Assessment of daily pollutant accumulation rates on impervious surfaces in two seasons

Aleksandar Djukić[1], Branislava Lekić[1], Vladana Rajaković-Ognjanović[1], Zorana Naunovic[1], Dušan Prodanović[1]*

[1]University of Belgrade – Faculty of Civil Engineering, Bulevar Kralja Aleksandra 73, 11000 Belgrade, Serbia
**Corresponding author email: djukic@grf.bg.ac.rs*

Highlights

- Pollution accumulation rates on asphalt surfaces found to be higher in summer than in autumn.
- Pollution accumulation rates on concrete surface vary by pollutant and season.

Introduction

Pollution from urban and road runoff is usually described as a two-stage process: accumulation of surface pollutants during dry weather periods and pollutants wash-off from surfaces during rainfall events. Early studies of pollutants deposited on road surfaces revealed that storm water pollutants are primarily associated with particles accumulated on impervious surfaces (Sartor and Boyd, 1972). The rate of contaminant accumulation on urban surfaces is influenced by various site-specific factors such as climate, land-use, traffic volume, vicinity of roads and streets, climate and other factors (Egodawatta and Goonetilleke, 2006, Müller et al. 2020).

Methodology

The experimental catchment at the Faculty of Civil Engineering, University of Belgrade, includes local parking inter-connection roadways (asphalt), parking lots (asphalt and cube stone), concrete walkways, a metal roof and green areas. The experimental site is located 50 m from the surrounding streets and separated from heavy traffic corridors by a 0.7 m high concrete wall and a line of planted trees that are intended to reduce the influence of nearby city traffic. The experimental catchment has a total area of 3330 m^2, where impervious surfaces cover 68.9% and pervious surfaces (green areas) cover 31.1% of the total area.

Sampling of materials deposited on impervious surfaces was performed using the “wet” vacuum sweep technique, due to its proven efficiency in collecting accumulated materials from impervious urban surfaces. The sampling method is described in detail in Djukić et al. (2018). The collected bulk liquid samples from asphalt and concrete surfaces, consisting of both the liquid and solid phase, were subjected to chemical characterization, which included 18 parameters: pH, turbidity, conductivity (κ), total solids (TS), total suspended solids (TSS), COD, nutrients (total nitrogen, total phosphorus), heavy metals (Fe, Zn, Cr, Cu) and anions (NO_2^-, NO_3^-, Br^-, Cl^-, SO_4^{2-}, PO_4^{3-}). The applied analytical methods are given in Djukić et al. (2016).

Sampling was performed in two sampling campaigns: during summer (July) and autumn (October). During the summer campaign samples were collected from the same location on the asphalt surface of the parking lot and concrete surface of the pedestrian walkway, while during the autumn campaign samples were taken from the same locations as in July, and additional samples were taken from the stone (granite) surface which is not used by either vehicular or pedestrian traffic. Each sampling campaign lasted 7 consecutive days and included collecting samples from the same location at the same time each day.

Results and discussion

Figure 1 shows results from the autumn sampling campaign for parameters COD, TS and TSS. The results show that the mass of pollutants per unit area of the tested surface decreases very quickly over time, so that after two to three days the mass of each parameter per unit of surface area tends to a certain value, which represents the net pollutant daily accumulation rate, i.e. the total accumulated mass of that parameter reduced by mass loss due to decomposition, wind drift and other reasons. This applies only if the sampling is done at intervals of 24 hours, from the same location and using the same sampling technique. A similar trend, as shown in Figure 1, was detected for all investigated parameters, except for pH, turbidity and κ, in both sampling campaigns.

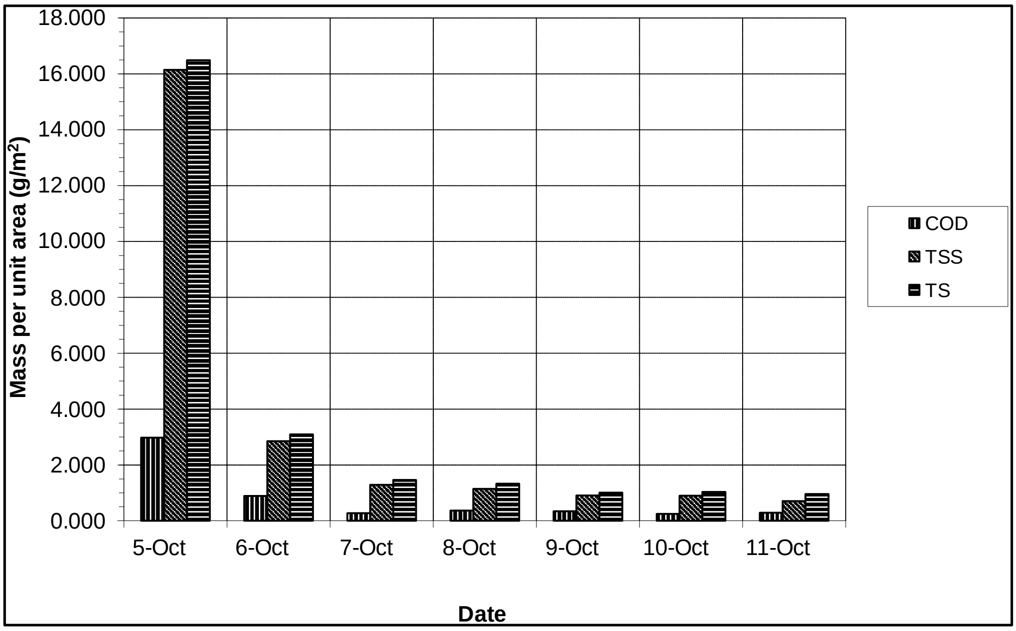

Figure 1. The Mass of COD, TSS and TS per unit of tested asphalt surface of the parking lot according to measurements in autumn

Table 1 provides an overview of daily accumulated amounts of selected parameters (net pollutant daily accumulation rates) derived from measurement results, for selected parameters.

Table 1. Daily accumulated amounts of selected parameters on examined surfaces during summer (July) and autumn (October)

	Daily accumulated amount (kg/ha/day)				
	July (summer)		October (autumn)		
Parameter	Asphalt	Concrete	Asphalt	Concrete	Granite
COD	4.1688	1.7239	2.8121	1.7651	0.6497
TSS	12.0818	4.0992	9.2331	2.9078	1.1537
TN	0.0869	0.0370	0.0655	0.0550	0.0434
TP	0.0250	0.0120	0.0147	0.0073	0.0032
Fe	0.2432	0.0732	0.2060	0.0916	0.0441
Zn	0.0183	0.0055	0.0108	0.0079	0.0077
Cr	0.0040	0.0018	0.0028	0.0023	0.0009

In general, the highest accumulation rates were measured on the asphalt surface. Asphalt surfaces on parking lots and roads are known as significant sources of pollution in surface runoff (Hvitved-Jacobsen et al. 2010, Müller et al. 2020). The lowest accumulation rates were measured on the granite (stone) surface.

Comparing the values of the daily accumulated amounts of the measured parameters from July and October, it can be concluded that, except for total nitrogen, accumulation on asphalt was higher in July than in October (48% higher for COD, 31% higher for TSS, 70% higher for TP, Zn, 43% higher for Cr, and 18% for Fe). For concrete, results ware different: the accumulation rate for COD was nearly the same, higher rates were measured for TSS (41%) and TN (64%) while lower rates were measured for TN (-33%), Fe (-20%), Zn (-31%) and Cr (-22%).

All this indicates that the pollution at the investigated locations depends on the characteristics of the surface, where greater surface roughness results in a greater capacity for pollution accumulation. The asphalt surface is also under the influence of runoff from the surrounding surfaces, including green areas, therefore, a portion of the materials deposited on the asphalt surface may originate from natural materials resulting from erosion from the surrounding land. These materials are then transferred to the surrounding concrete surfaces by traffic, wind or runoff.

Surface usage also plays a role, where surfaces designated for motor vehicle traffic (asphalt, in this case) were more polluted than pedestrian surfaces that are occasionally used for vehicle parking (examined concrete surface), and the least amount of accumulation was detected on the stone (granite) surface that has no direct contact with vehicles or pedestrians. Therefore, pollution accumulation on the stone surface examined in this study may be considered to originate predominantly from substances that have precipitated from the atmosphere, i.e. atmospheric deposit.

The Principal Component Analyses (PCA) was applied using XLSTAT software, on a total of 18 variables (measured parameters) and 21 samples, or a total of 378 variables grouped into 18 observations. The results of the PCA analyses for the October sampling campaign are presented in the form of a biplot in Figure 2, where points labelled from A1-0-0 to A1-0-6 denote samples from asphalt, from S1-0-0 to S1-0-6 samples from concrete, from K1-0-0 to K1-0-6 samples from stone (granite), while pH, κ (conductivity), COD, TS, TSS, Turb. etc. are variables - measured parameters.

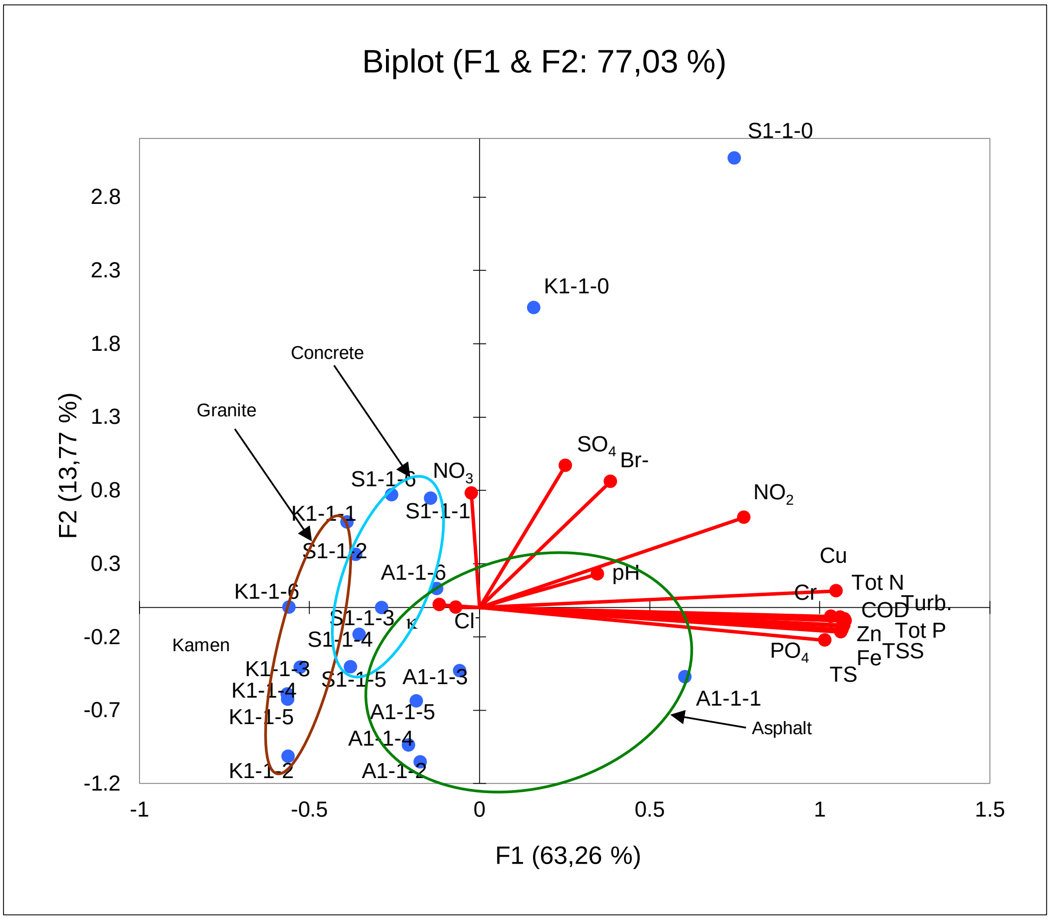

Figure 2. The Principal Component Analyses (PCA) biplot for the results of the analyses of the accumulated material on asphalt, concrete and stone surfaces of the October campaign

As shown in Figure 2, the first principal component (F1) is related to all of the measured parameters except Br-, No_3^- and SO_4^{2-}, which are related to the second principal (F2) component, while pH is related to F3 and κ and Cl^- to F4. The percentage of data variability covered by the principal components F1 and F2 is 77.03%. The data for samples collected on the first day of sampling (A1-0-0, S1-0-0 and K1-0-0) are considered as outliers. The reasons for this lie in the fact that these are samples that were taken following a long period of dry weather containing greater quantities of analyzed substances that had accumulated on these surfaces, the values of which significantly deviate from the values of the variables determined in the remaining samples.

Grouping of the results per sampling surface type can be observed and is marked in Figure 2. The samples from asphalt show the greatest variability, while the concrete and especially stone sample results are grouped in very narrow areas in the diagram in Figure 2. This can be explained by the capacity of surfaces in terms of pollution accumulation, due to lower surface roughness and smaller impacts from vehicular traffic.

The correlation analyses revealed that the following variables are very strongly correlated with F1: COD (r=0.993), TS (r=0.987), TSS (r=0.984), TN (r=0,981), TP (r=0,990), turbidity (r=0.992), Fe (r=0.991), Zn (r=0.982), Cr (r=0.915), Cu (r=0.942), i PO_4^{3-} (r=0.882). Of the remaining variables, SO_4^{2-} is strongly correlated to F2 (r=0,806). The biplot shows strong mutual correlation between all parameters except for pH, κ, Cl^-, SO_4^{2-}, Br^-, NO_2^-, NO_3^-.

Conclusions and future work

The highest accumulation rates were detected on asphalt surfaces and the lowest on granite (stone) surfaces. Daily pollutant accumulaton rates depend on the properties of the surface (composition, roughness, etc.), but may also depend on other external factors, such as wind speed, intensity of traffic in the area, etc., but to determine these relations, additional research is needed.

For the given conditions that prevailed in the experimental catchment in Belgrade, the net daily accumulated amounts of pollution on asphalt surfaces of the parking lot were higher during the summer months than at the beginning of autumn. This may indicate greater mobility of pollution at higher temperatures and lower air humidity.

For the concrete surface of the pedestrian walkway, research results do not provide a clear difference in pollutant accumulation rates between the two seasons. This conclusion differs from the results obtained for the asphalt surface, indicating differences in the processes that influence pollutant accumulation as well as differences in the type and nature of the accumulated materials in the two investigated locations. Further investigations are needed in this regard.

The PCA analysis revealed a strong correlation between TS, TSS, turbidity, COD, heavy metals, phosphorus and nitrogen compounds. The pH value, conductivity and NO_3^- concentrations demonstrated the lowest correlation with any of the analyzed variables. The PCA results show highest variability of results for asphalt and the lowest for stone surfaces.

Acknowledgement

The work was done as a preparation part of the ongoing project “Road and Environmental Safety related to water – pavement, Interactions” (RESAFE), No. 7051, from Program PRISMA, financed by Science Fund of the Republic of Serbia.

References

Djukić A., Lekić B., Rajaković-Ognjanović V., Veljović Dj., Vulić T., Djolić M., Naunović Z., Despotović J. & Prodanović D. (2016) Further Insight into the Mechanism of Heavy Metals Partitioning in Stormwater Runoff. Journal of Environmental Management, 168, 104-110. DOI: 10.1016/j.jenvman.2015.11.035

Djukić A., Lekić B., Rajaković-Ognjanović V., Naunovic Z., Prodanović D. (2018) Build-up and characterisation of pollutants on urban impervious surfaces. Water Science and Technology. 77 (8), pp.2123-2133. DOI: 10.2166/wst.2018.128

Egodawatta, P., Goonetilleke, A., (2006) Characteristics of pollutants build-up on residential road surfaces. In: Proceedings of the 7th International Conference on HydroScience and Engineering, Philadelphia, USA.

Hvitved-Jacobsen T., Vollertsen J. & Nielsen A. 2010 Urban and Highway Stormwater Pollution-Concepts and Engineering, CRC Press, Taylor&Francis Group, Boca Raton, FL, USA.

Müller A., Österlund H., Marsalek J., Viklander M. (2020) The pollution conveyed by urban runoff: A review of sources, Science of The Total Environment, Vol. 709. 136125, https://doi.org/10.1016/j.scitotenv.2019.136125.

Sartor, J.D., Boyd, G.B., 1972. Water Pollution Aspects of Street Surface Contaminants. Report EPA-R2-72-081. US EPA Office of Research and Monitoring.