SPATIAL PREDICTION OF TRANSPORT RELATED URBAN AIR QUALITY

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ABSTRACT:

The aim of this study is to explore the relationship between, transport, land-use and air quality and mapping of air pollutants by means of spatial information sciences, which would provide useful information for decision-makers. Integrated transport, land-use and air quality monitoring are prioritized especially in metropolitan areas. The complexity is straight forward, since data, indicators, variables, methods and approaches vary and isolated. Within the environmental studies, due to reasons of cost and measurement techniques, there exists limited number of sample points. Air quality studies are not exceptions, where sample points are sparse observations. This greatly reduces the availability of appropriate interpolation methods for estimating the total air quality. Geostatistics and multi-variate techniques provide the framework and the tools to build a consistent model for “integrating” information from various sources. Geostatistics introduce useful for up-scaling from the data that have been collected at limited points to provide complete areal coverage where the accuracy of the prediction is known. Air quality measurements namely SO_2 and PM obtained at the Istanbul Metropolitan Area between 1994 and 2007 were evaluated via spatial information sciences and results were discussed.

1. INTRODUCTION

In both developed and rapidly industrializing countries, the major historic air pollution problem has typically been high levels of smoke and Sulphur Dioixide (SO_2) arising from the combustion of sulphur-containing fossil fuels such as coal for domestic and industrial purpose. At current status, the major threat to clean air is now posed by traffic emissions. Traffic congestion is the result of the relationship between transport and land-use, where impacts are obvious in several metropolitans. At the current status data, indicators, variables, methods and approaches vary and systems for solving the complex problem are isolated. Hence, integrated policies are highly stressed to solve the complex problem.

The geoinformation sciences currently became the core component of integrated transport, land-use and environmental decision making systems (Geerlings and Stead, 2003; Sperling et. al, 2004). Clearly, given their important role in assisting policy making, it is important to quantify the uncertainties associated with environmental process models (Leopold et al, 2006). The number of sample points used in environmental studies is limited due to cost and techniques of measurements. Air quality studies are not exceptions, where sample points are sparse observations. This greatly reduces the availability of appropriate interpolation methods for estimating the total air quality. For such analyses geostatistics introduce useful for up-scaling the data on attributes that have been collected at points to provide complete areal coverage (Bierkens et al, 2000).

The integrated usage of geostatistical methods and geosciences can introduce valuable information to identify, visualize and explore the relationship between transport, land use and air quality. The obtained information is associated with quality, which will aid reliability to taken decisions. This study is organized as follows to introduce an integrated approach to transport, land use and air quality interactions. First, the study area and data used are introduced. Then methodology is briefly described. Thirdly, results of the spatial analyses are presented at the results and discussion section. Finally, major findings and future suggestions are given at the conclusion.

2. THE STUDY AREA AND DATA USED

The study area was selected as the Istanbul Metropolitan Area, which is one of the most important and the largest metropolitan of Europe with the population more than 12 million people.. Istanbul still receives considerable amount of immense migration from all over the country which leads the fast expansion of the city. Air pollution becomes one of the important problems of the city together with traffic congestion as a result of increase population and unplanned urbanization. Based on reports of the State Statistical Institute published in 2006, every fifth citizen of Istanbul owns a vehicle. The relationship between population and number of vehicles is illustrated in Figure 1. Both population and number of vehicles have an increasing trend after 1980s.

Emissions caused by the road traffic in Istanbul increased rapidly between years of 1990 and 2000, where the increase in CO, SO_2 and particulates were 50.1%, 55.7% and 82.5%, respectively (Becin, 2002). "Particulate matter," also known as particle pollution or PM, is a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles (EPA, 2008).

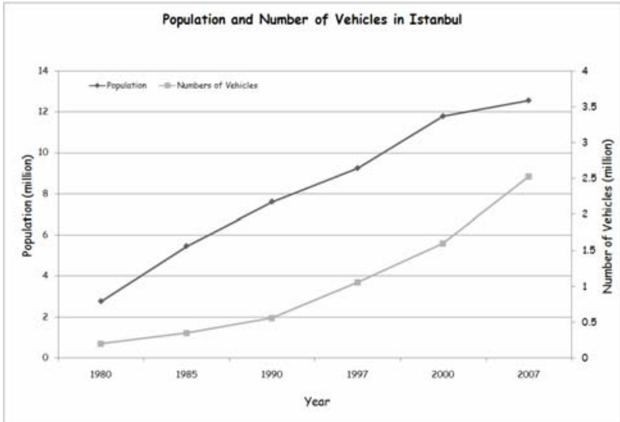

Figure 1 Population and number of vehicles in Istanbul

Sulfur dioxide, or SO_2, belongs to the family of sulfur oxide gases (SOx). These gases dissolve easily in water. Sulfur is prevalent in all raw materials, including crude oil, coal, and ore that contains common metals like aluminum, copper, zinc, lead, and iron. SOx gases are formed when fuel containing sulfur, such as coal and oil, is burned, and when gasoline is extracted from oil, or metals are extracted from ore. SO_2 dissolves in water vapor to form acid, and interacts with other gases and particles in the air to form sulfates and other products that can be harmful to people and their environment (EPA, 2008). The effects of pollutants for a determined index value can be examined in Figure 2 (AIRNOW, 2008).

Index Values	Level of Health Concern	Pollutant	Cautionary Statements
0-50	Good	Particle Pollution	None
		SO_2	
51-100*	Moderate	Particle Pollution	Unusually sensitive people should consider reducing prolonged or heavy exertion.
		SO_2	None
101-150	Unhealthy for Sensitive Groups	Particle Pollution	People with heart or lung disease, older adults, and children should reduce prolonged or heavy exertion.
		SO_2	People with asthma should consider reducing exertion outdoors.
151-200	Unhealthy	Particle Pollution	People with heart or lung disease, older adults, and children should avoid prolonged or heavy exertion. Everyone else should reduce prolonged or heavy exertion.
		SO_2	Children, asthmatics, and people with heart or lung disease should reduce exertion outdoors.
201-300	Very Unhealthy	Particle Pollution	People with heart or lung disease, older adults, and children should avoid all physical activity outdoors. Everyone else should avoid prolonged or heavy exertion.
		SO_2	Children, asthmatics, and people with heart or lung disease should avoid outdoor exertion. Everyone else should reduce exertion outdoors.
301-500	Hazardous	Particle Pollution	People with heart or lung disease, older adults, and children should remain indoors and keep activity levels low. Everyone else should avoid all physical activity outdoors.
		SO_2	Children, asthmatics, and people with heart or lung disease should remain

Figure 2. Index values and effects of pollutants on health

In order to diminish the congestion problem, since 80's the infrastructure of the town is under constant renovation, new roads, and motorways have been built, bridges laid, under-ground line is under construction. This unfortunately could not solve the problem of congestion and some negative side effects were observed, such as valuable agricultural lands and forest were cut through new routes and industrial and urban areas expand along the transportation network.

The air quality measurements were being firstly performed by Institute of Sanitation at 17 stations between 1994 and 2000 and then decreased to ten between 2000 and 2007. Location of the sampling stations and emission values are provided at the Istanbul Metropolitan Municipality web-page http://www.ibb.gov.tr/tr-TR/HavaKalitesi/. Emission values have been provided as daily averages. Stations automatically measures CO_2, CO, NO_x, SO_2, particulates, VOC and NMVOC parameters and several others on daily bases for 365 days. Locations of previous and current stations are illustrated in Figure 3. According to the National Environment Agency reports, a population of 10 million requires approximately 35 sampling stations for SO_2 and particulates, where this study results may aid decision makers for re-evaluating the number of sampling stations. (Ozturk, 2005; RTMEF, 2008)

From air quality emission parameters sulfurdioxide (SO_2), carbonmonoxide (CO) and particulates (PM), retrieved from six sampling stations at the European side of the Istanbul Metropolitan area for the period 2003-2006 were studied at our previous study, (Sertel, 2007). Within the scope of this study only sulfurdioxide (SO_2) and particulate matters (PM) are examined for the whole period and compared.

Measurements conducted by the municipality are considered as accurate, since relevant tests and calibration were conducted. (IBB, 2007).Additionally the impact of atmospheric parameters such as wind, temperature was neglected. .

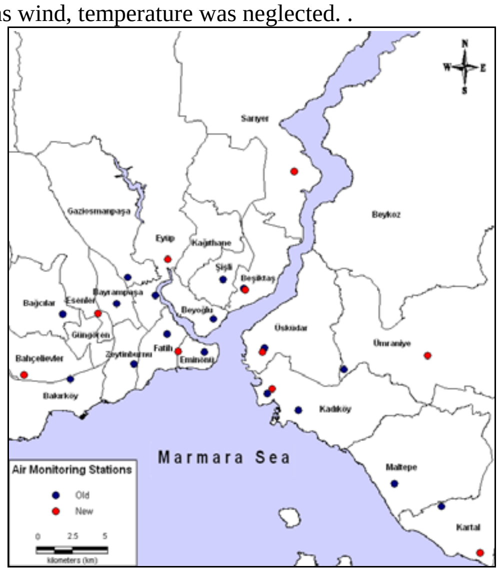

Figure 3 Locations of the previous and current air monitoring stations in Istanbul (Alkoy et al., 2007)

3. METHODOLOGY

Geostatistics provide optimal methods of spatial interpolation that include estimates of reliability at unsampled locations. Additionally, it provides the means of estimating the effects of uncertainty in the sampled data on the outcomes of spatial analysis and numerical models and particularly of air quality. If the possibility of increasing the amount of collected data arises, geostatistics provides solutions for data collection time, data collection location and selection of measured parameters. Kriging is a widely used technique for air quality data, since data is spatially continuous (Sampson and Guttorp, 1999; Shaddick and Wakeeld, 2002; Diem and Comrie, 2002, Nunnari et al., 2004, Potoglou and Kanaroglou, 2005). Among different types of kriging, ordinary and universal kriging are the most commonly used techniques. The general concept is that the prediction of the value **Y(s)**, such as SO_2 concentration, at any **s** location is obtained as a weighted average (W) of neighboring data (Bailey and Gatrell, 1995):

$$Y(s) = \sum_{i=1}^{n} w_i(s) Y(s_i) \qquad (1)$$

In both ordinary and universal kriging, the ultimate goal is to estimate the optimal values of the weights. One of the major advantages of kriging is the statistical evaluation of the results and the estimation of confidence intervals around predicted values. For this purpose, the mean square prediction error or kriging variance is used, where the variance is derived from the known covariance structure. For assessing the uncertainty and accuracy; time series plots comparing hourly predicted and observed concentrations for each monitoring station is recommended by Environmental Protection Agency (EPA) (EPA, 2001).

4. RESULTS & DISCUSSION

For the selected area several statistical and geostatistical methods were applied and results were compared accordingly:

Kriging method was applied to multi-temporal SO_2 and PM values obtained from 17 stations to create continuous SO_2 and PM maps of the Istanbul Metropolitan Area between 1994 and 1998. The SO_2 has continuous decrease for the mentioned period, hence only maps of 1994 and 1998 is provided in Figure 4.

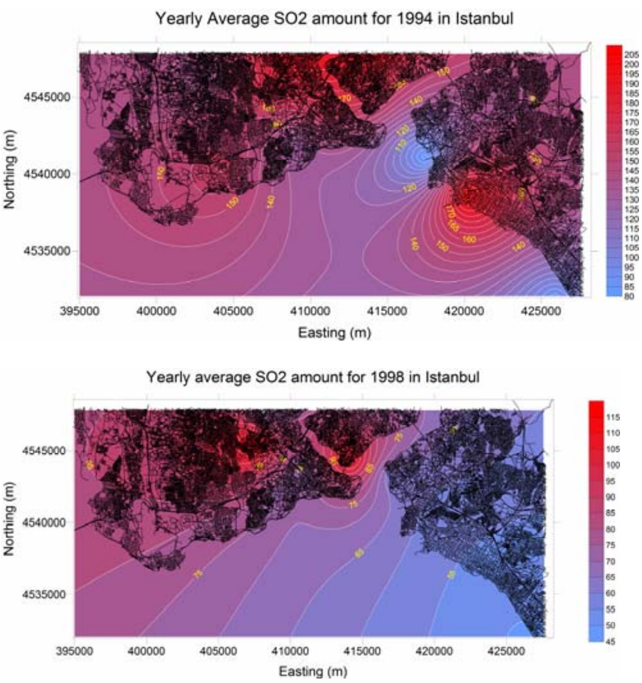

Figure 4 Kriging maps of SO_2 for years 1994 and 1998

PM maps are also achieved, which follows the same decrease trend. The upper limit value of SO_2 is determined as 125 according to European Union (EU) standards. Average yearly amount of SO_2 is higher than this value for several locations in Istanbul for 1994 and 1998. Higher SO_2 values were obtained around Eminonu, Sisli, Beyoglu, Bakirkoy, Bayrampasa and Gaziosmanpasa for all years which are highly populated and industrialized areas and covered by urban and built-up surfaces.

The index values and level of health concern was provided in Figure 2, where according to the SO_2 maps, the level health concern was changed from unhealthy to moderate from 1994 to 1998. For SO_2, monthly time series were plotted for January 2003 to December 2006 period, shown in Figure 5, in order to understand general distribution of these data. (Sertel et al, 2007)

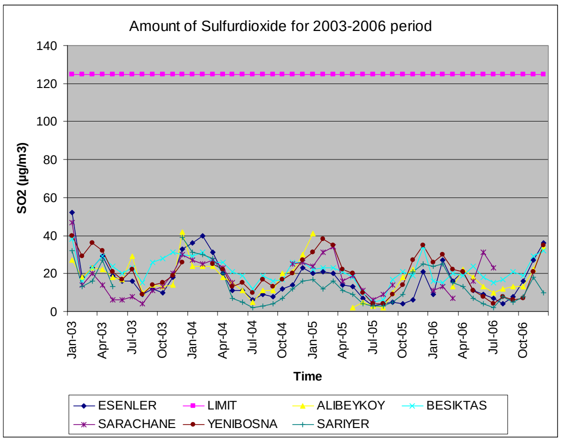

Figure 5 Monthly time series of SO_2 for the period 2003-2006

The time series for SO_2 showed that, the highest value was achieved in winter as 40, where summer values are about 10 especially in June and July. Maximum amount of SO_2 is determined as 125 according to EU standards, where SO_2 amounts belonging to all stations were under the limit. According to the result of the time series, the air quality emissions for the European side of the Istanbul Metropolitan area increases in winter time and there is a significant decrease in summer. Emission in winter is attributed to house, industrial gases and transport, where in summer season only industrial gases and transport is the source for emissions. Additionally, meteorological conditions of Istanbul in winter time are not mild, heavy fog and snow is frequent. In winter season, population of Istanbul is comparatively higher than the summer season as a result of this more vehicles take part in traffic which causes more emission. In addition to this, different quality of coal and fuel has been used in winter which contributes the differences in air quality parameters. According to the information retrieved from SO_2 maps within years 1994-2007, pre-cautions are taken by the decision makers and for human health the level of SO_2 can be grouped as “good”.

For the years 1994 and 1998, number of stations was seventeen and for the period 2007, it was decreased to ten. PM maps, achieved through kriging for the year 1994, 1997 and 2007, are illustrated in Figure 6. The road network of Istanbul Metropolitan Area is overlaid.

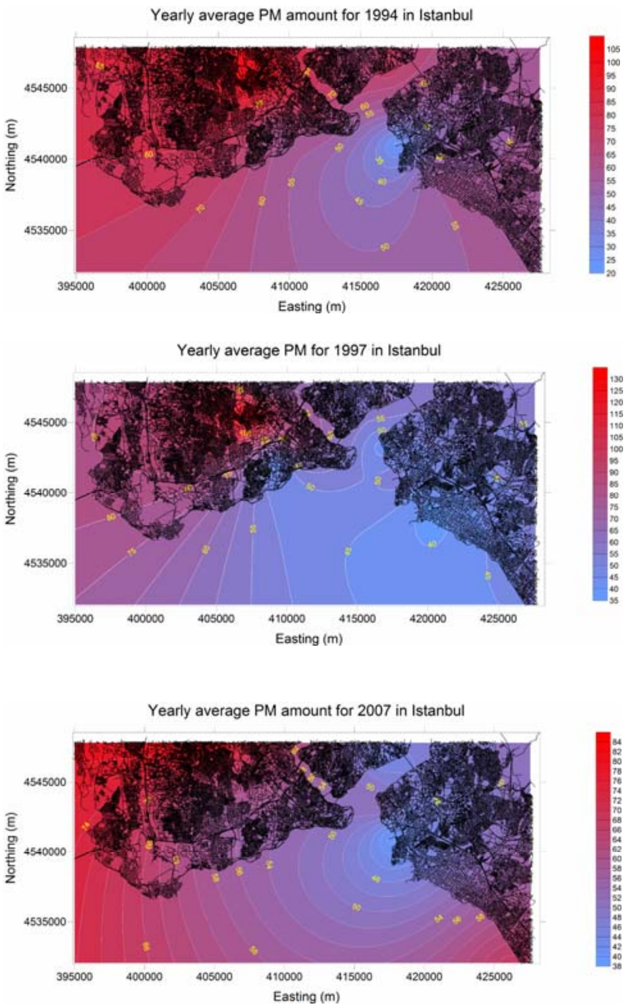

Figure 6 PM maps for the years 1994, 1997 and 2007

According to the monthly time series conducted for PM within the period of 2003-2006, the amount of PM was higher than the maximum value of 50, which was announced by European Union (Sertel et al., 2007). In Figure 6, however, the PM has a decreasing trend, although transportation infrastructure is enlarging and population is increasing. In the year 1987, the second bridge has not been completed yet, where the Transport European Motorway is newly constructed. In year 1997, the transportation network was already completed, where connections to the current transportation network, connection between first and the second bridge, was also done. However, the complete network begins to enlarge with new branches, which helps people to access the main network easily. The development is mainly observed at the northern side. In the year 2005, this development has not been decelerated, in fact very accelerated. (Demirel, 2006). Parallel to the enlarging network, there exists a rapid urbanization at the study area. According to the previously conducted studies at the European side of Istanbul Metropolitan Area by means of remote sensing, (Kaya and Curran, 2005), the urban area increased by 3359 ha between 1987 and 1992 and by 10,711 ha between 1992 and 1997. However, between 1997 and 2001, the rate of urban area increase decreased as a result of the 1999 earthquake. Overall, the urban area increased by 14,957 ha from 1987 to 2001 and the population almost doubled from 5.8 Min 1985 to 10.8 Min 2000. The urban area of the European side of Istanbul is increased by 126.7% between 1987 and 2001. Emissions caused by the road traffic in Istanbul increased rapidly between years of 1990 and 2000, where the increase in CO, SO_2 and particulates were 50.1%, 55.7% and 82.5%, respectively (Becin, 2002). However, due to the limited number of stations, kriging maps do not support the previously conducted studies.

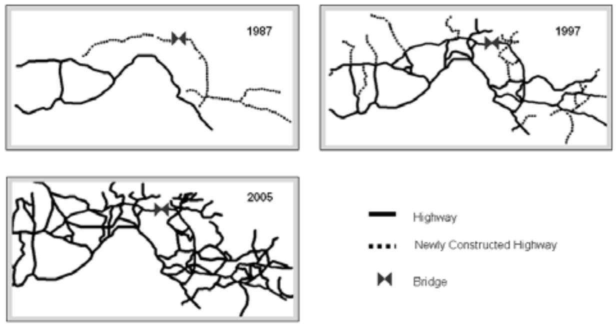

Figure 7 Temporal Changes of transportation infrastructures pertaining to 1987, 1997 and 2005

Kriging is an effective method to derive continuous variable maps of related regions using discrete station data. Number of points used in kriging procedure is important and affects the result map obtained from the method. Unfortunately, the monitoring data is only available for limited stations of Istanbul and therefore comparison of the spatial pattern between the model and the observations is limited. The achieved results should be integrated with an air quality model, where this model will provide the required sufficient input for geo-statistics. The decision-makers are aware of the problem, where several studies are being conducted by the Istanbul Metropolitan Municipality for determining the traffic related emissions. Additionally, the usage of Spatial Information Sciences for determining the air quality is foreseen.

5. CONCLUSION

Research results indicated that integrated usage of geostatistical methods, remote sensing and spatial analysis can introduce valuable information to identify, visualize and explore the relationship between transportation, land-use and air quality and reliability of the produced results. The spatial approach provided in this study will enlighten the complex task of decision makers and lead to more reliable decisions, since data and methods are integrated. To obtain more reliable and accurate results, the sampling stations number should be increased, where urbanization and transport network could be represented in a better manner.

REFERENCES

AIRNOW, 2008, A cross Agency Government Web-site, http://www.airnow.gov/index.cfm?action=aqibroch.aqi#aqipar (accessed 04 March 2008)

Alkoy, S., Dogru, A.O., Basaraner, M., Sahin, U., Ulugtekin, N., Seker, D.Z., 2007, Determination of the Epidemiological Aspects of Air Pollution by using GIS in Istanbul, 14th International Symposium on Environmental Pollution and its Impact on Life in the Mediterranean Region, 10-14 October 2007, Sevilla, Spain

Bailey, T.C., Gatrell, A.C., 1995, Interactive Spatial Data Analysis, Longman, Colchester

Becin, A., 2002. Environmental impacts of urban transport, MSc. thesis, Istanbul Technical University, Istanbul, Turkey.

Bierkens, M.F.P., Finke, P.A., Willigen, P., 2000, Upscaling and Downscaling methods for environmental research. Developments in Plant and Soil Sciences, Vol 88, Kluwer Academic Publishers, 190 ppt.

Chilés, J.P., Delfiner,P., 1999. Geostatistics – Modeling Spatial Uncertainty, Wiley Series in Probability and Statistics, pp.5

Demirel, H., 2006, A Novel Approach for Determining the Impacts of Road Transportation on Air Quality, *Fresenius Environmental Bulletin (FEB)*, 15. 8b, 891-897

Diem, J.E., Comrie, A.C., 2002. Predictive mapping of air pollution involving sparse spatial observations. Environmental Pollution, 119, pp. 99-117.

Geerlings, H., Stead, D., 2003. The integration of land use planning, transport and environment in European policy and research. *Transport Policy*, Elsevier Ltd, pp.187-196.

Istanbul Metropolitan Municipality (IBB), 2007, http://www.ibb.gov.tr/tr-TR/HavaKalitesi/Olcum/ (04 March 2008)

Kaya and Curran, 2006, Monitoring urban growth on the European side of the Istanbul metropolitan area: A case study, *International Journal of Applied Earth Observation and Geoinformation*, Volume 8, Issue 1, Pages 18-25

Leopold, U., Heuvelink, G.B.M., Tiktak, A., Fink, P.A., Schoumans, O., 2006.Accounting for change of support in spatial accuracy assessment of modelled soil mineral phosphorous concentration, *Geoderma*, Elsevier Ltd, pp. 368-386

Nunnari, G., Dorling, S., Schlink, U., Cawley, G., Foxall, R., Chatterton, T., 2004. Modelling SO2 concentration at a point with statistical approaches. Environmental Modelling & Software 19,pp. 887-905.

Ozturk, M., 2005, Determination of air quality in urban areas, Republic of Turkey,Ministry of Environment and Forest, www.cevreorman.gov.tr/belgeler1/hava_kalitesi.doc (accessed 04 March 2008) (in Turkish)

Potoglou, D., Kanaroglou, P.S., 2005. Carbon monoxide emissions from passenger vehicles: predictive mapping with an application to Hamilton, Canada, Transportation Research Part D 10, pp. 97-109

RTMEF, 2008, Republic of Turkey,Ministry of Environment and Forest, http://www.cevreorman.gov.tr/ belgeler5/cevre_durum.pdf, (accessed 04 March 2008) (in Turkish)

Sampson, P.D., Guttorp, P., 1999. Operational Evaluation of Air Quality Models, NRCSE Technical Report Series, NRCSE-TRS No:018, pp. 1-22, (http://www.stat.washington.edu/ NRCSE/pdf/trs18_aqmodels.pdf (accessed 04 March 2008)

Sertel, E., Demirel, Kaya, S., "Predictive mapping of air Pollutants: A GIS framework", *Proceedings CD of the Fifth International Spatial Data Quality Symposium*, ITC, CD Nm. 17, Enschede, Hollanda, 2007

Shaddick, G., Wakeeld, J., 2002. Modelling daily multivariate pollutant data at multiple sites, Journal of the Royal Statistical Society: Series C (Applied Statistics) 51, pp. 509- 511.

Sperling, D., Hanaoka, S., Okada, A., Okazaki, M., Shade, W., Yagishita, M., 2004. Environmental impacts due to urban transport. In *Urban Transport and the Environment, An International Perspective*, Nakamura, H., Hayashi, Y., May, A. Elsevier Ltd., ISBN: 0-08-044512-8, pp.100-188.

United States Environmental Protection Agency (EPA), 2001, Our Built and Natural Environments, A technical review of the interaction between land-use, transportation and environmental quality, EPA 231_R-01-002, http://www.smartgrowth.org/library/built.html (accessed 04 March 2008)

United States Environmental Protection Agency (EPA), 2008, Air Quality Criteria, http://www.epa.gov/ebtpages/ airairquairqualitycriteria.html (accessed 04 March 2008)