# SPATIAL AND TEMPORAL VARIATIONS OF NITROGEN DIOXIDE AND OZONE CONCENTRATIONS ASSESMENT USING A GIS BASED GEOSTATISTICAL APPROACH IN BALIKESIR, TURKEY

**Assoc. Prof. Lokman Hakan Tecer[1], Assoc. Prof. Sermin Tagil[2]**
[1] Namik Kemal University, Corlu Eng Faculty, Environmental Eng., Corlu/Tekirdag, **Turkey**
[2] Balikesir University, Department of Geography, Cagis Campus, Balikesir, **Turkey**

## ABSTRACT

Urban air pollution are sourced manily from traffic, industry, and heating systems. Rapidly increasing population, unplanned urbanization and industrialization are the main contributors to urban air pollution in many countries. Nitrogen dioxide ($NO_2$) and ozone ($O_3$) are the main pollutants that are formed from traffic, combustion related activities and photochemical smog processess. These pollutants have capable of causing adverse effects on human health and environment. Since $NO_2$ is a typically traffic related pollutant emissions are generally highest in urban atmosphere rather than rural areas. Ground-level and tropospheric ozone is one of the most harmful air pollutants causing health problems, premature deaths, reduced agricultural crop yields, changes in ecosystem species composition and damage to physical infrastructure and cultural. In this study, we have used a combination of passive sampling and GIS techniques to characterise the intra-urban scale and rural temporal-spatial distribution of air quality based on $NO_2$ and $O_3$ concentrations. The aim of this study is of locate sample points, characterize distribution patterns, perform the probability map, and map distributions of $NO_2$ and $O_3$, by means of spatial information sciences providing useful information for decision-makers. Firstly, the data were compiled from 48 sampling sites by using passive sampling on10-17 March 2010 in winter and on 13-20 August 2010 in summer. Later, estimated pollutants levels at un-sampled locations were carried out with the Inverse Distance Weighted (IDW) method. Finally, location exceed the Turkish Air Quality Standard critical threshold value were determined in the Balikesir city area by use of geostatistical algorithms (Indicator kriging). The results of the passive sampling study show that the winter and summer average concentrations are 28.85 $\mu g/m^3$ and 111.26 $\mu g/m^3$ for $O_3$; 22.65 and 13.56 $\mu g/m^3$ for $NO_2$ respectively. It is expected that where industrial activity is not excessively important, traffic and domestic heating system are the main source of $NO_2$ and $O_3$ precursors. Moreover, results show that there are multiple hotspots for $NO_2$ concentration and they are strongly correlated to the locations of traffic and domestic heating system in the Balikesir city area, using Indicator kriging (IK). Clearly close to roads, the major source of pollutants such as $NO_2$, the concentrations of pollutants will be highest. In addition to emissions, meteorology plays a strong role in both the general and in the local meteorological environments. $O_3$ concentrations are higher in summer than in winter season, given the same traffic volume, due to the local meteorological parameters such as solar radiation, wind circulation. It was demonstrated that geostatistical tools are quite appropriate techniques for air quality management in a polluted city area like Balikesir.

**Keywords** Nitrogen dioxide, Ozone, Geographical information science (GIS), Temporal and Spatial analysis, Balikesir.

## INTRODUCTION

Globally, anthropogenic air pollutants are concentrated in urban atmosphere. Urban air pollution are sourced mainly from traffic, industry, and heating systems. Rapidly increasing population, unplanned urbanization and industrialization are the main contributors to urban air pollution in many countries. It is well known that air pollution in an urban atmosphere cause adverse effects on human health and the environment. There is abundant evidence linking air pollution with aggravate airway pathology, respiratory symptoms, reduced lung function, hospital admissions and increased mortality [1-3].

Nitrogen dioxide ($NO_2$) and ozone ($O_3$) are the main pollutants that are formed from traffic, combustion related activities and photochemical smog processes. These pollutants have capable of causing adverse effects on human health and environment. Since $NO_2$ is a typically traffic related pollutant emissions are generally highest in urban atmosphere rather than rural areas. $NO_2$ also plays a major role in atmospheric photochemical reactions that produce ground-level $O_3$. It is one of the major sources of acid rain and play a critical role in determining concentrations of nitric acid ($HNO_3$), nitrous acid ($N_2O$), organic nitrates such as PAN, nitrate aerosols and other species in the atmosphere.

Ground-level and tropospheric $O_3$ is one of the most harmful air pollutants causing health problems, premature deaths, reduced agricultural crop yields, changes in ecosystem species composition and damage to physical infrastructure and cultural. $O_3$ is not directly emitted to the atmosphere but formed in complex photochemical reactions from $O_3$ precursor gases [4]. The $NO_2$ regime is the main factor determining whether $O_3$ is produced or removed in the troposphere heritage [5], and also $O_3$ is produced by natural sources in rural areas.

It has been known that emission, composition and kinetics of air pollutants are irtra-urban different and in many cases not representative of population exposure due to these differences [6,7]. There is several experimental studies show that air pollution data from fixed monitoring stations cannot directly be taken as true indicators of population exposure [8]. Many studies indicate the existence of a variability of air pollution between intra-urban and street scale areas for different pollutants such as $NO_x$, CO, particulate matter and other air quality indicators [9]. Therefore, the investigation of typical intra-urban situations is important in order to understand and interpret population exposure data in combination with reliable analyses of adverse human health effects

Mapping techniques are important to describe and quantify the pollution at locations where no measurements were available while monitoring atmospheric pollution [10]. A spatial correlation of atmospheric pollutants is not only a condition for an optimum interpolation of the data in space to map a pollution, but it also provides very useful insights on the structure of the air quality patterns. Geographical Information Systems (GIS) and geostatistics have opened up new ways to analyze spatial distributions of air pollution concentration distributed continuously on space, and to study hazard assessment and spatial uncertainty [11-13]. GIS make possible to analyze and manage of large spatial data bases. Air pollution studies are based primarily on distance-weighting methods [14,15] and kriging [15,16]. The inverse distance weighting (IDW) method typically assigns more weight to nearby point stand to distant points while

Kriging is a regression based technique that estimates values at un-sampled locations using weights reflecting the correlation between data at two sampled locations or between a sample location and the location to be estimated [17].

Results of the spatial patterns type of analysis often lead to further understanding of how spatial patterns of air pollution change from the one season to another season, or to estimations of how spatial patterns will change summer to winter. Therefore, useful conclusion scan be drawn to advance our understanding of the underlying factors that drive the changes in spatial patterns of air pollutants. In this study, we have used a combination of passive sampling and GIS techniques to characterize spatial pattern of air quality based on $O_3$ and $NO_2$ concentrations in the rapidly urbanizing Balıkesir city. The main objectives of this paper were to: analyze the temporal evolution and characterize the spatial distribution of $O_3$ and $NO_2$ levels using geostatistical techniques; incorporate this information in a GIS to produce accurate maps; explore the spatial variability of air pollutants using the spatial autocorrelation statistic, reveal the local spatial patterns of pollutants in order to identify the potential risk areas for $O_3$ and $NO_2$ pollution and its possible causes, and outline an approach that others can use to map air pollution concentrations for areas with a limited number of spatial observations.

## METHODS

### Site Description

In this study, Balikesir in the Marmara Region in western Turkey was choose as a urban area. The area is on the Balıkesir preference in the Marmara Region in the western Turkey (Figure 1)

The Balıkesir population according to the population census in 2009 is about 259.000. In Balikesir, traffic and heating system is likely to be the most important source of air pollution, especially in winter seasons. The city center of Balikesir was generally listed among the most polluted provinces with conventional $SO_2$ and PM pollution in winter season levels which were usually above limit values during long years in Turkey. The increase in the number of the vehicles in the city may be considered as an important factor for the general trend of increase in pollutant concentrations. Road transport is one of the major contributors to air pollution in Balikesir. It can be seen that the second largest percentage of mopeds and motorcycles, about 23% of its total vehicle fleet. The annual mileage per vehicle category was 16.033 km for passenger car, 26.876 km for LDV, 24.762 km for buses [18]. Besides the heating systems, industrial and traffic sources, the topographic structure, city layout plan and the negative meteorological conditions also contribute to the general perspective of air pollution in the city center. The geographical structure of the city center as in the shape of a bowl, the decrease in the dominant winds in winter months, high air pressure, the decrease in the temperature of air and the frequently occurring foggy days are cause to increase the effect of the pollution. The windrose diagram and wind class frequency distribution were depicted in Figure 2.

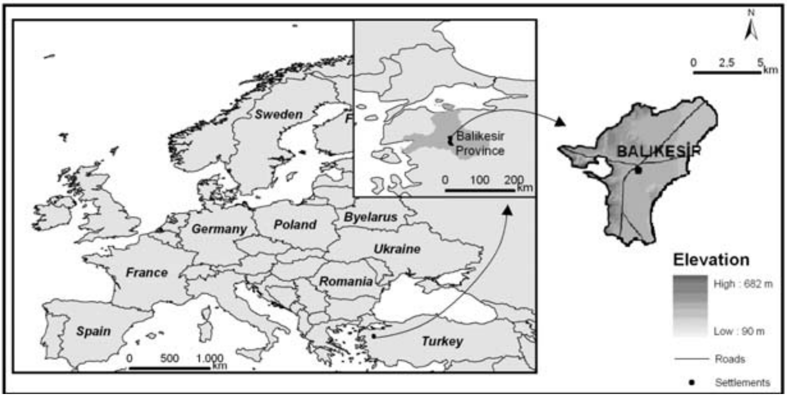


**Figure 1.** Location map of the study area, with reference to the Europe and Turkey

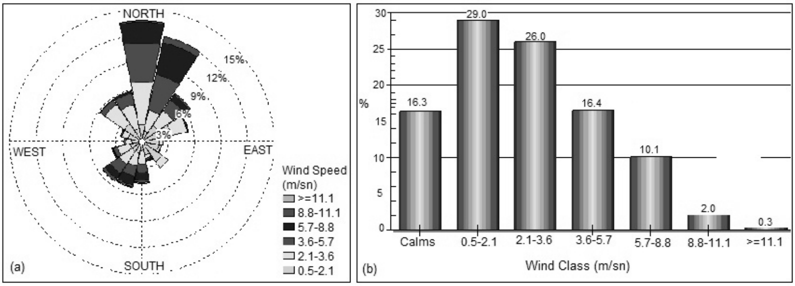


**Figure 2** (a) Wind rose diagram and (b) wind class frequency distribution in the study period

**Data and Evaluation of Passive Samplers**

The modeling and associated methods required three types of data: $O_3$ and $NO_2$ and a digital elevation model (DEM) created from the scanned 1:25000 scale geo-referenced topographic maps in order to draw study area bounder.

The selection of the location of monitoring stations is one of the most complex tasks. In this study, measurements were made at an urban background site (a site not directly influenced by any particular source), at a major highway, in street canyons, along open roads, downwind of industrial sites, in parks or in rural areas, because when passive samplers are used for screening purposes then usually sites are selected that are seen to be representative for a particular situation.

Passive sampling was carried out for representative periods, and at two times of the year, since meteorology can vary significantly from one season to the next. The period of temporal data collection was from March 10 to March 17, 2010 and 13-20 August for winter and summer, respectively, and these representative periods were converted to annual means. To demonstrate the seasonal change of $O_3$ and $NO_2$ levels, a winter campaign, heating season in Balikesir urban area, and summer campaign were organized on one-week sampling period.

The modificated analyst type diffusion tubes were chosen to sample $O_3$ and $NO_2$ concentrations in Balikesir Atmosphere (De Santis 2002). Diffusion tubes were mounted vertically to selected point at 2-3.5 m above the ground which roughly corresponds to the human breathing zone. The shelters with samplers were fixed on different object such as such as street lights, trees, traffic lights. During sampling campaign, passive samplers were exposed together with shelter. The diffusion tubes were sent to Anadolu University Environmental Engineering Laboratories in order to be analyzed by using ion chromatographic techniques.

**Geostatistics: Interpolation process**

In this study, two phases were completed to conduct the geostatistical work:

1. Determine outliers to normalize the data,
2. Predictions to get estimates of values of $O_3$ and $NO_2$ at un-sampled locations.

After being eliminated outliers, the interpolation process was produced a continuum of values placed on the whole study area. There are a range of methods available for interpolating spatially distributed data that can be applied for mapping air quality using passive sampling. In the study, concentration maps were obtained using an "Inverse Distance Weight (IDW)" algorithm, where the values at the "unknown" sites are calculated using relationship based on the distance between "measured" stations. In this method, the greater the distance, the lower is the effect of measured points on the unknown site. The spatial distribution of the pollutants in the urban area (Balıkesir city area) was analyzed for summer season, winter season and annual mean.

**RESULTS AND DISCUSSION**

**Temporal variation of pollutants concentrations**

Pollutants concentrations of different sampling sites in winter and summer seasons are presented in Table 1. One week sampling concentrations of $O_3$ ranged from 14.03 μg/m$^3$ to 42.43 μg/m$^3$ in winter and from 81.79 μg/m$^3$ to 70.39 μg/m$^3$ in summer season in urban area. In summer, rural $O_3$ concentrations are higher than winter season. As shown in Table 2, the mean $NO_2$ concentrations varied between sites, while mean winter concentrations were higher than the mean in summer. In the study period, annual mean of $O_3$ concentrations were above to the the European Union Framework Directive on Air Quality Assessment and Management (1996/62/EC), 60 μg/m$^3$ in summer at all sites. But $NO_2$ concentrations exceed European Union limit (40 μg/m$^3$) on long term average at urban traffic site in winter. These high values might be due to residential heating, urban traffic and industrial emission.

**Table 1.** Pollutants concentrations averaged over the sampling period (8 days), (μg/m$^3$)

| | $O_3$ | | $NO_2$ | | | $O_3$ | | $NO_2$ | |
|---|---|---|---|---|---|---|---|---|---|
| Sites | Winter | Summer | Winter | Summer | Sites | Winter | Summer | Winter | Summer |
| Motorway | 30.28 | 117.04 | 30.18 | 10.19 | Suburban | 35.1 | 111.59 | 14.38 | 10.16 |
| Urban, residential | 14.03 | 81.79 | 18.09 | 9.68 | Rural | 42.43 | 170.39 | 13.57 | 9.66 |
| Urban, traffic | 31.52 | 87.26 | 49.06 | 27.89 | | | | | |
| Industry | 19.16 | 99.23 | 11.79 | 14.65 | Mean | 29.4 | 111.53 | 21.45 | 12.7 |

## Spatial distribution and Seasonal Pattern

Interpolation was used to infer observed values over a space between the points to create a continuous surface. For the spatial interpolation, IDW was used to show the spatial patterns of the variables ($O_3$, $NO_2$). Map of $O_3$ and $NO_2$ estimated concentrations for annual; winter and summer in urban areas in Balikesir region are presented in Figure 3.

The $O_3$ and $NO_2$ exhibited very clear seasonal characteristics for the study areas (Figure3). The seasonal difference of concentration was almost similar for all pollutants in urban areas. One observed that the $NO_2$ concentrations were increased from summer to winter area owing to the decrease in solar radiation and to stable atmospheric conditions including inversion layers that are characteristic for the cold season. The natural dilution of pollutants is reduced compared to summer because of less thermal turbulences. However, in summer, the atmospheric mixing mechanisms are boosted by the strong solar radiation. Because of this, the spatial extend of the $NO_2$ is reduced compare to winter.

In contrast, $O_3$ concentration was decreased from summer to winter. The summer months experience higher $O_3$ level, because both rural and urban areas record more insolation during summers which helps in the photolysis of $O_3$ [19]. In the summer, annual mean concentration of $O_3$ was higher than 60 $\mu g/m^3$ limit values according to the European Union Framework Directive on Air Quality Assessment and Management (1996/62/EC). Oppositely, in the winter, annual mean concentration of $NO_2$ was higher than 40 $\mu g/m^3$ limit values according to the European Union Framework Directive on Air Quality Assessment and Management (1996/62/EC).

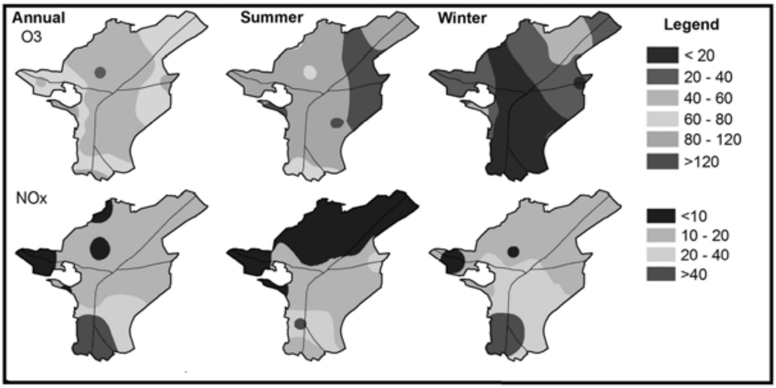


**Fig. 3.** Maps showing values of $O_3$, $NO_2$, benzene, toluene, ethylbenzene and m,p-xylene parameter for urban areas ( The Balikesir City), 10 x 10 km grid resolution, as a result of IDW interpolation method.

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 in the urban area. Additionally, meteorological conditions of the region in winter time are rainy, fogy and snowy. Also, in winter season, population of the city Balikesir (urban area) is comparatively higher than the summer season as a result of this more vehicles take part in traffic which causes more emission. In addition, the meteorology in the region shows an explicit winter and summer characteristics. In the winter months calm conditions and high stability of the atmosphere prevails, which hinder the pollutants from dissipating faster. Also, temperature inversion, which is a common phenomenon in the winter months and low mixing heights do restrict dilution process of the pollutants. Thus in the winter $NO_2$ showed a higher level of concentration.

## CONCLUSIONS

In this study, spatial variability of $O_3$ and $NO_2$ air pollutants characterized at urban sites in Balikesir,Turkey, using a combination of passive sampling data and GIS modeling techniques. Motorway traffic was identified as the main source of $NO_2$ in the urban area. Motorway lines variability appeared to be higher during hot spot of the sites for $NO_2$, while the opposite was the case for $O_3$. High $O_3$ concentrations were related to rural areas in summer months.

This study explored spatial pattern of $O_3$ and $NO_2$ in urban areas in the Balıkesir region. Thus, these areas should be receiving more attention: the northeast and southwestern region of Balıkesir, where significant increases in $NO_2$ occurred.

### Acknowledgment

We would like to expresses our sincere gratitude to TUBITAK for their financial support of this current work (project # 108Y166). We also thank to Tuncay Dogeroglu and Ozlem Ozden for their useful suggestions and data analysis.

## REFERENCES

[1] Moshammer H. and Neuberger M. The active surface of suspended particles as a predictor of lung function and pulmonary symptoms in Austrian school children, Atmospheric Environment 37, 2003, 1737–1744

[2] Hauck H., Berner A., Frischer T., Gomiscek B., Kundi M., Neuberger M., Puxbaum H., Preining O., AUPHEPTeam,. AUPHEP—Austrian project on health effects of particulates—general overview, Atmospheric Environment 38: 2004, 3905–3915

[3] Tecer L.H.; Alagha ,O.; Karaca F.; Tuncel G. and Eldes N. Particulate Matter ($PM_{2.5}$, $PM_{10-2.5}$, and $PM_{10}$) and Children's Hospital Admissions for Asthma and Respiratory Diseases: A Bidirectional Case-Crossover StudyJournal of Toxicology and Environmental Health, Part A, 2008. 71: 512–520.

[4] Chameides W.L., Fehsenfeld F., Rodgers M.O., Cardelino C., Matinez J., Parrish D., Lonnemans W., Lawson D.R., Rasmussen R.A., Zimmerman P., Greenberg J., Middleton P. and Wang T. Ozone precursor relationships in the ambient atmosphere, Journal of Geophysical Research 97, 1992, 6037-6055

[5] EEA Technical Report. Assessment of Ground-level Ozone in EEA Member Countries, with a Focus on Long-term Trends, European Environment Agency, May 29, 2009, ISSN 1725-2237.

[6] Wilson G.J., Kingham S., Pearce J., and Sturman A.P. A review of intraurban variations in particulate air pollution: Implications for epidemiological research. Atmospheric Environment, 2005, 6444-6462

[7] Wheeler A., Smith-Doiron M., Xu X., Gilbert N. and Brook J. Intra-urban variability of air pollution in Windsor, Ontario-Measurement and modeling for human exposure assessment. Environmental Research, 2008, 7-16.

[8] Vardoulakis S., Gonzalez-Flesca N., Fisher B.E.A. and Pericleous K. Spatial variability of air pollution in the vicinity of a permanent monitoring station in central Paris. Atmospheric Environment 39(15), 2005, 2725–2736

[9] Wilson G.J and Zawar-Reza P. Intraurban-scale dispersion modelling of particulate matter concentrations: Applications for exposure estimates in cohort studies. In Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes. Crete, Greece, 2006

[10] Hopkins L.P., Ensor K.B., and Rifai H.S. Empirical evaluation of ambient ozone interpolation procedures to support exposure models, Journal of the Air & Waste Management Association 49, 1999, 839–846

[11] Korre A. Durucan S. and Koutroumani A. Quantitative-spatial assessment of the risks associated with high Pb loads in soils around Lavrio, Greece, Applied Geochemistry 17, 2002, 1029-1045

[12] Gallois D, Fouquet C., LeLoc'h G., Malherbe L. and Ca´rdenas, G. Mapping Annual Nitrogen Dioxide Concentrations in Urban Areas. In Geostatistics Banff 2004, Leuangthong O, Deutch CV (eds.) Springer: Berlin 2005. pp. 1087–1096

[13] McGrath D., Zhang C.S, and Carton O.T. Geostatistical analyses and hazard assessment on soil lead in Silvermines area, Ireland, Environmental Pollution 127, 2004,239-248

[14] Phillips D.L., Lee E.H. and Hogsett W.E. Use of auxiliary data for spatial interpolation of ozone exposure in southeastern forests. Environmetrics 8, 1997, 43-61

[15] Falke S.R. Mapping Air Quality: Spatial Estimation of Pollutant Concentrations from Point Monitoring Data. D.Sc. Thesis, Environmental Engineering Program, Washington University, St. Louis, Missouri, 1999

[16] Mulholland J.A., Butler A.J., Wilkinson J.G., Russell A.G. and Tolbert P.E. Temporal and Spatial Distributions of ozone in Atlanta: Regulatory and Epidemiologic Implications. Journal of the Air & Waste Management Association 48, 1998, 418-426

[17] Wackernagel H. Multivariate Geostatistis, 3rd Edn., Springer, Berlin, 2003

[18] Tecer L.H., Ilten N. and Sert I. Input data collection study for motor vehicle emissions inventory at a city level, Presented at National Symposium of Air pollution and Control, 22 – 25 October, 2008, Hatay, Turkey

[19] Aschmann S. M., Arey J. and Atkinson R. OH radical formation from the gas-phase reactions of O-3 with a series of terpenes, Atmospheric Environment 36, 2002, 4347-4355