



## INVESTIGATION INTO HEAVY METALS IN STORM WASTEWATER FROM VILNIUS ŽIRMŪNAI DISTRICT AND POLLUTANTITS SPREAD MODEL IN NERIS RIVER

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**Abstract.** The paper discusses investigation into uncleaned storm wastewater pollution with heavy metals in Vilnius Žirmūnai district. The goal is to determine the dependency of storm wastewater pollution with heavy metals on transport intensity. After determining this dependency, sweeps from street points is experimentally studied with the most intensive transport flows. As the street sweeps together with storm wastewater are both outflow from streets and through outflow pipes directly to the Neris, heavy metals in the outflow pipe sludge are also studied for each pool. The following heavy metals have been experimentally studied: Pb, Mn, Cr, Zn, Cu, Ni. The flame atomic absorption spectrometry method was used. The process of analysis is explained in short and its results are provided. A mathematical model by Phoenix 3.5 version program showing the distribution of heavy metals in the Neris river stream is made on the basis of the results received.

**Keywords:** storm wastewater, outflow pipe, heavy metals, street sweeps, Neris river, Žirmūnai, spread of pollutants.

### 1. Introduction

Urban environment is a complicated system, because 70–90% of all the soil lies under the streets, pedestrian paths, buildings and therefore, its natural environmental recovery takes a lot of time, a natural energy and material circulation are destroyed. Street surface could protect soil from pollution like a filter, however natural filtration disappears and in this way, pollutants, heavy metals in this case (zinc, copper, lead, manganese, nickel, chrome) from the streets flow to the waste pipes and directly to the rivers (German *et al.* 2002]). Zinc (Zn) keeps in soil up to 70–510 years, cadmium (Cd) – 13–1100 years, copper (Cu) – 310–1500 years, lead (Pb) – 749–5900 years (Jankauskaitė 2002; Taraškevičius *et al.* 1998). Heavy metals cannot ruin or be destroyed, they accumulate in living organisms and have a harmful influence on human beings and living organisms and water biota (Lee *et al.* 2006; Brannvall *et al.* 2007).

One of the major pollutants in the city is transportat. Large amounts of transport pollutants go directly on the streets and around the driving part of the road (Jucevičienė 2003; Cserekye 2010). Most of the heavy metals from transport spread through flue gas, oils (during accidents), wearing tires and brakes, deteriorating street surface (Davis *et al.* 2001; Sorme *et al.* 2002).

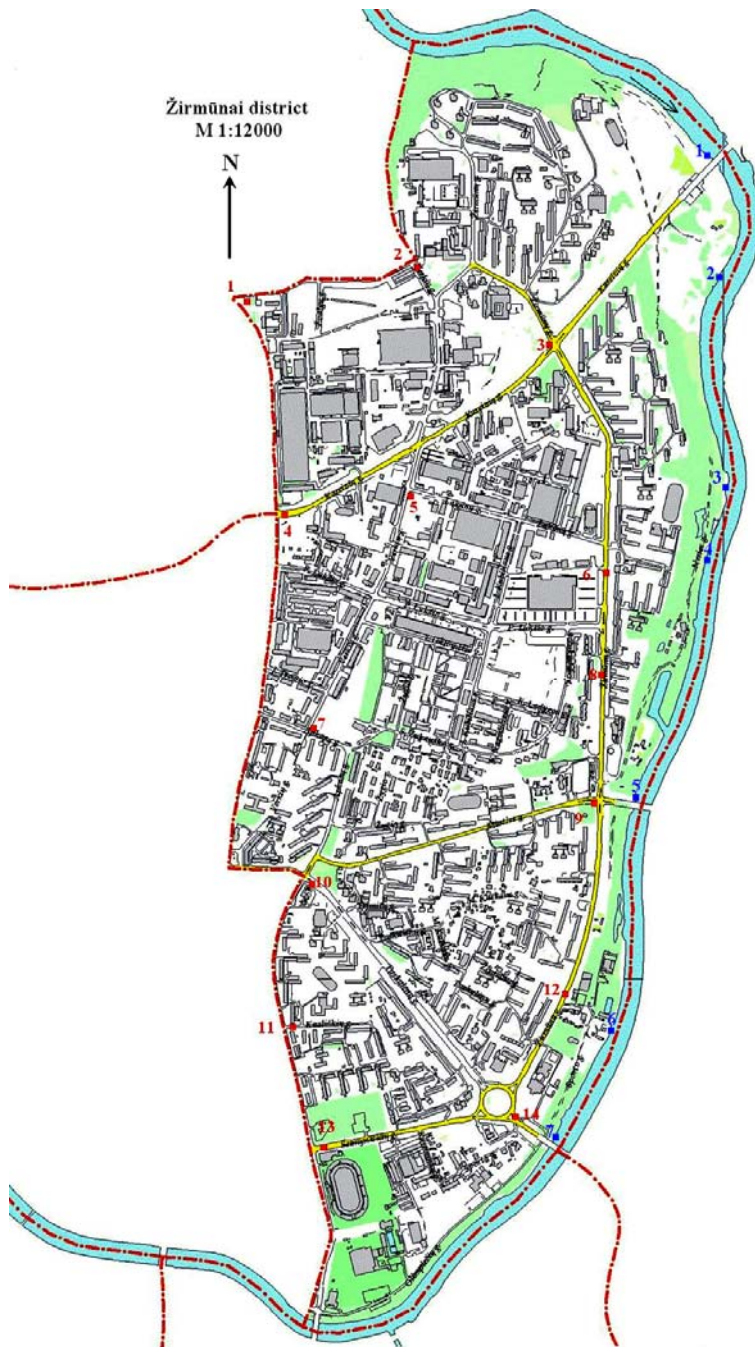
The main goal of the investigation is to determine through experiment, the pollution of uncleaned storm wastewater, outflowing into the Neris river through out-

flow pipes, with heavy metals starting from Žirmūnai district and make a model for pollutant spread in the river stream.

### 2. Investigation methodology

For performing a test for heavy metals concentration in storm wastewater outflow, the researchers chose Žirmūnai district in Vilnius city with the biggest number of inhabitants (Fig. 1). For acquiring the relation between storm wastewater outflow and those of heavy metals from the vehicles, the street sweeping samples from the street points having the greatest amount of vehicle flows and sludge samples from the outflow pipes in Žirmūnai district are taken. The samples taken are studied at research lab in the Department of Environmental Protection at VGTU according to methodology: “Measuring the concentration of heavy metals in the sewage, soil, ground and sludge with a flame atomic absorption spectrometry”.

Dried samples are sieved through Retsch AS200 sieves up to 1 mm sieve. Each sample is weighed by 0.500 g each and reduced with a 12 ml nitric acid (HNO<sub>3</sub>) and hydrochloric acid (HCl) solution with an appropriate proportion 1:3. Ready-made samples are mineralized with Milestone Microwave. After the mineralization process, sample solutions are diluted by 50 ml distilled water and analyzed with flame atomic absorption spectrometer Buck Scientific 210 VGP.



**Fig. 1.** Sampling points in Žirmūnai district. 1, 2 etc. – the highest intensity transport points (samples of sweeps); 5, 7 etc. – outflow number (samples of storm wastewater)

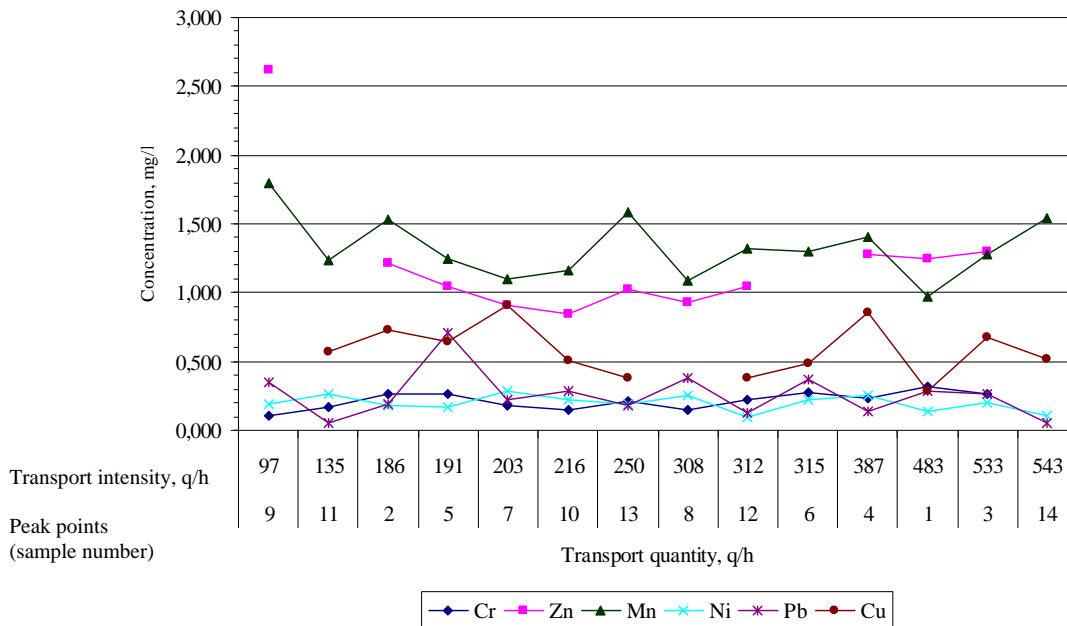
### 3. Investigation results

Concentration of heavy metals (Cr, Zn, Mn, Ni, Pb, Cu) (mg/l) in street sweeps (Fig. 2) and in sludge from the storm wastewater outflow pipes (Fig. 3) are measured with a flame atomic absorption spectrometer.

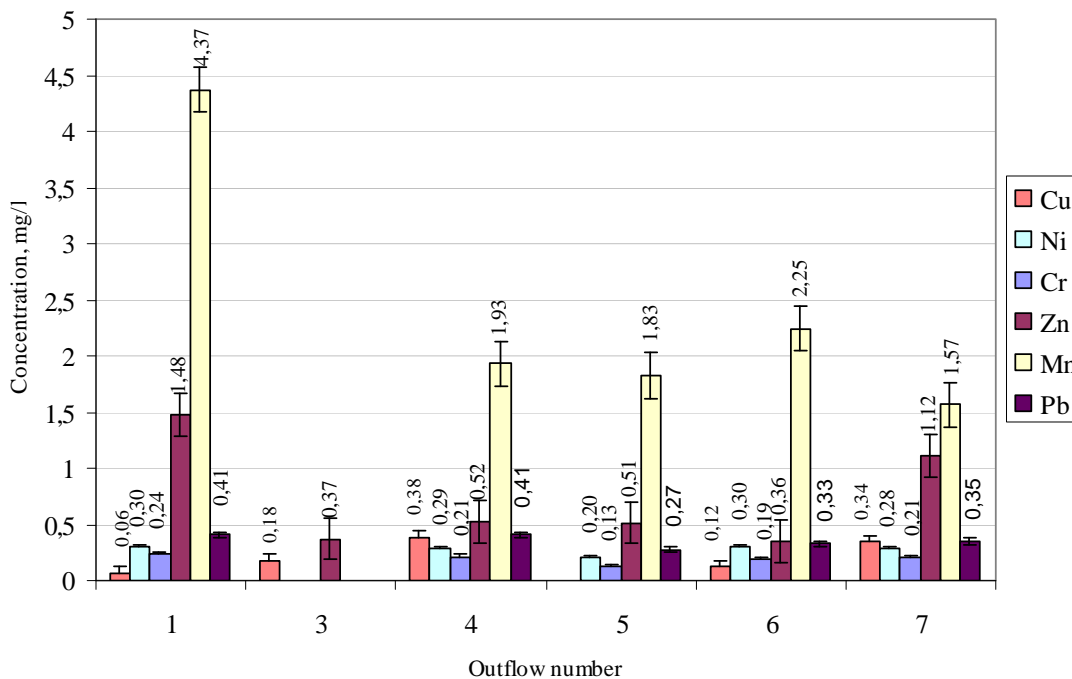
The highest concentrations are those of Mn, Zn, Cu (in street sweep) and Pb (in sludge). According to the

hygienic norms (HN 60:2004) heavy metals in street sweeps and sludge exceed the norms 11 times (Table 1).

According to the data analyzed, concentration of heavy metals in street sweeps have no direct dependency on transport intensity. It is clearly indicated in Fig. 4, where the concentration of the major heavy metals Zn and Mn in street sweep are presented subject to transport intensity.



**Fig. 2\*.** Comparison of heavy metals concentration (mg/l) of sweeps by transport quantity (q/h) at peak points  
 \*Comment. There are gaps in point 6 and 11 of Zn and in point 8 of Cu, because results are above confidence interval



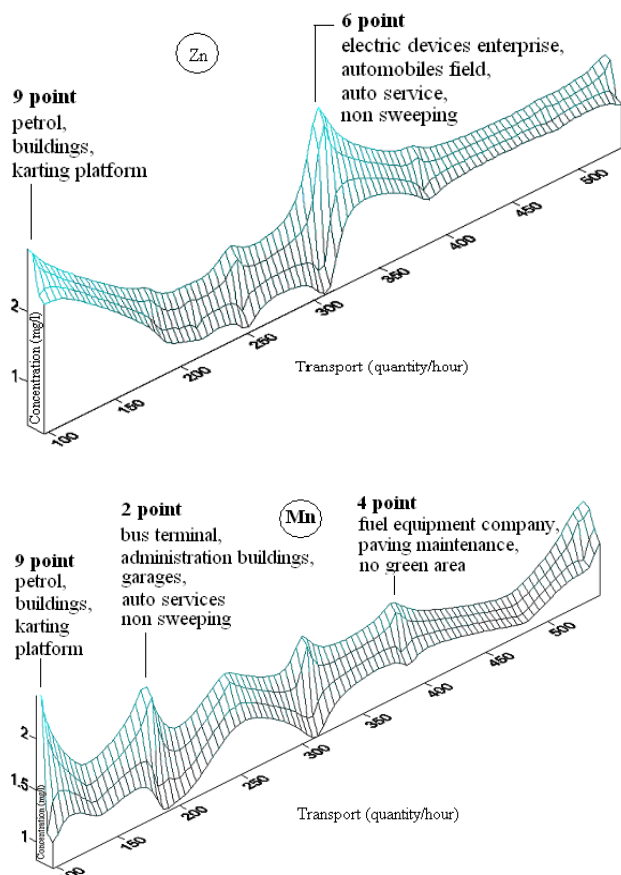
**Fig. 3.** Heavy metals concentration in outflow \*Comment. There are gaps in outflow 3 of Ni, Cr, Mn, Pb and 5 of Cu, because results are above confidence interval

Consequently, concentration of heavy metals in street sweeps depends on the surrounding environment (green zones, surrounding companies and industry, fuel, vehicle repair shops), frequency and time of vehicle stops because of the traffic jams and crossroads, driving speed, number of accidents, frequency of street sweeps works (sweeps export). Part of heavy metals get to streets from roofs (Cu, Zn, Pb), wearing street surfaces. A general concentration of heavy metals (general pollution) in Žirmūnai geographical territory is presented in Fig. 5. The highest rate of pollution is seen around points 6 and 9. These points are close to the Neris river valley. Close points are car parking lot,

car repair shop, administrative buildings, electricity company – in comparison with other points, the latter streets are rarely swept or almost never swept (point 6), karting field, administrative and residential houses, fuel station (point 9). The higher concentration of heavy metals lies in the northern part of Žirmūnai. The lowest concentrations are at points 11 and 14. Around these points, there are crossroads without traffic light-control, however, there's a market, residential houses, many trees (point 11), administrative buildings, fuel station, supermarket and streets are often cleaned (point 14).

**Table 1.** Heavy metals excess in samples by MPC

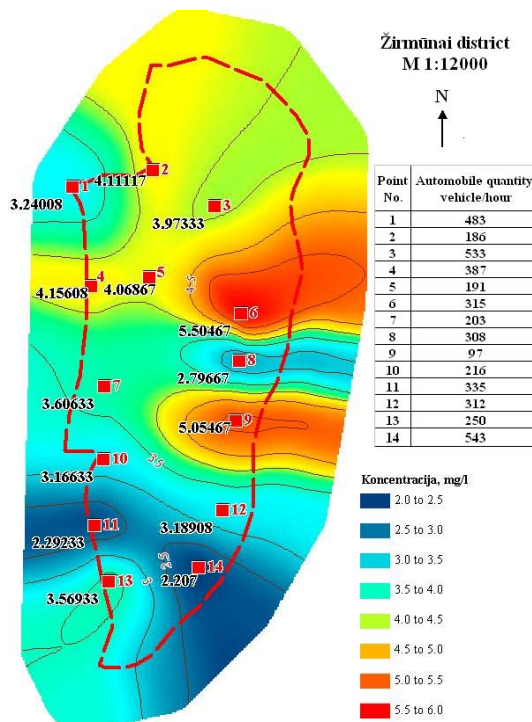
Sweeps from street						
MPC (mg/kg)	Cr	Zn	Mn	Ni	Pb	Cu
	100	300	1500	75	100	100
	no exceed					
Background MPC (mg/kg)	30	26	427	12	15	8.1
	in 1 point	to 11x	no exceed	to 3x	to 5x	to 11x
Sludge from outflows						
MPC (mg/l)	Cr	Zn	Mn	Ni	Pb	Cu
	0.5	0.4	–	0.2	0.1	0.5
	no exceed	to 4x	–	to 1.5x	to 4x	no exceed



**Fig. 4.** Common heavy metals concentration (mg/l) of sweeps by transport intensity

Generalized concentrations of heavy metals in street sweeps from different points and in sludge from outflow pipes are given in Table 2. Every analyzed point with samples taken belongs to different sewage collection pool, where the water is released to the river. A more detailed information on transport quantity flows and sampling points for each pool is also given in Table 2.

The highest concentration of heavy metals is found in outflow pipes 1, 4 and 7. Outflow pipes 1 and 7 are installed near bridges. The named three pipes belong to the pools with intensive transport.



**Fig. 5.** Geographical spread of common pollution of heavy metals in sweeps around sampling points in Žirmūnai district

#### 4. A model for the spread of pollutants in the river

Phoenics 3.5 program (acronym: *Parabolic Hyperbolic Or Elliptic Numerical Integration Code Series*), belonging to CHAM (Concentration Heat and Momentum Limited) is applied to constitute a model for determining the heavy metals concentration in the Neris river stream. This is a powerful Computational Fluid Dynamics (CFD) software presenting qualitative info on:

- How the fluids flow (air, water, steam, oil, blood, etc.) in equipment and around, for example in:
  - engines,
  - buildings,
  - human body,
  - rivers, lakes, oceans, etc.;
- how the composition of chemical and physical medium changes;
- how the forces influence the submerged bodies.

**Table 2.** Heavy metals concentration in outflow and pollution in each watershed

Outflow No.	Pollution evaluation by summarized heavy metals from outflow (mg/l)						Points No. of sweep analyses which belongs to watershed				Pollution evaluation by summarized heavy metals in sweeps (mg/l)						Automobiles quantity in street points (unit/hour)				Sumarized automobiles quantity in peak points of each watershed
	Cr	Zn	Mn	Ni	Pb	Cu					Cr	Zn	Mn	Ni	Pb	Cu					
1	0,2	1,5	4,4	0,3	0,4	0,1	2	3			0,6	2,5	2,9	0,4	0,5	1,4	186		533	719	
3		0,4				0,2	1	5			0,6	2,3	2,5	0,3	0,7	0,8	483		191	674	
4	0,2	0,5	1,9	0,3	0,4	0,2	4	6	7		0,8	6,5	3,8	0,8	0,7	1,5	387	315	203	905	
5	0,1	0,5	1,8	0,2	0,3		8	9			0,5	4,0	3,5	0,4	0,7	2,0	308		97	405	
6	0,2	0,4	2,2	0,2	0,3	0,2	12				0,2	0,9	1,3	0,2	0,1	0,4	312				312
7	0,2	1,1	1,6	0,2	0,4	0,3	10	11	13	14	0,7	12,4	5,1	0,7	3,6	1,9	216	135	250	543	1144
MPC (mg/l)	0,5	0,4	-	0,2	0,1	0,5					0,5	0,4	-	0,2	0,1	0,5					

Cells in grey exceed MPC and have maximum values of transport  
 Empty cells - results are above confidence interval

Phoenics program depends on three major functions:  
 1. task making (pre-processing), where the user describes situation to be solved;  
 2. modeling (data-processing), where the program calculates the determined conditions by the laws of science;  
 3. data provision (post-processing), where calculation results are provided in a graphical form (PHOENICS Overview ... 2007).

Program for modeling solves a differential equation by Navie-Stocks (1) (Baltrėnas et al. 2004, 2008; Ruther et al. 2005):

$$\text{div}(\rho \vec{V} \Phi - \Gamma_{\Phi} \text{grad} \Phi) = S_{\Phi}, \quad (1)$$

where:  $\rho$  – thickness  $\text{kg/m}^3$ ;  $\Phi$  – dependent variable (enthalpy, power of turbulence, etc.);  $\vec{v}$  – speed vector;  $\Gamma_{\Phi}$  –  $\Phi$  variable diffusion coefficient (coefficient of kinematic viscosity of movement equations, diffusion coefficient of diffusion equations);  $S_{\Phi}$  –  $\Phi$  member of variable flow rate equation.

A model for the spread of heavy metals in the Neris river from six storm wastewater outflows is made. Computerized modeling system – a tool for determining water quality when the pollutants get to the river.

Modeling process starts at the task window (Phoenics Commander Window), where task data are entered in to Q1 file.

The required data for making a model for the Neris river:

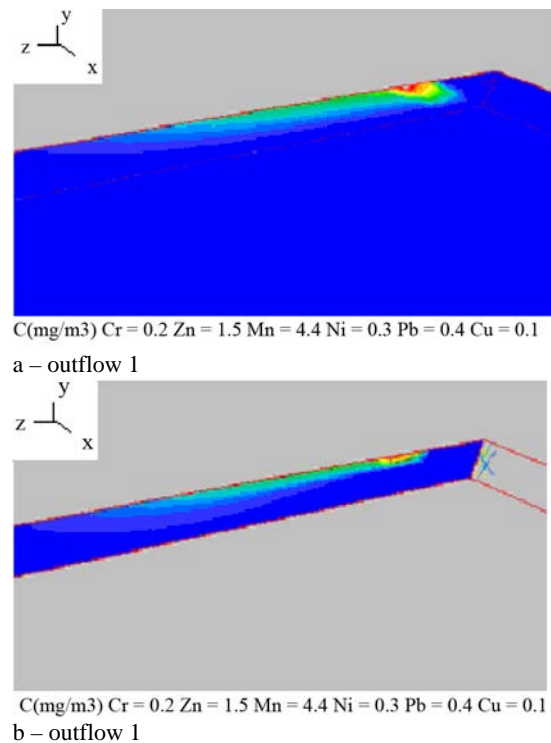
- size of the river (domain):  
 x – width 40 m (Neris is 80 m wide, but in this case, only half of the river is analyzed in Žirmūnai district),  
 y – depth 3 m,  
 z – length 4000 m in Žirmūnai district, while a segment taken for this model is 200 m;
- water pressure  $P = 1.0 \cdot 10^5$  Pa;
- water density  $\rho = 9.98 \cdot 10^2$   $\text{kg/m}^3$ ;
- river speed  $V = 1$  m/s;
- water speed from the outflow pipes  $W = 2$  m/s;
- concentration  $C$  ( $\text{mg/m}^3$ ) of heavy metals (Pb, Mn, Cr, Zn, Cu, Ni).

After filling the Q1 file and before the program makes calculations, information should be read with Phoenics

Satellite. Information is transferred in this way to the Satellite. Before providing a graphical representation of results, equations are solved with the help of Solver (Janikaite 2009; Paliulis 2006; Phoenics...2008).

For making the model, friction power, when the speed of water in the river  $V$  is close to zero beside the shore line and on the water ground, is considered. In this model, the total concentration of heavy metals from each outflow pipe and spread of pollutants analysed by the direction of river flow is taken.

Fig. 6 shows heavy metal spread in the river from the outflow pipe 1 (outflow 1) with the highest concentration. The background of concentration is seen until the 30 m distance. At a 23 m distance the concentration reaches around 2 m depth, but it is around 8 times smaller. The highest concentration spreads up to 6–7 m of the river length and 0.4 m depth.



**Fig. 6.** Heavy metals spread from outflow with maximum concentration: a – river surface, b – river depth

From the outflow pipe 3 (outflow 3) spread of pollutants is hardly visible, because concentration of heavy metals here is the smallest. At this point, concentration of pollutants stops spreading after 4–5 m length to the direction of river flow and spreads up to the depth of 0.3 m (Fig. 7).

Spread of pollutants from all the outflow pipes is shown in Fig. 8. Spread of pollutants grows together with the river flow and in this way pollutants spread in the river depth and width, therefore the named model shows a smaller background of concentration from the first outflow pipes. Pollutants move downstream because of advection and concentration decreases because of their spread and mixing with water. From the third outflow pipe concentration reaches river ground where the heavy metals accumulate in the sludge, living organisms and do not disappear from the natural cycle.

Distance of the spread of pollutants depends on the turbulence, water vortex, speed. The Neris river debit is 116 m<sup>3</sup>/s, pollutants are flown about 600 m in a day, it means about 25 m an hour (Pollution of ... 2008).

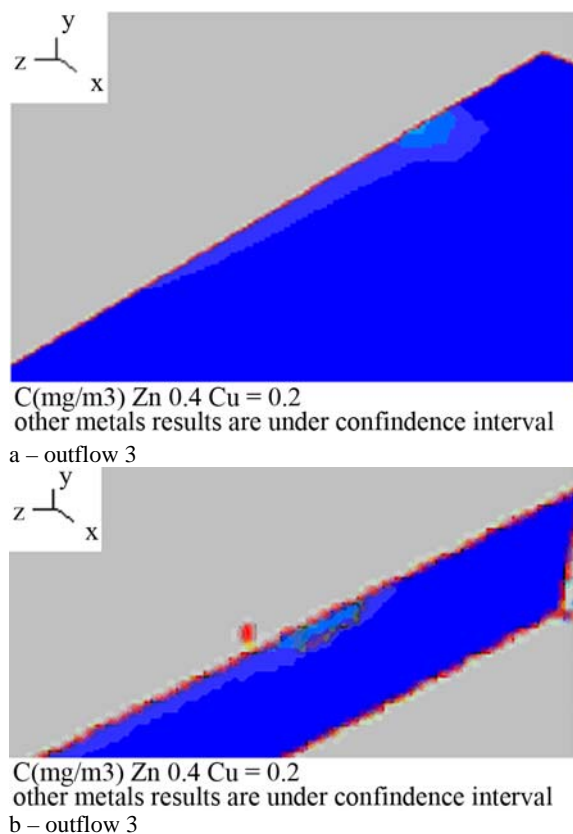


Fig. 7. Heavy metals spread from outflow with minimum concentration: a – river surface, b – river depth

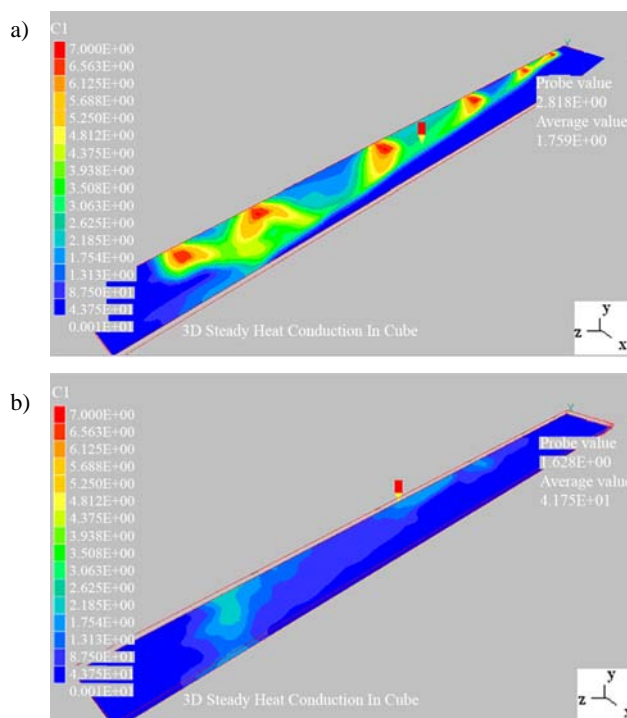


Fig. 8. Heavy metals spread from outflow in river model: a – river surface; b – river floor

### 5. Conclusions

1. According to the experimental model data, by performing a flame atomic absorption spectrometry method, heavy metal concentration in street sweep, as determined from the sweep out of intensive transportation points in Žirmūnai district, directly depends on transport amounts. Heavy metals concentration in street sweep from the streets is influenced by the nearby residing companies, oil stations, car repair shops, other buildings, frequency of car stops and their speed, street cleaning frequency, greenery.
2. Heavy metals concentration from the storm wastewater outflow pipes depends on the pollution level and car quantity in that pool, which itself falls into another pool.
3. The highest concentrations measured are Mn, Zn, Cu (in street sweep) and Pb (in sludge). According to the Hygienic standards HN 60:2004 (Highest permissible concentrations of hazardous chemical substances in the soil) heavy metals in street sweep and sludge exceed the permissible levels 1.1–11 times.
4. Average concentration of every heavy metal Pb, Mn, Cr, Zn, Cu, Ni in street sweeps is 2–3 times higher than in sludge from the outflow pipes.
5. The analysed heavy metals Pb, Mn, Cr, Zn, Cu, Ni from storm wastewater outflow pipes without any cleaning fall directly to the river and flow by the direction of the river. Concentration of pollutants, as the model shows, decreases because of turbulence.

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## SUNKIŲJŲ METALŲ KIEKIŲ TYRIMAS LIETAUS NUOTEKŲ IŠLEISTUVUOSE NUO VILNIAUS ŽIRMŪNŲ RAJONO IR JŲ SKLAIDOS MODELIS UPĖJE

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## Santrauka

Nagrinėjama nevalomų lietaus nuotekų tarša sunkiaisiais metalais Vilniaus Žirmūnų rajone. Siekiant nustatyti ryšį tarp lietaus nuotekų užterštumo sunkiaisiais metalais nuo transporto eksperimentiškai tiriamos sąšlavos nuo gatvių, kuriuos su lietumi išplaunamos į upę. Taip pat tiriami sunkieji metalai iš lietaus ištekamųjų vamzdžių į Nerį. Eksperimentiškai nagrinėjami šie sunkieji metalai: Pb, Mn, Cr, Zn, Cu, Ni. Tam panaudotas liepsnos absorbcijos spektrometrinis metodas. Trumpai aptariamas analizės procesas ir pateikiami tyrimų rezultatai. Remiantis gautais rezultatais sudaromas matematinis teršalų sklaidos modelis Neries upės tėkmėje taikant Phoenics 3.5 programą.

**Reikšminiai žodžiai:** lietaus nuotekos, išleistuvai, sunkieji metalai, gatvių sąšlavos, Neries upė, Žirmūnai, teršalų sklaida.

## ИССЛЕДОВАНИЕ КОЛИЧЕСТВА ТЯЖЕЛЫХ МЕТАЛЛОВ В ДОЖДЕВЫХ СТОКАХ РАЙОНА ЖИРМУНАЙ ГОРОДА ВИЛЬНЮСА И МОДЕЛЬ ИХ РАСПРЕДЕЛЕНИЯ В РЕКЕ

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## Резюме

Исследуется загрязнение неочищаемых дождевых стоков тяжелыми металлами в районе Жирмунай г. Вильнюса. Для определения степени загрязнения дождевых стоков тяжелыми металлами от транспорта экспериментально исследовался мусор с улиц, вымываемый с дождем в реку. Также исследовались тяжелые металлы в дождевых стоках, попадающих в реку Нерис. Экспериментально с применением абсорбционно-спектрометрического метода исследовались тяжелые металлы Pb, Mn, Cr, Zn, Cu, Ni. Рассмотрен процесс анализа и результаты исследований. На основе полученных результатов составлена математическая модель распределения загрязняющих веществ в течении реки.

**Ключевые слова:** дождевые стоки, тяжелые металлы, очистка, река, Жирмунай, распределение загрязняющих веществ.

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