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# Analysis and mapping of air pollution using a GIS approach: A case study of Istanbul

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## Abstract

In this study, GIS spatial analysis was performed in order to identify air pollution levels of Istanbul in relation to land use. Air quality parameters considered were Sulphur Dioxide ($SO_2$) and Total Suspended Particulate matter (TSP). Spatial correlation among 17 monitoring stations was investigated using variogram analysis. The spatial and temporal analysis of air pollution problems was based on ambient air quality levels in the winter season. The GIS spatial analysis indicated that air pollution levels in the city were strongly related to land use type.

## 1 Introduction

Due to the extremely high rate of immigration from other parts of Turkey, squatter settlement development and utilization of poor quality fuels, Istanbul has been experienced severe air quality problems in the last two decades. A rapidly growing population and use of lower standards of housing in the city caused more consumption of fuels. The amount of lignite burned per capita in the city was estimated at 235 kg in 1982, but gradually increased to 615 kg in 1989.

During the past two decades, air quality in Istanbul has been the subject of several studies. The first measurements in Istanbul were taken by Tebbens [1]. Ayalp [2] showed statistical relationships between air pollution data and meteorological parameters. As an extension of this study, Ertürk [3] used a statistical model using these data. Sen [4] also proposed a cumulative semi

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variogram methodology for $SO_2$ and TSP concentrations. Atmospheric conditions in Istanbul leading to air pollution episodes were investigated by Incecik [5]. Besides Batuk et al.,[6] interpreted the intense episodes in terms of meteorological conditions in Istanbul. Unal et al., [7] investigated the factors influencing the variability of $SO_2$ concentrations in Istanbul.

In this study, in order to identify air pollution levels of Istanbul in relation to land use and, a georeferenced spatial data analysis has been performed for winter data using the ILWIS – GIS [8].

## 2 Geography, climate and pollution sources

Istanbul with a population of close to ten million people is located at about 41° N and 29°E. The total area of the city is about 5700 $km^2$. The Bosphorus channel, oriented in NNE/SSW direction and with a length of 30 km separates the city in an Asian and European side. The Mediterranean and Black Sea control the general climate of Istanbul. The climate of Istanbul is generally warm to hot in summer and cold in winter. The daily means temperature is 6.5°C in winter and 21.8°C in the summer [7]. The main sources of the winter air pollution levels in the city are domestic heating, industry and motor vehicles. According to 1995 figures about 6 million tons poor quality lignite is annually used in the city. Furthermore more than 1 million vehicles circulate on an average daily basis in the city.

## 3 Data, spatial analysis and GIS

In this study, GIS spatial analysis was used to identify air pollution levels in relation to land use. For this purpose the average air quality levels of the 1995-1996 winter season (from October 1 to March 31) were analyzed. The land use data were derived from a 1995 planned land use map.

The average concentrations for the 95-96-winter season were derived by aggregation of the daily data for the winter period, using 17 air quality stations in the city, as shown in Figure 1. Figure 1 presents the location of air quality monitoring and meteorological data observation points. Besides the monthly average and maximum concentrations of $SO_2$ and TSP for the winter season were derived for the seventeen air quality station locations and are shown in Table 1.

Geostatistics can be described as a collection of techniques for the solution of estimation problems involving spatial variables [9,10,11]. These methods have been used to resolve a variety of problems such as mapping. One of the main features of geostatistics is its use of the spatial correlation in the estimation process. The spatial correlation structure is presented using variogram models. Before determining the variogram models for the data set the univariate statistics, histogram and probability plot were generated for the period of 1995 to 1996. The probability plots show that the pollution level approximates a normal distribution. Due to the skewness of the distribution the variogram analysis was performed on the log-transformed data set. The model results for both $SO_2$ and TSP concentrations reflect the spatial correlation structure.

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However, due to the limit number of data points available for Istanbul City, there is some scatter point in the variogram models. In fact the limited number of 17 existing air quality stations in the city, used in the variogram analysis, might partly explain the scatter in the variogram [14]. The geostatistical kriging method which overcomes some of the shortcomings of the traditional interpolation methods and its incorporation with a georeference i.e., a GIS, was used for the spatial estimation and modeling of the air quality.

## 4 Mapping of air pollution and results

In this study, the spatial distribution of air quality data was analyzed using kriging as the gridding method. As mentioned in the variogram analysis, due to the limited data set, selecting a unique variogram model from this data set was difficult. In this study we presented spatial distribution of air pollution with the result of the defaults parameters of the kriging method using the Golden Software [13].

The land use map was reclassified into the eleven main land use classes in the city i.e., industrial, small industry and storage, commercial, institutional, forest, recreational, military, residential (high density, medium density, low density). The analysis was carried out for an area of 430 $km^2$ that includes the operational air quality stations in 1995-96 in the city (Figure 2). In order to make a spatial analysis, air pollution concentrations were converted from Surfer to the GIS - ILWIS Software. The high density residential, commercial and industrial areas are mostly located on the European side, rather than the Asian side of the city (Figure 2). In order to find the winter air pollution levels per land use unit, the average $SO_2$ concentration was calculated per land use unit. Figure 3 indicates that the highest concentration occurred in the European side within the industrial land use unit. The second highest concentration was found to be in the central business districts (CBD) and high densely residential areas in close proximity of the industrial areas. The lowest average concentration occurred evidently in the Asian side within the forest area. The lower densely residential area located near the forest have the second lowest concentration level. The highest winter TSP concentrations also occurred in the industrial area (Figure 4). The military area and medium density residential area show the second highest TSP levels. The military area is located between industrial and high or medium density residential areas. Therefore the second high concentration can observed in the military area in additional to their own emissions due to the large building heating. The lowest TSP concentration was obviously encountered in the forest area and the low-density residential areas. Besides, it can be seen that the medium density area has a slightly higher average TSP concentration than the densely residential area. This result can be explained by the location of this area, which is in vicinity of the industrial and densely residential areas. In addition, mobile air pollution sources such as road traffic may affect these concentration levels. The location of the highly polluted area is mainly within the industrial, the commercial and the residential area in the European side of the city for both pollutants.

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The level of pollution that can cause harm is identified by air quality standards. The most frequently used reference guidelines are those of the WHO, EPA and the European Union (EU). The air quality standards are based on the different reference exposure time period for each pollutant such as daily, annual, hourly, etc. The EU standard has the limit value for $SO_2$ and TSP concentration for the winter season (1 October to 31 March). Therefore, the winter $SO_2$ and TSP concentrations were compared with the limit concentration of EU standards to test the exceeding level. The winter season limit concentration is given as 130 $\mu g/m^3$ for $SO_2$ and TSP in the EU guidelines. The annual limit concentration is 40-60 $\mu g/ m^3$ for $SO_2$ and 60-90 $\mu g/ m^3$ for TSP in the WHO guidelines. The winter season pollution level was also analyzed using the WHO guidelines. The exceeding levels were observed in the whole city for both the pollutants. The $SO_2$ concentrations, exceeding the EU standards are mostly observed in the European side of the city. The exceeding concentration area covers also the district of Kadikoy on the Asian side. The other districts on the Asian side are under the limit (Figure 5). Exceeding areas are those with the land use types i.e., high-density residential and commercial land use units (Figure 2). Areas exceeding the TSP air quality standard are indicated in Figure 6. The major part of exceeding areas is in the European side. The areas include the industrial, commercial and high-densely residential as shown in Figure 2. It must be observed that, also the higher traffic densities in the industrial and residential areas are observed mostly on the European side rather than the Asian side of the city. This also explains in part the differences observed between the two sides. The dispersion map of TSP levels over Istanbul City in the winter season shows the highest exceeding TSP concentration is observed mainly in an area encompassing the districts Bayrampasa and Gungoren. Zeytinburnu and Fatih districts re the next highest polluted districts (Figure 7).

The analysis of the location of the exceeding pollution level was put into perspective with meteorological and parameters. Wind speed and direction are important factors in the analysis of the location of areas with exceeding air pollution levels. Meteorological variables, e.g., temperatures, wind speed and direction etc., were analyzed in three meteorological stations namely Goztepe, Florya and Kirecburnu as shown in Figure 1. Dominant wind direction was determined as North, Northeast and East-Northeast in the three stations. Figure 8 shows the dominant wind direction for the two stations (Goztepe, Florya) which are located in the Asian side and the European side respectively. As expected that a negative correlation between the mean air monthly temperatures and pollution levels were found. This explains the high concentration levels in the winter season because of the operating of the space and building heating systems. The average wind speed is 2.4 m/s in Florya on the European side and the average wind speed is slightly higher in Goztepe meteorological station in the Asian side of the city (2.9 m/s). The average wind speed is 2.4 m/s in Kirecburnu station, located in the northern edge of the city.

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# 5 Concluding remarks

Air pollution problem in Istanbul has received wide public attention and has remained as the focal point among the environmental problems. Mean daily $SO_2$ and TSP concentrations higher than national air quality standards have been recorded many times. Recently, due to the stringent emission reduction air pollution levels were decreased.

In this study, average 1995-96 wintertime $SO_2$ and TSP levels were analyzed for Istanbul. Data from seventeen air quality and weather monitoring locations in the study area were used. Spatial correlation among the station data was investigated using variogram analysis. Daily data were aggregated to monthly and seasonal values in order to get an overall picture of air pollution levels over Istanbul. A standard kriging technique was, in first instance, used to generate tentative maps on levels of air pollution for the area. These maps were compared with air quality standards. Furthermore, air pollution levels in the city were related to land use type using GIS spatial analysis methods. Air pollution levels can be seen quite different in both sides of the city. Due to higher population, industrial and traffic densities, the European side is more polluted than the Asian side. More than 60% of the population lives on European side of Istanbul City. The land use units such as industrial, residential (high density) and trading center areas, indicate the highest air pollutant concentration levels. Meteorological conditions (e.g., wind speed, wind direction, temperature,) obviously affect the spatial distribution of air pollutant levels over Istanbul. The use of a Geographic Information System approach permit a georeferenced environmental assessment, and an accurate mapping of air pollution problems to be made.

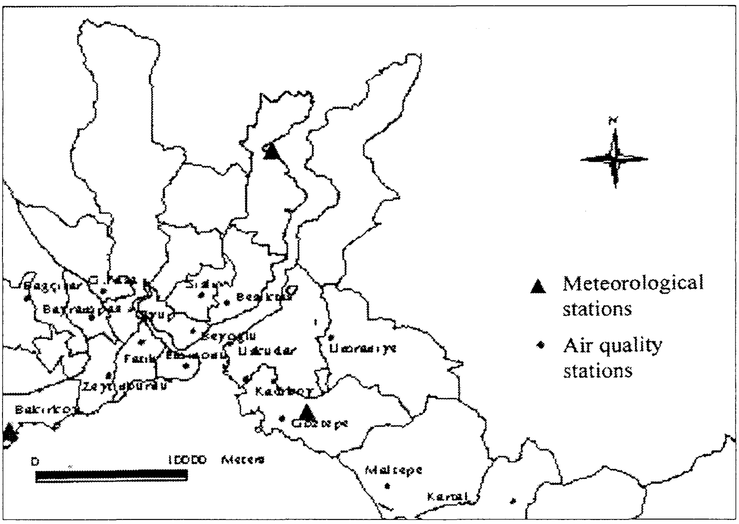


Figure1: The location of the air quality and meteorological stations in winter season.

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Table 1. The monthly average and the maximum concentration of $SO_2$ and TSP in all stations in the 1995-96 winter season

| Month | | SO2(µg /m3) | TSP(µg /m3) |
|---|---|---|---|
| October'95 | Maximum | 1088.0 | 377.0 |
| | Mean | 83.4 | 57.1 |
| | Std. Deviation | 94.5 | 54.6 |
| November'95 | Maximum | 696.0 | 530.0 |
| | Mean | 160.0 | 122.7 |
| | Std. Deviation | 116.5 | 91.5 |
| December'95 | Maximum | 727.0 | 578.0 |
| | Mean | 136.5 | 89.3 |
| | Std. Deviation | 90.2 | 72.1 |
| January'96 | Maximum | 469.0 | 367.0 |
| | Mean | 142.3 | 99.6 |
| | Std. Deviation | 74.9 | 62.9 |
| February'96 | Maximum | 762.0 | 870.0 |
| | Mean | 162.6 | 127.1 |
| | Std. Deviation | 109.5 | 112.0 |
| March'96 | Maximum | 338.0 | 272.0 |
| | Mean | 118.9 | 84.1 |
| | Std. Deviation | 63.5 | 51.1 |

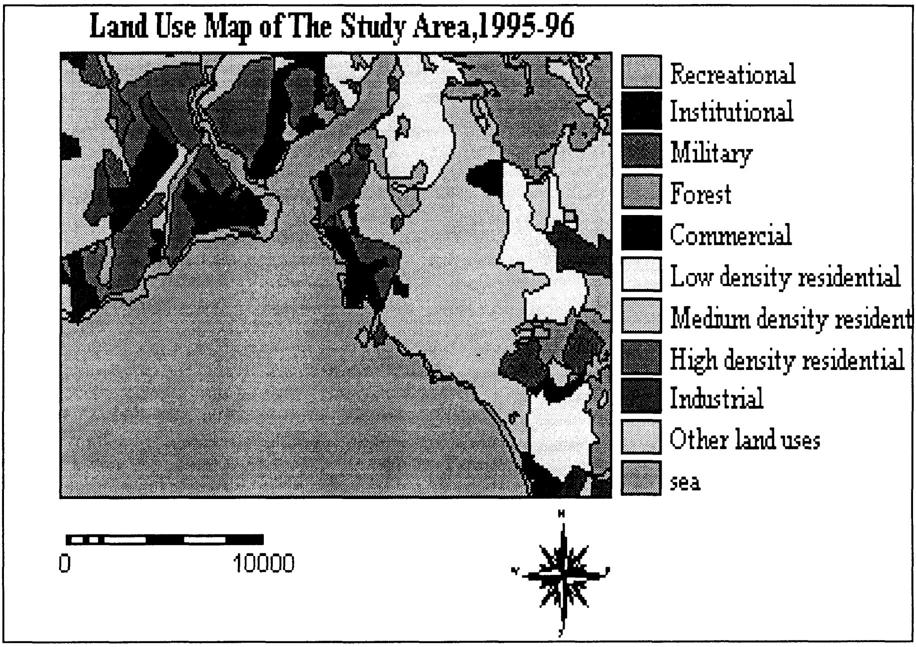


Figure2: The land use of the study area.

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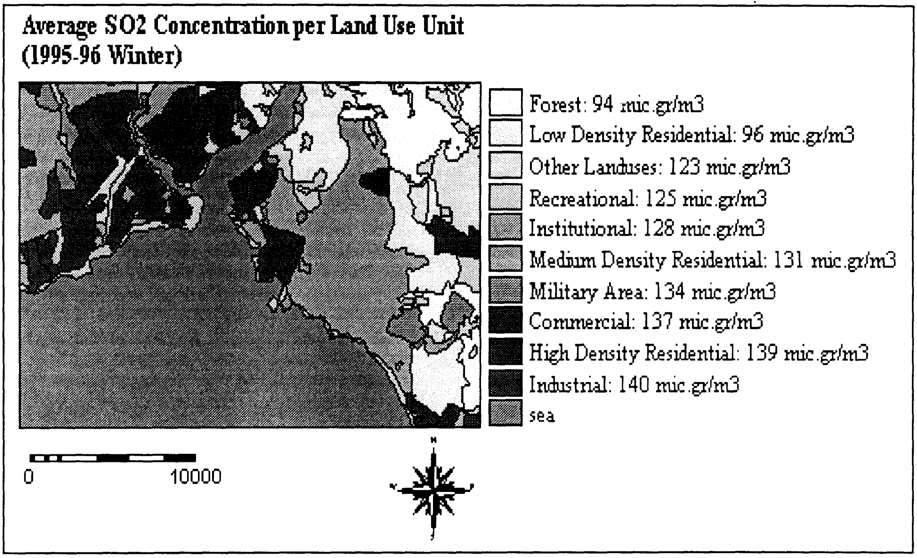


Figure 3: Average $SO_2$ concentration per land use in the 1995-96 winter season

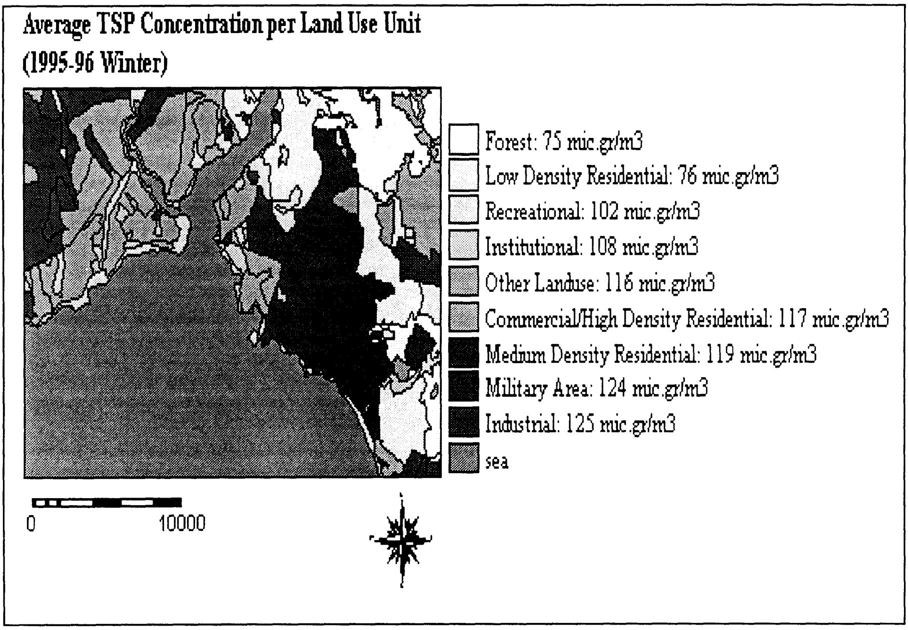


Figure 4: The average TSP concentration per land use unit

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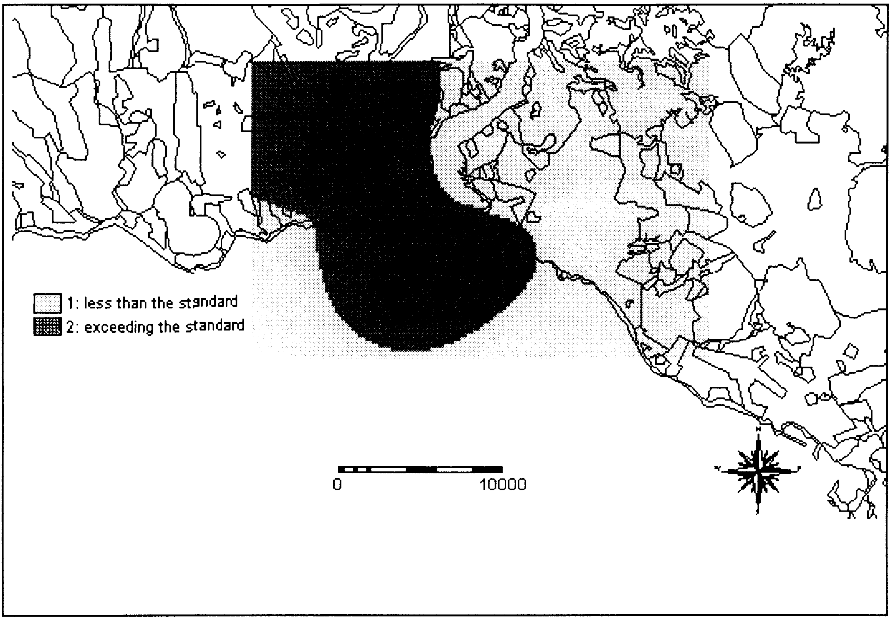


Figure 5: The distribution of exceeding SO2 concentration in 1995-96 winter season

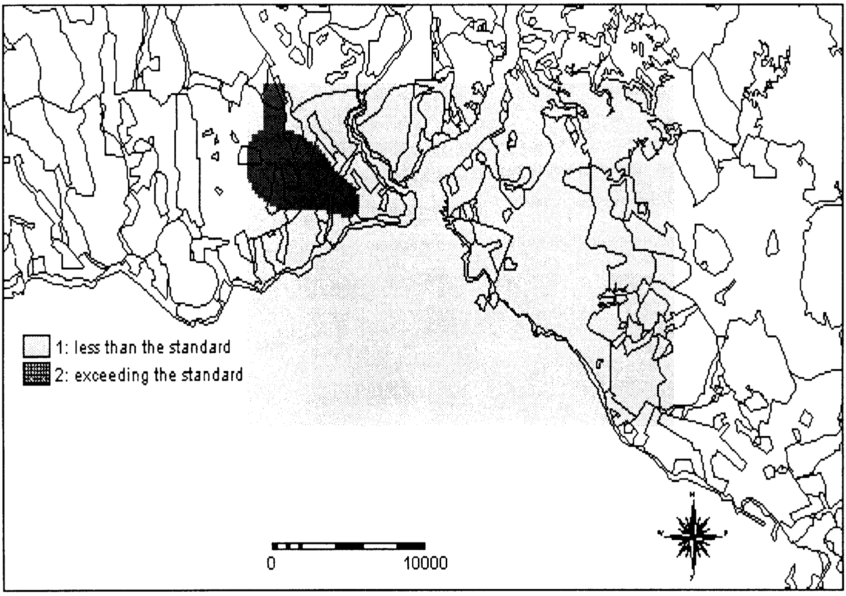


Figure 6: The distribution of exceeding TSP concentration in 1995-96 winter season

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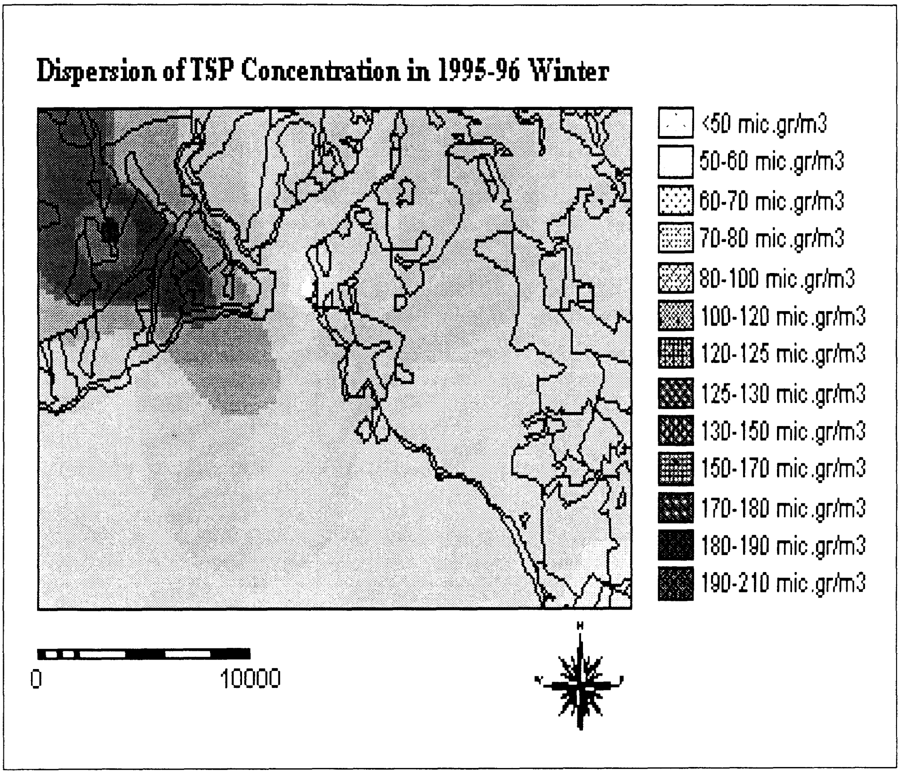


Figure 7: The distribution of the TSP concentration over the city in the winter season

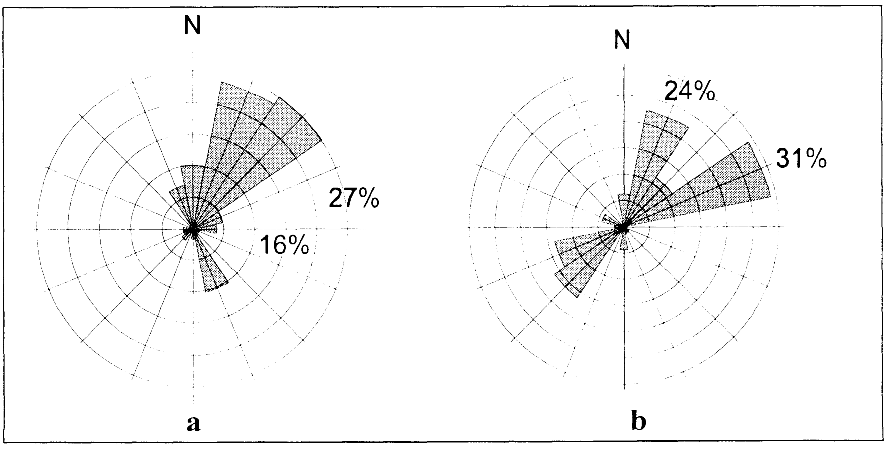


Figure 8: The dominant wind direction in the winter season
(a) Goztepe Station, (b) Florya Station

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## References

[1] Tebbens, B.D., Investigating air quality in Istanbul. *Bull. Istanbul Tech. Univ.* 22, pp.55-63, 1970.

[2] Ayalp, A., Istanbul'da atmosfer kirlenmesi. PhD. thesis, Istanbul University, 1976

[3] Ertürk, F. ,Investigation of strategies for the control of air pollution in the Golden-Horn region, Istanbul, using a simple dispersion model. *Envir. Poll. B* 11, pp.161-168, 1986

[4] Sen, Z., Regional air pollution assessment by cumulative semivariogram technique. *Atmospheric Environment* 29, pp. 543-548, 1995.

[5] Incecik, S. Investigation of atmospheric conditions in Istanbul leading to air pollution episodes. *Atmospheric Environment*, 30,15 pp. 2739-2949, 1996.

[6] Batuk, D.N., Gursoy, E., Ertut, H., Erdun, H. and Incecik, S., Analysis of SO2 and TSP under meso-scale weather conditions in Istanbul,Turkey. Trans Tech Publications, Switzerland. *Environmental Research Forum.* 7-8, pp. 73-83, 1997.

[7] Unal, Y.S., Incecik, S., Borhan, Y., Mentes, S., Factors influencing the variability of SO2 concentrations in Istanbul, Journal of the Air & Waste Management Association, 50, pp.75-84.2000.

[8] ILWIS, Version 2.23, The Integrated Land And Water Information System, © International Institute of Aerospace Survey & earth Sciences, ITC, Enschede, The Netherlands, 1998.

[9] Mather J. Air and air quality. The association of American Geographers USA

[10] Clark, I., Practical geostatistics. Applied science publishers ltd., London, 1979.

[11] Geo-eas (Geostatistical Environmental Assessment Software) User's Guide, 1988

[12] Koussoulakou, A., Computer-assisted cartography for monitoring spatio-temporal aspects of urban air pollution, Delft University Press, 239, 1990.

[13] Surfer User's Guide, Golden Software, 1996.

[14] Webster, R., and Oliver, M. A., Sample adequately to estimate variograms of soil properties. *J. of Soil Science*. Vol. 43. pp. 177-192, 1992.

[15] Winifred, The spatial distribution of air pollution in Sheffield. 1957-1959. *Int. J. Air Poll Cont.Assoc.*2.pp.175-187, 1959.

[16] Scorer, R. S. (editor), Meteorology of air pollution. Ellis Horwood limited. London. UK, 1990.