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# APPLICATION OF SPECTRAL ANALYSIS TO ASSESS THE IMPACT OF CAR TRAFFIC ON NITROGEN DIOXIDE CONCENTRATION

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Abstract
**The objective of this research was the assessment of the dependence between the road traffic volume and the concentration of nitrogen dioxide at the investigated section of a road. The concentration of nitrogen dioxide has been measured on the basis of the method of differential optical absorption spectroscopy, with the application of OPSIS analyzer located above a highly loaded street accessing the city of Gliwice. The road traffic volume was adopted on the basis of the data from the road traffic monitoring system in Gliwice**
**By means of the cross-spectrum analysis, which allows to investigate the harmonic structure of time series of concentrations and traffic volume, the road traffic volume has been identified to be the essential factor influencing local $NO_2$ concentration values. Taking advantage of $NO_2$ average concentration values in July 2013 during the working days between 6 am ÷ 3 pm, regression function has been determined. This function best describes the dependence between concentration and traffic volume within the given time frame. These functions feature non-linear characteristics.**

Streszczenie
**Celem pracy była ocena zależności pomiędzy natężeniem ruchu drogowego, a stężeniem dwutlenku azotu nad jezdnią na badanym odcinku drogi. Stężenie dwutlenku azotu było mierzone z zastosowaniem różnicowej optycznej spektroskopii absorpcyjnej, przy użyciu analizatora OPSIS zainstalowanego nad silnie obciążoną drogą dojazdową do centrum Gliwic. Natężenie ruchu drogowego na tym odcinku drogi zostało ustalone na podstawie danych z systemu ciągłego monitoringu ruchu drogowego funkcjonującego w Gliwicach.**
**Za pomocą metod analizy spektralnej szeregów czasowych, zidentyfikowano natężenie ruchu jako istotny czynnik wpływający na lokalne wartości stężenia $NO_2$ w badanym przedziale czasowym (w godzinach 6.00 ÷ 15.00 dni roboczych lipca 2013). Na podstawie zmierzonych stężeń $NO_2$ i stwierdzonego natężenia ruchu, znaleziono funkcję najlepiej opisująca badaną zależność. Funkcja ta posiada nieliniowy charakter.**

Keywords: **Air pollution; nitrogen dioxide; Motoring sources of $NO_2$; Differential optical absorption spectroscopy; OPSIS.**

## 1. INTRODUCTION

Rapid development of motoring that improves the possibilities of relocating of humans, has significantly changed the way of life and increased its comfort. It has also resulted in a meaningful economic growth by facilitating the transportation of goods. Motoring, however, has, at the same time, a negative effect on a human and the environment – production, operation and recycling of cars creates the emission of numerous pollutants to the air, water and soil [1, 2].

Currently, means of transportation create one of the main sources for air pollution: about 50% of nitric oxides, 30% of carbon monoxides and 25% of hydrocarbons existing in the air is emitted by cars [3, 4]. The increasing car number has brought about introduction of stricter car emission norms and development of

roads in terms of quantity, quality and capacity. In spite of that the progressive pressure on the environment is being observed [5, 6]. It leads consequently to the necessity of taking further actions limiting this pressure. While these actions are being conducted, it is essential to take into consideration one of many inseparable features of danger that car traffic creates – its strong time-related variation manifesting itself in visible periods of maximum concentration values.

Car traffic and concentrations associated with it has a periodicity of high amplitude and a dominant 24-hour period. Due to such short period of concentration variation, investigation of motoring impact variation requires conducting constant concentration measurements. Moreover, the measurements shall be executed in a way, which ensures that obtained concentrations are, above all, linked to motoring sources and the participation of other sources is possibly minor.

This research has essayed to evaluate diurnal $NO_2$ concentration variations connected with a local car traffic volume. In order to achieve that, a constant measurements of the $NO_2$ concentration values were taken above a highly loaded street accessing the city of Gliwice. The research was carried out in relation to the change of traffic scheme which resulted in limiting the access to A4 motorway (initially toll free) by the introduction of toll roads system. That results in increasing the road traffic volume on the city roads.

## 2. ASSUMPTIONS

The knowledge of the traffic volume at a given section of the road and its corresponding concentration of $NO_2$, measured in a constant manner above the investigated carriageway, may become the basis for the assessment of the dependency between the concentration of $NO_2$ of car engines origin and the road traffic volume. This happens in case when obtained concentrations of $NO_2$ are connected exclusively or almost exclusively with a vehicle traffic at an investigated road. It means, that background pollution as well as NO to $NO_2$ transformation are so insignificant that can be ignored. According to the authors, in order to comply with the above conditions in the best possible way, the following assumptions should be fulfilled:

1. Continuity of measurements is secured by the application of an optic method with an automated recording system at high frequency,
2. Setting a measuring beam of light at a small height above the road allows the $NO_2$ concentration value, in the zone of intensive mechanical air mixing caused by car traffic, to be assessed. This zone is characteristic of an even vertical profile of concentrations which means, that exhaust gases introduced to the air above the surface of the carriageway reach the measuring beam in a very short time, and the measured concentration falls in with the concentration affecting drivers and pedestrians in the investigated area,
3. Positioning the measurement path skew to the axis of the carriageway significantly makes the concentration measurement independent from the direction of the wind with the exception of the wind parallel to the axis of the carriageway or of the similar direction which can accumulate pollutions coming from vast sections of the road lying before the measurement axis,
4. The concentration of $NO_2$ originated from car engines, in the investigated section of the road is high against the background $NO_2$ concentration. To achieve that hours between 6 am and 3 pm and working days were taken into consideration as they feature the highest traffic volume, so then also the $NO_2$ emission connected with it,
5. Due to the short time of presence of NO and $NO_2$ emitted from engines in the air by the time they reach the measurement path, their transformation in the air, although present – especially under high insolation, is not taken into account.

Under presented assumptions, a part of $NO_2$ having source in NO emitted from motor vehicles, was not taken into consideration. In the same way insolation, which influences NO to $NO_2$ transformation through creation of conditions conducive to increase dynamic of such reaction, was neglected.

## 3. MEASURMENTS OF $NO_2$ CONCENTRATION VALUES

OPSIS optical analyzer was used to measure concentrations of $NO_2$. The device operates on the basis of DOAS technique (*Differential Optical Absorption Spectroscopy*). This method bases on the Lambert-Beer's law. It defines the dependencies existing between the quantity of absorbed radiation on the path of a beam of light and the number of molecules which are placed along the measurement path. [7, 8]

The measurement is based on the emission of a beam of light from a source which is a high pressure xenon lamp, along a specially chosen measurement path.

This lamp emits light of constant intensity and broad spectrum, taking into account, above others, the infrared and ultraviolet radiation.

Both the receiver and the transmitter are equipped with a mirror, wherein the light is focused at the end of the optical fiber, located in the focus of the mirror. After passing through the tested center, the beam reaches the receiver, from where it is sent to the spectrometer. Received light is being analyzed at this point, which allows to specify the size of the light losses as a result of the absorption of light along the measurement path.

The measurements of the $NO_2$ concentration were made in July 2012, concentrations measured were averaged to a full hour, corresponding to averaging observations of the traffic volume. The measurement was made on Pszczyńska street in Gliwice. The transmitter of the measurement beam was placed on the car wash at LUKOIL gas station. The receiver, together with the devices processing the signal and collecting data were located on the roof of a student club "Mrowisko", on the opposite side of the street. The measurement beam ran a slant over Pszczyńska street, at a height of approx. 4 m above the road surface. The overall length of the beam was approx. 240 m, of which about 100 m accounted for the area directly above the road surface (Fig. 1) [9].

The work concerns the road traffic on the section of Pszczyńska street (corner of Bojkowska) leading from the city center towards the junction of the A1 and A4 in Sośnica. The road traffic volume was adopted on the basis of the data from the municipal road traffic monitoring system


**Figure 1.**
**Location of the measurement section [source: http://maps.google.pl]**

## 4. RESULTS OF MEASUREMENTS

The analysis examining the dependence between the traffic volume and concentration of $NO_2$ for the whole month of July (Fig. 2) was done. A more detailed, exemplary distribution of concentrations are presented in a fragmentary part of Figure 2, covering the period from 22 July to 30 July 2012 (Fig. 3).

For the entire month, a relatively low correlation between the road traffic volume and the $NO_2$ concentrations was obtained, approximately 0.4.

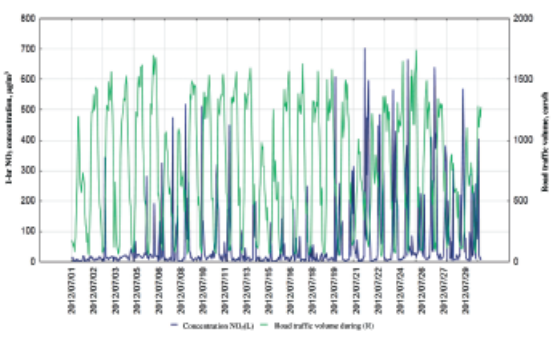

**Figure 2.**
**Summary course of nitrogen dioxide concentrations and the road traffic volume during 1.07.2012 – 30.07.2012**


**Figure 3.**
**Detailed comparison of nitrogen dioxide concentrations and road traffic volume within the period 22.07.2012 – 30.07.2012**

## 5. DEPENDENCIES BETWEEN TIME SERIES

In order to determine the dependencies between the rows of variable concentration values of $NO_2$ and the road traffic volume a Fourier spectral analysis with the option of cross-spectrum analysis was used. It allowed to examine the harmonic structure of the considered time series. Fig. 4 and 5 show results as

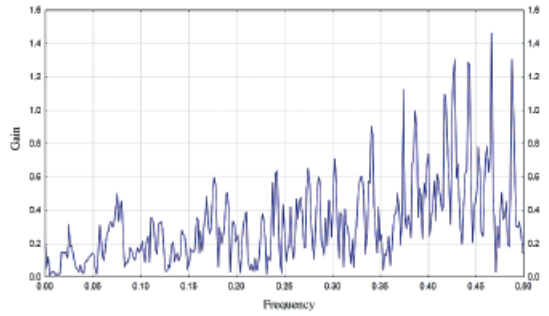


**Figure 4.**
**Gain function of the road traffic volume in relation to the concentration of $NO_2$**

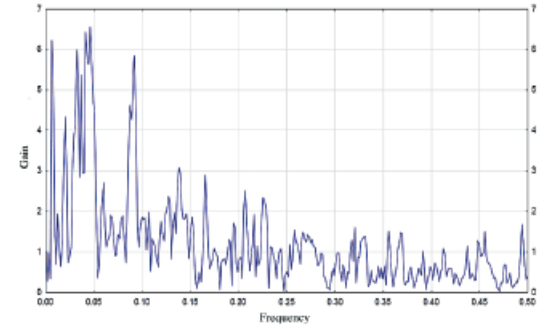


**Figure 5.**
**Gain function of $NO_2$ concentrations in relation to the road traffic**

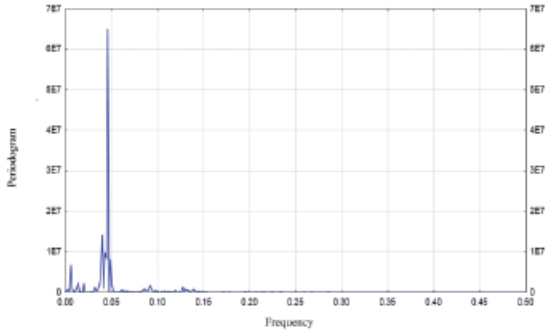


**Figure 6.**
**Periodogram for the road traffic volume**

the gain function graphs. Variables, such as volume of traffic expressed in number of cars passing per hour under the measurement beam and the $NO_2$ concentration expressed in $\mu g/m^3$, were taken into account. The analysis allowed to characterize the phase spectrum, thanks to which, basic dependencies and correlations between the examined, interrelated rows were shown. In the observed frequency range, characteristic for the analyzed variables, much higher values is obtained by the correlation of the $NO_2$ concentrations in relation to the road traffic volume than by the inverse correlation.

Figure 6 shows the periodogram of the road traffic volume. The highest value of the periodogram, of approx. $6.0 \cdot 10^7$, occurs at the frequency of 0.049.

By means of the gain graph and periodogram a main factor influencing local concentrations of $NO_2$ has been identified. This factor has a period of approx. 21 hours, thus similar to the characteristic 24-hour period of the motoring sources. The crucial meaning in such identification has a periodogram which presents frequencies, being the inverses of observed changes periods expressed in hours. In this way frequency 0.049 of dominant maximum presented on Fig. 6 corresponds roughly to a period of 21 hours. Taking into account the fact that the periodogram was prepared in a way to cover all days of the weeks of July – also Saturdays and Sundays featuring different day distribution of vehicle traffic on the observed section of the road, it can be assumed that the calculated period of 21 hours corresponds to a 24-hour one what means that the motor vehicle traffic is the basic source of measured concentrations of $NO_2$. This is confirmed by the periodogram chart, where there is one significant maximum. It is associated with the above mentioned period. Maxima that appear on this chart for other periods are negligibly lower.

Attributing the period of 24 hours to concentrations associated with the movement of the cars was based on the assumption that outside the heating season the only significant sources of variable concentrations of $NO_2$, beyond cars, can be industrial sources which, however, have emission periods of about diverse length, usually different from 24 h. What is more, they have different occurrence time of maxima, which stems from the variety of executed technological processes.

## 6. DEPENDENCE OF $NO_2$ CONCENTRATION ON THE CAR TRAFFIC

Taking advantage of the acquired information, an attempt to define the function describing the influence of the car traffic volume on the concentration of $NO_2$ has been made. In order to preserve the correlation of the concentration values with the right time of day it was decided that it has to be carried out by hours. For this purpose, average concentrations of $NO_2$ and traffic volumes for subsequent hours of working days in July were calculated. Data for hours from 6 am to 3 pm, for which the highest correlation

of around 0.92 between concentrations of $NO_2$ and traffic volumes have been observed, were selected to further proceeding. Such high correlation suggests the modest influence of other phenomena like background pollution or NO to $NO_2$ transformation on observed dependence. With these data, regression was performed, aiming at functions that best approximate the indicated dependency. As a result it was proved that the function that best describes this dependency is the polynomial of 2nd degree (Fig. 7); subsequent functions are exponential (Fig. 8) and power function (Fig. 9). The linear function (Fig. 10) matches both depended values in the worst degree. In the drawings, next to each of the points representing the input data for regression, the information on the hours to which they relate was introduced.

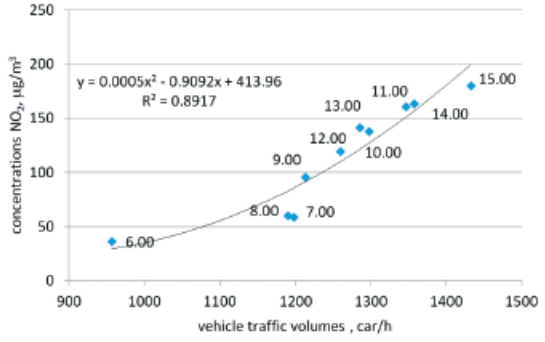


**Figure 7.**
**Polinomial regression of $NO_2$ concentrations depending on the road traffic volume**

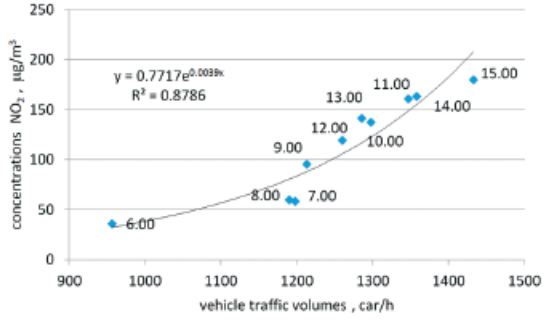


**Figure 8.**
**Exponential regression of $NO_2$ concentrations depending on the road traffic volume**

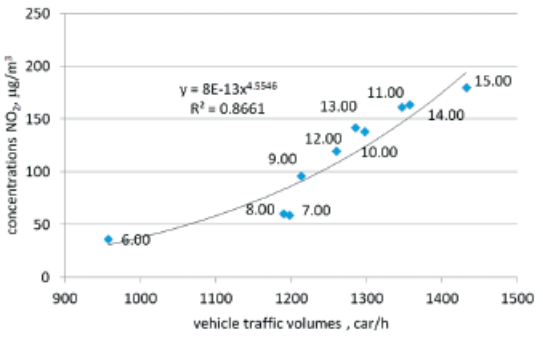


**Figure 9.**
**Power function regression of $NO_2$ concentrations depending on the road traffic volume**

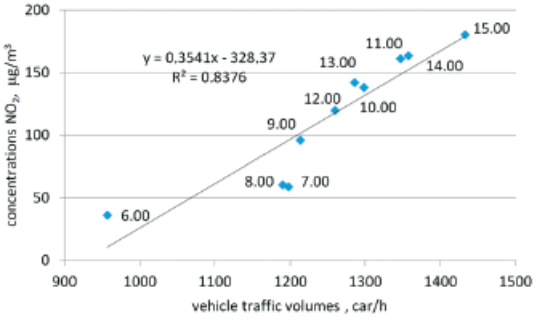


**Figure 10.**
**Linear regression of $NO_2$ concentrations depending on the road traffic volume**

## 7. CONCLUSION

1. Total $NO_2$ concentration values on the investigated communication route exhibit periodic fluctuations with a period close to 1 day.
2. A dependency of about high correlation (approx. 0.92) between the measured concentrations of $NO_2$ in specific, analyzed hours and the traffic volume was observed in the month of July.
3. This dependence, contrary to the intuitive expectations, is non-linear. This indicates the existence of other factors influencing the concentration values within the road than the emission rate.
4. One of such factors could be the mechanical turbulence growing along with the traffic volume, which results in the introduction of increased portion of $NO_2$ emitted from the engines to the level of the measuring path. This thesis is being verified.

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