Water quality assessment in pervious pavements with BOF-slag sub-base in a parking area in the North of Spain

Évaluation de la qualité de l'eau dans des chaussées perméables avec plate-forme de scories LD, dans une aire de stationnement dans le nord de l'Espagne

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RÉSUMÉ

Le développement urbain dans les dernières décennies a entraîné une augmentation des surfaces imperméables et donc, une augmentation des problèmes liés à la gestion de l'eau dans les villes. Ce contexte a fait émerger des techniques de drainage durables, telles que BMP ou SUDS. Bien que les chaussées perméables aient été largement étudiées auparavant, la recherche sur l'utilisation de matériaux recyclés dans ces chaussées reste limitée. Cet article présente une étude de 8 places de stationnements expérimentaux avec deux types de revêtements perméables réalisées dans la ville de Gijón (Espagne), en utilisant les laitiers d'aciéries de conversion comme agrégat de sous-couche. L'objectif principal était d'analyser l'évolution de la qualité de l'eau et de l'adéquation des laitiers d'aciéries de conversion à être utilisées avec des techniques de chaussées perméables. Pour atteindre ces objectifs, différents paramètres de la qualité de l'eau, les précipitations et les températures ont été mesurés pendant 14 mois. Grâce à ces données, l'influence des laitiers et le type de surface sur la qualité de l'eau, a été analysée. Les résultats obtenus montrent des niveaux de corrélation significatifs entre les facteurs climatiques et le pH, la conductivité électrique CE, les MES et la turbidité. Des niveaux élevés de pH et de CE ont été trouvés avec une tendance tout de même à la baisse, ce qui implique que les eaux d'infiltration pourraient être réutilisées dans certains usages résidentiels, industriels, récréatifs et agricoles.

ABSTRACT

Urban development in the last decades has brought an increase of impervious areas and, consequently, an increase of the problems related to water management in cities. Sustainable Drainage Techniques, also called BMPs or SUDS, have emerged in this context. Pervious pavements are probably the most intensively researched of these techniques. Although pervious pavements have been extensively studied before, research on the use of recycled materials in these pavements is limited. This paper presents a study of 8 experimental parking bays with two types of pervious pavements constructed in the city of Gijón (Spain), using Basic Oxygen Furnace Slag (BOF-slag) as a sub-base aggregate. The main objective of the research was to analyze water quality and the suitability of BOF-slag for use in pervious pavements. Water quality parameters, rainfall and temperature were measured during 14 months. With this data, the influences of BOF-slag sub-base and surface type in water quality were analyzed. Also significant correlation levels between climatic factors and pH, EC, TSS and turbidity were observed. In conclusion, high values for pH and EC were found in infiltrated water, albeit with a downward trend; nevertheless, the outflow water could be reused in certain residential, industrial, recreational and agricultural uses.

KEYWORDS

BMP, BOF slag, Pervious pavements, SUDS, Water quality

1 INTRODUCTION

Rapid growth of urban areas during the last decades has increased the problems associated with inefficient water management in cities (Makropoulos, Butler 2010). Sustainable drainage techniques, also called BMPs (Best Management Practices) or SUDS (Sustainable Urban Drainage Systems), were born as a solution to these problems. The potential of SUDS to store water for reuse in some non-potable applications has been reported in previous studies in many different countries such as Brazil (Ghisi, Bressan and Martini, 2007), Germany (Nolde, 2007), Japan (Furumai, 2008) and Spain (Gomez-Ullate *et al*. 2011b). Pervious pavements are the most studied sustainable drainage techniques because of their effectiveness in reducing runoff and pollutant concentrations. These systems are composed of three main layers of different materials: surface, base and sub-base. With these three permeable layers, pervious pavements are able to trap the contaminated runoff and filter it thereby reducing the concentration of pollutants. There are several experimental parking areas constructed with pervious pavements in different countries such as USA (Booth and Leavitt, 1999; Hunt, Stevens and Mayes, 2002; Brattebo and Booth, 2003; Dreelin, Fowler and Ronald-Carroll, 2006; Gilbert and Clausen, 2006; Boving *et al*., 2008; Collins, Hunt and Hathaway, 2010; Houle *et al*., 2010) , UK (Pratt, Mantle and Scholfield, 1995; Pratt, 1999), Germany (Dierkes *et al*., 2002), Asia (Lee *et al*., 2009), Brazil (Acioli, da Silveira and Goldenfun, 2005), and Spain (Rodriguez *et al.*, 2005; Gomez-Ullate *et al*., 2011a; Gomez-Ullate *et al*., 2011b).

There are many studies about the construction of pervious pavement parking areas. In 2002, Hunt, Stevens and Mayes studied the potential of different pervious pavements to reduce runoff in two different catchments in North Carolina and they concluded that pervious pavements did reduce runoff. They also pointed out the necessity of proper maintenance to reduce clogging and maintain infiltration capacity. The same conclusions were obtained by Dierkes *et al.* (2002), who studied the main problems associated with pervious pavement parking areas. In 2003, Brattebo and Booth studied the long-term effectiveness of different systems of pervious pavement parking areas, starting with previous studies carried out by Booth and Levitt in 1999, and focusing their study on analyzing for durability, infiltration capacity and stored stormwater quality. In 2006, Dreelin, Fowler and Ronald-Carroll studied the effectiveness of pervious pavements in the infiltration of water into clay soils. Also Gilbert and Clausen (2006) studied infiltrated storm-water quality and quantity in different driveways in a residential area located in Waterford (US). Boving *et al*. (2008) studied nutrients and bacteria mobilization through pervious pavements in relation with the parking occupation level. In addition to this, Lee *et al*. (2009) tested new porous concrete mixes in an experimental parking area, in order to obtain the best mixture required to reduce runoff and the effects of heat island in Taiwan. In 2010, Collins, Hunt and Hathaway analyzed the nutrients and solids removal capabilities of pervious pavements in an experimental parking area in the north of Carolina. Later, Gomez-Ullate *et al*. (2011a) analyzed the operation of an experimental pervious parking area focusing on runoff quantity and establishing the existence of three groups of surfaces with similar properties: open pervious pavements (different concrete blocks with slots), close pervious pavements (porous asphalt and porous concrete) and reinforced grass (different reinforcements). They concluded that the influence of surfaces on infiltration capacity is greater than the influence of geotextile. After this, Gomez-Ullate *et al.* (2011b) analyzed the results of different water quality parameters in water stored in the parking bays. They proved that after one year of storage, water quality is good enough to be used for irrigation of green areas or cleaning of roads.

Although there were so many researches about pervious pavements, they were mainly focused on testing different surfaces in order to study either their infiltration capacity or in establishing reduction rates between the pollutants concentrations in runoff and in pervious pavements outflow. Regarding the granular layers, only the grain sizes were studied in order to improve the pollutants retention, but the materials employed to construct these layers were not studied in detail. Nowadays, considering the continuous depletion of natural resources and also in order to reduce the cost-effectiveness relation, it has become necessary to study the performance of recycled materials in pervious pavements. Basic Oxygen Furnace Slag (BOF-Slag) is an industrial by-product derived from the steelmaking process of refining iron in a basic oxygen furnace. Its application in ground stabilization has been widely studied in pathogen reduction, phosphorus, arsenic and some heavy metals removal (Barca *et al*., 2012; Stimson *et al*., 2010; Xue, Hou and Zhu, 2009). In order to assess the field performance of this material combined with pervious pavements technology, a pervious parking with BOF-Slag in the sub-base layer was constructed in Gijón (Spain) and monitored for 14 months. The objectives of this paper are to discuss the relationship between pollutants in the outflow and climatology, to assess the influence of BOF-slag sub-base and surface type in water quality and to evaluate the water quality in order to reuse the stored water.

2 METHODS

For the development of this research, 8 experimental park bays were built in May 2010 using BOF-slag in the sub-base layer. These experimental car park bays were integrated into a high occupancy parking area located in the Science and Technology Park of Gijón (Spain). The car park bays were 4.2m x 2.4m and 0.5m in depth. They were designed to be completely waterproof and independent of the other car park bays. Consequently, each bay has been waterproofed separately, allowing the water to be stored within. Each parking bay has two outlets: bottom and emergency, both connected to a control manhole that allows for water sampling and measuring water levels within the pavement.

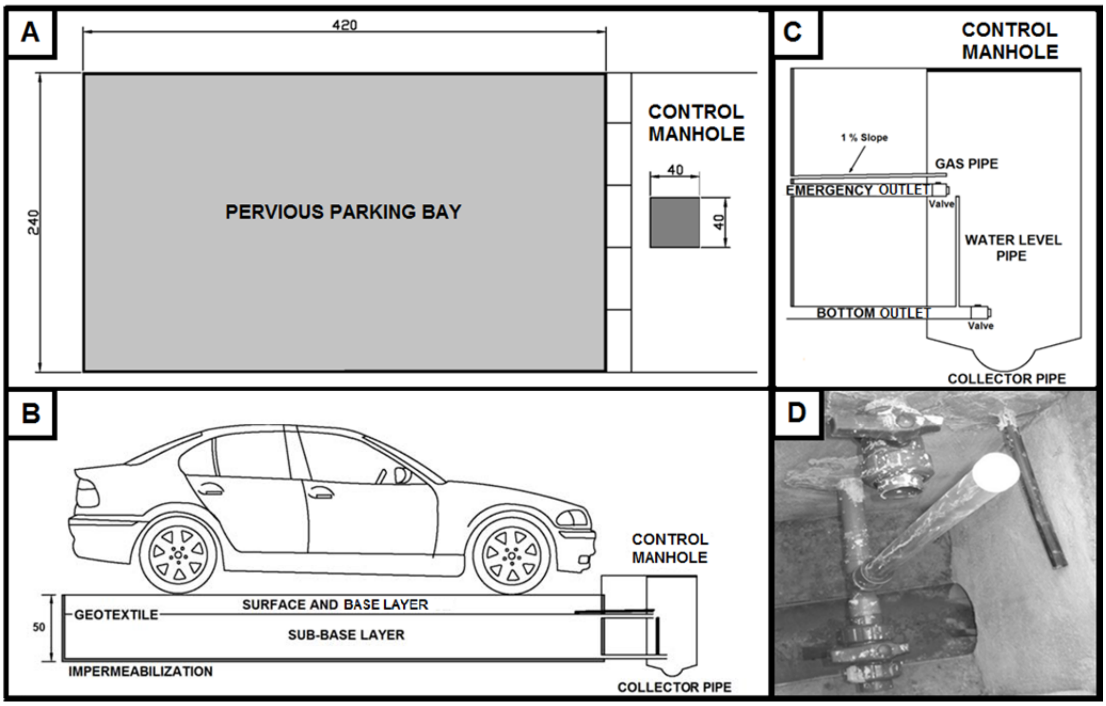

Figure1: Details of experimental parking bays: Scheme of parking bays (A), Section of parking bays (B), Scheme of control manhole (C), Photo of finished control manhole (D)

The sub-base layer of the 8 parking bays was composed of BOF-Slag which originated from the process of refining iron in a basic oxygen furnace. It is a granular type material, light gray, has a rough texture and high specific gravity. Its chemical composition is detailed in Table 1.

Table 1: Chemical composition of BOF-Slag (Data Sheet of CEDEX 2007)

CaO	SiO2	Al_2O_3	MgO	Fe	MnO	K_2O	P_2O_5	Cu	Mo	B
48%	16%	1.2%	5.2%	16%	5.9%	0.2%	0.5%	0.03%	0.08%	0.17%

The base of the 8 parking bays was constructed with limestone aggregates without fines. The wear coefficient, measured by the Test of Los Angeles, was less than 30, showing a sand equivalent that exceeds 40. The particle sizes of the aggregates used in the sub-base and base layers are shown in Table 2.

Table 2: Particle sizes of aggregates (mm)

LAYER	40	25	20	12.5	8	4	2	0.5	0.25	0.125	0.063
BASE OF LIMESTONE AGGREGATE	100	100	100	-	90-100	50-70	0-5	0	0	0	0
SUB-BASE OF BOF-SLAG AGGREGATE	-	100	75-100	-	45-73	31-54	20-40	9-24	5-18	-	0-9

A geotextile layer (Polyfelt TS20) was placed between these two granular layers. It served as a filter and separation between materials and particle sizes. It also provided support for the biofilms responsible for degrading hydrocarbons (Coupe *et al*., 2003).

Finally, two different pervious surfaces were used (Figure 2): 4 experimental parking bays were finished with Porous Asphalt (PA) and the other 4 bays with Interlocking Concrete Blocks (ICB).

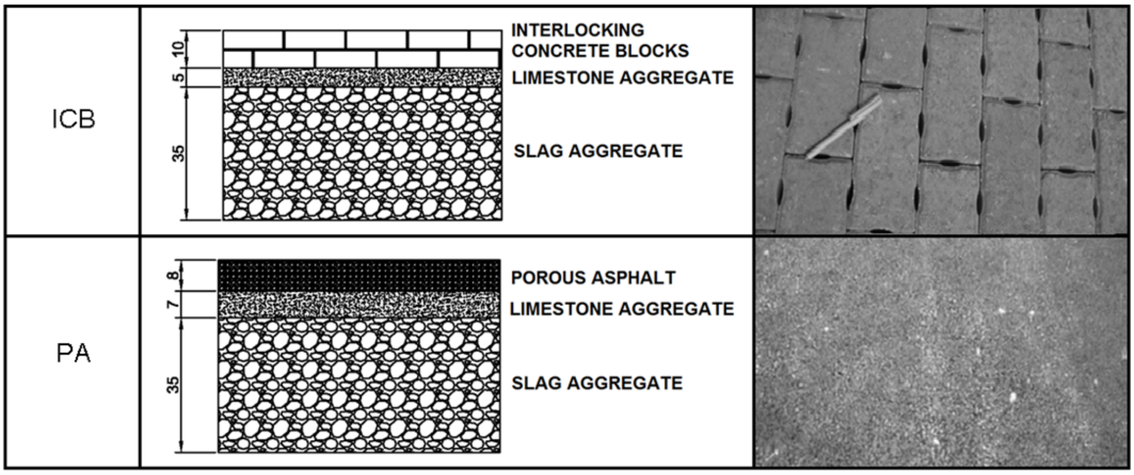

Figure 2: Sections and finished surface of pervious pavements

The ICB used were Montserrat® with special slots for the construction of permeable pavements. The ICB were placed directly on the base, confined within the perimeter of the corresponding parking bay without the use of topdressing and compaction. Meanwhile, the PA used was Spanish type PA-12, made with polymer modified bitumen, resulting in a final percentage of voids in mixture of around 25%.

Rainfall and temperature data with daily frequency during the period of the study was provided by the Spanish National Meteorological Agency (AEMET). The weather station used was No. 1249I, located 20 km away from the experimental site, in the city of Oviedo. Although the weather station is situated away from the experimental site, the obtained data approximates the weather conditions in the studied parking area.

Monthly inspection of the experimental parking bays was developed with the aim of verifying the general state of the different surfaces and to collect samples for water quality analysis. At each sampling stage, 500ml of stored water was taken from the bottom sink of each parking bay. The analyzed parameters were: pH, dissolved oxygen (DO), electric conductivity (EC), total suspended solids (TSS), turbidity and total petroleum hydrocarbons (TPH) (Table 3).

Between different samplings, the parking bays remain water- filled. The water renewal was ensured by the water evaporation and convection flows due to the difference of temperature between the stored water and the rainfall water.

Table 3: Water quality analyzed parameters, methodology and instrumentation.

PARAMETER	UNIT	METHODOLOGY	INSTRUMENTATION
pH	(-)	Hach Method 8156 (US-EPA accepted for SM 4500-H+B)	Hach HQ 40D Multi-parameter meter with PHC30103, LDO10103 and CDC401 probes
Dissolved Oxygen (DO)	(mg/L)	Hach Method 10360 (US-EPA Approved for 40 CFR 136)	
Electric Conductivity (EC)	(µS/cm)	Hach Method 8160 (US-EPA accepted for SM 2510 B)	
Total Suspended Solids (TSS)	(mg/L)	UNE-EN 872:1996	Sartorius Filtering ramp, glass microfiber filters, Rocker 400 Vacuum pump, desiccator and laboratory oven.
Turbidity	NTU	US-EPA Method 180.1	Hach 2100 P Turbidimeter
Total Petroleum Hydrocarbons (TPH)	(mg/L)	ASTM Method D7066-04	Horiba OCMA-310 absorption infrared oil detector and S-316 dissolvent.

3 RESULTS AND DISCUSSION

3.1 Climatic data

Meteorological data provided by the AEMET were statistically analyzed resulting in the graph showed in Figure 3.

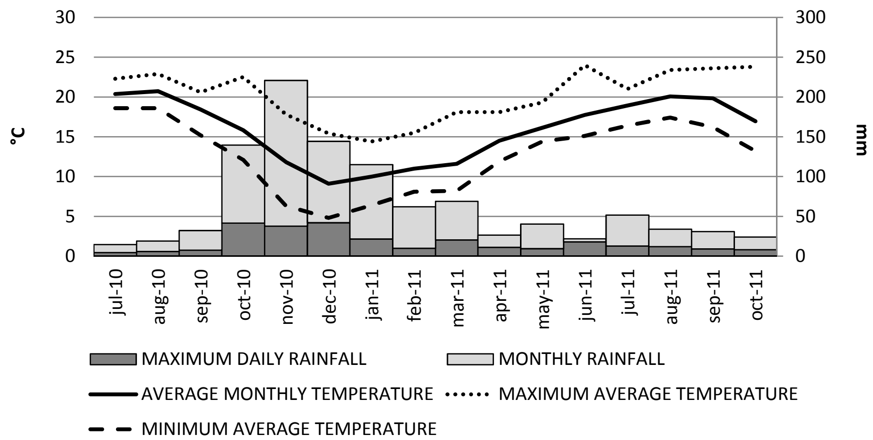

Figure 3: Climatic data during the research period.

The average rainfall intensity during the study period was 68.7 mm/month with an average daily intensity of 2.2mm/day. It can be seen that the largest concentration of rainfall occurred in the Autum-Winter of 2010-2011, with the highest record of 220.7mm/month in November 2010. The remaining periods can be viewed as low rainfall periods, highlighting that minimum rainfall occurred in the summer periods.

The average temperature for the study period was 15.5°C, with the hottest month being August 2010 (with an average temperature of 20.7ºC) and the coldest month being December 2010 (with an average temperature of 9.1°C). The monthly average difference between the maximum and minimum temperature was 7.5°C. The extremes were July 2010 with a temperature difference of 3.7°C and November 2010 with 11.5°C.

3.2 Water quality

The most representative statistical values of the obtained water quality parameters during the research period were calculated and shown in Table 4.

Table 4: Statistical values of the data obtained during the research period.

PARAMETER	SURFACE	PH	DO (mg/L)	EC (µS/cm)	TSS (mg/L)	TURBIDITY (NTU)	TPH (mg/L)
MAXIMUM	ICB	12.33	8.01	3539.31	19.45	9.74	6.38
	PA	12.51	7.47	3926.44	22.46	16.85	4.44
MINIMUM	ICB	11.56	1.22	2599.77	7.07	2.86	0.34
	PA	11.55	1.10	3008.14	6.65	4.29	0.24
AVERAGE	ICB	12.07	5.16	3003.16	10.63	6.61	1.37
	PA	12.15	5.29	3346.17	12.94	9.28	1.24

The evolution of all water quality parameters during the 14 months of the research period is shown in Figure 4.

The pH value was quite high, as can be observed in Figure 4 and Table 4. These values showed a high alkaline behavior. This could be explained taking into account the chemical composition of the sub-base and its high CaO content. The highest pH value was registered in December 2010, during a period of high rainfall that also caused an increase in the DO. The pH values were very similar in both types of surfaces, with average and maximum values slightly higher in the ICB bays.

Initial values of DO concentrations were close to 1mg/L, while in the months of November and December 2010 there was an increase in the concentration toward values of 7-8mg/L. After that, DO concentrations stayed in a range of 5 to 8 mg/L during the research period. No large differences were observed between both surfaces. Considering the non-ventilated conditions inside the parking bays, the increase of DO could be related to the water renewal due to the increased rainfall in the same period.

In Table 4 high values of EC can be seen in both types of permeable surfaces throughout the experimental period. The chemical composition of the BOF-slag, which was rich in Fe, CaO and metal oxides, and the proximity of the sea (4 km) (which is the source of various salts) could explain these high EC values. The progressive decrease of the EC with time (Figure 4) can be associated with the water renewal inside the parking bays. Comparing the two different surfaces, the EC of the ICB bays was lower than that of the PA bays, both in the average and extreme values. This was mainly due to one PA bay recording high values of EC throughout the observation period.

The registered values of TSS are considerably low, below 35 mg/L. The maximum values were recorded in November 2011 in both types of surfaces, probably due to the long dry season preceding that month that could motivate a first flush especially loaded with TSS. Besides, there was a significant increase in the concentration of solids in the period January to April 2011 that could have been caused by some external input, such as a work site that mobilizes large amounts of solids. Comparing the two different surfaces, there was a higher reduction in the concentration of TSS in the ICB bays than in the PA bays, coinciding with the results obtained by Gomez-Ullate *et al.* (2011b).

Regarding the turbidity, the trend was the same as observed in the TSS, with values lower than 17 NTU. Comparing the two different surfaces, ICB registered lower values of TSS and Turbidity.

Initial values of TPH were high starting from values close to 6.4mg/L in July 2010, and this was probably due to a little degradation of waterproofing at the beginning, increased by hot temperatures and a reduced amount of water stored in the bays. These values decreased progressively in successive rainfall events until November 2010, when they stood at 1 mg/L, and thereafter concentrations were kept below that level. The average concentration of TPHs present in the stored water was very similar in both types of the permeable surfaces, being slightly higher in the ICB bays.

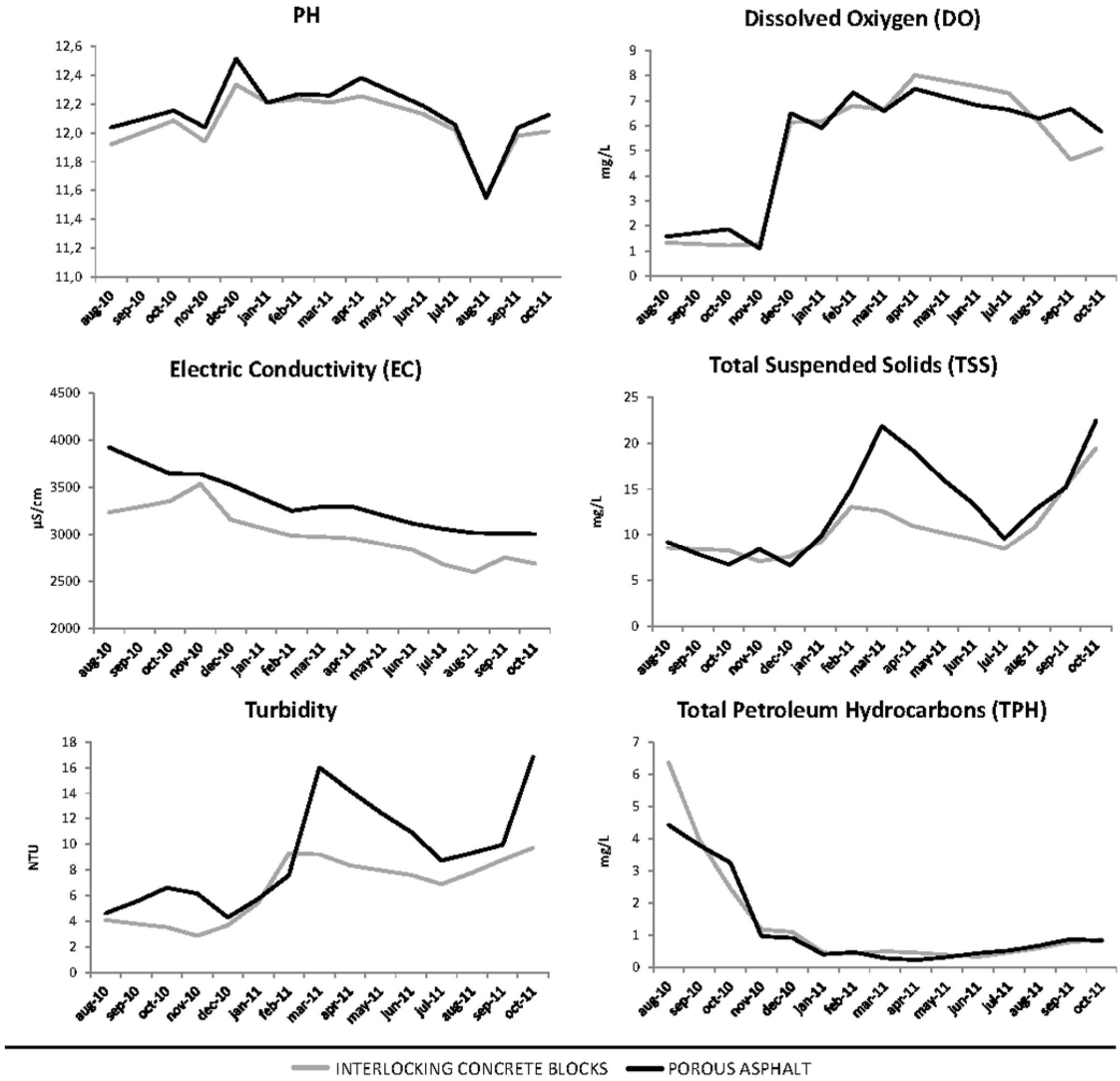

Figure 4: Water quality results of outflow from the experimental parking bays

Considering the high residence time of the water inside the parking bays, longer than 1 year, it could be stated that, for the normal use of the pervious pavement structures, in which the residence time of water is shorter than 3 months, the overall water quality could be better than the obtained in this research.

The registered values of EC were higher than the maximum values for water reuse or disposal in agricultural applications permitted by Spanish Royal Decree 1620/2007. However, considering physicochemical water quality parameters, the stored water in pervious pavements with BOF-Slags aggregates in the sub-base layer could be used for some urban, industrial, recreational and environmental purposes. Although the higher pH values could be toxic for most fauna, these structures could be suitable in areas that suffer acid rains or where there is acid runoff such as industrial or agricultural areas so as to compensate the alkalinity of the stored water.

Table 5: Uses and Maximum allowable values of physicochemical water quality parameters according to Spanish Royal Decree 1620/2007, for regenerated water reuse.

REGENERATED WATER USES		TSS (mg/L)	Turbidity (NTU)
URBAN	Residential	10	2(1)
	Services	20	10
AGRICULTURAL*	Products for consume.	20-35(2)	10(3)
	Pasture and Aquaculture.	35	–
INDUSTRIAL	Process water, cleaning water, and other industrial uses.	35	15(4)
	Refrigeration and condensation towers.	5	1
RECREATIONAL	Irrigation of golf courses.	20	10
	Ponds, water bodies and ornamental waters without public access.	35	–
ENVIRONMENTAL	Groundwater recharge through localized percolation, irrigation of forests and green areas and silviculture.	35	–
	Direct groundwater recharge	10	2

(1) 2 NTU in tap water and 5 NTU in supply network.

(2) 20 mg/L for direct irrigation on fresh food product; 35mg/L for the rest of uses.

(3) 10 NTU for direct irrigation on fresh food product (without treatment).

(4) 15 NTU for process and cleaning waters except in alimentary industry.

* Maximum allowable EC: 3000 µS/cm

3.3 Relation between climatic parameters and water quality

In order to characterize the relationship between weather conditions and variations in pollutants concentration, a study of the Pearson's linear correlation coefficient was carried out between climatic parameters and water quality parameters, with resultant values showed in Table 5. These correlation values were interpreted according to the classification made by Bisquerra (1987).

Table 6: Pearson correlation levels between climatic factors and water quality parameters.

CLIMATIC FACTOR	SURFACE	PH	DO	EC	TSS	TURBIDITY	TPH
ACCUMULATED RAINFALL	ICB	0.17	-0.36	0.68	-0.48	-0.63	-0.11
	PA	0.19	-0.41	0.40	-0.50	-0.46	-0.03
MEAN TEMPERATURE	ICB	-0.69	-0.21	-0.39	0.15	0.12	0.40
	PA	-0.65	-0.17	-0.15	0.00	0.09	0.41

Despite the differences that there could be between the weather station register (20 Km away) and the rainfall in the experimental site, there are significant correlation levels with the concentration of DO and parameters related to the presence of salts and solids (i.e. EC, TSS and Turbidity). There was moderate to high correlation between accumulated rainfall water and EC, which supports the hypothesis outlined above, associating the highest rainfall input to higher salt concentrations mainly due to the proximity of the sea. The negative moderate to high correlation, with TSS and turbidity could be associated with the dilution of solid particles, while the correlation with DO concentration confirms the influence of water renewal inside the parking bays.

Regarding temperature, there was a high correlation with pH and moderate correlation with TPH concentration. The correlation with pH was due to the increase of CaO dissolution in the sub-base and a little modification of the equilibrium constant was observed. Correlation with TPH could be associated with the starting dry and warm periods and some initial degradation of the waterproofing. The continuous washes with the initial rainfall events dissolved them, so that TPH concentration decreased to normal levels after November 2010.

4 CONCLUSIONS

The overall quality of stormwater infiltrated and stored in a pervious pavement sub-base with BOF-slag was evaluated for 14 months at 8 parking bays, measuring the pH, DO, EC, TSS, turbidity and TPH. Furthermore, the results have been interpreted by analyzing the influence of climatic parameters of temperature and rainfall.

BOF-slags have proved useful as sub-base of pervious pavements, adequately fulfilling their role of support from the other layers of the pavement and as storage media for the infiltrated stormwater. Although the parking bays keep water-filled between the different samplings, the continued downtrend of EC and the high values of DO are indicators of water renewal inside the parking bays.

The main drawback encountered has been the high pH and EC values of the effluent water. However, a downtrend of both parameters was observed, suggesting that in the long term they could achieve acceptable values, especially by increasing the water renewal and by reducing the residence time. Comparing the two types of surfaces used, EC, TSS and turbidity were lower in the ICB bays than the PA bays.

Significant correlation levels were observed between rainfall and the salts and solids content. Correlation values obtained indicate the influence of rainfall on EC values , and the dilution of water in the case of turbidity and TSS. pH was influenced by temperature, showing a high correlation level which is mainly associated with increased dissolution of the constituent compounds of the BOF-slag.

Some registered values of EC, especially in PA bays, were higher than the maximum values permitted for water reuse in some field applications, according to the Spanish Royal Decree 1620/2007.Considering physicochemical water quality parameters, stored water in pervious pavements with BOF-Slags aggregates in the sub-base could be used for some environmental, recreational, industrial and urban purposes. Although the higher pH values could be toxic for the most fauna, it could be concluded that these structures could be suitable in areas that suffer acid rains or where is acid runoff such as industrial or agricultural areas.

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LIST OF REFERENCES

Acioli, L.A., da Silveira, A.L.L. and Goldenfun, J.A. (2005), "*Experimental study of permeable reservoir pavements for surface runoff control at source*", 10th International Conference on Urban Drainage10th International Conference on Urban Drainage, Copenhagen, 21-26 August 2005.

Barca, C., Gérente, C., Meyer, D., Chazarenc, F. and Andrès, Y. (2012), "*Phosphate removal from synthetic and real wastewater using steel slags produced in Europe*", Water research, vol. 46, no. 7, pp. 2376-2384.

Bisquerra Alzina, R. (1987), *Introducción a la estadística aplicada a la investigación educativa: un enfoque informático con los paquetes BMDP y SPSSX*, 1ˆedn, Ppu, Barcelona.

Booth, D.B. and Leavitt, J. (1999), "*Field evaluation of permeable pavement systems for improved stormwater management*", Journal of the American Planning Association, vol. 65, no. 3, pp. 314-325.

Boving, T.B., Stolt, M.H., Augenstern, J. and Brosnan, B. (2008), "*Potential for localized groundwater contamination in a porous pavement parking lot setting in Rhode Island*", Environmental Geology, vol. 55, no. 3, pp. 571-582.

Brattebo, B.O. and Booth, D.B. (2003), "*Long-term stormwater quantity and quality performance of permeable pavement systems*", Water research, vol. 37, no. 18, pp. 4369-4376.

Collins, K.A., Hunt, W.F. & Hathaway, J.M. (2010), "*Side-by-side comparison of nitrogen species removal for four types of permeable pavement and standard asphalt in eastern north carolina*", Journal of Hydrologic Engineering, vol. 15, no. 6, pp. 512-521.

Coupe, S.J., Smith, H.G., Newman, A.P. & Puehmeier, T. 2003, "*Biodegradation and microbial diversity within permeable pavements*", European Journal of Protistology, vol. 39, no. 4, pp. 495-498.

Dierkes, C., Kuhlmann, L., Kandasamy, J. & Angelis, G. (2002), "*Pollution retention capability and maintenance of permeable pavements*", Global Solutions for Urban Drainage, pp. 1.

Dreelin, E.A., Fowler, L. and Ronald Carroll, C. (2006), "*A test of porous pavement effectiveness on clay soils during natural storm events*", Water research, vol. 40, no. 4, pp. 799-805.

Furumai, H. 2008, "*Rainwater and reclaimed wastewater for sustainable urban water use*", Physics and Chemistry of the Earth, vol. 33, no. 5, pp. 340-346.

Ghisi, E., Bressan, D.L. and Martini, M. (2007), "*Rainwater tank capacity and potential for potable water savings by using rainwater in the residential sector of southeastern Brazil*", Building and Environment, vol. 42, no. 4, pp. 1654-1666.

Gilbert, J.K. and Clausen, J.C. (2006), "*Stormwater runoff quality and quantity from asphalt, paver, and crushed stone driveways in Connecticut"*, Water research, vol. 40, no. 4, pp. 826-832.

Gomez-Ullate, E., Castillo-Lopez, E., Castro-Fresno, D. and Bayon, J.R. (2011a), "*Analysis and Contrast of Different Pervious Pavements for Management of Storm-Water in a Parking Area in Northern Spain*", Water Resources Management, vol. 25, no. 6, pp. 1525-1535.

Gomez-Ullate, E., Novo, A.V., Bayon, J.R., Hernandez, J.R. and Castro-Fresno, D. (2011b), "*Design and construction of an experimental pervious paved parking area to harvest reusable rainwater*", Water Science and Technology, vol. 64, no. 9, pp. 1942-1950.

Houle, K.M., Roseen, R.M., Ballestero, T.P., Briggs, J.F. and Houle, J.J. (2010), "*Examinations of pervious concrete and porous asphalt pavements performance for stormwater management in northern climates*", Low Impact Development 2010: Redefining Water in the City - Proceedings of the 2010 International Low Impact Development Conference, pp. 1281.

Hunt, B., Stevens, S. & Mayes, D. (2002), "*Permeable pavement use and research at two sites in Eastern North Carolina*", Global Solutions for Urban Drainage, pp. 1.

Lee, M.-., Chiu, C.-., Kan, Y. and Yen, T. (2009), "*Experimental study of pervious concrete on parking lot*", Geotechnical Special Publication, pp. 125.

Makropoulos, C.K. and Butler, D. (2010), "*Distributed water infrastructure for sustainable communities*", Water Resources Management, vol. 24, no. 11, pp. 2795-2816.

Nolde, E. (2007), "*Possibilities of rainwater utilisation in densely populated areas including precipitation runoffs from traffic surfaces*", Desalination, vol. 215, no. 1-3, pp. 1-11.

Pratt, C.J. (1999), Use of permeable, reservoir pavement constructions for stormwater treatment and storage for re-use.

Pratt, C.J., Mantle, J.D.G. and Scholfield, P.A. (1995), "*UK research into the performance of permeable pavement, reservoir structures in controlling stormwater discharge quantity and quality*", Water Science and Technology, vol. 32, no. 1, pp. 63-69.

Rodriguez, J., Castro, D., Calzada, M.A. and Davies, V. (2005), "*Pervious pavement research in Spain: Structural and hydraulic issues*", Proceedings of the 10th International Conference on Urban Drainage (ICUD),Copenhagen/Denmark, 21-26 August.

Stimson, J., Chae, G.-., Ptacek, C.J., Emelko, M.B., Mesquita, M.M., Hirata, R.A. and Blowes, D.W. (2010), "*Basic oxygen furnace slag as a treatment material for pathogens: Contribution of inactivation and attachment in virus attenuation*", Water research, vol. 44, no. 4, pp. 1150-1157.

Xue, Y., Hou, H. and Zhu, S. (2009), "*Competitive adsorption of copper(II), cadmium(II), lead(II) and zinc(II) onto basic oxygen furnace slag*", Journal of hazardous materials, vol. 162, no. 1, pp. 391-401.