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INFLUENCE OF THE ROAD TRAFFIC ON QUALITY OF THE WATER OF SILNICA RIVER

WPŁYW RUCHU KOMUNIKACYJNEGO NA JAKOŚĆ WÓD RZEKI SILNICY

Abstract: Silnica River is a small river cutting through the city of Kielce from the North to the South-West. It has its source in Masłowskie Range at a height of 360 m a.s.l. and it flows into Bobrza River. It is ranked among mountain rivers at a 6.4 ‰ gradient. Its river-bed has belonged to Kielecki Protected Landscape Area since 2006. Next to Szydłowek estate the artificial water body was build – Kielecki Bay. Beneath Kielecki Bay, Silnica River flows in regulated river-bed. Because of no separated storm water drainage, the rainwater washes away pollutants among others from industrial plants, houses, pavements, and streets into Silnica River. The aim of this study is to present results of the research on influence of the road traffic on physiochemical properties of the water of Silnica River. Points of the heaviest traffic volume in Kielce located at the river were analysed. The research program included analysis of pH and heavy metals: Pb, Cd and Ni. Atmospheric conditions were observed at the same time. The obtained results showed that depending on analysed point the pollution of the Silnica River water reached different levels. This is a result not only of external factors such as praximity of roads and the road traffic volume but also the processes occurring in water environment.

Keywords: Silnica River, road transport, land use, biogenic compounds, heavy metals

Human activity contributes to degradation of individual components of the environment. Apart from industry, public utilities and farming the highest and at the same time the most negative influence is caused by the road traffic that emits 15 thousands of chemical compounds to the environment [1]. Noxious substances being a mixture of many substances occur in different states of aggregation [2]. Substances emitted from motor vehicles are dispersed in the air, water and soil causing pollution of particular environmental compartments. Their influence depends not only on means of transport and road traffic volume but also on processes shaping pollutant spread in the environment. Additionally the transportation causes deformation of the lie of the land, disturbance of bedrock structure and devastation of plant and animal life.

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The highest amount of exhaust gases is emitted during idle run for example when warming up a car in the winter and when waiting before a crossroad, accelerating and braking [3]. However depending on type of fuel used, an amount of noxious components in exhaust gases from vehicles after burning of 1 kg of fuel is different (Table 1).

Table 1

Amount of noxious components in exhaust gases from vehicles after burning of 1 kg of gasoline and diesel oil [4]

Type of components	Amount of components [g · kg^{-1} fuel]	
	Petrol	Diesel oil
Carbon oxide (CO)	465.69	20.81
Hydrocarbons (HC)	23.28	4.16
Nitrogen oxides (NO_x)	15.83	18.01
Sulphur trioxide (SO_3)	1.86	7.80
Aldehyde	0.93	0.78
Carbon black	1.00	5.00
Lead (Pb)	0.50	—

In Poland a typical car travelling 10 thousand kilometres a year consumes approx. 14.5 thousand kilograms of fuel and emits 328 kg of carbon oxides, 110 kg of hydrocarbons, 20 kg of nitrogen and sulphur oxides and 5 kg of carbon black [3]. However one has to remember that the amount of chemical compounds in atmosphere depends both on the number of motor vehicles, a number of kilometres they travel and fuel type, and on size, construction and working conditions of the engine [3, 5]. A concentration of automobile exhausts is variable in time and at the same time proportional to the road traffic volume. That is why a minimum concentration of pollutants is observed in night hours while maximum concentrations are found during the highest road traffic volume [4].

The chemical compounds in atmosphere are subject to various processes, especially physical, chemical and photochemical ones, which cause changes of pollutant concentration because of forming new substances or pollutant transportation. Wind speed,

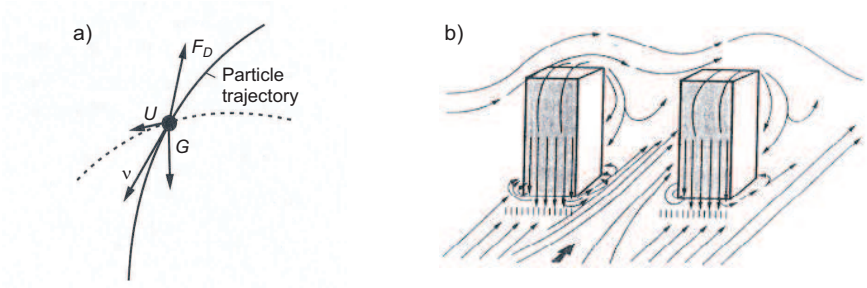

Fig. 1. Diagram: a) particle falling in the air, where U – wind speed, v – particle fall velocity, G – body force coming from gravitational acceleration, F_D – resisting forces of medium [5]; b) air flow above and around buildings [6]

particle fall velocity, body force coming from gravitational acceleration, resisting forces of medium should be taken into consideration (Fig. 1a) as well as medium viscosity in which a given particle is moving, diameter of falling particle, type, motion and thermodynamical parameters of medium and a presence of various obstacles during analysing a trajectory of particle falling in the air (Fig. 1b). Both meteorological conditions and development and use of the land near roads have tremendous influence on migration of pollutants.

Apart from land use, closeness of pollution source and meteorological conditions, the following hydrological factors significantly influence quality of water of surface streams:

– water depth, cross-section area, discharge and velocity distribution in a river,

– slope of energy drop line and a line of free surface of water and longitudinal profile of a river,

– formed free surface under constant atmospheric pressure,

– external body forces coming from terrestrial field of gravity, resisting force of flow caused by viscosity and hydrostatic pressure forces,

– type of flow – laminar flow, turbulent flow, transition form [5, 7].

An influence of air mass causes both positive and negative effects for the environment. Airing, accelerating the evaporation and preventing cool air from accumulation in sheltered and concave places influences positively the nature because it prevents dangerous substances to be deposited in one place. On the other hand a contamination of water and soil at closer or more distant locations to a source of emission of exhaust gases is an effect of negative wind influence [5, 8].

Study area

Silnica River flowing into Kielecki Bay and cutting through the centre of Kielce from the North to the South thus having profound importance for shaping hydrological conditions in the most urbanised part of the city was selected for the research [9]. It has its source in Masłowskie Range at a height of 360 m a.s.l. and it is the left-bank tributary of Bobrza River. The watercourse has 18.9 km in length. Silnica is ranked among mountain rivers at a 6.4 ‰ gradient. A catchment area is 49.9 km^2 and 44 % of this area is urbanized. A river-bed of catchment has belonged to Kielecki Protected Landscape Area since the second half of 2006 [10, 11].

A section of Silnica River including 4 crossroads of the city of Kielce has been selected for the research (Fig. 2).

The first measurement profile was located at Jesionowa St. that is a direction towards Łódź. It is a section of 950 m in length being at the same time a section of the state road No. 74 [12] cutting through the recreation ground located at Kielce Bay and Silnica River. Single- and multi-family building and an outbuilding is situated along the street.

Whereas IX Wieków Kielc St. with 2^{nd} measurement point is located in the city centre. This street is a part of regional road No. 702, it is 1.1 km long and functions as the North section of the city centre ring road. Cross-section of this road is very expanded and comprises two roadways with two or three lanes each, and the number of

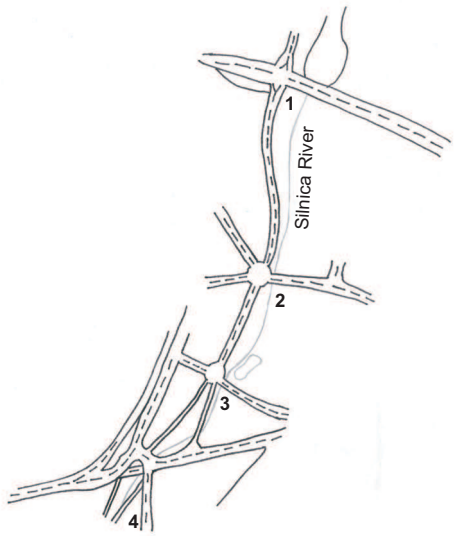

Fig. 2. Places of sample collection: 1 – Jesionowa Street, 2 – IX wieków Kielc Street, 3 – Ogrodowa Street, 4 – Krakowska Street

lanes increases at exits of crossroads [12]. An outbuilding and multi-family building is situated at various distances to the street.

Ogrodowa St. (3rd measurement point) is a section of DW regional road No. 760 on the way: Kielce – Piekoszów – Łopuszno, and at the same time it links the city centre with the Western residential area of the city [13]. The street goes through corridor–like way along which there are high trees separating the street from the public park on the one side, while there are the high outbuilding and single- and multi-family building on the other side of the street.

Krakowska St. is a section of DW regional road No. 762 on the way: Kielce – Małogoszcz towards Kraków [13]. 4th profile of sampling was located next to split level junction. On the East and South-eastern side of the street in the close neighbourhood there are recreation grounds (Kadzielnia Reserve) and single-family building, while on the North side there is a housing estate with the high multi-family building.

Experimental part

The research was carried out every first Monday each month starting from September to November 2007. It comprised an analysis of traffic volume in selected streets, and a quality of water and bottom deposits of Silnica River flowing close to selected measurement points. In defined hours, a number of motor vehicles moving on selected sections of the streets was counted taking into consideration a division into cars, trucks and buses. Atmospheric conditions with regard to such components as precipitation, insolation and wind speed were observed simultaneously.

The chemical analysis included both tests of water and bottom deposit samples. A solid material was collected from a layer located at a depth of 0–10 cm. Ground samples of deposits were dried to reach constant mass at 105 ^{o}C, and then it was triturated in agate mortar and sieved to obtain a fraction of grains of a diameter ≤ 100 μm. 3 samples of 2 g in mass were collected for mineralization from a representative and homogeneous batch of the material and underwent mineralization supported by microwave radiation and concentrated trioxonitric(V) acid. The AAS method was used to determine heavy metals (Pb, Cd, Ni) in water samples and extraction solutions obtained from microwave mineralization of bottom deposits. A correctness of determination was confirmed by standard addition method with an accuracy of ±4 %. Statistica 6.0 computer application was used to compile the results.

Results and discussion

The motor transport is one of the factors that influence air quality in Kielce. The transport tremendously contributes to total amount of pollutants emitted to the atmosphere including dust containing heavy metals like Pb, Cd and Ni. In the city centre in rush hours during the highest traffic volume and the slowest traffic, huge emission of pollutants is reported what is linked to frequent starts and stops of vehicles [14].

The analysis of traffic volume was carried out in selected measurement points, and on the basis of tests of water and bottom deposit samples a cleanliness of Silnica River was evaluated. The selection of measurement points was dictated by the importance of particular streets for the city of Kielce and resulting increased road traffic. Additionally the closeness of watercourse was of significant importance in order to define an influence of the road traffic on quality of water of Silnica River.

On the basis of the research it was observed that traffic volume was the highest at the measurement point No. 1 and it was the lowest in the measurement point No. 4 while in measurement points No. 2 and 3 the number of all vehicles was comparable (Table 2). A quantitative distribution of cars and buses moving on the roads during the research coincides with total traffic volume in these days. However it was different in the case of trucks which volume is the highest in the measurement profile No. 4 and the lowest in the measurement point No. 2. It should be added that in the measurement point No. 3 the trucks were not reported at all.

Substances emitted to the atmosphere are spread by the wind and get mixed with a surrounding air. It leads to standardization of concentration of these compounds in the layer of turbulent atmosphere [5]. A level of dilution of a dangerous substance depends on development and use of the land, and on meteorological conditions in observed time.

Along with Silnica River course that is from the point No.1 to the point No. 4, a general fall of the ground is visible within the valley. Topographic features of the city show properties of depression what influences natural airing system of the city. A low wind speed or the weather calm favours formation of local concentrations of pollutants, whereas higher speed of the wind contributes to dispersion and decrease of local concentrations. However such situation takes place if there are possibilities for the

so-called airing of the city that is if there are corridors without building perpendicular to prevailing directions of the wind [14].

Table 2

Traffic volume (between the hours of 7.00 and 19.00) in the analysed streets of the city of Kielce during measurements performed from September to November 2007

Type of transport	Month	Streets			
		Jesionowa	IX wieków Kielc	Ogrodowa	Krakowska
Cars	IX	34232	27360	29039	23740
	X	30440	31740	28440	22816
	XI	33232	29976	31920	27000
Trucks	IX	1828	1038	0	1959
	X	1744	1156	0	1748
	XI	1382	1156	0	1864
Buses	IX	1226	626	647	528
	X	1248	664	607	588
	XI	1226	626	637	573
Total		106558	94342	91290	80812

It was observed that Western and South-western winds dominated in the analysed stands. The best conditions for pollutant spread were found in Krakowska St. where the area is open towards the North. However as far as Ogrodowa St. is concerned, because of the street location in a "tunnel" formed by trees and public park on the one side, and high building on the other side, pollutant spread is very limited. Such conditions cause that emitted substances are deposited in the area of their emission source.

The results of tests of water samples and bottom deposits of Silnica River (Table 3; Fig. 3) confirm the complexity of factors contributing to the quality of water of this watercourse. Chemical potential of hydrogen ions (pH) in water of the river in general amounts from 6.5 to 8.5 what indicates low aggressiveness. It should be also emphasized that high values of pH do not favour washing out the metals from the bottom deposits.

Average values of this factor in individual measurement points in Silnica river-bed ranged from 5.9 to 8.0, and extreme values amounted to 5.8 and 8.0. These values decreased along the course of the river that is from the measurement point No. 1 towards the measurement point No. 4. The lowest pH was reported in Krakowska St. profile located next to road interchange, whereas the highest pH was observed in the profile placed below the water basin – Jesionowa St. profile.

Based on the results it can be noted that the content of heavy metals is diverse both in water samples and in bottom deposits collected in the individual measurement points of tested river. An average lead concentration in water samples decreases along with the river course from 0.143 to 0.103 ppm. As far as cadmium is concerned, the opposite situation is observed. The content of this metal in the water increases from 0.004 ppm at the measurement point No. 1 to 0.011 ppm at the measurement point No. 3 whereas it decreases to 0.004 at the measurement point No. 4. The results of analyses for nickel

indicate a lower amount of this metal in water samples collected from measuring points No. 2 and 4 compared with samples collected from the points No. 1 and 3.

Table 3

The results of tests of water samples and bottom deposits of Silnica River collected from 4 measurement points from September to November 2007

Measurement points	Month	Analytes						
		Water				Sediment		
		pH	Pb [ppm]	Cd [ppm]	Ni [ppm]	Pb [ppm]	Cd [ppm]	Ni [ppm]
1	IX	8.1	0.049	0.001	0.040	155.1	18.2	15.10
	X	7.8	0.050	0.002	0.045	108.0	14.5	11.26
	XI	8.0	0.044	0.001	0.029	100.1	9.25	17.31
2	IX	6.8	0.036	0.003	0.033	122.1	34.1	31.22
	X	7.1	0.045	0.003	0.042	148.9	37.2	40.01
	XI	6.9	0.042	0.002	0.012	117.2	32.0	38.73
3	IX	6.8	0.030	0.002	0.031	102.2	21.67	38.90
	X	6.3	0.038	0.005	0.044	133.1	24.52	29.07
	XI	6.5	0.049	0.004	0.034	110.0	22.84	28.08
4	IX	5.9	0.035	0.001	0.029	87.22	9.22	11.02
	X	6.1	0.027	0.002	0.020	77.24	11.41	10.29
	XI	5.8	0.041	0.001	0.037	78.13	8.53	10.83
RSD [%]			19	22	16	18	19	21
RS			0.011	0.0005	0.014	21.34	3.92	5.23
Background			—			15	< 0.5	5

Together with samples of the water of Silnica River, the bottom deposits were also collected and analysed for Pb, Cd and Ni after mineralization supported by microwave radiation. Based on the results, at first the increase and then the decrease of the content of the metals in tested material can be found along with the watercourse. The highest

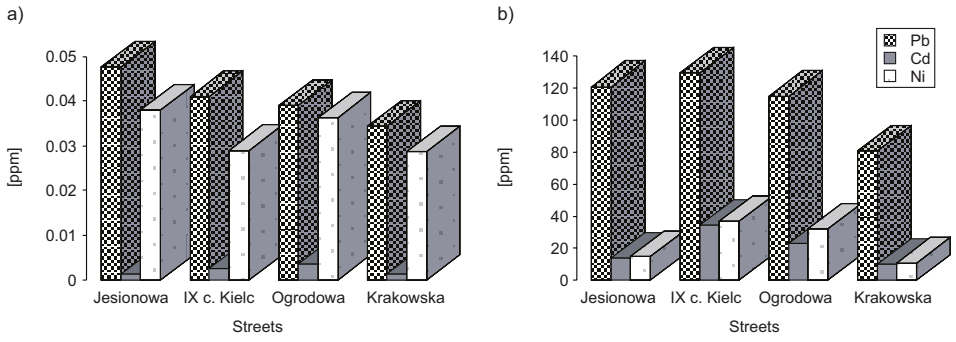

Fig. 3. Average concentration of heavy metals in water (a) and bottom deposits (b) of Silnica River in individual measurement points

average amounts of tested metals were observed at the measurement point No. 2 whereas the lowest ones at the point No. 4.

The concentrations of metals obtained in samples of bottom deposits and water indicate transportation of the material and accumulation of heavy metals at the measurement point No. 2, despite the highest traffic volume is observed in Jesionowa St. (point No. 1). After penetration to the water of Silnica River, heavy metals precipitate and then depose at the measuring point No. 1 because of high pH of water environment. However a fall of water from sluice and land slope causes that suspended material and eroded material are carried by the river from the deposition place for longer distances and that is why metals have accumulated in the bottom deposit at point No. 2.

Additionally a land use in individual measurement points is an important factor. As far as Jesionowa St. is concerned, the direction of deposition is parallel to the water course, while IX Wieków Kielc is characterized by falling the contamination in the place of generation. At the measurement point No. 3 in Ogrodowa St. where the traffic volume is less at points No. 1 and 2, motion of the air-mass resulting from land use causes a migration of pollutants in direction perpendicular to the water course. It determines the amount of deposited substances in the river. The best conditions for dispersion of heavy metals emitted by transport were found in Krakowska St. what was confirmed by the results of water samples and bottom deposits collected from Silnica River.

Recapitulation

The migration of pollutants in the environment is a complex process what results from factors that contribute to the motion of particles in individual media. Compounds emitted to the air are subject to both physical and biological processes that cause deposition, transfer for long distances and transformation of these compounds.

Pollutants begin their travel in the watercourse during the exchange of substances between the air and the water. Most of heavy metals are fixed and transported in rivers with the suspension what leads to formation of bottom deposits in surface water characterized by fast and slower flow. One should remember that the material accumulated on the bottom of river-bed may be a source of secondary pollution of the ecosystem due to changing chemical properties and despite no inflow of pollutants.

Pollutants brought into water ecosystems undergo various processes including transportation and sedimentation causing their migration for diverse distances. Some part of compounds of heavy metals undergo more or less permanent deposition in the bottom deposits. Depending on properties of pollutants themselves as well as water environment properties and hydrological factors such as speed and characteristic of the flow or river-bed morphology, these compounds get decomposed. During Evaluation of the rates of heavy metal pollution of water basins, their content in bottom deposits in particular in the finest clayey layer is determined. They can be transported with clayey layers for long distances and join even sea sediments [15]. This aspect of bottom deposits makes them especially useful material for research on determining major

sources of pollution because they work as absorption column and provide clear picture of phenomena occurring in water above them [16].

Silnica River cutting through the centre of Kielce from the North to the South is cut by routes of high traffic volume. However the building found in tested area comprising 4 measurement points is very diverse determining the quality of water ecosystem. The concentration of heavy metals in the water samples and in the bottom deposits is a result not only of the close location of routes and the amount of moving vehicles but also of land use and meteorological conditions that determine the process of deposition or migration for long distances.

Based on performed analyses it was observed that the bus traffic volume and contamination of Silnica River by heavy metals was higher in IX Wieków Kielc St. than that of Jesionowa St. This is because apart from meteorological conditions, the building had considerable influence that limited the migration of pollutants and influenced deposition in the place of generation. However in Jesionowa St. despite higher car and truck traffic volume, the water of Silnica River was less contaminated by heavy metals. Open space typical for that section of Jesionowa St. contributed to that situation. Pollutants generated during road traffic migrate for long distances due to the wind what causes their less concentration in the place of formation.

The performed research indicates that further analysis is necessary including monitoring of the road traffic volume and physiochemical properties of the water and bottom deposits of Silnica River. It will allow to track trends of changes in the environment.

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WPŁYW RUCHU KOMUNIKACYJNEGO NA JAKOŚĆ WÓD RZEKI SILNICY

Samodzielny Zakład Ochrony i Kształtowania Środowiska,
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Abstrakt: Silnica jest niewielką rzeką przecinającą miasto Kielce z północy na południowy zachód. Wypływa z Pasma Masłowskiego na wysokości 360 m n.p.m. i uchodzi do Bobrzy. Ma charakter rzeki górskiej ze spadkiem wynoszącym 6,4 ‰. Koryto rzeki od połowy 2006 r. wchodzi w skład Kieleckiego Obszaru Chronionego Krajobrazu. Na wysokości osiedla Szydłówek wybudowany został sztuczny zbiornik – Zalew Kielecki. Poniżej zalewu Silnica płynie w sztucznie uregulowanym korycie. Na skutek braku osobnej kanalizacji woda deszczowa spłukuje i wprowadza do Silnicy zanieczyszczenia m.in. z terenów placów zakładowych, posesji, chodników, ulic. Celem pracy jest przedstawienie wyników badań nad wpływem ruchu komunikacyjnego i zagospodarowania terenu na właściwości fizykochemiczne wód rzeki Sinicy. Przeanalizowane zostały punkty o największym natężeniu ruchu samochodowego dla miasta Kielce. Program badawczy obejmował analizę pH oraz metali ciężkich Pb, Cd i Ni. Równocześnie prowadzono obserwację warunków atmosferycznych. Wody rzeki Silnicy, w zależności od analizowanego punktu, charakteryzowały się różnym stopniem zanieczyszczenia, co jest efektem wpływu zarówno zagospodarowania terenu, jak i panujących warunków atmosferycznych.

Słowa kluczowe: Silnica, ruch komunikacyjny, zagospodarowanie terenu, związki biogenne, metale ciężkie