End-of-Life approach in permeable pavement systems: A forensic study of the particle-related pollutants retained in porous concrete and porous asphalt surface layers

Fin de vie des systèmes de chaussées perméables : une étude médico-légale des polluants liés aux particules retenus dans les couches de surface en béton poreux et en asphalte poreux

Andrés-Valeri, V.C.[(1)*]; García-Argüelles, S.[(1)]; Sañudo-Fontaneda, L.A.[(2)]; Rodríguez-Gallego, J.L.[(3)]; Rodriguez-Hernandez, J.[(1)]; Sierra, C.[(4)]

(1)GITECO, Universidad de Cantabria; (2)CEGE, Universidad de Oviedo;
(3)INDUROT, Universidad de Oviedo; (4)Universidad de León
*Corresponding autor: valerio.andres@unican.es

RÉSUMÉ

Les systèmes de chaussée perméable (PP) sont devenus l'une des techniques de drainage durable les plus utilisées et les plus étudiées, offrant une atténuation du débit de pointe, une réduction du volume et une recharge accrue des eaux souterraines. De plus, les chaussées perméables offrent également de grands avantages en matière de réduction des polluants. Cependant, le devenir des polluants filtrés dans ces systèmes est encore inconnu. Pour cette raison, ce travail expérimental a analysé les sédiments déposés sur deux surfaces perméables couramment utilisées dans les systèmes de chaussée perméable : l'asphalte poreux et le béton poreux, collectés par aspiration dans un parking expérimental de la ville de Santander (Espagne) après dix ans d'utilisation continue sans maintenance. Les résultats obtenus indiquent que la quantité de sédiments déposés sur les deux surfaces et dans leur structure poreuse est assez similaire même si leurs tailles de particules sont légèrement différentes. Les polluants liés aux particules se sont également avérés très similaires dans les deux surfaces perméables, et proviennent principalement des activités de circulation, mettant en évidence la présence d'une énorme quantité de métaux lourds et de HAP.

ABSTRACT

Permeable Pavement systems (PPS) are one of the most used and studied Sustainable Drainage techniques, providing great benefits in pollutant reduction. However, the fate of filtered pollutants in these systems is still not fully considered. For these reasons this experimental work analyzed the sediments deposited over two permeable surfaces commonly used in PPS internationally: Porous Asphalt and Porous Concrete, collected by vacuuming in an experimental parking area in the city of Santander (Spain) after 10 years of continuous use. The obtained results indicate that the amount of sediments deposited over both surfaces and in their superficial pores is quite similar even if their particle sizes are slightly different. Particle-related pollutants have been found to be also very similar in both permeable surfaces, and mainly originated by traffic activities, highlighting the presence of a significant quantity of heavy metals and PAHs.

KEYWORDS

(BMP, Nature Based Solutions, Pollution, SUDS, Sediments)

1 INTRODUCTION

In the last years, the increased social, political, and technical awareness about sustainability matters have changed the path of urban development. Nature-based Solutions (NbS) and Green Infrastructure (GI) are now the core of urban development plans in most cities and countries in order to increase the amenity of urban areas and face problems related to climate change and pollution (*Nesshöver et al., 2017*). Even if NbS have many ecosystem functions such as thermal regulation and biodiversity improvements, water related functions are still one of their main applications. In this context, NbS techniques related to water management have been commonly called Sustainable Urban Drainage Systems (SUDS) and have been used during the last two decades to mitigate flooding and pollution in stormwater runoff of urban areas in countries such as the UK, USA, or Australia (*Castro-Fresno et al., 2014*).

Permeable Pavement systems (PPS) have become one of the most used and studied SUDS (*Andres-Valeri et al., 2016*). Among the great benefits that this technique provides highlights their capacity to reduce runoff volumes and peak flows, and their capacity to increase groundwater recharge (*Sañudo-Fontaneda et al., 2014*). Apart from water quantity issues, permeable pavements also provide great benefits in terms of pollutant removal, being extensively documented their effectiveness reducing suspended solids, hydrocarbons, nutrients and bacteria pollution *(Mullaney and Lucke, 2014; Tota-Maharaj and Scholz, 2010*). PPS cross sections, generally composed by granular layers, geofabrics and a permeable surface (*Andres-Valeri et al 2016*), performs as a filtering media, where the pollutants are retained by different mechanisms, mainly by filtration and biological processes.

Different studies about runoff pollution pointed out that particle-bound pollutants are the major source of pollution in urban runoff waters (*Sansalone and Buchberger, 1997*). Sediments deposited over the urban surfaces are washed by rainfall and runoff and are finally transported through the drainage systems into the sewage systems and/or water bodies (*Castro-Fresno et al., 2014*). Even if it is clear that nowadays sustainable drainage techniques in general, and PPS in particular are able to reduce pollution in urban runoff, the fate of the particle-related pollutants in these systems is not necessarily defined. For these reasons, and in the framework of the D4RUNOFF project, an EU funded project related to NbS that started in September 2022, this research has been developed as the first approach to find the fate of pollutants in PPS. With this aim, the sediments deposited over the pavement surface of PPS in an experimental permeable parking area in the North of Spain, were collected after 10 years of continuous use without maintenance. These sediments were classified and analyzed looking for the most common pollutants in urban runoff and the obtained results were finally discussed.

2 MATERIALS AND METHODS

The experimental permeable parking area of “Las Llamas” park is located in Santander, a coastal city in Northern Spain with an average yearly rainfall near to 1200 mm/year (Cfb KöppenGeiger’s climate classification), and was built in 2008. The parking area consist of 45 parking bays, made up with different permeable pavement cross sections and permeable surfaces as summarized in previously published research (*Sañudo-Fontaneda et al., 2014*). The parking area has been on use since its construction with an occupation rate of 100% during working days and near to 90% in weekends and holydays.

After ten years since its construction, an experimental campaign was performed in the parking area to collect the sediments deposited over two types of permeable pavements: porous asphalt (PA) and porous concrete (PC). After being brushed to lose compacted sediments, and by using an industrial vacuum cleaner, 6 parking bays were fully vacuumed: 3 parking bays for each permeable surface (PC and PA). The sediments collected were initially cleaned and heated in order to avoid organic matter pollution, and were latterly wet-sieved and classified according to their particle size. Finally, sediments were grouped according to their particle size in 3 fractions: <125µm, 125-500 µm and 500-2000 µm, leading to the groups PA125, PA500, PA2000 for each particle size range in PA pavements (resp.) and PC125, PC500 and PC2000 (resp.) for PC pavements. Each group was analyzed by Induced Coupled Plasma Mass Spectrometry (ICP-MS) and Gas Chromatogrtaphy Mass Spectrometry (GC-MS) looking for potential pollutants that can be found in urban runoff, especially hydrocarbons and heavy metals.

3 RESULTS AND DISCUSSION

3.1 Physical Characteristics

The obtained results for the particle sizes of the sediments vacuumed for each selected permeable surface are summarized in Table 1. Comparing both permeable surfaces, the quantity of sediments collected is slightly higher for PA surfaces. Additionally, a higher amount of fine sediments has been found in PA surfaces, probably due to the different pore structure in both surfaces, which probably lead to a higher accumulation of sediments in PA surfaces, especially fine sediments.

Table 1: Quantity of sediments collected in the 3 parking bays of each permeable surface (PA and PC)

Particle size	**PA**(gr)	**PC**(gr)
<125 µm	47,1	55,5
125-500 µm	143,2	172,8
<125 µm	47,1	55,5
Total	**553,9**	**479.2**

3.2 Chemical Analysis

The chemical characterization of the obtained sediments is shown in Tables 2 and 3. According to these results the highest concentration of practically all constituents was found in the finer fraction for both permeable surfaces, being these results in accordance with previously published research (*Zhao et al., 2010*). Additionally, it was found that most of the pollutants that were found in the collected sediments are in some way related to automotive industry (Cu, Pb, Zn, Ni, Mn and Ba). Analyzing the most common heavy metals in stormwater runoff: Cu, Pb and Zn, the obtained results showed enriched concentrations in the finer fractions, showing the fraction <125µm increments near to, or higher than, 100% in relation to coarser fractions.

Table 2: Metals and metalloids concentration in all fractions of both permeable surfaces (PA and PC)

	Al	Ba	Bi	Cd	Cu	Fe	Hg	Mn	Ni	Pb	Sr	Ti	Zn
	%	ppm	ppm	ppm	ppm	%	ppb	ppm	ppm	ppm	ppm	%	ppm
PA2000	0,05	76,6	0,04	0,19	8,65	0,54	14	158	23,9	22,62	249,3	0,003	18,6
PA500	0,08	335,5	0,11	0,28	60,61	0,85	20	267	8,8	12,27	232,3	0,005	112,3
PA125	0,2	395,9	0,74	0,76	258,62	1,11	80	812	28,2	45,57	170,3	0,008	407,8
PC2000	0,18	91,9	0,06	0,22	14,24	0,61	17	287	6,2	28,29	276,6	0,011	48,8
PC500	0,31	277,7	0,36	0,35	88,15	1,18	40	541	118,8	26,81	178,5	0,013	344,2
PC125	0,78	294,4	1,01	0,87	216,62	1,63	152	1321	28,4	56,78	164,1	0,026	589

These results are supported by other studies like *Zhao et al. (2010)*, which analyzed particles from 0 to 2000µm and found the highest metal concentrations in the 44–62µm fraction. Also studies from cities like Aviles (Spain) or London (UK) looked into small grains size for metal pollution (*Ordoñez et al., 2003; Harrison et al., 1981*) finding pollutants concentrations similar to those obtained in this research.

Table 3: PAHs concentration (ppm) in all fractions of both permeable surfaces (PA and PC)

	PC 125	PC 500	PC 2000	PA 125	PA 500	PA 2000
Acenaphthylene	0,0362	0,0343	0,0055	0,0087	0,0090	0,0125
Fluorene	0,0055	0,0004	-	0,0017	0,0003	0,0005
Phenanthrene	0,0822	0,0304	0,0024	0,0218	0,0089	0,0139
Anthracene	0,0297	0,0263	0,0042	0,0076	0,0068	0,0102
Fluoranthene	0,0956	0,0400	0,0039	0,0308	0,0137	0,0151
Pyrene	0,1124	0,0518	0,0058	0,0563	0,0253	0,0305
Benzo(a)anthracene	0,0486	0,0319	0,0046	0,0125	0,0145	0,0105
Chrysene	0,0453	0,0067	-	0,0412	0,0223	0,0165
Benzo(k)fluoranthene	0,0873	0,0514	0,0070	0,0346	0,0304	0,0231
Benzo(b)fluoranthene	0,0289	0,0155	0,0023	0,0071	0,0075	0,0055
Benzo(a)pyrene	0,0555	0,0434	0,0069	0,0134	0,0183	0,0150
Indene(1,2,3-c,d)pyrene	0,0625	0,0462	0,0064	0,0134	0,0176	0,0147
Dibenzo(a,h)anthracene	0,0535	0,0496	0,0095	0,0117	0,0206	0,0184
Benzo(g,h,i) perylene	0,1138	0,0647	0,0077	0,0255	0,0268	0,0209
TOTAL	0,8570	0,4926	0,0662	0,2862	0,2220	0,2074

For both PA and PC, the greater concentration of the 16 PAH compounds is found at the finest fraction of the collected sediments (<125 µm). This fact is more attenuated in PA samples than in the PC, where differences between particle sizes are twofold, while in PC the PAH in the coarser fraction is smaller in an order of magnitude in relation to the finer one. The differences between PA and PC in the PAH content of coarser particles, is mainly due to the elemental composition of bituminous binders used in PA pavements that can significantly affect PAH release (*Wassenaar and Verbruggen, 2021*). Other PAHs sources such as combustion or automotive lubricant spills should be considered.

4 CONCLUSIONS

The obtained results showed that the amount of sediments deposited over PA and PC surface layers and removed by vacuum cleaning is quite similar. However, a higher amount of finer sediments was found in PA surface layer probably due to the pore structure of this surface layer.

Pollutants found in both permeable surfaces are clearly related to traffic activities and automotive industry. Heavy metal concentration showed to be in the range of values reported by previous studies related to road sediments and stormwater pollution.

Finer particles showed to be more polluted than coarser ones both for PA and PC pavements. The concentration of the most important heavy metals showed to be near to 100% higher in finer fractions than in coarser ones for both permeable surfaces.

Finer particles also showed to attach more PAHs than coarser ones. However, PC pavements showed reduced quantities of PAHs in coarser fractions than PA, probably due to the composition of PA pavements, where the use of bituminous binders lead to increased amount of some PAHs in the coarser fractions that were mainly associated with the disaggregation of particles from PA pavements surfaces.

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