Assessment of regional air pollution variability in Istanbul

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SUMMARY

Air pollution concentrations have temporal and spatial variations depending on the prevailing weather conditions, topographic features, city building heights and locations. When the measurements of air pollutants are available at set measurement sites, the regional variability degree of air pollutants is quantified using the point cumulative semi-viariogram (PCSV). This technique provides a systematic method for calculating the changes in the concentrations of air pollutants with distance from a specific site. Regional variations of sulphur dioxide (SO2) and total suspended particulate (TSP) matter concentrations in Istanbul city were evaluated using the PCSV concept. The data were available from 16 different air pollution measurement stations scattered all over the city for a period from 1988 to 1994. Monthly regional variation maps were drawn in and around the city at different radii of influence. These maps provide a reference for measuring future changes of air pollution in the city.

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KEY WORDS: air pollution; point cumulative semi-viariogram; regionalization; radius of influence; sulphur dioxide; total suspended particulate; variability degree

1. INTRODUCTION

The atmospheric boundary layer is polluted due to industrialization, population increase and transportation activities, particularly during the winter months due to heating by burning fossil fuels that releases emissions into the atmosphere. This is a major health risk to the residents of large cities where the problem is more serious and more complex because of the irregular construction of buildings and their associated heat island effects. Local and temporal restrictions at the time of air pollution occurrences are insufficient and temporary with marginal benefits. It is, therefore, necessary to establish a scientific approach to collect systematic air pollutant measurements and to extract the information from them so decisions can be made on sound foundations.

The most difficult aspect in the systematic assessment of air pollution is the selection of the locations of measurement stations, so that regional variability can be adequately estimated. Historical information and expert opinions should be used for the allocation of sampling sites. Given the sampling network, several questions (Şen; 1995) are often asked, such as:

1. How to quantify, from limited and irregular site measurements, the regional air pollution distribution?

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2. How to model the changes over the area of interest?
3. How to construct maps reflecting the degrees of regional variability?

Almost all the efforts of the majority of researchers have been directed at the modelling of air pollution at a single location, particularly using univariate time series methods (Larsen, 1971; Merz et al., 1972; Chock et al., 1975; Zinsmeister and Redman, 1980; Taylor, 1915; Taylor et al., 1986). Such efforts are incapable of providing regional information on the air pollutants’ spatial variations, they are only suitable for providing temporal knowledge for the measurement sites. On the other hand, a few researchers have focused on modelling the spatial pattern using methods that require an involved mathematical background and a vast amount of data (Melli et al., 1981; Haslett and Raftery, 1989). Perhaps the most frequently used approach to display spatial variations of air pollutants is through hand-drawn maps. Other researchers have used data reduction methods, particularly principal component analysis (Peterson, 1970, 1972; Henry and Hidy, 1979) to summarize the regional variation in air pollution.

Şen (1995) proposed the use of a cumulative semi-variogram (CSV) technique for evaluating qualitatively the regional features of air pollution concentration and dispersion. Here this method is implemented for two air pollutants (SO₂ and total suspended particulate (TSP) in the city of Istanbul. These two pollutants are measured most frequently on a regional scale at different sites in and around the city centre. Also, under favourable weather conditions these pollutants occur in high concentrations and their mean daily and monthly concentrations at several stations become higher than air quality standards at many instances during the winter season. Recently, Anh et al. (1997) used CSV to estimate the regional dependence or air pollutants for Sydney in Australia. The average radius of influence was determined as 17 km for this city. However, a constant radius of influence is not reliable because it should also depend on the variation or the meteorological conditions.

### 2. POINT CUMULATIVE SEMI-VARIOGRAM METHOD

The classical semi-variogram (SV) was defined by Matheron (1963) for measuring spatial dependence for irregularly sampled sites. Let \( C_1, C_2, \ldots, C_m \) be the measured concentrations at \( m \) sites in the area of interest, and let \( d_{ji} \) be the distance between site \( j \) and \( i \). Then, SV at distance \( d \) is defined as (Clark, 1979; Journal and Huijbregts, 1978; Isaaks and Srivastava, 1989)

\[
\gamma_d = \frac{1}{2N_d} \sum_{i=1}^{N_d} (C_i - C_j(d))^2
\]

where \( N_d \) is the number of \( d \) equally spaced sites. The point cumulative semi-variogram (PCSV) was proposed by Şen (1989) as an extension of the ordinary SV and for use in earth sciences. PCSV attempts to measure the spatial variability around a site. In other words, it gives the regional effect of all other sites within the area on the site of concern. Let \( C_e \) be the concentration at the site of interest \( e \) and let \( d_{e1}, d_{e2}, \ldots, d_{e(m-1)} \) be the ordered distances of site \( e \) from the remaining \( (m - 1) \) sites. Then the PCSV of \( e \) at distance \( d \) is defined as

\[
\gamma_e(d) = \frac{1}{2} \sum_{d_i < d} (C_e - C(d_i))^2
\]

Figure 1 gives the plot of $\gamma_c(d)$ versus $d$. This can be done for each site which results in $m$ sample PCSV curves. Note that no *apriori* selection of distance classes is required for computing PCSV as is commonly used when calculating SV. The PCSV provides information on sources for the site of interest and helps in defining the radius of influence and structural behaviour of regionalized variables near the site.
3. FEATURES OF THE STUDY AREA AND DATA

The Istanbul city metropolitan area is situated around the location, latitude 41°N, longitude 29°E at the north-western corner of Turkey, as shown in Figure 2. This historical city has expanded on an unexpected scale in both industrialization and population during the past two decades. Consequently, the local and central authorities have faced many environmental problems, such as air, land and water
pollution. At time, air pollution episodes with favouring meteorological conditions surpass WHO standards, as shown by Incecik (1996).

The SO₂ records are actual measurements of the gaseous acidity of the air and an acidimetric titration method is used for its measurement. The air sample is labelled through a dilute hydrogen peroxide solution where SO₂ is absorbed and oxidized to form H₂SO₄ and the results are related to sulphur dioxide concentration in the sample. On the other hand, TSP is measured by a filter soiling method. The darkness of the stain is converted to a concentration value. The measurements at each site are obtained by the same instruments and the same calibration procedures.

Currently, there are 16 air pollution monitoring stations established to measure SO₂ and TSP concentrations within the atmospheric boundary layer over Istanbul. These stations are scattered on the European and Asian sides of the city as shown in Figure 2. Table I gives the location of the sites and some of their statistical features. Six of these stations are located on the Asian side where the air pollution level is lower than that on the European side. Historical expansions have taken place on the Marmara seacoast in the south (Figure 2). Table I gives the mean and standard deviation of SO₂ and TSP. The average SO₂ for stations on the Asian side is 135.8 ppm whereas that on the European side is 165.82 ppm. This shows that the European side is more polluted. TSP shows the same pattern. It should also be noted that the average standard deviation is higher on the European side.

Table II gives the monthly averages at each station for the two pollutants with SO₂ in the first line and TSP in the second line. Since, there is no air pollution problem in August it is not included in the table. It is obvious that high pollutant levels occur in the winter months.

### 4. PCSV INTERPRETATIONS

Radius of influence determination is a difficult problem in meteorology (Cressman, 1959; Sasaki, 1960; Barnes, 1964). It is defined as the radius of a circle that contains all locations that influence
Table II. Monthly averages of SO₂ and TSP concentrations

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the location of interest. It is well known that as the distance from the location increases, the dependence decreases non-linearly and reaches a point at which this dependence disappears altogether. Plotting the PCSV for the station of interest will reveal its radius of influence. Figure 3 shows the plots of some examples of PCSV for for Istanbul. From the figure it is possible to see the following:

1. For all stations, the greater the distance the greater the cumulative variogram value, indicating the decrease in the dependence between the pivot and the surrounding stations.
2. Some of the plots show parabolic patterns but others show cubic ones. The steeper the tangent of the PCSV at a point, the smaller the dependence and vice versa. The cubic pattern, as shown in Figure 3(a), indicates that after a certain distance there is another source of high pollution that causes the dependence.
3. Some PCSVs intersect the horizontal axis, which indicates that the air pollutant between the pivot site and the other nearby sites at distances less than the distance of the intersection are almost the same.
Figure 3. Sample SO$_2$ PCVs at different locations for February
4. Comparisons between the PCSVs indicate that their curvatures are different from each other. The smaller the slope the less the effect of the atmospheric diffusion mechanism and the air pollutant concentrations remain constant.

5. AIR POLLUTANT VARIABILITY DEGREE MAPS

In order to show regional variability, it is possible to draw maps of PCSV values at the distances corresponding to different degrees. This gives a picture of the air pollution concentration maps at equal distances around each station. Cressman (1959) proposed, as a rule-of-thumb, using the distances 750 km, 1000 km radius of influence. Thus, three maps are used to summarize air pollution data. However, in cities like in our case, the radis of influence of air pollutants cannot be very large because the concentrations can change over a city over significantly shorter distances (20 to 25 km). In this study we chose radii of influence of 3, 5, 10, 15 and 20 km and their regional maps are provided. Here only the maps for December, January and February are presented. A detailed account and figures are available in Öztopal (1996).

Figures 4–9 show the regional SO$_2$ and TSP variation degree spatial distributions for December, January and February, respectively. The following interpretations can be made.

1. The existence of a straight (Bosphorus) between the Marmara and Black Seas shows a distinct effect on the regional distribution of the pollutants. The Bosphorous plays the role of a ventilation channel by allowing the passage of northerly and north-westerly wind systems that are created because of the Icelandic high-pressure centre during the winter period.
2. Pollutant concentrations are comparatively greater on the European side than on the Asian side. This may be due to various factors, such as the population is sparce on the Asian side; industrial plants are more concentrated on the European side; the Asian side is more rugged with valley-type

![Figure 4. SO$_2$ regional variation maps for December at different distances](image-url)
Figure 4. (Continued)
Figure 4. (Continued)

Figure 5. TSP regional variation maps for December at different distances
Figure 5. (Continued)
Figure 6. SO₂ regional variation maps for January at different distances
Figure 6. (Continued)

Figure 7. TSP regional variation maps for January at different distances
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Figure 7. (Continued)

Figure 8. SO$_2$ regional variation maps for February at different distances
Figure 8. (Continued)
Figure 9. TSP regional variation maps for February at different distances
topographic features open to the northerly winds; and finally, the Asian side receives more rainfall than the European side.

3. The most extensive SO₂ concentrations appear at 3 km distances reaching the Black Sea coast in the north during December. In fact, at each distance, there are always highly polluted centres with closed contour lines on the European side. Such centres appear on larger distance scales (20 km) on the Asian side.

4. TSP spatial distribution maps at different distances for December, January and February are presented in Figures 5, 7 and 9, respectively. It is clear that TSP concentrations are not far dispersed but remain within and in the close vicinity of the Istanbul metropolitan area boundaries. At small distances there is no TSP transportation that reaches the Black Sea coast. In January, however, the
regional effectiveness of TSP increases and covers the whole area, but it is always under the influence of the Bosphorous ventilation channel. Local TSP concentration peaks appear in the form of closed contour lines and the locations of these centres remain the same in all maps. In February, TSP variability decreases to a point almost without closed contour lines, hence explicit TSP centres occur at small scale distances but these centres become pronounced at larger distances, especially on the European side.

6. CONCLUSION

Monthly air pollution data for the city of Istanbul have been used to show the usefulness of PCSV as a tool for determining the regional air pollution distribution. The derived maps at 3 km, 5 km, 10 km, and 20 km distances allow us to make inferences about the dispersion of SO₂ and TSP for long and short distances. One of the main objectives has been to introduce PCSV as a technique for studying spatial dependence, along with other tools used in spatial statistics.

REFERENCES