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Evaluation of Metals Leaching in Permeable Asphalt Pavement and Conventional Asphalt Pavement

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Abstract

A permeable asphalt pavement (PP) and a conventional asphalt pavement (PD) have been tested regarding the potential leaching of the metals Cd, Cr, Fe, Pb, Mn, Ni and Zn during 11 rain events immediately after their construction. Water samples were picked up for the rain water and in four sampling points of both pavements during every rain, two located at the surface of the pavements (PPE and PDE), and other two after infiltration in the pavements (PPI and PDI). The results show that there was introduction and transport of Cr, Fe, Pb, Mn, Ni and Zn during surface runoff on pavements. After water infiltration in the pavements, there was significant removal of Cr in the PD pavement, Pb and Zn concentrations did not decrease in depth and concentrations of Fe and Ni increased after infiltration. However, the concentrations of all metals in the leaching water are very low comparing with the minimum standard legal values set up for irrigation and discharge on water courses.

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1. Introduction

One of the measures used for improving storm water management in urban areas has been the implementation of green infrastructures that include the use of porous materials in roads such as *permeable asphalt pavements* (PP) in alternative to the traditional ones (the *conventional asphalt pavements* (PD)). The mixture of the surface layer of PP must have a void index between 16% and 22%, in order to allow good drainage [1]. Its application is indicated in parking areas and in areas with low traffic, and normally allows good drainage of rainwater, recharge of aquifers, reduction of urban heat island effect caused by evapotranspiration, reduction of road traffic noise and spray effect and the elimination of aquaplaning [2] - [4].

However, rainwater runoff on road pavements may pose a risk to public health and the environment due to the washing, introduction and transport of pollutants produce in tires, cars, road asphalt and surrounding areas, especially if discharged into surface and underground water sources [5]. Pollutants of greatest concern are heavy metals (namely cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), nickel (Ni), zinc (Zn)), nitrogen, phosphorus and oils that are difficult to degrade in the environment and influence soil moisture and its properties [6].

Pagotto *et al*. [7] concluded that PP contained lower concentrations of Cu and Pb than PD, based on field results. Roseen *et al.* [4] carried out a monitoring around a road drainage pavement for five years and did not detected significant concentrations of hydrocarbons, Zn and total suspended solids (TSS) leaching the pavement. The results obtained by Jiang *et al*. [8] in a permeable bituminous pavement showed that it was very effective in the retention of Cu, Zn, Pb and Cd. However, they did not study the leaching of pollutants through the pavement.

This research is focused on the study of eventual leaching of seven heavy metals (Cd, Cr, Fe, Pb, Mn, Ni and Zn) through two different pavements (a PP of double layer porous asphalt (DLPA) and a conventional PD) during 11 rain events immediately after their construction and without traffic. The DLPA intended to mitigate the problem of sealing when two surface-active bituminous mixtures act as a filter that prevents larger sediments from moving to the next layers and subsequently avoid the contamination of the leachate.

This initial research intends to evaluate the impact of pavements materials in the rainwater quality, without traffic, during surface runoff and infiltration taking in account the legal standards set up in the Portuguese Decree Law No. 236/98 [9]. for final water uses, namely for irrigation and discharge in water courses.

2. Materials and Methods

2.1. Characteristics of the PP and PD pavements

The experimental setup (Figure 1) is located in a area with no traffic, located at Capinha (Fundão, Portugal). Construction started in October 2016 and occupied a total area of $24m^2$, divided into two areas of $12m^2$ for each pavement PP and PD. The soil foundation was classified as a sand with load capacity and low permeability, which leads to a very small quantity of water infiltrated in the soil. A drainage pipes system was placed in the last layers of both pavements for draining infiltrated water (*leaching water*) to collection boxes.

Figure 1: Experimental pavements: PD (right) and PP (left).

The pavements were formulated according to the indication's setup at the work schedule of Portuguese roads [10]. The PP structure incorporates a double drainage bituminous layer (DLPA), with 7cm of total thickness, followed by a base layer with aggregates of 5/15mm with 9cm depth and a reservoir of loose aggregates of 15/25mm with 25cm depth. The DLPA is composed of a 3cm thick top drainage bituminous mixture with aggregates of size up to 10mm (PA1) and a bottom 4cm thick bituminous mixture with aggregates of size up to 15mm (PA2). Both blends incorporated cellulosic fibers into their composition according to the study Afonso *et al*. [11] and 50/70 bitumen.

The top layer with fine aggregates acts as a sieve that reduces the entry of sediments that tend to accumulate in the pores, and it prevents the clogging of the thick aggregate bottom layer, facilitating the drainage [12]. The PD is typically comprised of a 5cm thick surfacing AC 14 surfacing layer (HMA1), a 9cm AC 20 base layer (HMA2) and a substrate layer of mixed aggregates *tout-venant* with 20 cm.

The chemical characteristics of each layer of the pavements PP and PD were determined by dispersive energy spectroscopy (EDS), using a Hitachi equipment, model S-2700 (RONTEC, USA), and the determined elementary analysis (in percentage of mass) is shown in the Table 1.

2.2. Water sampling

In order to observe the possible washing and leaching of metals through both pavements after precipitation events, the water quality variation between the top and the base of the pavements was evaluated during 11 precipitation events, shortly after the construction of the pavements, between November 2016 and March 2017, including the first precipitation event after construction. Water samples were collected shortly after each precipitation event at five sampling points identified in the scheme of Figure 2, through drainage pipes directed to the collection boxes. For the collection and storage of the water samples, 0.5 L PET bottles were used. The determination of the heavy metals Cd, Cr, Fe, Pb, Mn, Ni and Zn were carried out by an atomic absorption spectrophotometer GBC906 (Australia), according to the procedures of the ISO 15586: 2003 [13].

Table 1: Elementary analysis of PP and PD pavements.

	PP			PD		
Chemical element	**PA1**	**PA2**	**Aggr.**	**HMA1**	**HMA2**	**Tout-venant**
Na	4.28	4.57	2.96	4.45	3.89	2.84
Mg	1.80	1.95	0.81	1.57	1.26	0.73
Al	13.04	13.36	10.58	12.12	11.34	9.96
Si	26.12	26.40	29.55	27.28	28.02	30.60
P	0.37	0.41	0.08	0.31	0.25	0.17
S	0.78	0.73	-	0.70	0.50	-
K	4.30	3.54	5.42	3.93	4.65	4.89
Ca	0.47	0.32	0.62	0.54	1.05	0.57
Ti	0.17	-	0.20	0.21	0.28	0.20
Fe	1.40	1.14	2.51	1.39	1.45	2.17
O	47.27	47.58	47.27	47.40	47.31	47.62
Cu	-	-	-	-	-	0.24

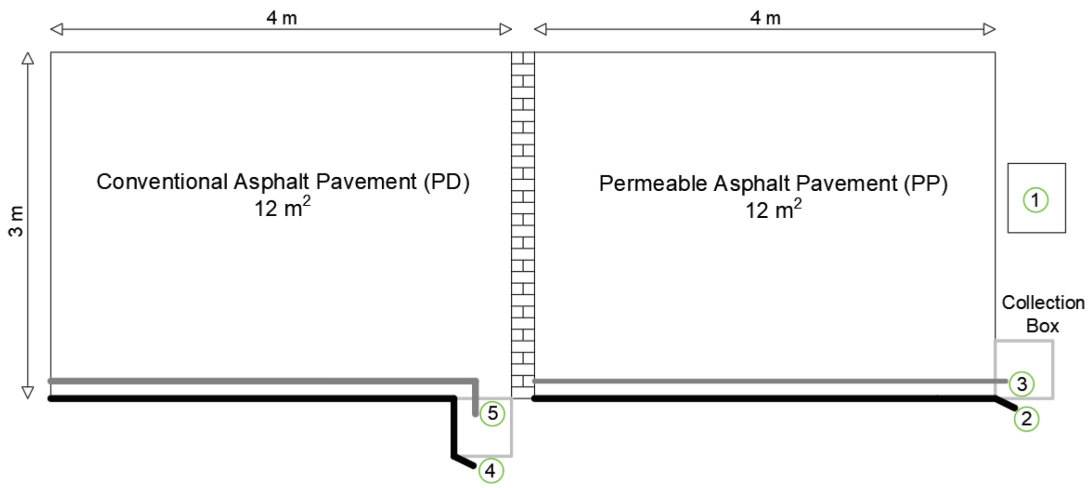

Figure 2: Water sampling points.

Point 1: Rainwater before entering both pavements (RW).

Point 2: Rainwater after surface runoff on the PP pavement (PPE).

Point 3: Rainwater after infiltration into the PP pavement (PPI).

Point 4: Rainwater after surface runoff on the PD pavement (PDE).

Point 5: Rainwater after infiltration into the PD pavement (PDI).

3. Results and Discussion

The mean, maximum, and minimum values of the metal analyzes on the 11 water samples at the five sampling points are presented in Table 2 in accordance with the limit values setup in the Portuguese regulations, while the variations in the metal concentrations over the sampling time are presented in Figures 3 to 8. A good drainage of both pavements after each rainfall was verified by local inspection.

TABLE 2: Heavy metals concentrations for the five sampling points (in mg/l).

Parameter		RW(1)	PPE(2)	PPI(3)	PDE(4)	PDI(5)	SV
Cr	Average	0.00	0.41	0.24	1.82	0.20	
	Min	0.00	0.04	0.08	0.69	0.04	
	Max	0.00	1.10	0.50	3.66	0.56	2; 20
Fe	Average	0.00	0.05	0.47	0.10	0.23	
	Min	0.00	0.02	0.22	0.03	0.11	
	Max	0.00	0.10	0.93	0.18	0.43	2; NS
Mn	Average	0.00	0.06	0.05	0.01	0.01	
	Min	0.00	0.00	0.00	0.00	0.00	
	Max	0.00	0.18	0.10	0.03	0.02	2; 10
Ni	Average	0.00	0.11	0.17	0.09	0.12	
	Min	0.00	0.05	0.08	0.03	0.05	
	Max	0.00	0.21	0.28	0.14	0.19	2; 2
Pb	Average	0.00	0.02	0.03	0.03	0.03	
	Min	0.00	0.01	0.02	0.01	0.01	
	Max	0.00	0.03	0.05	0.05	0.04	1; 20
Zn	Average	0.00	0.05	0.05	0.05	0.07	
	Min	0.00	0.03	0.01	0.01	0.02	
	Max	0.00	0.09	0.11	0.16	0.10	NS; 10

SV: standard values allowed for discharge of treated wastewater to water courses (first value) and for irrigation waters (second value) according to the Portuguese Decree Law No. 236/98 [9]. NS: no standard limit.

None of the heavy metals analysed were detected in the rainwater samples. The metal Cd was not detected at any of the sampling points. In the investigations of Legret and Colandini [14], with pavements subject to road circulation, Cd was detected in the surface waters of a PP, having been removed in the porous layers of the asphalt. The

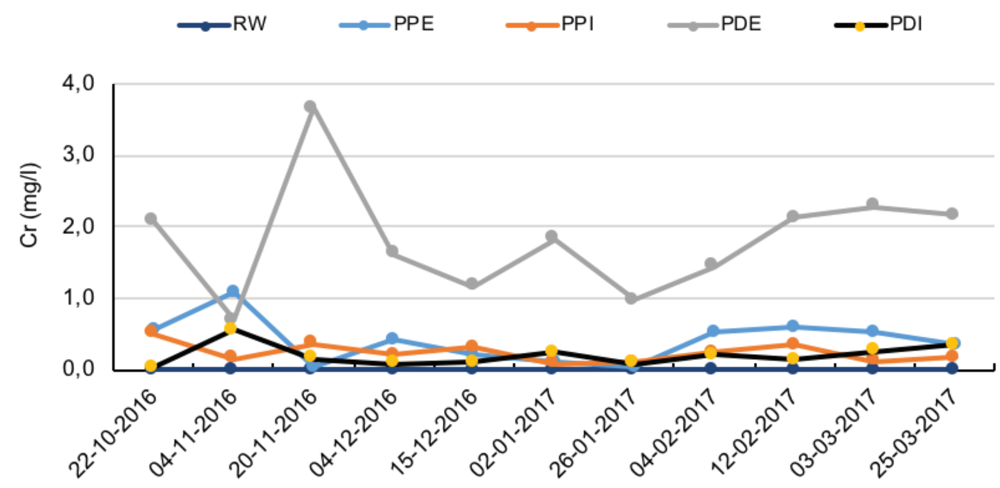

Figure 3: Variation of Cr along the sampling time.

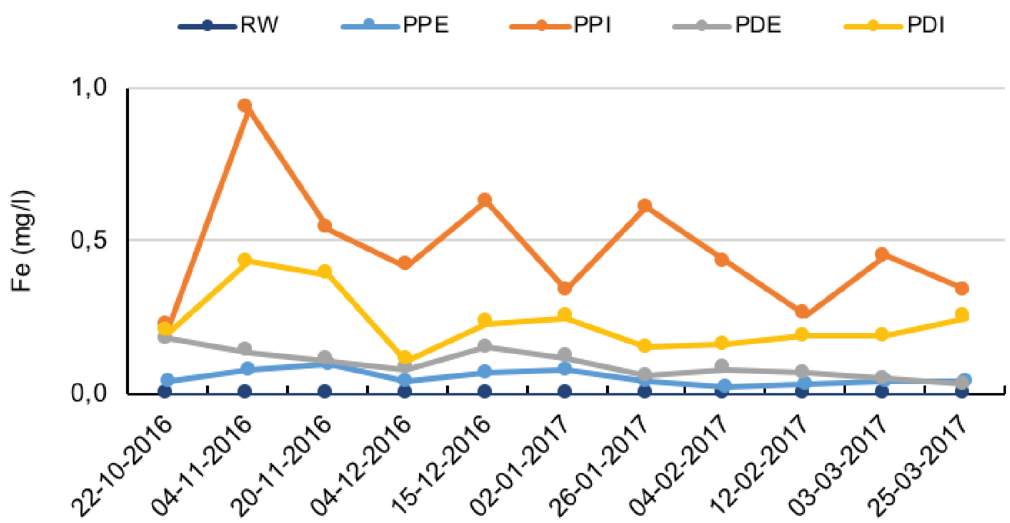

Figure 4: Variation of Fe along the sampling time.

remaining metals were detected at the four sampling points located on both pavements, which proves that these compounds are incorporated in the runoff and infiltration waters after contact with the different layers of the materials. Some metals were also removed during the infiltration of the water in the pavements.

The metals Mn, Pb and Zn were found at very low concentrations at the sampling points of the pavements, with averages not exceeding 0.07 mg / l. The maximum concentrations of these metals in both pavements are much lower than the limit values defined in the current legislation for irrigation and discharge on water courses.

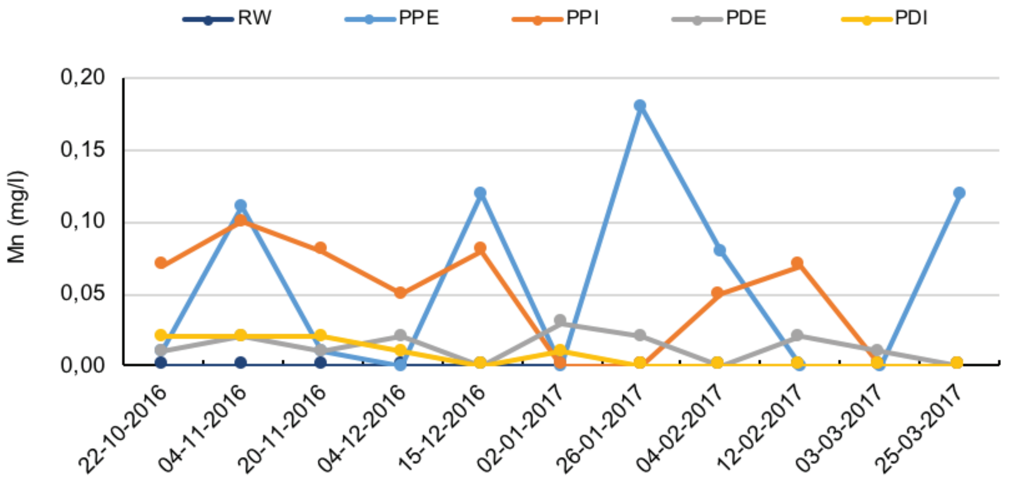

Figure 5: Variation of Mn along the sampling time.

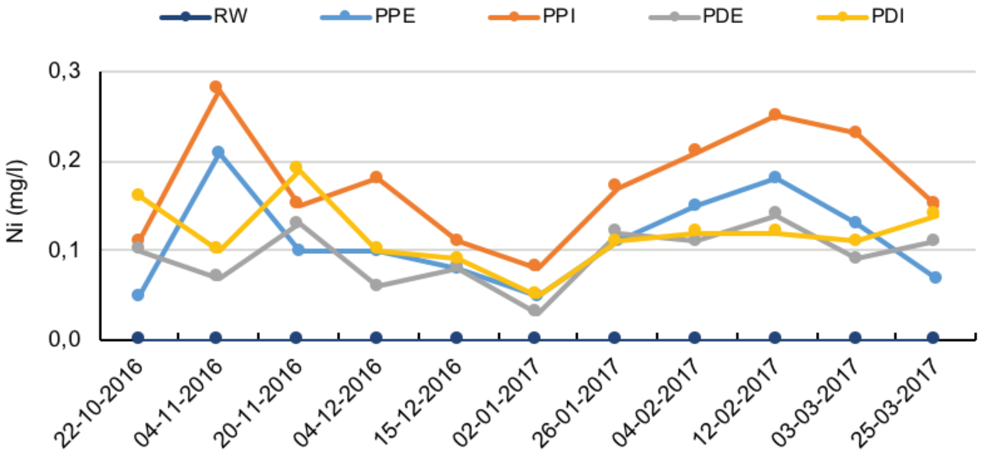

Figure 6: Variation of Ni along the sampling time.

The Cr was found at low concentrations on both pavements (Figure 3), and the highest value (3.66 mg/l) was found on the PD surface. Part of the Cr was trapped during the infiltration of water in both pavements, with a mean removal value higher in PD (1.62 mg/l) than in PP (0.17 mg/l).

Fe was detected at low concentrations on both pavements (Figure 4), with a higher average value in the PPI leachate (0.47 mg/l) than in the PDI leachate (0.23 mg/l). This metal increased during water infiltration in both pavements, with a higher average value for PPI (from the runoff water to the infiltered water, the mean Fe concentration increased 0.42 mg/l). This circumstance can be associated to the presence of Fe in the structures of PA1, PA2 and aggregates layers in PP, and of the layers HMA1, HMA2 and *Touit-venat* in PD (see Table 1), wghich was then released into the water.

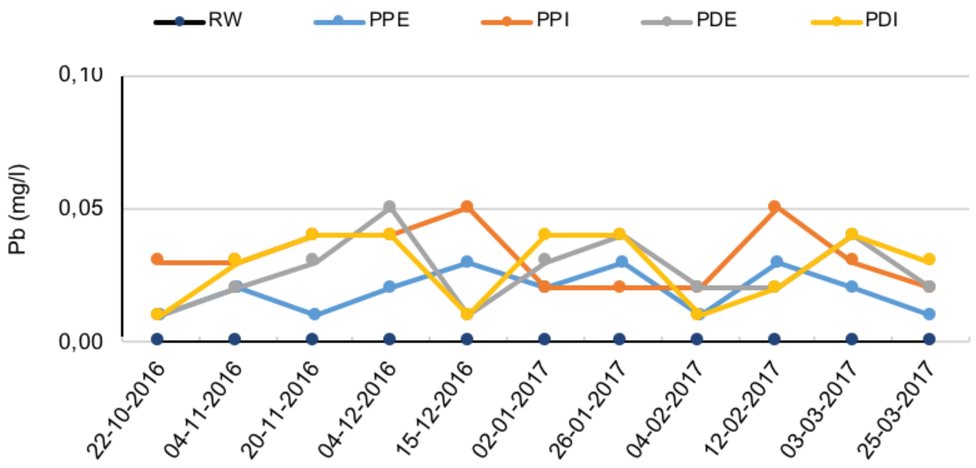

Figure 7: Variation of Pb along the sampling time.

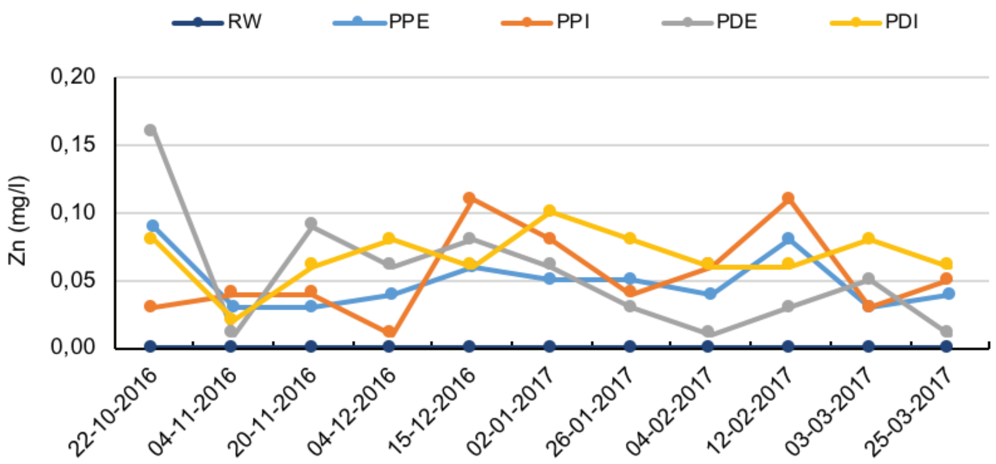

Figure 8: Variation of Zn along the sampling time.

The Mn presented very low concentrations at the sampling points of both pavements (Figure 5), especially in PD. There was a low incorporation of this metal in the runoff water and a slight removal through the water infiltration was observed in both pavements, with an average removal of 0.01 mg/l.

Ni was detected at low concentrations on both pavements (Figure 6), and the highest value (0.28 mg/l) was detected in PP. The mean values in the leachate were 0.17 mg/l (in PPI) and 0.12 mg/l (in PDI). This metal increased a little bit during water infiltration in both pavements, with a higher average value for PPI (from the runoff water to the infiltered water, the mean Ni concentration increased 0.06 mg/l).

The Pb has very low concentrations at the four sampling points (average values range between 0.02 mg/l and 0.03 mg/l, Figure 7). There was practically no incorporation of this metal, or its removal, when the water infiltrated the pavements. Similar behavior was observed for Zn (Figure 8). The mean values at the four pavement sampling points ranged from 0.05 mg/l to 0.07 mg/l, with no Zn uptake or removal being detected when the water seeped into the pavements.

Although Cr, Fe, Mn, Ni, Pb and Zn metals were not detected in percentage terms in the elementary analysis of the various layers of the pavements (see Table 1), they appear in the surface runoff waters of both pavements (PPE and PDE points) and in the leaching waters after rain water infiltration in the pavements (PPI and PDI points). This circumstance is related to the elementary analysis of the several layers of pavements that present inorganic elements in greater quantity than the metals.

However, the analysis of water samples showed that these metals are present in the pavements and that they are washed, incorporated and transported in water runoff and infiltration waters. Therefore, these effluents should be monitored regularly to prevent concentrations of metals reaching values that could cause concern to the environment and public health. The concentrations of metals detected in the leaching waters are low in relation to the minimum values established in the Portuguese Decree-Law No. 236/98 for the use of treated wastewater in irrigation or for discharge into watercourses. Therefore, the leaching water of these pavements, without the effect of traffic, could be reused for agricultural purposes or discharged into surface water courses.

Regarding the concentration of metals in the runoff waters and the infiltrated waters of the four sampling points it was observed the following: Cr and Mn were removed during infiltration with greater values for Cr in PD; there was no significant alteration in the values of Pb and Zn from runoff water to infiltrated waters; and there was an increase in Fe and Ni concentration after infiltration.

The removal of Cr was higher in the classic PD than in the PP pavement. However, the studies of Legret nd Colandini [14] and Jiang *et al*. [8] shown that PP has a high removal efficiency in Cu, Zn, Pb and Cd than PD pavements.

The results also seem to indicate that the sampling time (five months after the construction of the pavements) is not enough for an in-depth analysis of the washing and leaching of metals in these materials. It will require a longer sampling time and, later, pass the analysis methodology to traffic roads, where the impact of the incorporation of metals in water quality may be more significant. However, this experimental work already allows to verify that it is necessary to control the leaching of these metals in road pavements.

4. Conclusions

Both PP and PD pavements showed good drainage after each precipitation event. However, the results show that Cr, Fe, Mn, Ni, Pb and Zn are washed, incorporated and transported after rainwater surface runoff and infiltration in PP and PD pavements. There was only considerable removal of Cr on the PD pavement. Fe and Ni leaching occurred during infiltration, with higher values for PP. The average concentrations of Pb and Zn at the water surface, and after infiltration in the pavements, remained practically constant. For all the metals, the values leached at PPI and PDI points have maximum concentrations much lower than the limits setup in the legislation for reusing these effluents in agricultural irrigation or for discharge into surface waters.

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References

[1] WAPA, *Porous Asphalt Pavements*, Wisconsin Asphalt Pavement Association, September 2015, 1–12, (2015).

[2] R. Elvik, P. Greibe. *Road safety effects of porous asphalt: A systematic review of evaluation studies*, Accid. Anal. Prev., **37**: 3, 515–522 (2005).

[3] A. Fini, P. Frangi, J. Mori, D. Donzelli, F. Ferrini. *Nature based solutions to mitigate soil sealing in urban areas: Results from a 4-year study comparing permeable, porous, and impermeable pavements*, Environ. Res., **156**: 443–454 (2017).

[4] R. Roseen, T. Ballestero, J. Houle, J. Briggs, K. Houle. *Water quality and hydrologic performance of a porous asphalt pavement as a storm-water treatment strategy in a cold climate*, J. Environ. Eng., **138**: 1, 81–89 (2012).

[5] G. Burton, R. Pitt, *Stormwater Effects Handbook - A toolbox for watershed Managers, Scientists and Engineers*, Lewis Publishers, CRC Press LLC, USA (2001).

[6] R. Pitt, S. Clark, K. Parmer, *Potential groundwater contamination from intentional and nonintentional stormwater infiltration*, Risk Reduction Engineering Laboratory,

Office of Research and Development, U.S. Environmental Protection Agency, USA (1994).

[7] C. Pagotto, M. Legret, P. Cloirec. *Comparison of the hydraulic behaviour and the quality of highway runoff water according to the type of pavement*, Water Res., **34**: 18, 4446–4454 (2000).

[8] W. Jiang, A. Sha, J. Xiao, Y. Li, Y. Huang. *Experimental study on filtration effect and mechanism of pavement runoff in permeable asphalt pavement*, Constr. Build. Mater., **100**: 102–110 (2015).

[9] Decree Law No. 236/98 de 1 de Agosto, *Estabelece normas, critérios e objetivos de qualidade com a finalidade de proteger o meio aquático e melhorar a qualidade das águas em função dos seus principais usos*, Ministério do Ambiente, Diário da República Portuguesa, No. 176, 3676–3722, Lisboa, Portugal (1998).

[10] Estradas de Portugal S.A., *Caderno de Encargos Tipo Obra, Pavimentação, 14.03 Características dos materiais e 15.03 Métodos construtivos*, Vol. V. Estradas de Portugal, Lisboa, Portugal (2014).

[11] M. Afonso, M. Dinis-Almeida, and C. S. Fael. *Study of the porous asphalt performance with cellulosic fibres*, Constr. Build. Mater., **135**: 104–111 (2017).

[12] M. Hamzah, N. Abdullah, J. Voskuilen, G. van Bochove. *Laboratory simulation of the clogging behaviour of single-layer and two-layer porous asphalt*, Road Mater. Pavement Des., **14**: 1, 107–125 (2013).

[13] ISO 15586, *Water quality. Determination of trace elements using atomic absorption spectrometry with graphite furnace*, Norma Int. Int. Organ. Stand. Genebra, Switzerland, p. 7, 2003.

[14] M. Legret, V. Colandini. *Effects of a porous pavement with reservoir structure on runoff water: water quality and fate of heavy metals*, Water Sci. Technol., **39**: 2, 111–117 (1999).