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# DETERMINATION OF THE SPATIAL AIR POLLUTANTS DISTRIBUSTION ON THE ISLAND OF CYPRUS USING DIFFUSIVE SAMPLING AND STATISTICAL MODELLING

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## ABSTRACT

The objective of this work was to determine and to depict the spatial distribution of air pollutants over the whole area of Cyprus in air pollutants distribution maps. During the UNOPS project “Preliminary Assessment of Ambient Air Quality in Cyprus” $NO_2$ diffusive samplers were exposed at 250 sites, $SO_2$ and hydrocarbon samplers at 80 sites during several campaigns over one year. At first the spatial distribution was determined by interpolation. Better results were obtained by a new developed Neural Network simulation tool with the input parameters emissions inventory and population density and trained by the results of diffusive sampling. The resulting pollution map reflects very well the real conditions.

**Key Words:** Air pollutants distribution, $NO_2$, $SO_2$, benzene, Interpolation, Neural Network,Cyprus

## 1. INTRODUCTION

### 1.1 Methods of Diffusive Sampling

The Diffusive Sampling is an ideal measurement technique for large scale air pollution surveys with a large number of sampling points, which allow high spatial resolution. It is one of the approaches used in this project (Baumbach and Pfeiffer 2004) to perform a Preliminary Air Quality Assessment, as recommended in the Guidance report on preliminary assessment under EC air quality directives (Hout, 2000).The analytical methods used for the diffusive sampling analyses of $NO_2$, $SO_2$, and $O_3$ are listed in Table 1 (Hangartner, 2001).

Table 1. Components and applied methods of Diffusive Sampling

| Component | Principle | Analytical method |
|---|---|---|
| Nitrogen dioxide $NO_2$ | Absorption on triethanolamine | Photometry |
| Sulphur dioxide $SO_2$ | Absorption on potassium carbonate and glycole | Ion Chromatography |
| Volatile Organic Compounds VOC | Adsorption on activated charcoal | Gas Chromatography |

A quality assurance has been carried out by comparison of diffusive sampling results with according continuous monitoring averages. The results were very sufficient and will be presented in the paper. For the component ozone continuous monitoring had been preferred and background sites.

### 1.2 Sites and Periods

The distribution of sampling sites in Cyprus is shown in Figure 1. For the component $NO_2$ 250 sites had been chosen, for $SO_2$ and VOC 80 sites. The density of the sampling sites was based on the spatial variability of the pollution levels, which vary with the type of pollutant, source distribution, local orography and meteorology. In the cities the sampling site density was concentrated. The required sampling period shall cover 14 % of the reference period of the one year limit value for $NO_2$, $SO_2$ and VOC, according to Council Directives 1999/30/EC (1999) and 2000/69/EC (2000). In this Preliminary Assessment $NO_2$ and $SO_2$ were sampled every second month over one year period. The exposure time per campaign was one month, therefore the time coverage is approximately 50% within the year's period. The sampling period for VOCs was 15 months, having each campaign a duration of 1 month, thus, the time coverage was 100%.

## 2. POLLUTANT CONCENTRATIONS AT THE SITES

### 2.1 Nitrogen dioxid - $NO_2$

The results of diffusive sampling are evaluated for each site and each component as average over the whole sampling period (annual averages) as colored points. ).In Figure 1 these points are depicted exemplarily for the component nitrogen dioxide ($NO_2$).

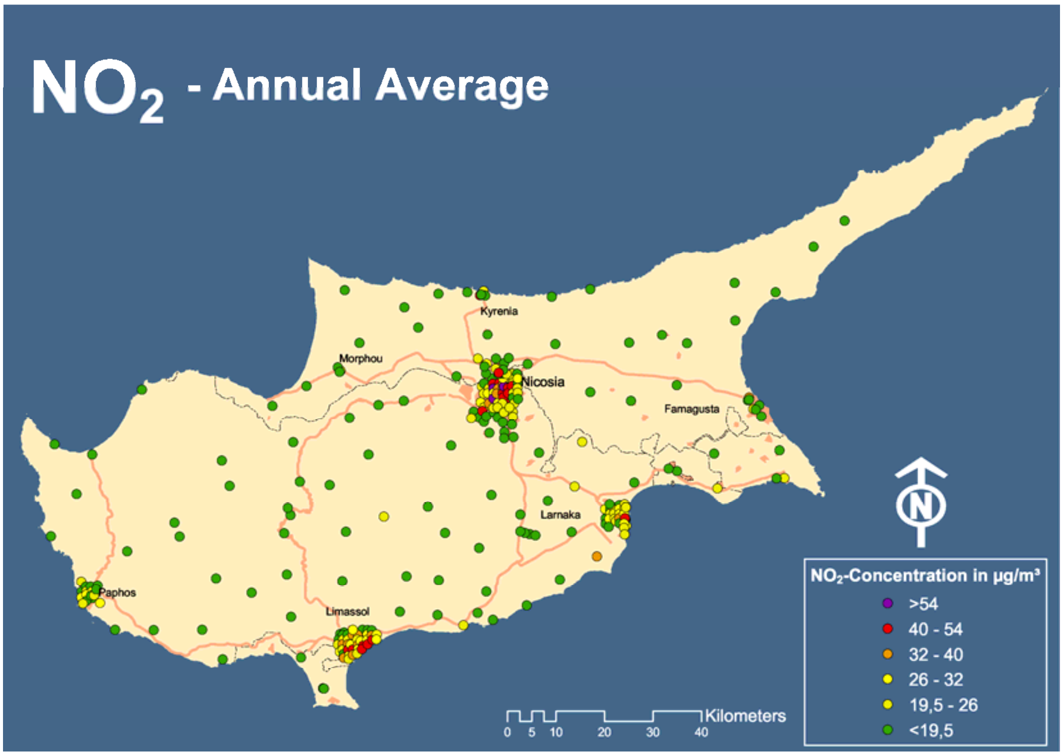


Figure 1. $NO_2$ concentrations in Cyprus – annual average values 2002/2003

For a preliminary assessment of air quality under EU directive 96/62/EC (1996) the overall goal is to obtain an overview of the temporal and spatial distribution of air pollutants. This allows to locate zones of exceedances or near-exceedances of relevant EU limit values. Due to the fact that ambient air quality measurements deliver only point values of pollutant concentrations, additional efforts have to be carried out to obtain a spatial distribution. The European Commission recommends for this purpose the diffusive sampling technique in combination with modeling - which modeling method is not specified, only a summary of available methods is given in the Guidance on Assessment under the EU Air Quality Directives (2002). The most commonly used method is the application of interpolation algorithms. Therefore, interpolation maps have been produced from the average results of point measurements (Figure 1) to get an overview of the pollutants distribution and to provide a widely applied method. These interpolated maps are showing a realistic picture of the air quality situation in Cyprus, since the diffusive sampling measurement campaign was carried out with an unusual high density of sampling sites. In the following, a selection of results of interpolation calculations are presented as pollutant maps of annual and seasonal averages in µg/m³. In the project report the maps are available for the whole island and all major cities of Cyprus and contain all pollutants measured by diffusive sampling ($NO_2$, Benzene, $SO_2$ and Ozone). The interpolated concentration values are depicted in a 1x1 km grid over Cyprus, which is aligned to the geographic coordinate system UTM, WGS 1984. For the cities this grid is too coarse, therefore filled contours have been chosen. In the Cyprus maps as well as in the city maps each colour shows the average pollutant level of the observed location. The chosen concentration scales are adapted to present and EU limit values. Transition colours have been avoided, since this would pretend a non-existent spatial resolution and precision regarding the predictions – therefore concentration ranges are shown. To find ones way in the maps, the major roads and the green line are depicted. For the cities, topographic maps are lying beneath the transparent interpolation results.

### 2.2 Sulfur dioxid – $SO_2$

In Figure 2 the mean summer season $SO_2$ distribution over Cyprus is depicted. Large, continuous parts of Cyprus are not affected by $SO_2$ especially the mountain areas in the west part Troodos and Akamas and the finger in north east (Karpasia). They are marked dark green, indicating $SO_2$ concentrations below 5 µg/m³. Yellow (8-12 µg/m³) and orange (12-20 µg/m³) colours occur mainly at the south coast in a coherent area from Larnaca and Limassol and also in the city of Nicosia (in the middle). The most important $SO_2$ sources are the power plants of Kyrenia at the north coast (yellow) and Vassilikos, Moni and Dhekelia at the south coast. All of them cause average concentration values in their close vicinity of 8 to 12 µg/m³ (yellow), respectively up to 20 µg/m³ (orange) in the case of the power plants of Moni and Vassilikos. Shorter Peak values are much higher, of course. Especially in summer with a general high power consumption due to the extensive use of air conditioning units they emerge quite clearly, in winter they are superposed by other emission sources and also there are more windy situations, thus the plumes from the power plants are spread over wider areas and the concentrations are lower.

## 2.3 Benzene distribution in urban areas

The Benzene distribution (as most important VOC component) in urban areas is depicted in Figure 3 as example for the city of Nicosia. It shows concentrations up to 8 µg/m³ and higher. The highest concentrations occur in the city centers with the highest traffic loads.

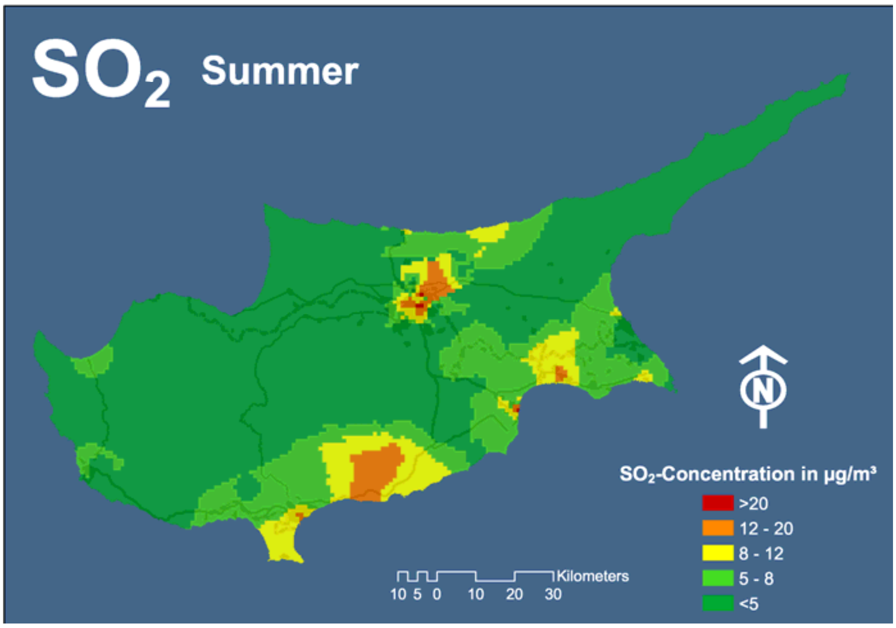


Figure 2. Mean interpolated $SO_2$ distribution over Cyprus for summer season

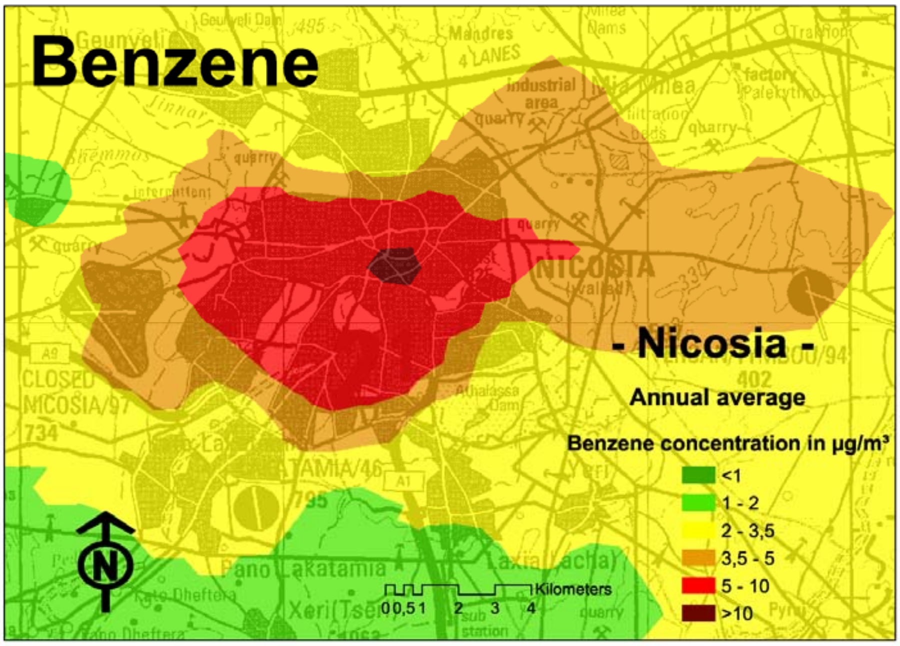


Figure 3. Mean annual interpolated Benzene distribution in Nicosia

# 3. NEURAL NETWORK MODELLING

## 3.1 General aspects

Neural Networks are a powerful flexible tool for finding systematics and dependencies in very complex processes and which considers all the concentrations measured by diffusive sampling and other important parameters: The idea behind this is to rebuild the human neural network in a computer software environment. Just like in nature, such a software can learn from the data that have been fed into it and find dependencies between different parameters. The distribution of air pollutants mainly depends on (Baumbach 1996):

- Meteorological conditions, especially wind speed and wind direction. Both parameters generate a wind field that influences strongly the dispersion of gaseous pollutants.
- Emission sources are the cause for air pollution. They are mapped in an emissions inventory. The population density indicates further emission sources, not captured in the emissions inventory.
- The topography directs the wind field and therefore influences the dispersion of air pollutants. The spatial distance of a certain site to an emission source correlates with the measured pollutant concentration, depending on the dispersion conditions and is therefore an important input variable for modeling a concentration field. In addition, the elevation correlates with the formation of certain pollutants, especially Ozone.

A realistic modeling approach should, if possible, include the parameters described above and regard the local conditions of the investigated area. At present there exists no stand alone method, that considers all these parameters: Different tools are incorporated into modelling systems.

## 3.2 Input Parameters for neural networks

For air pollution modelling, the neural network is trained with measured data of pollutant concentrations, meteorological data, topographical data and data from the emissions inventory.

A so called “controlled” training algorithm has been applied within this project (Pfeiffer 2005): The operator provides the network, the real results of actually measured values of all input parameters and also the desired output of the network - the pollutant concentration as measured by diffusive sampling.

A randomly selected part of the training data is set aside for later model validation.

All links between the different network layers and neurons are now set, their functions and weightings are determined. In the recall mode, the trained network is fed with the input data. These input variables have been prepared in a one by one km grid, that covers the whole island of Cyprus. The network now applies the learned correlations of the training sites to this grid and calculates the pollutant concentrations at the sites where no pollutant measurements exist, but the training input data.

The neural network was trained with the following variables:

- NOx emissions:
  The most important emissions in Cyprus have been distributed around their source according to wind statistics.
  - In the case of the point sources which are the power plants and the cement factories, a Gaussian dispersion model was run for each of these sources.
  - In the case of the highways a decay curve from the diffusive sampling measurements was applied (Figure 4).
  - Also for the cities a decay curve was calculated and weighted with wind statistics, so that a plume for each major city in Cyprus could be calculated.
- Population density:

  For the population density a new digital map was created, since the original data were only provided as points or as polygons of the district. For this purpose every village in Cyprus was digitised according to it's actual shape. The base for this was the 1:250.000 map of Cyprus.

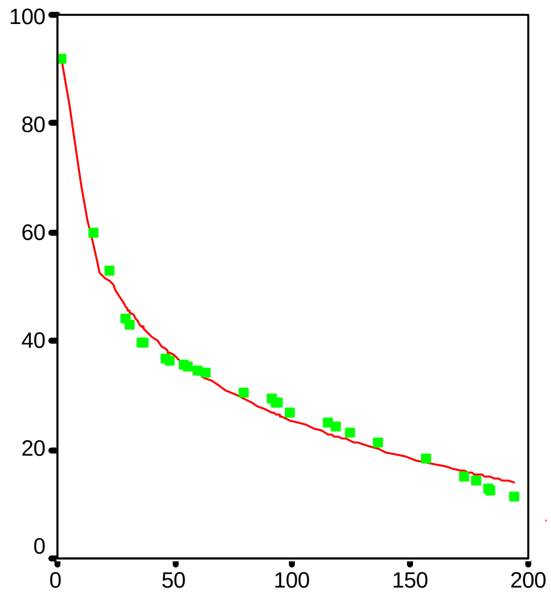


Figure 4. Decay of $NO_2$ with increasing distance to highway

### 3.3 Results of Neural Network modelling

The pollutant distribution map calculated by the neural network is depicted in Figure 5.

The features that don't appear in the interpolated maps like the highways and major roads are captured in this map since more variables are considered rather than the spatial distance between the diffusive sampling sites. Whether important emissions sources can be seen in the interpolation maps depends very much on the location of the diffusive sampling sites. This doesn't happen with the neural network model, since one part of its input is the emissions inventory.

The training data set for $NO_2$ was very good since it was measured at 250 places over Cyprus. The more input the neural network gets, the better it can learn the dependencies and correlations between the different parameters.

To assess the quality of the modelled map, the results of a test set from 50 diffusive sampling sites which has not been used for the training of the Neural Network model were compared with the modelled results for these sites. This comparison is shown in Figure 5. Some higher $NO_2$ values are underestimated by the model, because they are situated close to sources. The correlation coefficient could be determined as 0.62 – a very good result for a comparison of modelling and real measurements.

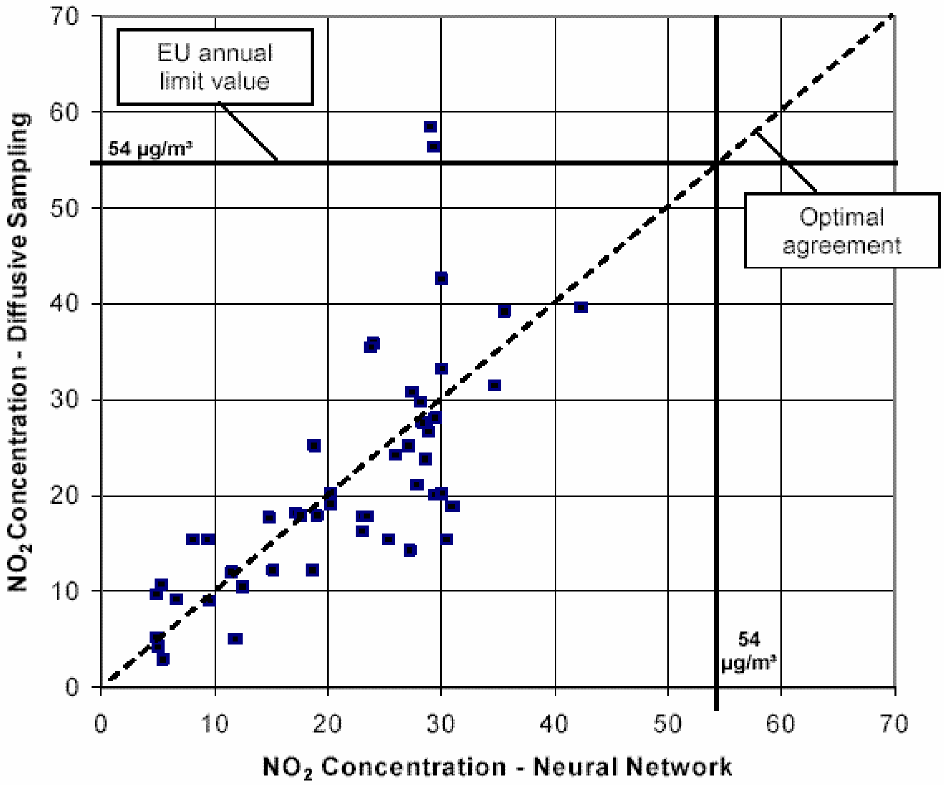


Figure 5. Quality assurance of the final model – comparison of NO2 diffusive sampling results from the test data set and modelled NO2 values with n= 50

## 4. INTERPRETATION AND CONCULUSIONS

The highest pollutant loads are located in the major cities of Cyprus, especially Nicosia, Limassol and Larnaca. Here, the highest concentration values are measured by diffusive sampling and the emission sources are densely concentrated. Some special features deserve more attention: The highway between Nicosia and Larnaca up to Limassol emerges very clearly as the major line source in Cyprus since these are the largest cities and furthermore the major airport of Cyprus is in Larnaca. Other important $NO_2$ sources are the power plants and a cement factory. They are very well reflected in the $NO_2$ distribution map (see Figure 6). Large parts of Cyprus have a low $NO_2$ level (green colour), since there are no major sources – especially the Troodos mountains (west part of Cyprus) and the area in the north, where agricultural usage dominates, partly even without machines.

Finally it can be stated that the Neural Network is a good method for modelling if a great number of measurement results is available and if these results shall be used

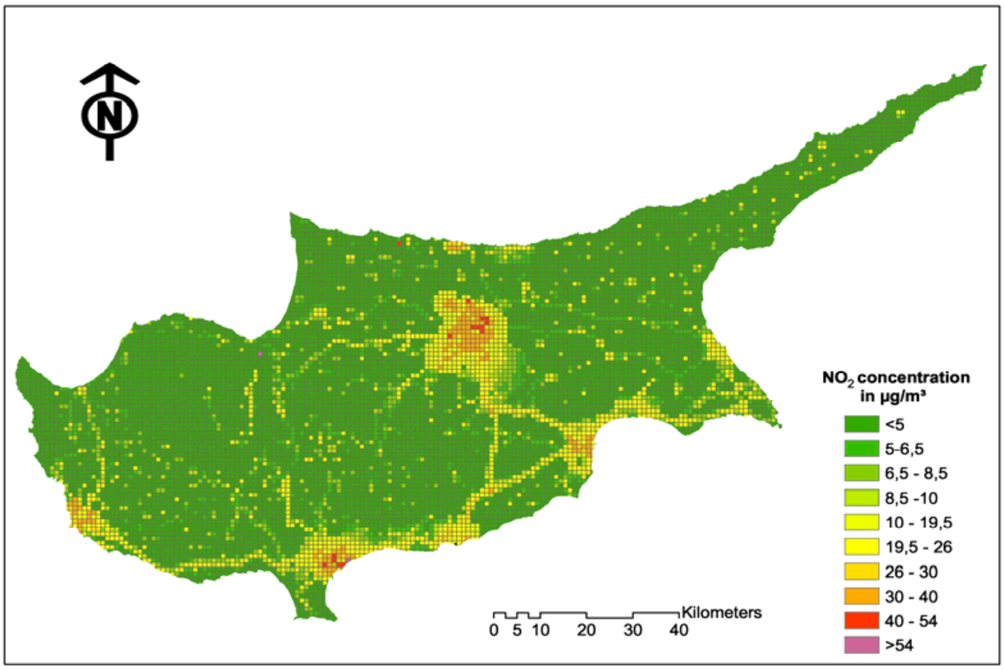


Figure 6. Annual average $NO_2$ distribution calculated with neural network

directly as input data for training the model. The neural network is more flexible than the usual statistic methods since it finds out the best correlation by training with real values.

## 5. ACKNOWLEDGEMENTS

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