EKOLOGIJA. 2011. T. 57. Nr. 1. P. 39–45

Analysis and evaluation of the effect of the solids from road surface runoff on the sediments of river bed

Marina Valentukevičienė[1],

Gytautas Ignatavičius[2]

[1] Department of Water Management, Vilnius Gediminas Technical University, Saulėtekio al. 11, 10223 Vilnius, Lithuania

[2] Centre for Ecology and Environmental Studies, Faculty of Natural Sciences, Vilnius University, M. K. Čiurlionio 21/27 03101 Vilnius, Lithuania

In order to reduce a negative impact of heavy traffic on the river (i. e. emission of artificial and natural particulate matter and nutrients) various scientific investigations are carried out to decide if the use of street roads is allowed or prohibited. This is particularly relevant for the towns, belonging to the transport corridors of the Lithuania's road networks where in some towns the circuit roads haven't yet been developed, i. e. Marijampolė (a transit town on the road of Via Baltica). Two transport corridors of European significance, the Via Baltica highway connecting Northern Europe with Central and Western Europe and the branch of IXB transport corridor IXD Kaliningrad – Marijampolė – Kaunas, cross in Marijampolė County.

Based on the scientific investigations that the use of street roads for heavy traffic causes emission of pollutants, especially those of small suspended particles and silt into the ambient water several tens of times higher than that by using the circuit roads, and generates the increase in the pollutant emission up to several tens of times, it could be stated that the use of circuit roads should be obligatory. Thus, in rainy Lithuanian autumn when the precipitation often varies around 10 mm/h, the use of street roads, when travelling of flooded and more rarely cleaned the streets of Lithuanian towns, should be only recommended if the circuit town roads are effectively developed by the new generation of road networks, i. e. less dangerous for the environment, situated from a more suitable safe distance and containing a proper runoff treatment. The dependencies used for calculating pollution loads need to be determined more accurately by test, analyzing the stormwater on the surface of roadway pavement, with further statistical estimation of the data. The experimental research performed is closely related to the study of the issues of planning and traffic pollution of various roads.

Key words: traffic emissions, particulate matter, river sediments, sieve analyses, stormwater runoff, stormwater outlets

INTRODUCTION

On rainy days, road traffic, especially when using heavy trucks, causes also the secondary pollution (Ljubomirova et al., 2008) with suspended solids (S_S). Heavy loaded trucks destroy road pavement, lift the remnants of destroyed pavement into the ambient storm water (Šliupas, 2009), spread sand and silt mixture as well as uncollected mud (Brannvall et al., 2006), and when using such trucks on "dry" road pavement (without rain or snow) – fine and very dangerous micro elements are initiated during traction. For example, by the statistics of Marijampolė Municipality (Lithuania), the load of heavy trucks in Marijampolė makes 53.6 per thousand inhabitants (increase per year even up to 21%), while the total load of trucks in Lithuania is 37.4 per thousand inhabitants. Thus, it could be stated that Marijampolė town, though not determines but contributes greatly to the total pollution of urban surface water with fine sand (ISO 14688 grades) and silt particulate matter (Brannvall, Martinėnas, 2007) as well as to the increased level of suspended solids (S_S). Data of observations, carried out in several recent years, shows that in the Šešupė River (Marijampolė town), like in many other Lithuanian rivers, the pollution of ambient surface water with S_S remains one

* Corresponding author. E-mail: gytisi@takas.lt

of the most important problems of the environmental protection. By the end of October 2009, like in the previous middle of the April 2009, the average daily concentration of S_S in certain days increased till the 14 mg/L value in all the largest storm water outlets of the Šešupė River. In Marijampolė, concentration of S_S at the high – volume outlets was increased by more than 1.5 times per year. In 2007, emission of S_S in the rivers and lakes was limited by the newest and significantly more-binding Lithuanian legal act *Order of the Minister of the Ministry of Environment of the Republic of Lithuania No D1-193. Regulation on surface water management.* By this Order, it was decided to reduce the currently valid annual and instantaneous limit values for suspended solids (with the permissible average of the S_S concentration of exceeded limit values). For example, the average of the annual limit values of the S_S concentration is 30 mg/L, for instantaneous limit – till 50 mg/L. Correspondingly, the annual limit values for S_S will be reduced from 50 to 30 mg/L, and could not be exceeded for more than once per a calendar year.

In the recent years, the area of streets asphalted in the town of Marijampolė, has increased till 96 km, whereas in total (streets asphalted and uncovered) – even by 131 km. This is demonstrated by the data of the Marijampolė Municipality strategic map of the Marijampolė town, according to which, 73% of streets are affected by the equivalent individual car level higher than 566 cars per thousand inhabitants, causing pollution from roads, streets and industrial activities. From the geopolitical point of view, Marijampolė County is an important transition region. Two transport corridors of the European significance, the Via Baltica highway connecting Northern Europe with Central and Western Europe and the branch IXD of IXB transport corridor Kaliningrad–Marijampolė–Kaunas cross in Marijampolė County. The county also has a well-developed road network; its territory is crossed by the following significant highways: A7 – Marijampolė–Kybartai, A16 – Marijampolė–Prienai–Vilnius, A5 – Kaunas–Marijampolė–Kalvarija.

According to the scientists, the use of town streets not only increases the pollutant loads (especially suspended solids) but also "aggressively" affects the asphalt pavement. The scientists affirm that a vehicle in studded tires having travelled 1 km on "bare" asphalt, mills out about 20 mg of dust from the asphalt wearing course of road pavement (R. Vaiškūnaitė et al., 2009). Due to the above reasons, in many countries (Germany, Sweden, France, etc.) heavy trucks inside towns are prohibited. However, they are still allowed to go inside towns in Lithuania, Latvia, Estonia, Poland, and Russia and also in some other countries where the circuit roads haven't yet been developed. Stormwater (snow melting water) from asphalted streets flows into stormwater collection systems, and finally to the outlets (Kowalkowski et al., 2007, Kowalkowski, 2009), situated on surface water bodies (rivers, lakes etc.). High stormwater flows can be dangerous to traffic because of hydroplaning or aquaplaning of the wheels (Beljatynskij et al., 2010); therefore runoff water must be collected to the drainage systems. In case if the collected storm water is not treated, nearly all suspended solids (especially silt and fine sand) will be transported from the streets to the river bottom sediments (Baltrėnas, Kazlauskienė, 2009). The case study of specific Marijampolė town Šešupė River sediments from storm water outlets can be the real example of complexity in pollutant transport from heavily loaded by transport streets. The additional goal of the study is the aspect of the correlation between the particles and Oxygen Demand with the mentioned organic pollutants.

RESEARCH METHODS

The Šešupė River is a tributary of the Nemunas River and drains the southwest Lithuanian Lowland. An excavating segment of the river is preserved in its almost straight form between Marijampolė town hydropower station and the pedestrian bridge. This segment of the river is about 1 km long and lies within the town central part. The middle part of this area was the subject of a detailed field work by the authors. Until recently, the river was not excavated for yet another distance downstream; hence, this area was not taken under consideration here. The section of the river, situated within the investigated part, is referred to as the storm water intake system. The storm water outlets, developed within a coastal area where original river sediments are mostly gravel and coarse sands, are up to coast lines. Catchment areas of the discharge measuring sites vary from 0.2 km^2 to 0.5 km^2.

Granulometric composition and distribution aspects of the stormwater outlets and its environmental impact have been the major subject of the study. The granulometric composition was studied by the "Laboratory of road research" of Vilnius Gediminas Technical University, stormwater from outlets and intake was tested by JSC "Suduvos vandenys" (Wastewater laboratory). Field work was carried out in April, October, November and December of 2009. The precipitation rate in research period was in the form of moderate rain, when the precipitation rate is between 2.5–7.6 mm with a maximum of 10 mm per hour.

The local hydrodynamic conditions (Sakalauskiene, Ignatavicius, 2003) that generate suspended solids, influence the size and degree of sorting these particles within and on the surface of these features. Armoring, or the development of a segregated layer of coarse grains at the bed surface, can occur over long stretches of gravel-bed rivers, but in the sandy streams of storm water outlets is restricted spatially to the outlet elements. These S_S layers generally develop in zones of high-shear stress either at low or at high flow (e. g., the heads of point outlets or the downstream end of pools) (Fig. 1).

Fig. 1. The head of point outlets (Šešupė River)

The S_S scale has been a primary focus for the assessment and sampling in ecological research. Pools, riffles, and runs / glides typically are viewed as discretely occurring macrophyte types that utilize organic matter and nutrients from the water differently, depending on the river bottom sediment change.

Suspended solid transport in stormwater outlets has been studied in the laboratory by granulometric analysis, and in the field. A simplified method is proposed that can be run as an extension of the existing outlet stormwater quality evaluation in order to simulate the advection and deposition of solids within the entire stormwater system. Stormwater suspended solids are perceived as general turbidity. In combined sewers and separate stormwater outlets, suspended solids originate mainly from asphalted street inputs via the sand, and consist of transport related matter, tire residual, domestic waste products, air dust, petrol products, and other transport refuses (Åberg, 2006; Kumpiene, 2006). Of course, these solids are only a problem in the sewers if they are disposed of via the waterborne stormwater system in the first place. Although street cleaning, such as "sweeping" and "washing out", should reduce the quantities of suspended solids in stormwater outlets (Ignatavičius et al., 2009), they will not eliminate them (Schwitzguébel et al., 2009).

The primary motivation for developing the method was to improve the understanding of the behaviour of suspended solids throughout the stormwater system, from inflow to outflow. This method could be potentially applied to all aspects of the engineered improvement systems, including the design of storage facilities and the development of efficient screening systems for the identification of S_S effect and the assessment of its impact on future changes in the river behavior and in stormwater flow rates, resulting either from the provision of source control or from climate change.

The conditions in small pipes contrast with those in main collectors, in which flow and the movement of solids are more continuous. Conditions in main stormwater collectors can be unsteady, but the variations of flow rate with time (resulting either from diurnal variations in snow melting flow or from variations in storm inflow during rainfall) are more gradual than in small pipes. The distinction between the intermittent and continuous flow is an important hydraulic feature within drainage systems, and clearly has an effect on suspended solids behavior. This paper concentrates on granulometric studies of suspended solids from different stormwater collectors and outlets to the river. The granulometric analysis was carried out following LST EN 933-1 : 2002; LST EN 933-1 : 2002 / A1 : 2005, the water samples were collected and analysed following the international standards. Suspended solid samples were collected from the end of the stromwater outlet pipes and the river bottom sediments nearby stormwater intakes surrounded by plant macrophytes. These sampling procedures were recorded on GPS data and were the following: (right river coast) 54°33.336', 23°20.518'; 54°33.340', 23°20.520'; 54°33.366', 23°20.539'; 54°33.386', 23°20.554'; 54°33.469', 23°20.623'; 54°33.475', 23°20.630'; 54°33.549', 23°20.733'; 54°33.637', 23°20.782'; 54°33.732', 23°20.847'; 54°33.837', 23°20.839'; (left river coast) 54°33.438', 23°20.570'.

RESULTS AND DISCUSSION

The data included in the Table show the levels of pollution load on the river of stormwater outlets and are the means from the field work measurements of the wet weather period. As can be seen from the experimental results, the outlets of stormwater in the 1 km river segment resulted in the highest loading of suspended solids and nutrients, while the use of the short-excavated section did not affect the separation of S_S.

Similar results were obtained when water was analysed by a dry weather condition (3 days without rain, all nights -negative air temperature) method, and the results were in agreement with the Lithuanian legal act requirements. We can see that the first doses of stormwater increased the load of suspended solids to the river (Figs. 2–4).

Results also showed that measured Biological Oxygen Demand (BOD_7) and suspended solids were obtained at a level approximately 60% of dependency following 1st equation.

$$BOD_7 = 0.14S_s^3 - 1.49S_s^2 + 4.59S_s + 9. \quad (1)$$

Fig. 3 shows the dependency (approximately 60%) of the Chemical Oxygen Demand (COD_{Mn}) on suspended solids concentration as obtained during the research.

In the second order polynomial dependency after the initial data was statistically evaluated, i. e. a 2nd equation was obtained.

$$COD_{Mn} = -0.018S_s^2 + 0.25S_s + 3.49. \quad (2)$$

However, it was found that after evaluation of granulometric composition, the same second order polynomial dependency of fine particles quantity percentage (Q^P) on suspended solids concentration occurred (3rd equation, when particle size was <1 mm; 4th equation, when particle size was <0.5).

$$Q_1^P = -1.88S_s^2 + 37.16S_s - 88.83; \quad (3)$$

$$Q_{0,5}^P = -1.80S_s^2 + 36.41S_s - 97.25. \quad (4)$$

In the case of particle size <0.063 mm, the dependency of finest particles quantity percentage on suspended solids concentration was not much greater than the insignificant level of the mentioned polynomial equation when using linear, logarithmic, power and exponential equations (Fig. 4).

As reported in the literature by Brannvall and Martinėnas (2007), it means that fine particles due to the moisture, precipitation, wind and coagulation in the natural geographic

Table. **Research results when the stormwater outlets were evaluated separately one by one**

Stormwater outlets / Water quality analyses	1	2	3	4	5	6	7	8	9	10	11
Suspended solids, mg/L	6	6	7	5	6	10	12	8	11	5	8
Chemical Oxygen Demand, COD_{Mn}, mgO_2/L	12	14	13	12	15	14	16	10	12	13	11
Biological Oxygen Demand, BOD_7, mgO_2/L	4.2	3.8	3.9	3.8	4.0	4.3	4.5	4.7	4.1	5.1	4.6

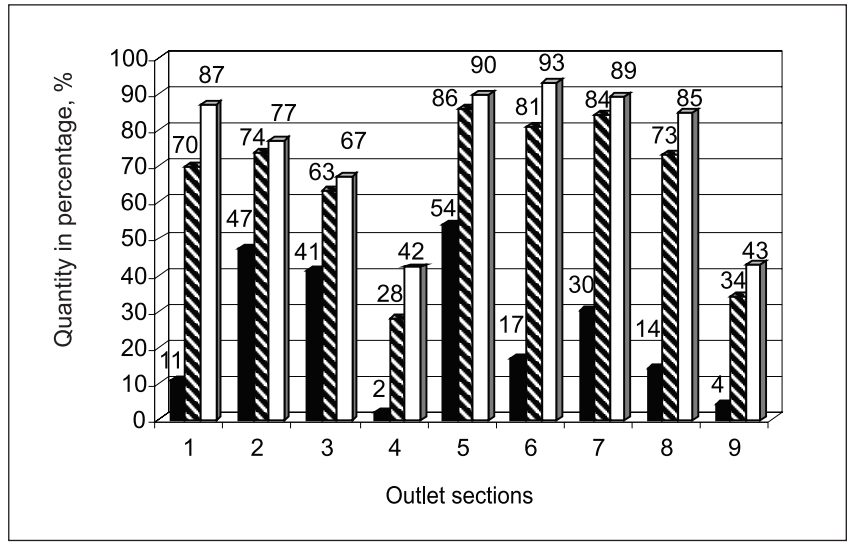

Fig. 2. Distribution of particle sizes from different stormwater outlet sections (white columns – particle size <1 mm, lined – <0.5 mm, black – <0.063 mm)

Fig. 3. The dependences of Oxygen Demand on suspended solids concentration (• BOD7, ♦ CODMn)

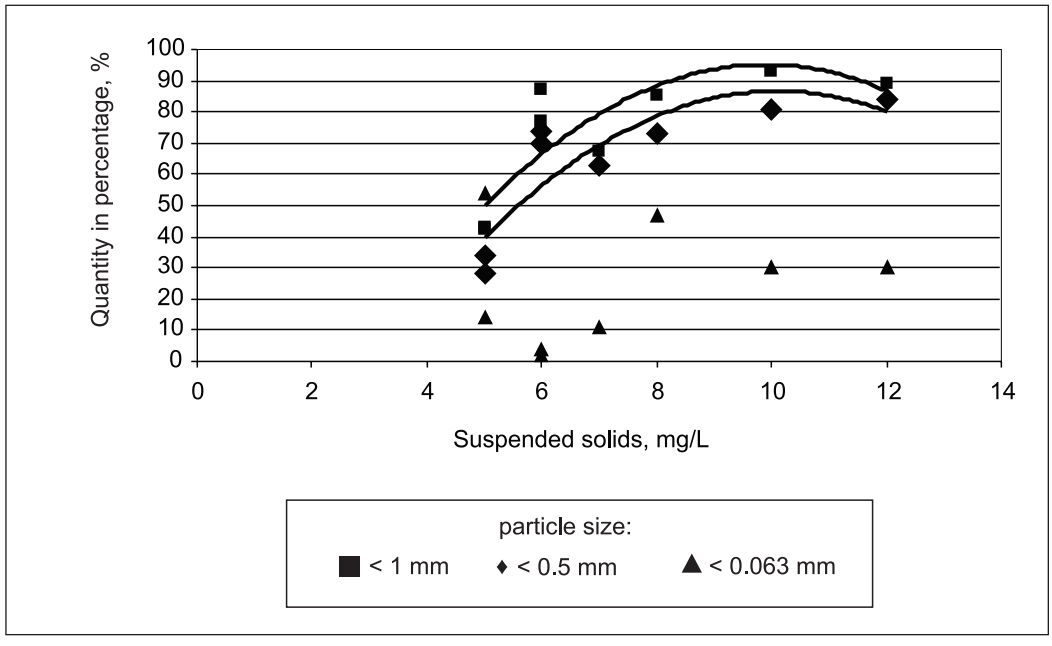

Fig. 4. Dependency of fine particles quantity percentage (Q^p) on suspended solids concentration

environment have about 100 times higher deposition rates. During their backwash, the stormwater transport processes a higher load of suspended solids; therefore more small fractions of suspended compounds were preferentially removed by the stormwater flow. These coated fine sand fractions (<1 mm particle size) have a high level of suspended solids compound removal and mobility. The top layer between the river sediments fine sand particles and stormwater pollution also increases the eutrophication of river bay (Fig. 5).

As reported by Baltrėnas and Kazlauskienė (2009), a suspended solid sand fraction itself has no fixed organic layer. An effective organic layer formation is due to adsorption of organic compounds. Organic compounds are more readily adsorbed on a fine sand particle surface in an aqueous solution, irrespective of whether the surface is treated with freshwater or not. In the case of the removal of both the organic and suspended solid compounds that were investigated, it was found that there was an improvement of the river water quality.

In an in-line stormwater, an increase of organic and S_S concentration in the river water resulted in a decrease in Oxygen Demand. In the finest sand with an organic layer, where organic and suspended solids removal is due to the biological impact, large quantities of undesirable compounds are removed. An increase of organic and S_S concentration into the stormwater, especially organic compounds, allowed the organic products of the finest particles of the fine sand to be formed, and therefore the quality of water with low S_S concentrations was acceptable. At outlet sections 5, 6, 7 and 8, the observed effect of silt and fine sand precipitation

Fig. 5. Eutrophication of the Šešupė River near the stormwater outlet

that used stormwater and an integrated biological process, the results were almost the same as the results in the first three sections (Fig. 2). Reliable results, obtained during in line-outlet of stormwater containing organic residuals or its precipitation through fine sand fraction particles (Fig. 3) showed that oxygen demand and suspended solid concentrations into the stormwater were considerably reduced as compared to the use of BOD_7 and COD_{Mn}. It can be said that under natural conditions, normalized organic and suspended solids removal by the river flow that has been excavated by the ladder dredger, is higher than when using a natural river flow.

CONCLUSIONS

1. The results of the performed investigations demonstrate that the time necessary for the start up of a flow that removes organic and suspended solids from stormwater can be reduced by treating the runoff water from high- loading streets.

2. The positive correlation between Oxygen Demand on the concentration of suspended solids was obtained to both BOD_7 and COD_{Cr} that can be useful for the evaluation of pollution loads from stormwater outlets to the river.

3. This research showed that in an in-line sedimentation process, where the stormwater from high loading streets was used, this enhanced the biological process where a high concentration of suspended solids was found in the stormwater outlets.

4. When sedimentation was carried out under the conditions of natural precipitation, the fine sand susceptibility to fouling by the organic layer was lower than that under the conditions of stormwater runoff.

5. The results from the tested stormwater quality and sediment removal were strongly influenced by fine sand particles coated with organic compounds and the petrol products of runoff water.

6. It can be concluded that the process investigated can be beneficial and effective in solving problems encountered in highly loaded by transport streets. Such processes still need to be proved in more extensive investigations, however, the results of this study can be applied as a basic scenario to shorten start up time necessary for removing suspended solid compounds in the stormwater.

ACKNOWLEDGEMENTS

The authors of this article are grateful to the "Laboratory of road research" of Vilnius Gediminas Technical University and Prof. Habil. Dr. A. Laurinavičius for participating in the granulometric analysis. We are thankful to everyone who helped during the Šešupė River research activities.

Received 7 March 2011
Accepted 21 April 2011

References

1. Åberg A., Kumpiene J., Ecke H. 2006. Evaluation and prediction of emissions from a road built with bottom ash from municipal solid waste incineration (MSWI). *Science of the Total Environment*. Vol. 255. P. 1–12.
2. Baltrėnas P., Kazlauskienė A. 2009. Sustainable ecological development reducing negative effects of road maintenance

salts. *Technological and Economic Development of Economy.* Vol. 15. N 1. P. 178–188.

3. Beljatynskij A., Prentkovskis O., Krivenko J. 2010. The experimental study of shallow flows of liquid on the airport runways and automobile roads. *Transport.* Vol. 25. N 4. P. 394–402.
4. Brannvall E., Mažeikienė A., Valentukevičienė M. 2006. Experimental research on sorption of petroleum products from water by natural clinoptilolite and vermiculite. *Geologija.* Vol. 56. P. 5–12.
5. Brannvall E., Martinėnas B. 2007. The Pecularities of Fine Particles Dispersion over the Roadside. *The Baltic Journal of Road and Bridge Engineering*. Vol. 2. N 1. P. 39–44.
6. Ignatavicius G., Sakalauskiene G., Liaskevic J., Raulinaitis M. 2009. Cooperation of State institutions and the public in solving water protection issues. *Environmental Research, Engineering and Management***.** Vol. 47. N 1. P. 76–84.
7. Kowalkowski T. 2009. Classification of Nutrient Emission Sources in the Vistula River System. *Environmental Pollution.* Vol. 157. P. 1867–1872.
8. Kowalkowski T., Gadzała-Kopciuch M., Kosobucki P., Krupczyńska K., Ligor T., Buszewski B. 2007. Organic and Inorganic Pollution of Vistula River Basin. *Journal of Environmental Science and Health.* Vol. 42. N 4. P. 1–6.
9. Kumpiene J., Ecke H., Maurice C. 2006. Impact of grassed swales on the fate of metals leached from roads built with municipal solid waste incineration bottom ashes. *Coal Combustion Byproducts and Environmental Issues.* Springer Publishers, NY. P. 87–98.
10. Sakalauskiene G., Ignatavicius G. 2003. Effect of drought and fires on the quality of water in Lithuanian rivers. *Hydrology and Earth System Sciences***.** Vol. 7. N 3. P. 423–427.
11. Schwitzguébel J. P., Kumpiene J., Comino E., Vanek T. 2009. From green to clean: a promising and sustainable approach towards environmental remediation and human health for the 21st century. *Agrochimica*. Vol. LIII. P. 1–29.
12. Šliupas T. 2009. The impact of road parameters and the surrounding area on trafic accidents. *Transport.* Vol. 24. N 1. P. 42–47.
13. Ljubomirova V., Djingova R., Van Elteren J. T., Veber M., Kowalkowski T., Buszewski B. 2008. Investigation of the solubilization of car-emitted Pt, Pd and Rh in street dust and spiked soil samples. *International Journal of Environmental Analytical Chemistry*. Vol. 88. N 7. P. 499–512.
14. Vaiškūnaitė R., Laurinavičius A., Miškinis D. 2009. Analysis and Evaluation of the Effect of Studded Tyres on Road Pavement and Environment (II). *The Baltic Journal of Road and Bridge Engineering.* Vol. 4. N 4. P. 203–211.

Marina Valentukevičienė, Gytautas Ignatavičius

AUTOMOBILIŲ KELIŲ LIETAUS NUOPLOVŲ POVEIKIO UPĖS DUGNO NUOSĖDOMS ANALIZĖ IR VERTINIMAS

S a n t r a u k a

Automobilių transporto sukeliama vandens telkinių tarša yra aktuali aplinkosaugos problema Lietuvoje. Siekiant ją išspręsti, vykdomi įvairūs moksliniai tyrimai ir eksperimentai, kuriais įvertinamas transporto intensyvumo šalia vandens telkinių esančiose gatvėse poveikis vandens kokybei bei dugno nuosėdų sankaupų susidarymui. Šiame straipsnyje, remiantis atliktais moksliniais tyrimais, analizuojama, kokį poveikį Šešupės upės atkarpai Marijampolėje turi dvi ją kertančios tarptautinės „Via Baltica“ magistralės atšakos. Tyrimų rezultatai rodo, kad miesto gatvėmis važiuojantis sunkusis transportas kelis kartus padidina teršalų kiekį gatvių lietaus nuoplovose. Tyrimų duomenimis, į Šešupę išleidžiamos gatvių lietaus nuotekos yra nepakankamai išvalomos, todėl kelia pavojų upės ekologinei būklei. Rekomenduojama lietingą rudenį riboti tranzitinio sunkiojo transporto eismą miestų gatvėmis nukreipiant jį aplinkkeliais ir taip mažinant gatvių teršalų patekimą į vandenį.

Raktažodžiai: transporto teršalų emisija, kietosios dalelės, upių nuosėdos, sieto analizė, lietaus nuoplovos, lietaus nuotekų išleistuvai