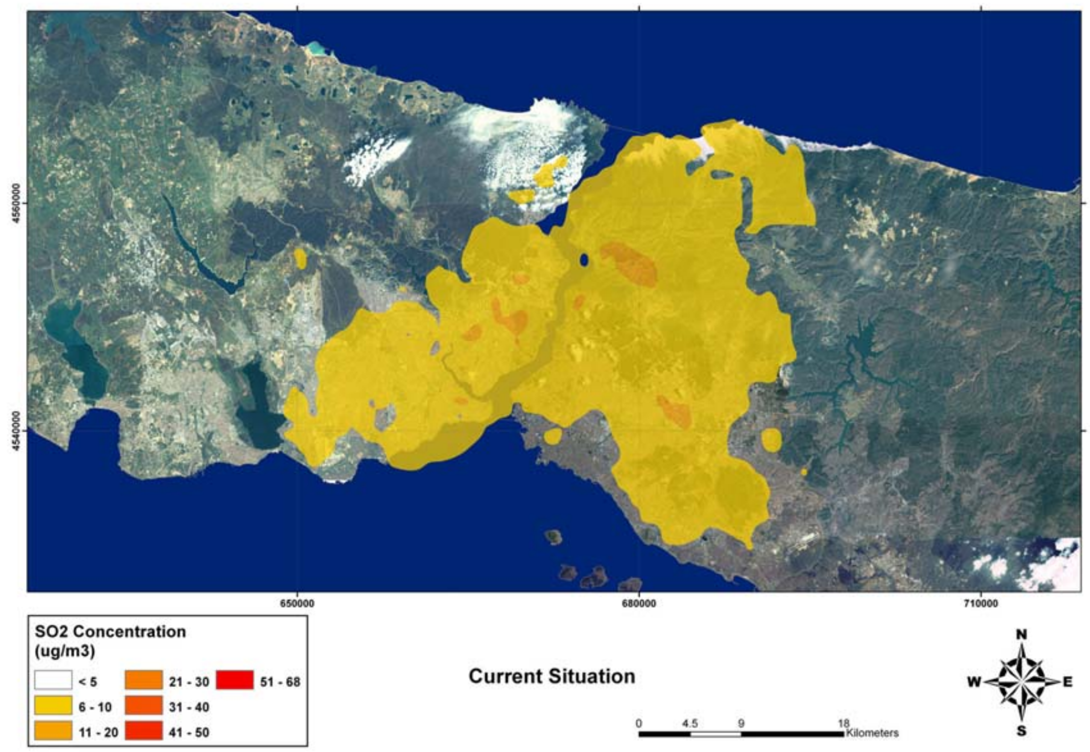
- ✓ In addition to these two methods, a few more conventional statistical methods (i.e. determination of standard deviation, minimum, maximum, mean) were also used for model performance evaluation.

- ✓ Comparison of average predicted and monitored concentrations show that overall accuracy of the predictions for all pollutants was high except PM10. The overall accuracies of NO_X, CO and SO_2 concentration predictions (d) were about 44%, 57% and 58% respectively while the accuracy was 37% for PM_{10} concentration prediction. When each monitoring station was evaluated separately, the accuracies of the prediction at Umraniye, Aksaray and Uskudar stations was better than overall accuracy with values of 76% for NO_X, 75% for CO, 67% for SO_2 and 50% for PM_{10}. However, the accuracy in Sariyer station was found as 39% for PM_{10} and SO_2, 41% for CO. The relevant analysis of the root of mean square error (RMSE) indicated that there was a normal error in the model prediction. It should be noted that the uncertainty of the predictions might arise from two different sources: the emission calculations and dispersion modeling.

Scenarios for Modeling

- ✓ As a final stage in the study, several scenarios were generated which can be examples for decision makers of the city of Istanbul to indicate the usage of the decision support system developed. The system developed enables to estimate the result of a case causing drastic changes on air pollution in a reasonable period. In order to illustrate this, three scenarios were produced.

✓ As it is related to the fuel usage changes in residential areas in Istanbul, the main theme in the first scenario is the reduction of natural gas consumption in houses. Turkey imports natural gas from its neighbor countries such as Russia, Azerbaijan, and Iran. Turkey has faced threat of natural gas crisis several times until now. The aim of this scenario is to switch the fuel types in residential areas when a natural gas crisis occurs. The scenario assumes that lignite with a sulfur content of 1% will be used instead of natural gas in houses during the winter season. The results of the scenario show that overall seasonal SO2 concentrations are increased in almost all regions of the city during the winter season (Fig. 5). Maximum concentration increases from 20 μg/m^3 to 70 μg/m^3. It means that the concentrations after the scenario are approximately four times higher than the current situation.



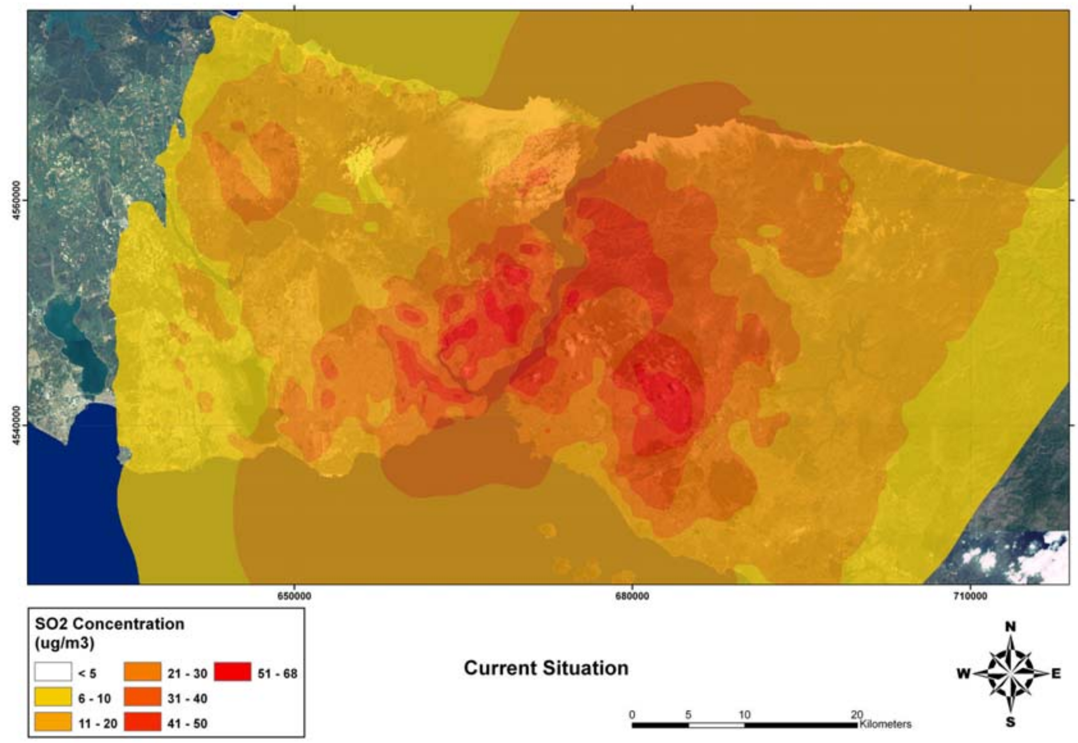


Fig 5. Seasonal average SO2 concentrations in the winter for the scenario, (□g m-3)

- ✓ The second scenario is that several sand and gravel processing plants in Gaziosmanpaşa region stop operating. These plants cause high PM_{10} concentrations. The aim of this scenario is to see the effects of this action to the present urban air quality in Istanbul. The results of the second scenario show that the high annual mean PM_{10} concentrations (60-90 $\mu g/m^3$) around Gaziosmanpaşa and Büyükçekmece districts (near sand and gravel processing plants) disappears after the plants stop operating.

- ✓ The third scenario is simpler. It was assumed that all present pollutant sources are working in the study area and only the big power plant emitted high SO_2 emissions, changes the fuel type as natural gas instead of fuel oil-6. The aim of this scenario is to see the effects of this power plant to the present urban air quality in Istanbul. Daily SO_2 concentrations decrease in the regions around the power plant after modeling the third scenario. While the maximum daily SO_2 concentration is found as 1200 $\mu g/m^3$ in the region in December 22, 2007, the concentrations between 100-500 $\mu g/m^3$ occur in the region after assuming the change of fuel type (natural gas instead of fuel oil-6) of the power plant.

Task 5 (Management)

- ✓ A decision support system for urban air quality management was developed for the first time for a metropolitan city in Turkey within the scope of this study. According to the results of the study, Istanbul Metropolitan Municipality has prepared an action plan titled "Istanbul Air Quality Strategy" to have a better air quality in future.

- ✓ Istanbul Metropolitan Municipality, Environmental Protection and Control Department has newly started to use the decision support system developed in cooperation with Housing and Urban Development Department. The system has been used to estimate the effects of the new industries that will be established in the city before getting their permission to operate.

4. CONCLUSIONS

- ✓ Decision support systems suitable to urban air quality management are not routinely applied in Turkey, although such systems are in operation in other European middle-sized and larger cities. However, present studies in Turkey often have a low spatial resolution and do not take the full advantage of GIS and administrative databases.

- ✓ A decision support system was developed for urban air quality management in the city of Istanbul. Calculation of a comprehensive emission inventory, air quality modeling, air quality mapping by GIS and scenario analysis for air pollution abatement were carried out as the components of this system. Air quality modeling was the main component of the system and CALPUFF, a Langrangian puff dispersion model was mainly used for air quality predictions. CALMET meteorological preprocessors were used to produce meteorological data for CALPUFF model in the system.

- ✓ The decision support system developed in this study provides easy access to the softwares to determine the air quality anywhere and anytime in the study area. The system has been also developed as a tool to have an idea about the results of a case causing changes on air quality within a reasonable run time.