Abstract: Emissions from road traffic play a key role for the impact on entering several types of pollutants into the air, causing that the troposphere (not only in the vicinity of roads) depends on the intensity and type of the transport. Due to exploitation of vehicles and road surfaces, gaseous pollutants and particulates are released into the atmosphere. The paper presents results of research studies on the concentration of PM$_{10}$ dust, and the concentration of heavy metals (Al, Cd, Cu, Cr, Ni, Pb and Zn), which it contains. The PM$_{10}$ concentration measurements were performed using MicroPNS HVS16 sets of dust collectors with control modules. Qualitative and quantitative indications of heavy metals were performed using AAS. The presented approach differs from the previous ones with the method of obtaining results for the reference state, which previously were set out in the same sites, in which later were investigated the effect of motor traffic on the qualities of the air. Samples of the airborne particulate matter and surface dust were collected twice in the same area for a period of 28 days in April 2004 (an area without human intervention) and 2012 (an area of operation). The study was conducted on the area of the current section of the northern ring road of Opole (PL). It was shown that the land-use change, which is the exploitation of new road, causes PM$_{10}$ concentration increase and raise of the designated heavy metals in the air. Based on the estimated EF and Wilcoxon test it was stated that transport significantly affects the level of Pb, Cd, Zn and Cu. It was indicated that the speed of vehicles is one of the key factors influencing the degree of air degradation. It was also concluded that the former approach applied in the assessment of the air quality being based on the comparison of its quality at source and the quality in areas away from human activity, is justified.

Keywords: road traffic, PM$_{10}$, heavy metals, AAS

Introduction

Road transport interferes in the environment, affecting all of its components: the atmosphere, soil, water, surface soil, geological structure, vegetation and animal world.

1 Department of Thermal Engineering nd Industrial Facilities, Opole University of Technology, ul. Mikołajczyka 5, 45–271 Opole, Poland, phone: +48 77 400 63 91, fax: +48 77 400 63 42, email: t.olszowski@po.opole.pl
Air pollution, in terms of environmental protection, is considered as one of the most important problems related to transport activities since road traffic emission is a major source that releases several types of toxic substances into the atmosphere [1].

Besides the gaseous pollutants, carriers of toxic compounds in the form of particulate matter are also released into the atmosphere, as a result of vehicles and road surfaces exploitation. The dust pollution emissions generated during use of any form of transport are divided into two categories [2]: direct (exploitation of vehicles and roads, and ground resuspension); indirect (caused by chemical reactions with the primary air pollutants). Airborne particulate matter generated by transport is characterised by a wide diversity in size and chemical composition. Equivalent diameters of particles range from several nanometers to 100 micrometers [3]. From the perspective of human health protection, fractions smaller than 10 mm defined as PM$_{10}$ that cause significant respiratory, circulatory and nervous systems problems, are considered the most dangerous [4, 5]. For this reason, in many countries, including all EU countries, permissible limits of ambient air concentrations of PM$_{10}$ and heavy metals, which they contain, were introduced [6, 7].

The main sources of particulate matter and contained therein inorganic compounds being released by road transport, except the exhaust gases [8, 9], are: wear of abrasive parts of vehicles (tires, brake linings), substrate resuspension, abrasion of road surface (asphalt) and – in the countries with moderate climate – chemical agents used for road maintenance [2, 10–14]. Road transport, both in the developed and developing countries, is the main source of solid particle emission [15]. As it was indicated in [16], the estimated percentage of road traffic in total PM$_{10}$ emission from anthropogenic sources, amounts to approximately 56 %. However, in Europe the percentage is estimated at the level of 50 % [17].

Particulate pollutants coming from land transport pose a significant threat because they contain toxic inorganic compounds. The primary compounds enriching atmospheric aerosol are, primarily: Ba, Cd, Cr, Cu, Fe, Ni, Pb and Zn [14]. The composition of exhaust emissions from vehicles depends on several factors, primarily on the type of fuel used (most of the solid particles is generated during combustion of diesel fuel) [18], engine type and age, configuration of the exhaust system and air protection equipment [19]. The main source of Ba, Cu, Fe and Zn is the wear of brake linings and discs [20]. Mechanical abrasion of tires causes mainly the release of Zn [2] and additionally triggers the release of Cd, Cu, Cr, Ni and Pb [21]. Mechanical abrasion of road surface causes the emission of Cr, Ni, Pb and [22]. Final important source that releases the solid particles into the air is the road surface resuspension, which causes the level increases of Cd, Cl, Cu, Pb and Zn in the air [23].

Analysing the available literature data, it can be said that:

– road traffic generates significant amount of pollutants and is the main source of anthropogenic airborne particulate matter,
– the highest concentrations of pollutants occurs within 10–50 m from the road and decreases with distance,
– the traffic intensity, the age of vehicles and the quota of the various types have considerable impact on the amount of the pollutants emitted,
previous research studies on determining the impact of road traffic on the air quality were carried out by comparing the obtained results to the quality results for areas that were not directly affected by transportation and located in other areas.

So far, no comparative studies for the area were conducted, in which selected qualitative and quantitative parameters of the air – before and during the exploitation of the carriageway will be specified. The article is a case study of land-use change “BEFORE-AFTER” on the example of a new medium traffic road. The main objective of this study was to analyse and evaluate the changes in the volume of atmospheric immission that are typical particulates generated by road traffic. The scope of the investigation consisted of carrying out two medium-term measurement campaigns in the same area, i.e. in its original state (before the road was constructed) and during the phase of its constant exploitation. The research hypothesis assumed that the change in the land use does not contribute to an increase in the degree of the ambient air pollution.

Materials and methods

Measurement site and monitoring period, weather conditions

Research studies on the real impact of transport route on the air quality were conducted on the northern section of the Opole ring road (50°38′32″ N, 18°00′36″ E, Silesian Lowland, Poland, Central Europe). The examined, newly built section of the National Road E94 is an extension of the existing ring road, and its length is 3.5 km. The road was built as an answer to the need to transfer the transit out of the centre of the city of Opole and was commissioned in 2007. Before October 2004 (start of construction work), the area was a barren land (75 %) and forestry (25 %). The average daily traffic intensity is approximately 11500 vehicles. The generic structure of motor vehicles is as follows (2010): motorcycles 0.004 %; passenger cars 65.26 %; light-duty vehicles (LDV) 9.93 %; heavy-duty vehicles (HDV) 24.126 %; coaches 0.53 %; farm tractors 0.15 %.

![Fig. 1. The map of the area and location of the measurement points](image-url)
The map of the area and location of the measurement points are shown in Fig. 1.
The measurement campaigns were carried out twice in April 2004 and 2012. In both measurement periods, the measuring media were located in two points: Point ‘0’ (p0) in braking/acceleration zone and Point ‘1’ (p1) in the vehicle zone of steady-movement. Measuring media were situated at distance of 1700 m from each other. The samplers’ location points were 10 m from the western end of the planned/and the existing road. The airborne particulate matter measurements were carried out continuously for 28 days.

**The methodology of sampling and analysis**

The procedure for estimating the PM$_{10}$ concentration volume was conducted in accordance with guidelines of the European Standard [24]. Daily measurements of the PM$_{10}$ airborne particulate matter, at both sampling points (p0 and p1) were carried out in the same periods using Micro PNS HV16 sets of dust collectors with control modules. The indicated flow rate was 68 m$^3$/h. Whatman glass microfiber filters, grade GF/A with a diameter of 150 mm were used as separators for particulate matter. Filters were seasoned for 24 h in constant temperature and humidity conditions, before they were used, and then weighed on a differential dosing scales (repeatability coefficient 2 $\mu$g).

PM$_{10}$ fraction was collected on a filter during automatic, periodical (24 h) change of filters from tray. The filters were seasoned and weighed again after aspiration. The content of PM$_{10}$ [$\mu$g/m$^3$] fraction was measured on the basis of the following formula (1).

$$C = \frac{(m_1 - m_0)}{V}$$  \hspace{1cm} (1)

where:

- $C$ – PM$_{10}$ [$\mu$g/m$^3$] concentration,
- $m_1$ – mass of the filter sputtered with dust [g],
- $m_0$ – the mass of the clean filter [g],
- $V$ – volume of the air which has flow through the filter [m$^3$].

The expanded concentration measurement uncertainty (U) did not exceed 3.1 %.

Determination of heavy metals (Al, Cd, Cr, Cu, Ni, Pb and Zn) was conducted using the air-acetylene flame AAS method (atomic absorption spectrometry – SOLAAR M6 spectrometer – for Cr acetylene – N$_2$O flame).

In the case of PM$_{10}$, using glass disk, circles with a diameter of 36 mm were cut out from sputtered glass microfiber filters. The samples were taken up based on the US EPA 3052 method. Each PM$_{10}$ sample (on glass microfiber filter – 36 mm) was placed in a Teflon lab dish filled with a mixture of nitric(V) acid (9 cm$^3$) and hydrofluoric acid (3 cm$^3$). The samples were mineralised in a microwave mineralizer MILESTONE, Standard D. The product, a subject to mineralisation, was put into measuring beaker (25 cm$^3$) and then it was refilled with deionized water. Microwave digestion time was 15 minutes (in this 5 minutes for raising the temperature to 180 °C in and 10 minutes for keeping the temperature at 180 °C).
The AAS quality control was performed by carrying out the concurrent analyses of reference material; SRM 1648a (particulate matter). Table 1 shows the concentrations of metal elements in the reference materials and the accuracy obtained using AAS method.

Table 1

<table>
<thead>
<tr>
<th>Element</th>
<th>AAS</th>
<th>SRM 1648a – particulate matter</th>
<th>D* [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean [mg/kg]</td>
<td>Certified value</td>
<td>Uncertainty</td>
</tr>
<tr>
<td>Pb</td>
<td>0.598</td>
<td>0.655</td>
<td>0.033</td>
</tr>
<tr>
<td>Ni</td>
<td>74.6</td>
<td>81.1</td>
<td>6.8</td>
</tr>
<tr>
<td>Cu</td>
<td>572</td>
<td>610</td>
<td>70</td>
</tr>
<tr>
<td>Cr</td>
<td>374</td>
<td>402</td>
<td>13</td>
</tr>
<tr>
<td>Zn</td>
<td>4591</td>
<td>4800</td>
<td>270</td>
</tr>
<tr>
<td>Cd</td>
<td>69.4</td>
<td>73.7</td>
<td>2.3</td>
</tr>
<tr>
<td>Al</td>
<td>3.26</td>
<td>3.43</td>
<td>0.13</td>
</tr>
</tbody>
</table>

* Deviation: the difference between the AAS and the certified values, divided by the certified value, and expressed in [%].

Expanded uncertainties for the determination of heavy metals are: 11 % for Cd, 10 % for Cr, 21 % for Cu and Zn, 20 % for Al and Ni, 13 % for Pb (PM$_{10}$), 14 % for Cd, 12 % for Cr, 23 % for Cu and Zn, 19 % for Ni, 16 % for Pb (dust surface). The quantititation limits are: [µg/m$^3$] 0.001 (Cr, Cu, Ni, Pb), 0.01 (Al, Zn), 0.0005 (Cd), [mg/kg] 0.02 (Cd, Cu), 0.03 (Zn), 0.06 (Cr, Ni, Pb).

Results and discussion

The PM$_{10}$ concentration values obtained in both periods of the research studies are shown in Fig. 2. The results of the measured average PM$_{10}$ concentration values for the considered measuring points indicate that the exploitation of transportation routes affects the airborne particulate matter emission. The average concentration value from both points amounted to 32.21 µg/m$^3$ in the base year, and to 39.44 µg/m$^3$ in 2012. The permissible values related to the calendar year (40 µg/m$^3$) were not exceeded. A relative rise in ‘after-before’ concentration amounted to the level of 22.5 %. Higher values of PM$_{10}$ concentration were observed at the p0. The area representing the acceleration and braking of vehicles zone was characterised by a relative increase of 29.6 % (only 14.7 % was obtained at p1). This result confirms that the vehicle speed affects the amount of the emitted pollutants. On the other hand, the results at the p0 are also influenced by the proximity of the old and exploited (also in 2004) road. Wilcoxon signed-rank test was used for comparison of concentrations measured at both
points during both periods. The two-tailed critical value that corresponds to the level of
confidence was considered in the research studies, and the critical p-value was 0.05. The statistical analysis showed that the land use change leads to an increased burdens related to the environment.

The relationship of the measured concentrations of PM$_{10}$ in the areas of linear sources and in the areas of reference (M/B) is presented in Table 2. The results indicate that the commonly accepted approach to relate the results of research on the impact of road traffic with the results obtained in distant areas is justified. High values of the M/B coefficient, obtained in Galicia and Euskadi may contradict to this conclusion. However, one should bear in mind that PM$_{10}$ measurements for the main area were conducted in an area with heavy road traffic.

<table>
<thead>
<tr>
<th>References</th>
<th>Main area (M)</th>
<th>Background (B)</th>
<th>M/B</th>
</tr>
</thead>
<tbody>
<tr>
<td>[25]</td>
<td>Zabrze (road)</td>
<td>Zabrze (city)</td>
<td>1.18</td>
</tr>
<tr>
<td>[26]</td>
<td>Guangzhou (city-road)</td>
<td>semi rural area</td>
<td>1.10</td>
</tr>
<tr>
<td>[27]</td>
<td>Hualien (road)</td>
<td>Henghuen (national park)</td>
<td>1.63</td>
</tr>
<tr>
<td>[28]</td>
<td>Ag.Sofia (city-traffic)</td>
<td>Panorama (suburban)</td>
<td>1.94</td>
</tr>
<tr>
<td>[29]</td>
<td>Euskadi (road)</td>
<td>Euskadi (rural)</td>
<td>2.43</td>
</tr>
<tr>
<td>[29]</td>
<td>Canary Is. (road)</td>
<td>Canary Is. (rural)</td>
<td>1.97</td>
</tr>
<tr>
<td>[29]</td>
<td>Galicia (high traffic)</td>
<td>Galicia (rural)</td>
<td>2.89</td>
</tr>
<tr>
<td>This study</td>
<td>with road</td>
<td>without road</td>
<td>1.22</td>
</tr>
</tbody>
</table>

![PM10 concentration in 2004 and 2012. Boxes show the range between the 25th and 75th percentiles. The whiskers extend from the edge of the box to the 5th and 95th percentile of the data. The horizontal line inside indicates the median value](image-url)
It is worth mentioning that the obtained average value of PM$_{10}$ concentration was at the similar level that was measured by other authors on the roads with similar traffic. Querol et al [29] obtained the PM$_{10}$ concentrations at the range of 33–54 µg/m$^3$, Yang [27] at 39.4 µg/m$^3$. Higher M/B values, which they have measured, indicate lower concentration value obtained in the areas of reference. On the other hand, it may indicate that the area analysed in the study in 2004 was enriched with dust from natural sources and the nearby town.

Table 3 presents average concentrations of the determined heavy metals in PM$_{10}$ [µg/m$^3$]. The results supported by statistical analysis (the Wilcoxon test) show that the exploitation of the carriageway greatly impacts the enhanced immission level of the analysed heavy metals. Except for Al, a remarkable increase in concentrations of metals in the air is observed in 2012 to 2004. The mean results from the two measurement points indicate that the largest increase is related with Cu (3.35), Zn (3.13) and Pb (3.05). Concentrations of Cd and Cr have increased more than twice, and Ni concentration increased by 30 %. Cd, Cr, Ni and Pb concentrations during the stable exploitation of the road, are at the same values as can be measured on the road with similar traffic intensity [13, 30, 31].

<table>
<thead>
<tr>
<th></th>
<th>Pb</th>
<th>Ni</th>
<th>Cd</th>
<th>Cu</th>
<th>Cr</th>
<th>Zn</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>avg before p0</td>
<td>0.0096</td>
<td>0.0047</td>
<td>0.00092</td>
<td>0.0095</td>
<td>0.0018</td>
<td>0.0308</td>
<td>0.0621</td>
</tr>
<tr>
<td>avg after p0</td>
<td>0.0293</td>
<td>0.0064</td>
<td>0.00258</td>
<td>0.0320</td>
<td>0.0053</td>
<td>0.0885</td>
<td>0.0655</td>
</tr>
<tr>
<td>avg before p1</td>
<td>0.0086</td>
<td>0.0043</td>
<td>0.00088</td>
<td>0.0087</td>
<td>0.0017</td>
<td>0.0242</td>
<td>0.0642</td>
</tr>
<tr>
<td>avg after p1</td>
<td>0.0259</td>
<td>0.0054</td>
<td>0.00204</td>
<td>0.0288</td>
<td>0.0049</td>
<td>0.0839</td>
<td>0.0625</td>
</tr>
<tr>
<td>avg before</td>
<td>0.0091</td>
<td>0.0045</td>
<td>0.00090</td>
<td>0.0091</td>
<td>0.0018</td>
<td>0.0275</td>
<td>0.0632</td>
</tr>
<tr>
<td>avg after</td>
<td>0.0276</td>
<td>0.0059</td>
<td>0.0023</td>
<td>0.0304</td>
<td>0.0051</td>
<td>0.0862</td>
<td>0.0640</td>
</tr>
</tbody>
</table>

The exception is concentration of Zn, which on the examined area was significantly higher. This compound primarily arises from tire wear and mechanical abrasion of road surface, and taking into consideration the quality of road surfaces in Poland (which are the worst one in the whole EU and perhaps even in Europe) than such result does not surprise. Higher concentrations of Cu were also noticed, which may confirm the above statement. A minor increase in the concentration of Al (1.3 %) suggests that for this compound exists different source of origin than transport (confirmed by the Wilcoxon test). A number of quantitative occurrences of particular metals in the air (Zn > Cu > Pb > Ni > Cr > Cd) is almost identical as in studies of other cited authors (Zn > Cu > Pb > Ni > Cd > Cr).

Next to the values of PM$_{10}$ concentration, speed and technical aspects of driving vehicles (braking/accelerating) have also evident impact on emission levels of solid particulates. Significantly higher concentration values of compounds are observed in the slow movement zone (p0). Wherein, the result is undoubtedly affected by the proximity of the adjacent and exploited road, what took place also in 2004.
The relative difference in concentrations of heavy metals in PM$_{10}$ between acceleration/braking and stabilized movement zones in 2012 amounted to: 26.5 % for Cd, 19.2 % for Ni, 12.9 % for Pb, 11.3 % for Cu and about 5 % for Zn and Al. It means that travelling at quasi-uniform speed (often > 100 km/h) is more ‘green’ than dynamic changes of speed, and it also supports the opinion of [32].

High values of relative increase rates (RIR) seem to confirm the previously given information about the impact of transport as the main source of emission of heavy metals being examined. The RIR fraction was calculated on the basis of the following formula (2).

$$RIR = \left( \frac{A - B}{B} \right) \cdot 100\%$$  \hspace{1cm} (2)

where:  
\(A\) – data with road (2012),  
\(B\) – data without road (2004).

RIR for Cu, Zn, Pb, Cr and Cd assumed the values; 234.6, 213.3, 204.9, 186.2, 156.8, respectively. Slight increase of Ni (30.2) and Al (1.3) resulting mainly from the abrasion processes of tyres and road surface can indicate that this are not the dominant compound emitted by transport means [3].

Figure 3 presents a scatter plot which depicts the relation between the average concentrations of heavy metals directly marked in the suspended particulate matter before and after the change in land use. Significant quantitative changes were observed. Compared with 2004, in 2012 the concentration of Cu, Zn, Pb, Cr and Cd in PM$_{10}$ increased by 2.7, 2.6, 2.5, 2.4, 2.1 times, respectively. Only in the case of Ni the observed increase was slight.

The research results are often interpreted with the Enrichment Factor (EF) by which they are usually compared with concentrations of aluminium, scandium or silicon in relation to the concentration of accumulated in airborne particulate matter [31]. Scandium, silicon and aluminium rarely enrich the atmospheric aerosol from anthropo-
genic sources. Proportional amount of the examined compound in relation to the reference element in soil and in PM$_{10}$ may indicate the source of origin. It is assumed that EF > 10 indicates that the pollution is of anthropogenic origin, whereas the EF of < 7 indicates geological origin [33]. The Enrichment Factor, calculated with the formula (3), was used to complete the measurement data analysis. Aluminium was used as the background element in this study paper because its soil concentration was stable and ambient concentration was little impacted with human activity. In calculations, data about the values of the concentrations of elements included in the soil of the Opole Region, was obtained from [33, 34].

\[
EF_i = \left( \frac{C_i}{C_{Al}} \right)_{air} / \left( \frac{C_i}{C_{Al}} \right)_{soil}
\]

where: 
$C_i$ – is the concentration of element in the environmental sample,
$C_{Al}$ – concentration in the reference material (aluminium) in the air and soil.

Figure 4 shows the EF values for the elements identified in the PM$_{10}$ in 2004 and in 2012.

According to the applied classification, all the elements identified in the PM$_{10}$ originate from anthropogenic sources (EF > 10). It is undoubtedly influenced by the proximity of the surface emitter, which is the city of Opole. However, the change in land use, where the research is conducted, contributes to the enrichment factor increase. This applies to all elements, although in the case of Ni this increase is not significant. A high value obtained in the case of Pb (EF $\approx 6 \cdot 10^4$) and Zn ($\approx 2 \cdot 10^5$) is also interesting. It is probably connected with local conditions, as other authors who examined the influence of road transport, obtained different EF values: $\approx 3 \cdot 10^5$ for Pb and $\approx 2 \cdot 10^2$ for Zn [31], $\approx 5 \cdot 10^2$ for Pb and $\approx 6 \cdot 10^3$ for Zn [30]. The situation is similar in the case of EF for Cd ($\approx 2 \cdot 10^4$), which was estimated by Gaudry and others to be one order of magnitude lower. A similar value was obtained at the motorway in
France in the case of Ni and Cr (≈ 9 · 10 and ≈ 7 · 10), respectively [31]. EF value for Cu (≈ 7 · 10^2) is identical as observed by other cited authors. In accordance to the research objective, the relation between the EF identified in 2012 and the one marked in 2004 is important. The obtained values of: 2.5 (Cd), 2.8 (Cr), 3.3 (Cu), 1.3 (Ni), 3.0 (Pb) and 3.1 (Zn) finally confirm the thesis according to which the road transport significantly influences the air quality.

Conclusions

The research paper aimed at demonstrating the scale of the impact of transportation route on the air quality. The results obtained directly, in the ‘before – after’ relation, confirm observations of other authors and indicate that the exploitation of roads and motor vehicles causes high emission of gaseous and dust pollutants into the environment. Therefore, the adopted research hypothesis should be rejected. It is obvious that in the period prior to the change of use, the land was also enriched by anthropogenic pollution. However, ‘adding’ another source, a source directly affecting the environment, visible led to negative change in the air (and surface) quality. A significant influence of the speed of vehicles as a factor affecting the scale of polluting the air with toxicants, becomes visible. Hence, it is recommended that the amount of zones causing the ‘slow-down’ of road traffic in the newly-designed and modernised junctions should be limited. The values of measured PM_{10} concentrations and heavy metals in the air are lower than those obtained on motorways and roads with heavy traffic. However, the characteristic relations between the analysed pollutants, identified using indicators, can be considered as retained. The above stated thesis does absolutely not incapacitate the method of conducting the research at source and the comparitions of results with the data from distant areas. Such method is reasonable and recommended. It seems that the obtained results can help to deepen the knowledge about environmental conditions of exploitation of communication routes, although they are limited to traffic with medium intensity.

References

Particulate Matter and Elements – a Case Study of Land-Use... 1183


Abstrakt: Emisja z ruchu drogowego jest istotnym źródłem wprowadzania szeregu rodzajów zanieczyszczeń do powietrza, co powoduje, że jakość troposfery (nie tylko w sąsiedztwie dróg) uwarunkowana jest intensywnością i rodzajem transportu. W wyniku eksploatacji pojazdów i nawierzchni jezdnych do atmosfery uwalniane są zanieczyszczenia gazowe oraz pyłowe. Praca przedstawia wyniki badań dotyczących koncentracji pyłu PM$_{10}$ i zawartych w nim metali ciężkich (Al, Cd, Cu, Cr, Ni, Pb i Zn). pomiary stężenia PM$_{10}$ wykonano przy użyciu zautomatyzowanych zestawów pobierania pyłów MicroPNS HVS16. Oznaczenia jakościowe i ilościowe metali ciężkich wykonano przy użyciu spektrometrii AAS. Zaprezentowane podejście różni się od dotychczasowych sposobem uzyskania wyników dla stanu odniesienia. Koncentracje analizowanych związków określono w tych samych miejscach, w których później badano wpływ ruchu pojazdów silnikowych na jakość powietrza. Próbki pyłu zawieszonym pobierano dwukrotnie na tym samym terenie przez okres 28 dni w miesiącu kwietniu, w 2004 (teren pozbawiony ingerencji ludzkiej) i 2012 r. (teren eksploatowany). Badania prowadzono na obszarze obecnego odcinka północnej obwodnicy Opola (PL). Wykazano, że zmiana sposobu użytkowania terenu, jakim jest eksploatacja nowej drogi, powoduje wzrost stężenia PM$_{10}$ i oznaczanych metali ciężkich w powietrzu. Na podstawie wyznaczonej wartości współczynnika wzbgacania (EF) i analizy testem Wilcoxona stwierdzono, że transport wydatnie wpływa na poziom Pb, Cd, Zn i Cu. Wykazano, że prędkość pojazdów jest jednym z kluczowych czynników wpływających na stopień degradacji powietrza. Ponadto stwierdzono, że dotychczasowa metoda wykorzystywana przy ocenie jakości powietrza polegająca na porównaniu jego jakości u źródła z jego jakością na terenach oddalonych od działalności człowieka jest uzasadniona.

Słowa kluczowe: ruch drogowy, PM$_{10}$, metale ciężkie, ASA