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Soil and plants contamination with selected heavy metals in the area of a railway junction

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Abstract: Heavy metal (As, Mn, Ni, Sn, Ti) concentrations were determined in soil and plant samples collected in different areas of the railway junction Iława Główna, Poland. Soil and plant samples were collected in four functional parts of the junction, i.e. the loading ramp, main track within the platform area, rolling stock cleaning bay and the railway siding. Four plant species occurring in relatively higher abundance were selected for heavy metals analysis, although in the loading ramp and platform areas only one species could be collected in the amount which makes chemical analysis possible. The selected species included three perennials (*Daucus carota, Pastinaca sativa and Taraxacum officinale*) and one annual plant (*Sonchus oleraceus*).

The entire area of the railway junction showed elevated concentrations of heavy metals when compared to the control level. It was most pronounced for the platform area and railway siding. The concentration of arsenic, manganese and nickel in plants growing in these parts of the junction exceeded the toxic level. The highest contamination of soil and plants found in the platform area suggested advanced emission process of the analyzed metals from wheel and track abrasion. Literature review showed that the concentration of the investigated metals in soil was generally higher than that found in centers of cities and along traffic roads proving that the railway is an important linear source of soil contamination.

Introduction

Environmental pollution with heavy metals resulting from the transportation sector has been analyzed mainly in relation to the effect of the road traffic. There are a few papers devoted to the effect of the railway transport on the environment. The operation of railway tracks involves the presence of solid contaminants on the line. The contaminants may originate from the dispersion of freight goods such as coal and minerals or the presence of ballast stone thrown on to the track either by the passengers of the train or during ballast cleaning operations. Railway track suffers from severe wear induced by wind-borne sand particles (Grieve 2001). These phenomena may lead to contamination of the air in the railways vicinity. For example, results from the investigation of ambient aerosol in Zurich-Juchhof, central industrial area of Zurich, at a site located in the immediate vicinity (10 m) of a major railway line showed that more than half of the manganese particles emitted by railway traffic through wheel and track abrasion are found in the coarse mode range (2.5–10 m), and that on average particles are larger for cargo trains than for passenger trains (Bukowiecki et al. 2007, Gehrig et al. 2007). Airborne concentrations of manganese associated with fine particulate matter were observed to be more than 100 times greater in the subway environment than in home indoor or outdoor settings in NYC subway (Chillrud et al. 2005).

In the recently published papers contamination of soil and plants with PAHs and heavy metals (Pb, Cd, Cu, Zn, Hg, Fe, Co, Cr, Mo) in the vicinity of railways was analyzed (Malawska and Wiłkomirski 2001, Liu et al. 2009, Wiłkomirski et al. 2011). Information on soil and plant contamination with other heavy metals which are components of rails, wheels and traction (Mn, Ni, Sn, Ti) (Key to Metals 2009) and As which is present in the soil along a right-of-way from old railroad ties dipped in an arsenic solution, arsenic weed-control sprays, and arsenic-laced slag used as railroad bed fill (MDEP 2003) is sporadic.

All these metals have an adverse effect on human health (Jabłońska-Czapla et al. 2014). Inorganic arsenic is carcinogenic in humans. Long-term exposure produces lung tumours via inhalation and a range of cancers via the oral route (Enterline et al. 1995, Environment Agency 2009a). Manganese can lead to numerous health problems, especially in nervous and respiratory systems (Roels et al. 1992, Leggett 2011). Nickel, tin, and titanium can also cause disturbances in respiratory system (EHC 1980, 1982, Environment Agency 2009b).

The main aim of this work is to present information concerning pollution level of soil and plants with heavy metals (As, Mn, Ni, Sn, Ti) in the area of four functional parts of the railway junction Iława Główna (Poland). The study was a supplement to the investigations carried out in this area (Wiłkomirski et al. 2011).

Due to scarcity of information on emission of these metals by the railway system some data on soil and plants contamination by other anthropogenic activities (nor directly connected to emission from heavy industry and commercial power industry sectors) were presented to illustrate the level of railway impact on the environment stated in our study.

Material and methods

Study area

The investigations were carried out in the area of the railway junction Iława Główna located in northern Poland about 200 km north of Warsaw on the Warsaw–Gdańsk railway route in the western part of the Mazurian Lake Region. This region covered mostly by forests and lakes is relatively clean, since no heavy industry is concentrated there. The junction having such location is the relevant place to investigate the influence of railway transportation on environmental pollution. After World War II, the very old railway junction Iława Główna (built in 1870) became an important junction in Polish Railway Network. Very heavy passenger and goods traffic is concentrated in the area of the junction because Iława Główna is situated at the crossing of a few important railway routes. The railway junction covers an area of almost 2 km^2 within which the different functional parts are situated. Our investigations were carried out at four sites of the junction:

1. The railway siding which consists of many tracks where goods trains wait for unloading. The sampling area was situated in the most frequently used track of the railway siding.
2. The loading ramp which is the track located close to the loading platform where different goods (at present mostly coal) are reloaded from hopper wagons to heavy lorries.
3. Track (referred to as "platform") which is located in the passenger part of the junction and focuses main stream of local and long distance trains.
4. The rolling stock cleaning (referred to as "cleaning bay") which is the separated and unsecured railway track with no facilities preventing the leakage.

Soil and plant sampling

At each of the four investigated sites, a surface covering a total of 120 m^2 was established. The surface consisted of two subsurfaces (60 m^2 each): the first covering a fragment of the tracks situated between the rails (rail gauge) (A) and the second one located outside both rails up to the end of railway ties (B). This allowed us to find the potential differences between the level of contamination inside and outside rails.

Soil samples were collected in predetermined investigation areas in September 2008. The railway basement soil collected from the depth of 0–20 cm was sieved (5 mm sieve) directly at the sampling area.

Each time, 15–20 individual samples were taken thereby providing a mean mixed sample of about 1 kg of the soil representing ballast bed either from the subsurface located between the rails or outside rails.

Dried soil samples were sieved (1 mm sieve) in the laboratory and used for further analysis.

The reference soil samples were collected at three points: (1) the vicinity of a small factory about 500 m southwest of the railway junction, (2) hilly field about 500 m southeast of the railway junction, and (3) field in the suburb town of Iława about 2 km east of the railway junction.

Four plant species occurring in relatively higher abundance were selected for heavy metals analysis, although in the loading ramp and platform areas only one species could be collected in the amount which makes chemical analysis possible. The selected species included three perennials (*Daucus carota*, *Pastinaca sativa* and *Taraxacum officinale*) and one annual plant (*Sonchus oleraceus*). All the collected plant specimens were divided into aerial parts and roots.

Heavy metal analyses were carried out after mineralization using nitric acid and microwaves for plant samples and aqua regia in open system for soil samples. Heavy metal contents (As, Mn, Ni, Sn, Ti) were established by the inductively coupled plasma (ICP) mass spectroscopy technique for plants and ICP-optical emission spectrometry technique for soil samples. The quality assurance and quality control was performed by analyzing the standard samples of known composition.

All the analyses were carried out in Central Chemical Laboratory of Polish Geological Institute which possesses accreditation certificate AB 283.

Results and discussion

In majority of cases the contents of heavy metals in the soil of the junction were higher than at control sites, with exception of titanium. Excluding the cleaning bay area, concentration of heavy metals in all parts of the junction rails was higher inside the rails when compared to their outside (Tab. 1).

In all the investigated plants, the contents of heavy metals were higher in roots than in aerial parts (Tab. 2).

The arsenic concentration, which was the lowest among all investigated elements in soil, exceeded the control level 3–5 times amounting to the range of 14–22 mg kg^{-1}, with the exception of the loading ramp where no increase of concentration was found (Tab. 1). In plants growing in the loading ramp no occurrence of arsenic was found. In plants collected from other parts of the junction, arsenic concentration ranged from 2 to 4 mg kg^{-1} in roots and only in *Taraxacum officinale* growing in the platform area arsenic was detected in leaves in the concentration of 3 mg kg^{-1} (Tab. 2).

Excessive uptake of arsenic by plants is considered to disrupt enzyme function and impair phosphate flow in the plant system, with the general tolerance level considered to be around 2 mg kg^{-1} plant tissue (Kabata-Pendias and Mukherjee 2007, Martin et al. 2009).

Table 1. Content of heavy metals in soil samples collected at the different parts of the railway junction Iława Główna (milligrams per kilogram)

Sampling site	As mg/kg	Mn mg/kg	Ni mg/kg	Sn mg/kg	Ti mg/kg
Railway siding (A)	22	1005	35	19	299
Railway siding (B)	22	867	30	19	267
Loading ramp (A)	4	233	16	5	120
Loading ramp (B)	4	194	8	4	118
Platform area (A)	14	897	120	33	910
Platform area (B)	7	451	37	10	273
Cleaning bay (A)	8	345	17	18	188
Cleaning bay (B)	20	415	22	20	214
Control					
Soil 1	4	132	8	4	317
Soil 2	5	103	6	2	289
Soil 3	4	120	6	2	302

Table 2. Content of heavy metals in aerial parts and root of selected plants collected at the different parts of in railway junction Iława Główna depending on place (milligrams per kilogram dry weight)

		As	Mn	Ni	Sn	Ti
Railway siding						
Daucus carota	AP	n. d	96.9	5.3	2.2	33.6
	R	4	172.6	16.2	4.3	74.4
Sonchus oleraceus	AP	n. d	75.3	3.4	1.9	28.6
	R	5	225.0	20.5	3.9	102.4
Pastinaca sativa	AP	n. d	86.5	3.8	1.8	18.3
	R	4	168.8	15.2	2.9	75.9
Loading ramp						
Sonchus oleraceus	AP	n. d	163.7	3.6	2.3	28.8
	R	n. d	177	8	1.7	99.7
Platform area						
Taraxacum officinale	AP	3	171.8	15.7	4.3	46.9
	R	3	177.1	18	4.7	66.8
Cleaning bay						
Daucus carota	AP	n. d.	116.5	6.5	4	24.9
	R	2	167.1	10.9	5	30.9
Taraxacum officinale	AP	n. d	77	6	6.2	24.8
	R	3	141.5	15	6.2	53.1

Terrestrial plants growing at uncontaminated sites usually contain <0.2 mg kg^{-1} arsenic (Cullen and Reimer 1989). If the arsenic concentration in the soil exceeds 2 mg kg^{-1}, many plants show growth disturbances; some plants are however tolerant to even higher concentrations of arsenic in the soil (Benson et al. 1982, Pitten et al. 1992, Száková et al. 2011).

Most arsenic is used to produce copper chrome arsenate (CCA), pesticide and wood preservative (ATSDR 2007). Elevated concentrations of arsenic have been detected in soils of former railway corridors in South Australia. It resulted from a long-term application of As-based herbicides to control grass growth along former railway corridors. A study of former railway corridors revealed considerable surface (0–10 cm) contamination with As (<20 to >1000 mg kg^{-1}) (Smith et al. 2006). In the arsenic contaminated soil collected from a former CCA wood-treating facility, arsenic concentration was found to be 131 mg kg^{-1} (Fayiga et al. 2007).

Organoarsenic-based chemical warfare agents (CWAs) still pose a notable risk in countries where former military bases in which these weapons were stored have not been reclaimed yet (Pitten et al. 1992). In Loecknitz, Germany which is located close to the Polish border the mean value of arsenic concentration in soils contaminated with such chemical warfare was 923 mg/kg^{-1}. Soil samples taken from uncontaminated sites of the same geographic area showed arsenic background level of 10–50 mg kg^{-1} (Pitten et al. 1992). Mean value of arsenic concentration in velvet grass (*Holcus lanatus*) harvested in this area was 4.3 mg kg^{-1} (Pitten et al. 1992). The amount of arsenic taken up by plants growing at sites with considerable arsenic contamination did not differ greatly from plants growing on slightly contaminated soil. In both samples the above-ground organs contained less arsenic than roots (Pitten et al. 1992). This observation is in line with our results (Tab. 2) and was confirmed by other authors (Larsen et al. 1992, Merwin et al. 1994).

Metropolitan regions are characterized by complex and high production of hazardous substances. Therefore, soils in residential areas and industrial centers show a strong anthropogenic impact. In soil survey made in Berlin when about 4000 soil samples were taken in suburban areas with little or no contamination as well as industrial areas in and around the city, the mean concentration of arsenic was 5.1 mg kg^{-1} for the entire town area with 6,8 mg kg^{-1} in its industrial part (Birke and Rauch 2000).

Manganese concentration in soil exceeded the control level 2–8 times in individual parts of the junction reaching the highest value – 1005 mg kg^{-1} at the railway siding (Tab. 1). The concentration of manganese in plants was at a similar level – about 170 mg kg^{-1} in roots and 75–225 mg kg^{-1} in aerial parts of the plants (Tab. 2). Different metal contents in the leaves of dandelion (*Taraxacum officinale*) reflect the level of environmental pollution and this plant is often used as a bioindicator (Kuleff and Djingova 1984, Kabata-Pendias and Dudka 1991) . In dandelion harvested in the platform area and cleaning bay the manganese concentration ranged from 77 to 172 mg kg^{-1} and from 141 to 177 mg kg^{-1} for leaves and roots, respectively (Tab. 2).

Manganese concentration in plants between 20 and 500 mg kg^{-1} is considered as a normal level; toxicity occurs in plants if the level of manganese exceeds 500 mg kg^{-1} (Adriano 1986, Stokes et al. 1988). Toxicity of manganese in plants is manifested by dark spots on the leaves top and margin chlorosis and defoliation (Horst 1988).

Investigation of the railway effect on soil contamination was performed in the mountain region of Sichuan, China (Liu et al. 2009). Samples of soil were collected from a flat slope, cut slope and embankment. The mean concentrations of manganese at all three sites were significantly elevated compared to those at the control site. The highest concentration of manganese (676.0 mg kg^{-1}) occurred at the cut slope site, which was about four times that of the local background level. Manganese also indicated moderate enrichment in the soils within the range of 10 m at the cut slope site and 25 m at flat site. Heavy metal concentrations decreased with the distance from the track. In our study the increase in manganese concentration in soil when compared to the control level was even higher (4–9 times) in the railway siding and platform areas (Tab. 1).

Methylcyclopentadienyl manganese tricarbonyl (MMT) is a compound added to unleaded gasoline as antiknock compound. It has been suggested that the combustion of MMT in gasoline constitutes a major source of environmental contamination by manganese in high traffic cities (Joselow et al. 1978, Loranger et al. 1994a). Significant differences were found in mean atmospheric manganese concentrations in the urban area compared to the rural area (Loranger et al. 1994b). Analysis of soil samples taken at different distances (10, 50 and 100 m) from an important highway in Montreal revealed decreasing concentrations of manganese as the distances increase. The concentration of manganese was above 30% higher near the highway when compared to the distance of 100 m (768 mg kg^{-1} and 523 mg kg^{-1}, respectively) (Normandin et al. 1999). The authors suggested that the roadside-soils were contaminated by manganese arising from the use of MMT in unleaded gasoline. In dandelion collected in this area, 10 m from the road, the mean concentration of manganese was found to be 15, 26 and 23 mg kg^{-1} for the stem, leaves, and the roots, respectively. No significant differences in manganese concentration and no correlation could be established between the manganese concentrations in dandelion collected in this area and the distance from the highway (Normandin et al. 1999).

Close to high-traffic roads in the center of Rome the concentration of manganese in soil was found to be 546 mg kg^{-1} and in dandelion growing in this area its concentration was 61 mg kg^{-1} and 41 mg kg-1 in roots and leaves, respectively (Malizia et al. 2012).

In herbaceous and germinaceous plants collected near moderately-high traffic volume roadsides in Utah, the manganese concentration in leaves ranged from 44–117 and 43–104 mg kg^{-1}, respectively (Lytle et al. 1995).

The manganese concentrations in dandelion growing in the platform and cleaning bay areas of the Iława Główna junction were several times higher than the levels found in dandelion growing close to above mentioned traffic roads (Tab. 2).

Nickel concentration in soil was from 2 to 13 times higher compared to the control level and reached the maximum value at the platform area (120 mg kg^{-1}) (Tab. 1). The contents of nickel in plant roots was in the range of 8–20.5 mg kg^{-1} with the maximum value found at the platform area where also the highest concentration of nickel in aerial part (*Taraxacum officinale*) – 15.7 mg kg^{-1} was found. In the other parts of the junction, nickel concentration in aerial parts of plants ranged from 3.8 to 6.5 mg kg^{-1} (Tab. 2).

The concentration of nickel in plants in the range of 0.1–5 mg kg^{-1} is considered to be sufficient and the level of 5–10 mg kg^{-1} exceeds normal one but is lower than toxic (Kabata-Pendias and Pendias 2001). Phytotoxic nickel concentrations vary widely among plant species and cultivars and have been reported in the range 40 to 246 mg kg^{-1} (Kabata-Pendias and Pendias 2001). Nickel phytotoxicity has been frequently studied with commonly reported symptoms including chlorosis followed by yellowing and necrosis of leaves, restricted growth, and tissue injury (Kabata-Pendias and Mukherjee 2007, Rooney et al. 2007, Environment Agency 2009b). According to the Institute of Soil Science and Plant Cultivation (IUNG), a normal concentration of Ni in soil ranges from 2 to 50 mg kg^{-1} and a permissible threshold value is 50 mg kg^{-1} (Szczepocka 2005).

Soil and vegetation samples were analyzed at three railway yards inactive for about 20 years on the Island of Montreal. Nickel concentrations in the soil ranged from 26 to 43 mg kg^{-1}. Concentration of nickel in the above-ground parts of dozen of plant species ranged from 1.3 to 7.0 mg kg^{-1} (Murray et al. 2000).

In soil collected from sites located along two major roads carrying traffic flow from W-E and N-S directions of Poznań, Poland, the mean concentration was 5.1 mg kg^{-1} with maximum value of 9.0 mg kg^{-1} and in dandelion leaves, the concentration of nickel ranged from 4.3 to 7.0 mg kg^{-1} (Diatta et al. 2003). In leaves of dandelion plants collected in 13 sites of Warsaw, the mean concentration of nickel was 4.3 mg kg^{-1} (Kabata-Pendias and Krakowiak 1997).

The inner city and surrounding area of Berlin showed enriched concentrations of nickel (a mean value of 10.7 mg kg^{-1} with maximal value of 71.2 mg kg^{-1}), with respect to the regional geochemical background (5.3 mg kg^{-1}) for more than 2000 samples (Birke and Rauch 2000).

In the Iława Główna junction higher concentrations of nickel in the soil were found, particularly in the platform area and similar concentration in leaves when compared to traffic roads and urban environment (Tab. 1, 2).

The soil in the whole area of the junction contains elevated concentrations of tin exceeding the control level 2–5 times with the highest concentration of 33 mg kg^{-1} in the platform area (Tab. 1). The content of tin in plants ranged from 2.2 to 6.2 mg kg^{-1} and from 1.7 to 6.2 mg kg^{-1} in leaves and roots, respectively (Tab. 2).

Relevant literature data indicated the concentration of tin in soil in the range of 0.6 to 8.6 mg kg^{-1}. The average values of tin in 15 different types of soils in the USA ranged between 0.6 and 1.7 mg kg^{-1} (Shacklette and Boerngen 1984, Eckel and Jacob 1988, Eriksson 2001).

There is no evidence that tin is either essential or beneficial to plants. It is considered toxic to both higher plants and fungi. A common range of tin in food plants is reported to be between <0.04 and <0.1 mg kg^{-1}, and in grass from 0.2 to 1.9 mg kg^{-1} (Kabata-Pendias and Pendias 2001).

In 32 soil samples collected along the highway and motor way connecting Nigda with Adana in Turkey, the tin concentration ranged from 6.8 to 15 mg kg^{-1} with the mean concentration of 8.56 mg kg^{-1} (Yalcin et al. 2007).

The mean concentration of tin in the soils of Berlin was 10.8 and 14.7 mg kg^{-1} for the entire area within city limits and industrial area, respectively (Birke and Rauch, 2000).

Titanium content in soil is at this same level as in the control site and only in the platform area a 3-fold higher concentration – 910 mg kg^{-1} was found (Tab. 1). The concentration of titanium ranged from 18.3 to 46.9 mg kg^{-1} and from 30.9 to 102.4 mg kg^{-1} in leaves and roots, respectively (Tab. 2).

The range of titanium contents in surface soils is from 0.02 to 2.4%. The calculated mean for worldwide soils is 0.33%. Titanium in food-plants ranged from 0.13 to 6.7 mg kg^{-1} (Kabata-Pendias and Mukherjee 2007). The highest contents of titanium, about 100 mg kg^{-1}, were found in plants from loess and some weathered in situ soils. Toxicity symptoms at the content of 200 mg kg^{-1} were observed in bush bean, in the form of necrotic and chlorotic spots on leaves (Kabata-Pendias and Pendias 2001).

In a roundabout in Szczecin, Poland, the concentration of titanium in dandelion was found to be 21.38 and 7.62 mg kg^{-1} in leaves and roots, respectively. This site is located above 15 km from the "Police" Chemical Plant where TiO_2 is produced. The concentrations of titanium in dandelion collected in the vicinity of the "Police" plant were 28.17 and 11.5 mg kg^{-1} in leaves and roots, respectively (Ligocki et al. 2011).

In our study the concentration of titanium was higher both in leaves and roots of dandelion and on the contrary to the result from the roundabout the higher titanium concentrations were found in roots when compared to leaves (Tab. 2).

Among the functional parts of the Iława Główna railway junction, the platform area and the railway siding are places with the highest heavy metal contamination. The content of each heavy metal in the soil of all the investigated parts exceeded the average amount of these elements in Poland's soils (Kabata-Pendias and Pendias 1999). According to the Dutch List, the soils of the the Iława Główna railway junction can be categorized into group B with respect to the concentration of nickel, and tin, and for arsenic – into group A. The concentration of arsenic in soil reaching 22 mg kg^{-1} is near the limit value for soil – 25 mg kg^{-1} and is even exceeded for nickel – 70 mg kg^{-1} for industrial and communication areas (Official Journal of Law 2002).

The concentration of arsenic, manganese and nickel in plants growing in the platform area and railway siding exceeded the toxic level. Trace metals in leaves and roots of dandelion from 132 sites in Poland were analyzed for monitoring air/soil pollution (Kabata-Pendias and Dudka 1991). Baselines for the analyzed heavy metals were estimated on the basis of their concentration found in the rural areas of the least polluted parts of Poland. The manganese baseline concentrations for dandelion proposed by Kabata-Pendias and Dudka (1991) are between 15 and 170 mg kg^{-1} for the leaves and between 5 and 50 mg kg^{-1} for the roots. For nickel these values are proposed at the level of 0.5–4.0 mg kg^{-1} and 0,2–3.5 mg kg^{-1}, respectively.

Chemical fingerprints of *Taraxacum officinale* considered as normal concentrations in a plant at background levels (in unpolluted regions in Europe and USA) are given by Djingova et al. (2004). These values are as follows: As 0.1–0.4 mg kg^{-1}, Mn 15–200 mg kg^{-1}, Ni 0.3–4 mg kg^{-1}, Ti 5.6 mg kg^{-1}.

Our findings showed that the concentration of manganese and nickel found in dandelion growing in the platform area and railway siding are several times higher, particularly in roots when compared to the baseline for these metals (Tab. 2). The arsenic concentration in leaves of dandelion growing in the platform area exceeded the normal level 8 times and the concentration of nickel was found to be 4 and 8 times higher than the chemical fingerprint for this element (Tab. 2) (Djingova et al. 2004).

In Kabata-Pendias and Dudka (1991) work, significantly higher concentrations of manganese and nickel were detected in leaves compared to roots. Higher metal contents in leaves compared to roots illustrate a significant source of their aerial origin. The opposite phenomenon was stated in our study. It suggests that the process of heavy metals uptake from soil prevails in the junction area; it is particularly pronounced in the platform area. A similar pattern was found for Pb, Cd, Cu, Zn, Hg, Fe, Co, Cr in this site (Wiłkomirski et al. 2011). It indicates that soil has been heavily burdened with these metals due to a many years' operation of the junction.

Conclusions

The content level of investigated heavy metals was much higher in the area of all the functional parts of the Iława Główna junction than in the control sites. The highest contamination of soil and plants was found in the platform area, where movement of trains is very intensive which confirms an advanced process of the analyzed metals emission from the wheel and track abrasion. A high level of heavy metals in the railway siding, where trains remain in one place for a long time, proves an additional negative environmental effect of transported goods which contain harmful water-soluble substances. These findings indicate a need for renovation works including replacement of rails, railway wooden ties and ballast bed due to long-time operation of the railway junction. The concentration of all investigated metals in soil and plants within the studied area was higher than the corresponding values found along traffic roads and in city centers. This confirms that railway transportation is an important linear source of soil contamination.

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Zanieczyszczenie gleby i roślin wybranymi metalami ciężkimi na terenie węzła kolejowego

W pracy przedstawiono wyniki badań dotyczące zawartości wybranych metali ciężkich (As, Mn, Ni, Sn, Ti) w glebie i roślinach na obszarze węzła kolejowego Iława Główna.

Próby gleby i roślin pobierano w czterech częściach węzła, a mianowicie na rampie załadowczej, torowisku głównym, myjni i bocznicy kolejowej. Na całym obszarze węzła kolejowego stwierdzono podwyższone stężenia metali ciężkich w porównaniu z terenem kontrolnym. Najwyższe stężenia stwierdzano na torowisku głównym i bocznicy kolejowej. Stężenie arsenu, manganu i niklu w roślinach występujących na tym obszarze przekracza poziom toksyczny. Najwyższe zanieczyszczenie gleby i roślin stwierdzane na torowisku wskazuje na występowanie procesów emisji metali spowodowanych ścieraniem kół i szyn. Porównanie z danymi literaturowymi wskazuje, że stężenie badanych metali w glebie jest większe niż w glebach centów miast i wzdłuż drogowych szlaków komunikacyjnych, co dowodzi, że linie kolejowe stanowią istotne liniowe źródło zanieczyszczenia gleby.