EUROPA XXI
Vol. 28, 2015, pp. 139-150
http://dx.doi.org/10.7163/Eu21.2015.28.7

Institute of Geography and Spatial Organization
Polish Academy of Sciences
www.igipz.pan.pl

THE INFLUENCE OF CAR TRAFFIC ON THE SANITARY STATE OF THE SOILS

Marek Degórski, Izabela Zawiska
Institute of Geography and Spatial Organization
Polish Academy of Sciences
Twarda St. 51/55, 00-818 Warsaw, Poland
m.degor@twarda.pan.pl, ikrajewska@twarda.pan.pl

Abstract. The influence of car transport on the sanitary state of the soils is the subject of numerous investigations, carried out in various regions of the world, including Poland. The purpose of the study here presented was to determine the content of the heavy metals (Ni, Pb, Cu, Zn, Cd, and Cr) in the soils of the areas situated along the roads, characterised by different intensities of traffic, different throughput capacities and smoothness of car traffic flow, as well as different road qualities. Investigations have been carried out in various regions of Poland, in the vicinity of the national roads, expressways, as well as motorways. The samples were collected along the transects, located perpendicularly to the road edge, at distances of 1, 3, 5, 10, 20, 50, and 100 metres from the road edge. The analysis of the results obtained allowed for the formulation of the following conclusions: the differences as to the heavy metal content in the soils between the particular segments analysed reach the ratio of over 100 times; the decrease of heavy metal content in the soils follows the distance away from the road towards the open space, and is characterized by a more regular distribution in the case of the areas along the national roads and less regular in the case of areas along the motorways; with similar intensities of traffic, the impact of the motorways on the environment is decidedly lower than of the national roads.

Keywords: soil contamination, heavy metals in soils, influence of road transport on soils.

Introduction

The influence, exerted by the car transport on the sanitary state of the soils, has been the subject of numerous studies, performed in various regions of the world, characterised by the intensive road traffic, such as USA (Apeagyei et al. 2011), or Western Europe (Jullien & François 2006)[1]. In all the studies, concerning the problem of road traffic in the context of environmental pollution, accumulation of the contaminants is emphasized on the areas, situated in the direct neighbourhood of the roads (Karczewska et al. 2004; Bojakowska et al. 2009). According to T. Kopta (2001), in the countries of the OECD, featuring very high intensity of road traffic, the share of transport-generated pollution in the total emission of pollutants amounts to 63% for the nitrogen oxides, 50% for the

[1] The paper presents the findings from the research project under the grant agreement no. NN 306 564940 financed with the resources from the Polish National Science Center.

chemical substances of organic origin, 80% of carbon oxide, 6.5% for sulphur dioxide, and 10–25% for suspended dusts. Particularly dangerous are the very small particles of soot, that is – of pure carbon. These particles are very reactive and that is why toxic substances very easily adhere to their surfaces, including heavy metals. Among the latter, the most important from the point of view of car transport as the emitter of the contaminants and of the soil as the place of their accumulation, are: (i) plumb, which, in the form of the TEL, was added to the majority of fuels and contributed to the dispersion of plumb aerosols; (ii) cadmium, being the component of the fuel oils, of the brake disks and clutch elements, and an antioxidant in tires; (iii) zinc, present in lubricants, tires, brake disks and clutch elements, (iv) copper, which is a component in the tires, the brake disks and clutch elements (Wołowiec 2005; Legret & Pagotto 2006, Plak et al. 2010). The particles of metals, freed as the result of the exploitation processes of the vehicles, and contained in the dusts, react with the components of the soils or are adsorbed on the humus colloids. The accumulation of the heavy metals concentrates, still, mainly on the surface horizons of the soils, and since they do not undergo biodegradation to simple compounds, they can remain in the soil for a very long time, even for several centuries (Degórski 2011).

The spatial distribution of the contamination of soils with heavy metals, caused by road transport, depends upon many factors, resulting, in particular, from the organisation of the road traffic. Higher concentrations of zinc and cadmium are observed in these places, where cars must brake more often, and hence there is a higher tear of the tires and the elements of the braking system. The contamination of the soils with plumb is the effect of traffic intensity, but nowadays, due to the introduction of the leadless gas, this problem is no longer so important (*Wpływ współczesnej motoryzacji*… 2009).

The objective of the studies here presented was to determine the content of heavy metals in the soils of the areas, situated next to the roads, characterised by various traffic intensities, various traffic throughput capacities, and smoothness of the car flow, as well as road qualities. Investigations were carried out in different regions of Poland, next to the national roads, expressways, and motorways.

Methodology of investigations

When selecting the segments of roads for the study, the average daily traffic of trucks in the years 2000, 2005, and 2010, the increase in the traffic intensity during the period considered, as well as the road category, were accounted for. The study was carried out for six road corridors and included eight segments of the national roads and motorways.

In each of the selected road corridors four transects were chosen, perpendicular to the edge of the road, namely:

- national road no. 8 – two transects, located in the north-eastern Poland, in the vicinity of the localities of Budzisko and Suwałki; two in the southern part of the country in the vicinity of the localities of Szczytna and Koźnice;
- expressway S8, in the vicinity of the town of Radzymin;
- national road no. 17, transects are located at the boundaries of the localities of Trzcianka and Ryki;
- national road no. 94, transects are located at the boundaries of the localities of Godzikowice and Buszyce;
- motorway A1; transects are located at the motorway service point near Grudziądz (1) and at the national road no. 91 in the vicinity of Pelplin (2);

- motorway A4 – the transects are located between Wrocław and Opole.

In order to limit the influence of additional factors, which shape the properties of the soils, all of the transects selected were located in similar edaphic conditions – the soil substrate having similar granulation and the similar forms of land use, as well as similar typological position. Thus, the investigations were carried out for the brown-earth soils, having developed in the clayey sands, the respective areas having been used as meadows. The samples for analysis were taken along the lines perpendicular to the axis of the road, from the points located at distances from 1 to 100 metres from the road edge. The material was collected from the mineral surface horizon of the soil (the humus horizon A, depth of 5 cm) and from the enrichment horizon B, at the depth of 30 cm. The distances from the road edge, at which samples were taken, were 1, 3, 5, 10, 20, 50 and 100 metres. In view of lack of access to the surface due to the existing road infrastructure, soil samples for two segments analysed were taken only at distances of 10, 20, 50 and 100 metres away from the edge of the road.

Samples, collected during the field studies for geochemical analyses, were dried in the temperature of 105°C, and then were sifted through the sieve with the diameter of the stitch equal 2 mm. Analysis were performed for the fraction <2 mm. The contents of the organic matter and of the carbonates were determined with the use of the method of losses in thermal treatment, conform to the procedure, proposed by Heiri et al. (2001). The concentration of the carbonates was calculated according to the formula Ca_{rb} [%] = 1,36 · LOI950, where LOI950 is the quantity of CO_2, emitted from the samples due to the thermal decomposition of the carbonates (Heiri et al. 2001). The mass of carbon, bound in the carbonates was assumed to correspond to the total inorganic carbon (TIC) quantity, the respective formula being TIC [%] = 0.27 · LOI950. The analyses of total contents of carbon (TC), nitrogen (TN), and sulphur (TS) have been performed with the elementary analyser VarioMax CNS (Elementar). The organic carbon content, TOC, was determined as TOC = TC–TIC. The analyses of the content of nickel (Ni), plumb (Pb), copper (Cu), and zinc (Zn), were carried out in the solutions, prepared on the basis of the nitrohydrochloric acid ($HCl : HNO_3$ = 3:1 vol/vol). The contents of Fe, Mn, Cu and Zn were determined with the AAS method using the spectrometer Varian Spectr AA 220. The correctness of the analyses of the contents of C, N, S, as well as Ni, Pb, Cu, and Zn was controlled with the help of the reference materials CP1, NIST1646a, SQ001C, and Sulfadiazin. The total content of cadmium (Cd) and chrome (Cr) was determined with the method of emission spectrometry with excitation of ICP in argon. Altogether, 168 soil samples were analysed.

Heavy metal content in the soils analysed

National road no. 8

As this was already noted in the outline of the methodology of investigations, in the case of the road DK8, the soil was analysed at two segments of the transport corridor, situated in northern and southern parts of Poland. In the soils analysed along the transects situated at the road leading to the boundary with Lithuania (Photograph 1), which is characterised by the biggest number of trucks passing during the day, the highest values of heavy metal content in the soils were registered (Fig. 1). The values, which were registered, for instance, in the vicinity of Suwałki, were, for the case of Cu, close to thirty times higher, for Zn – ten times higher, and for Ni – four times higher than those observed in the southern part of the country, e.g. on the segment of Szczytna (Fig. 2). Similarly, close to three times higher values for cadmium and chrome in the soils were noted in the neighbourhood of the border crossing in Budzisko than in the soils located along the motorway A1 in the vicinity of the service area near Grudziądz (Fig. 3).

Photograph 1. Taking of the soil samples at the national road no. 8 in the vicinity of Budzisko (photograph by M. Degórski)

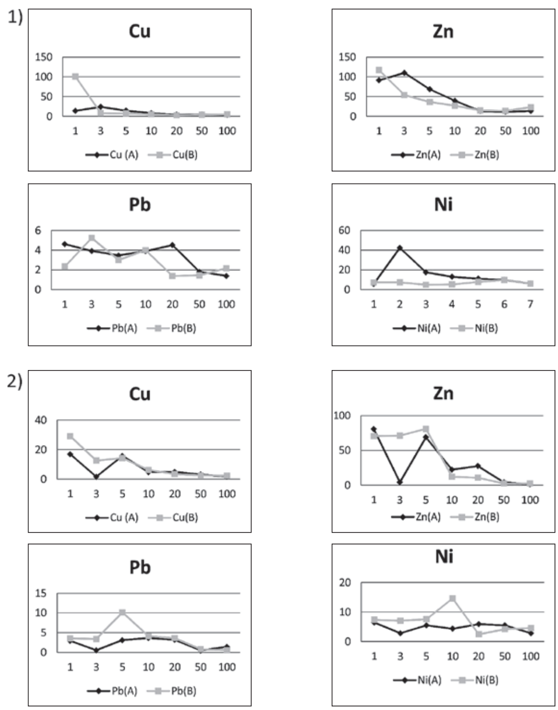

Figure 1. Content of heavy metals, Cu, Zn, Pb, Ni (mg/kg^{-1}) in the soil samples taken from the horizons A and B along the transects, located at the national road no. 8, in the vicinity of the localities of Suwałki (1) and Budzisko (2)

Source: own elaboration.

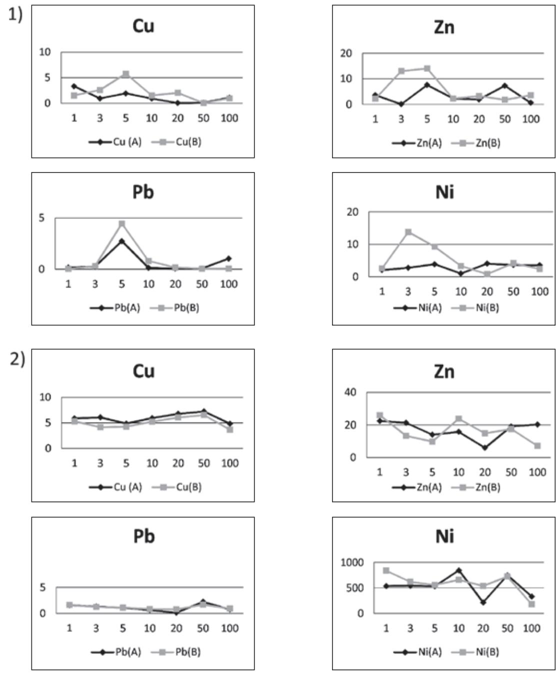

Figure 2. Content of heavy metals, Cu, Zn, Pb, Ni (mg/kg-1) in the soil samples taken from the horizons A and B along the transects, located at the national road no. 8, in the vicinity of the localities of Szczytna (1) and Koźmice (2)
Source: own elaboration.

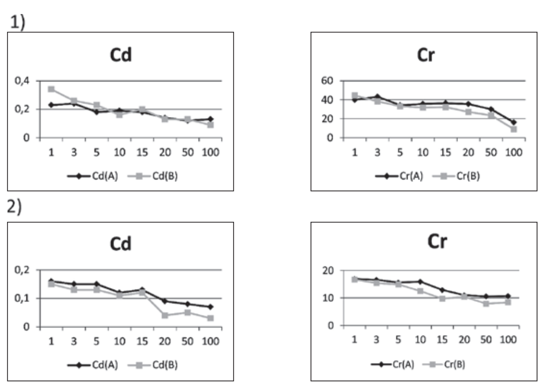

Figure 3. Content of Cd and Cr (mg/kg^{-1}) in the genetic horizons A and B of the soils samples analysed, collected for the study along the transects, situated at the national road no. 8, in the vicinity of the locality of Budzisko (1), and at the motorway A1, in the vicinity of Grudziądz (2)
Source: own elaboration.

When analysing the distribution of the heavy metal content in the soil profiles, in the majority of samples, collected in the neighbourhood of the border crossing in Budzisko, higher concentrations of the elements considered were observed in the sub-surface enrichment horizon (B), at the depth of 30 cm, than in the surface humus horizon (A). A clear decreasing trend along distance from the road is well visible with respect to the content of Cu and Zn. The maximum concentrations of Pb and Ni were noted in the horizon B, for plumb – at the distance of 5 m, while for nickel – at the distance of 10 m away from the edge of the road.

In the samples of the soil, collected along the transect, situated near to the town of Suwałki, the highest concentrations of Cu and Zn were registered at the very road, but the values for Cu dramatically fall off already at the distance of 3 m from the road, while the content of Zn decreases gradually. High content of Cu was noted only in the surface samples of the soil, while of Zn – in the samples taken from both depths. The content of plumb in the samples collected along this transect does not display a trend with respect to the distance from the road. The maximum content of Ni is registered at the distance of 3 m, in the horizon of enrichment (B), at the depth of 30 cm. A significant correlation has been observed between the contents of Zn, identified in horizons A and B, in the samples, collected along this transect. This implies similar conditions of transport of contaminants to the soil and their accumulation.

The concentrations of the heavy metals along the transects near to Koźmice and Szczytna do not display (except for Ni) the trend, associated with the distance from the road. The values for Pb increase insignificantly in the samples from both depths, located 5 m from the road (Szczytna) and 50 m from the road (Koźmice). In the samples, collected along the Szczytna transect, the statistically significant interrelation was noted between the concentrations in horizons A and B, while for the transect of Koźmice, such interdependence was noted for the concentrations of Cu, Pb and Ni.

The expressway S8

The influence of the expressway on the content of heavy metals in the soils was analysed for the transect located in the neighbourhood of the town of Radzymin (Fig. 4). The content of heavy metals in the samples analysed is the lowest among all the soils considered. The trend of decreasing concentrations of heavy metals away from the edge of the road has not been observed in the samples. The sole interdependence registered was that of the copper content in horizons A and B. The analysed segment of the road has been functioning for the shortest time of all those considered in the study. It can be supposed that during the short time of use of the road in conditions of fast movement of vehicles, without braking and standing in the jams (congestion), the process of contamination of soils takes place very slowly.

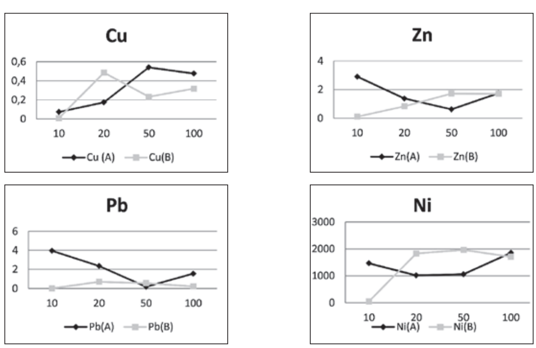

Figure 4. Contents of heavy metals, Cu, Zn, Pb, Ni (mg/kg^{-1}) in horizons A and B of the soils analysed, sampled for the study along the transects, located at the expressway S8, in the vicinity of the town of Radzymin

Source: own elaboration.

The national road no. 17

In the case of the national road no. 17 the analyses were carried out for the soils from the transects situated at the boundaries of the localities of Trzcianka and Ryki (Fig. 5). In the majority of soil samples, taken near to the locality of Trzcianka, higher concentrations were observed in the surface layer of the soil (humus horizon A) than in the samples, taken from the depth of 30 cm (the enrichment horizon B). The downward trend along the distance from the road is visible in the concentrations of Pb and Zn. The maximum concentrations of both these elements were observed in the humus layer (A), at 1 m from the road edge. In the samples, collected along this transect, the correlation was observed of the content of Pb in the horizons A and B.

In the majority of samples of the soil, collected near to the town of Ryki, higher concentrations of the elements considered were registered in the surface layer of the soil (A). The decreasing trend along the distance from the road is visible in the concentrations of Cu, Zn and Pb, with the higher concentrations of plumb having been observed in the horizon from the depth of 30 cm (B). The maximum concentrations of these elements have been registered at the distance of 3 m from the edge of the road. In the samples of the soil, taken along this transect, the correlation of the content of Zn was observed in the horizons A and B.

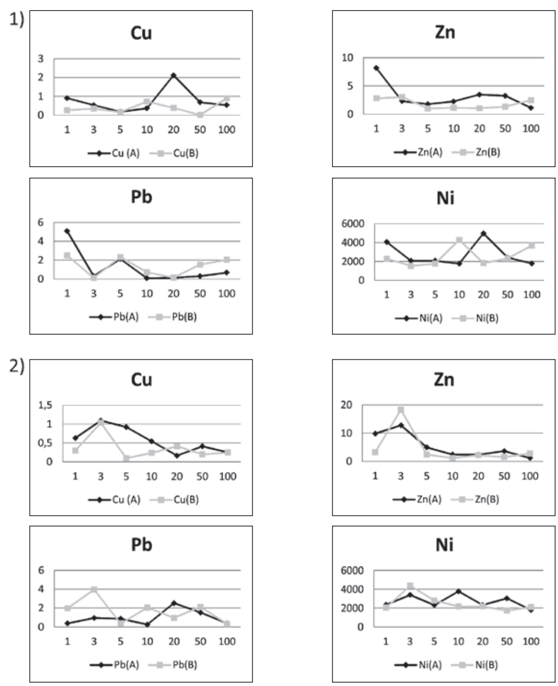

Figure 5. Contents of heavy metals Cu, Zn, Pb and Ni (mg/kg^{-1}) in the horizons A and B of the soils taken for analysis along the transects, situated at the national road no. 17, in the vicinity of the localities of Trzcianka (1) and Ryki (2)

Source: own elaboration.

Motorway A4 and national road no. 94

The surroundings of the motorway A4 between Wrocław and Opole are constituted primarily by the cultivated fields, while there are very limited surfaces of fallow lands and meadows. The results of analyses of heavy metal concentrations, which were carried out for the samples, collected along both transects, show similar trends. The investigations performed showed very low concentrations of plumb in the soils. A slight decreasing trend with the distance from the edge of the road has been observed in the results for the content of copper (Cu) and zinc (Zn), see Figure 6.

Regarding the national road no. 94, analysis was performed of the soil samples along the transects, situated at the boundaries of the localities of Godzikowice and Buszyce (Fig. 7). A very clear decreasing trend of the heavy metal concentrations with the distance from the road was observed along the transect, situated near to the locality of Godzikowice. Insignificantly higher values were observed in the samples, taken from the surface layer of the soil. In the samples, collected along this particular transect, correlation was noted between the concentrations of all the heavy metals considered for the horizons A and B. In the profile of Buszyce no trend was identified concerning the variability of heavy metal content. It is interesting to note that an increase is observed of the plumb concentrations, both in the surface part of the humus layer (A), and in the soil taken from the depth of 30 cm, at the distance of 5 m from the road.

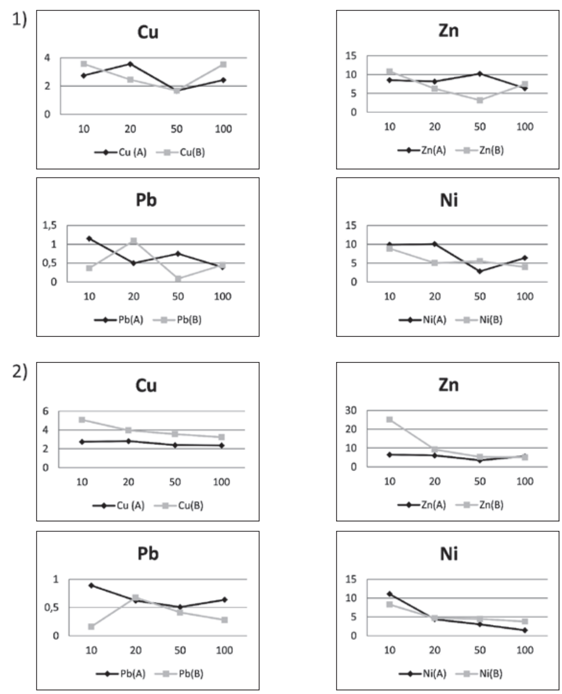

Figure 6. Contents of heavy metals, Cu, Zn, Pb, and Ni (mg/kg^{-1}) in horizons A and B of the analysed soils, collected for analysis along the transects, located at the motorway A4 between Wrocław and Opole (1, 2)
Source: own elaboration.

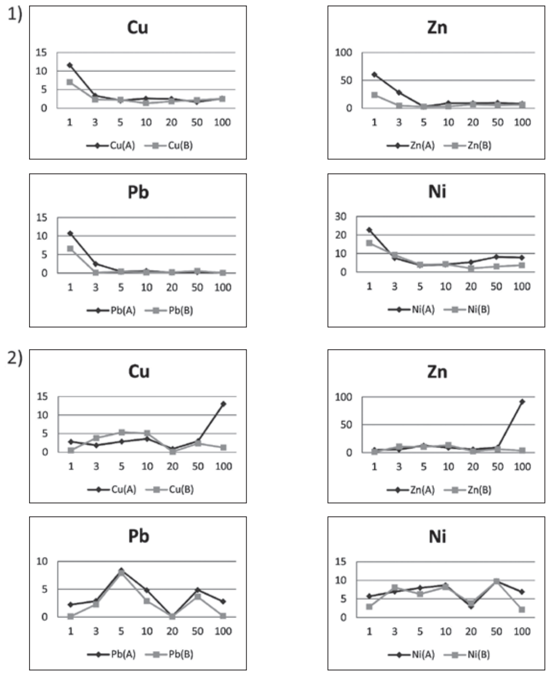

Figure 7. Contents of heavy metals, Cu, Zn, Pb, and Ni (mg/kg^{-1}) in horizons A and B of the analysed soils, collected for analysis along the transects, located at the national road no. 94 in the vicinity of the localities of Godzikowice (1) and Buszyce (2)
Source: own elaboration.

Motorway A1 and national road no. 91

The influence of the motorway on the content of heavy metals in the soils was compared with that of the national road, which is an old transport route, by analysing soil samples taken from the locations near to the town of Pelplin (the old route) and a motorway service station at the motorway A1 (Fig. 8). The results obtained, concerning the concentrations of heavy metals, showed the concentrations several times higher in the soils along the old transport route than along the motorway. The second regularity, observed in this case study, concerned the spatial distribution of the heavy metal content in the soils. And so, along the transect, perpendicular to the old transport route, the highest values of concentrations of Cu, Zn, Pb, Cd, and Cr were registered at the edge of the road, these values decreasing with distance away from the road. On the other hand, in the samples taken from the transect perpendicular to the motorway, the changes of the element content in both soil horizons considered do not display any dependence upon the distance from the road.

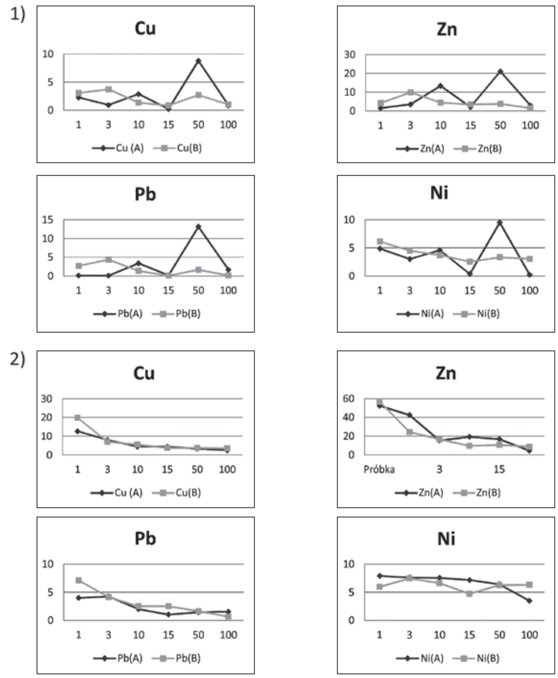

Figure 8. Contents of heavy metals Cu, Zn, Pb, and Ni (mg/kg^{-1}) in horizons A and B of the soils analysed, collected along the transects situated at the motorway A1 in the vicinity of Grudziądz (1), and at the national road no. 91 in the vicinity of Pelplin (2)
Source: own elaboration.

Factors of the road traffic and the contamination of soils

The analysed soil material is characterised by high variability of the concentrations of heavy metals along the road segments considered. The analysis of all samples showed the statistically significant interdependence of content of iron and nickel (r=0.6636), of copper and zinc (r=0.7283), as well as cadmium and chrome (r=0.812), which might indicate the presence of similar factors, decisive for the accumulation of these elements in the soil. High interdependence of concentrations of cadmium, zinc, chrome and copper may constitute the confirmation of their simultaneous emission due to the tear of tires and other components of vehicles, such as brake disks and blocks.

The highest concentrations of these heavy metals were observed in the soils, located close to the old transport routes, where traffic intensity is nowadays still high, and the smoothness of this traffic is hampered. In addition, the highest contents of cadmium, which is the component of fuel oils, were observed in the locations of truck parking places, where engines are often not turned off and the contamination of soils follows, due to continuous action of the exhaust gases – like in the vicinity of the border crossing point in Budzisko.

In the soils analysed no dependence was registered between the concentrations of heavy metals and the organic matter as well as calcium carbonate. On the other hand, very interesting results were obtained from the analysis of dependence of heavy metal content upon the distance from the road – in very general terms it can be stated that there is a trend of decreasing concentrations in the accumulation and enrichment horizon along the increasing distance from the road.

Conclusions

The investigations performed, concerning the analysis of heavy metal content in the soils, located close to the transport routes, allowed for the formulation of the following conclusions:

1. the differentiation in the concentrations of the particular heavy metals in the soils among the particular analysed segments of the transport corridors reached, at the extreme, the ratio of values exceeding 100 – the highest values being noted close to the border crossing to Lithuania, national road no. 8, transect of Suwałki, while the lowest – at the expressway S8 – the transect of Radzymin;
2. the decrease in the concentrations of heavy metals in the soils takes place away from the road towards the open space and the shape of this decrease is more regular in the case of the areas along the national roads, and less regular in the case of areas along the motorways.

The very important elements in the current sanitary state of the soils are, besides the traffic intensity, the velocity, with which the vehicles move, and the time of action of the pressure exerted on the soil. The second group of factors, decisive for the magnitude of accumulation of heavy metals in the soils, is associated with the habitat factors, especially the pedological ones, such as buffering properties of soils, their sorption capacities, or their biochemical activity. Considering the fact that all of the soils analysed developed from the same lithological material (clayey sands), are now under the same form of use (meadows), and are characterised by similar physical and chemical properties, it can be concluded that the environmental conditions, in which the soil analyses were performed, were also similar. Thus, we are left with the issue of intensity of the road traffic and the time period of its impact on the environment. When the time period of influence is similar, then the main causes, decisive for the content of heavy metals in the soils, are constituted by traffic intensity, road parameters, and velocity. Under such circumstances it can be stated that for similar intensity of traffic the impact of the motorways on the environment is distinctly weaker than that of the national roads. Yet, the time duration of accumulation of the contaminants in the soils remains also an important factor.

References

Apeagyei E., Bank M.S., Spengler J.D., 2011. *Distribution of heavy metals in road dust along an urban-rural gradient in Massachusetts*. Atmospheric Environment, 45, 13, pp. 2310–2323.

Bojakowska I., Duszyński J., Jaroń I., Kucharzyk J., Lech D., Maksymowicz A., 2009. *Zróżnicowanie zawartości metali ciężkich w glebach przy drogach wylotowych z Warszawy*. Przegląd Geologiczny, 57, 12, pp. 1073–1077.

Degórski M., 2011. *Influence of traffic into the environment properties and human*. UGI Regional Geographic Conference, United Integration with the World, Conference Proceedings, CD, 20111743H5VYV4, Santiago, pp. 1-9.

Jullien A., François D., 2006. *Soil indicators used in road environmental impact assessments Resources*. Conservation & Recycling, 48, 2, pp. 101–124.

Karczewska A., Kabała C., Lizurek S., Zając S., 2004. *Zanieczyszczenie gleb metalami ciężkimi w sąsiedztwie Szosy Jakuszyckiej na obrzeżach Karkonoskiego Parku Narodowego*. [in:] J. Štursa, K.R. Mazurski, A. Palucki, J. Potocka (eds.), Geoekologické problémy Krkonoš. Sborn. Mez. Věd. Konf., November 2003, Szklarska Poręba. Opera Corcontica, 41, pp. 60–65.

Kopta T., 2001. *Twój samochód zagraża twemu życiu*. Polski Klub Ekologiczny, Wrocław.

Legret M., Pagotto C., 2006. *Heavy metal deposition and soil pollution along two major rural highways*. Environ. Technol., 27, pp. 247–254.

Plak A., Bartmiński P., Dębicki R., 2010. *Wpływ transportu publicznego na zawartość wybranych metali ciężkich w glebach sąsiadujących z ulicami Lublina*. Proceedings of ECOpole, 4, 1, pp. 1–10.

Wołowiec K., 2005. *Kadm, żelazo i ołów w próbkach śniegu zebranych w sąsiedztwie drogi krajowej 762*. Zeszyty Studenckiego Ruchu Naukowego Akademii Świętokrzyskiej im Jana Kochanowskiego, Materiały 14 Sesji Studenckich Kół Naukowych Akademii Świętokrzyskiej im Jana Kochanowskiego w Kielcach.

Wpływ współczesnej motoryzacji na środowisko z uwzględnieniem takich zjawisk jak: efekt cieplarniany, smog, skażenie gleb metalami ciężkimi, sposoby ograniczenia emisji spalin, 2009, www.zadane.pl.