Comparison of the pollutant potential of two Portuguese highways located in different climatic regions

AE Barbosa and JN Fernandes

National Laboratory for Civil Engineering. E.mail: aestela@lnec.pt

Abstract

The accomplishment of the Water Framework Directive requires a good understanding of the impacts of the different pollution sources. In the framework of G-Terra study, two Portuguese highways located in different climatic regions from Portugal have been monitored. The role of climatic variables in controlling the presence of 6 selected pollutants in the roads runoff was evaluated. The results showed the relevance of the rain depth and the antecedent dry period in the discharge of higher concentrations of pollutants. Highways located in more arid areas, are more likely to produce acute impacts. The Total Suspended Solids and the Chemical Oxygen Demand appear to be important target pollutants to be controlled in Portugal.

Introduction

The accomplishment of the Water Framework Directive in terms of a good ecological status for all water bodies, by 2015, requires a good understanding of the impacts of pollution sources and the control of the most relevant ones. For the case of roads (and other diffuse sources of pollution) it is most relevant that the evaluation of pollutants’ concentrations and loads are assessed taking into consideration both the road and the climate characteristics.

Parameters such as the Event Mean Concentration (EMC), Site Median Concentration (SMC) and pollutant load characterize road runoff quality and are useful to understand the potential impacts of road runoff discharged into the environment. Nevertheless these calculations may hide the occurrence of peaks of concentrations. It is known that under different conditions highway runoff may cause not only chronic impacts but acute effects on the chemical quality and ecological status of the receiving water [4, 7].

When assessing impacts and risks in receiving water masses, attention should be paid to distinguish between acute and cumulative impacts. Typically, short term impacts occur at time scales of less than 1 hour up to 1 day, and are related to hydraulic effects; discharge of biodegradable organic matter or of suspended solids [6].

Road runoff in Portugal showed values of Total Suspended Solids (TSS) and Chemical Oxygen Demand (COD) that surpass the permitted level for discharge of point effluents (Decree-Law 236/98) in 15% and 50% of the samples, for COD, and in 62% of the samples for TSS [1, 2]. Therefore, these pollutants are on focus in Portugal and a good understanding of their genesis and removal process by rainfall is of most importance.

The final goal of an ongoing research project named “Guidelines for Integrated Road Runoff Pollution Management in Portugal”, G-Terra, is to characterize road runoff and improve the understanding of the inter-relationship between pollutants and specific site variables [3]. In the framework of G-Terra, two Portuguese highways have been monitored in 2008 and 2009: A1 site is located in central Portugal, and A22 is placed in southern Portugal. The two monitored highways are located in very different geographic and climatic regions from Portugal, as shown in Fig. 1. For the monitoring period A1 presented an average annual daily traffic (AADT) of 27746 and A22 of 24000. The studied catchment area is of 22800 m^2 (100% impervious) for A1, and of 15422 m^2 (85% impervious) for A22.

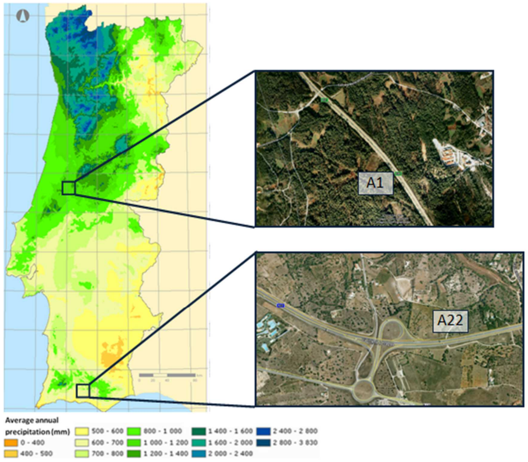

Fig. 1. Location of the two sites and average annual precipitation.

The objective of this paper is to compare the two roads using the results of the monitoring study, and further understand the role of climatic variables in controlling the pollutants presence in road runoff. The sort of impacts that may be expected are evaluated as well.

Methodology

An automatic equipment consisting of a rain gauge, automatic sampler and flow meter, associated to a V-notch weir, were placed at each site, at different times. The monitoring period was of 4 months for A22, and of 2 months and 10 days for A1. The collected data consisted of rainfall and flow (recorded each 5 minutes) and between 6 to 8 discrete samples along 10 or 11 events. The samples were analyzed by contracted laboratories for a total of 18 quality parameters. The laboratories followed standard and certified procedures for analysis and quality control of results. The results of the quantity and quality data were analyzed and the common characterization for the runoff was produced [3].

For the present analysis a set of 6 quality parameters were selected: TSS; COD, Total Organic Carbon (TOC), copper (Cu), iron (Fe) and Kjeldahl Nitrogen (N-Kjel). The selection was based on the following criteria: parameters that represent different sorts of pollution; that were, for both roads, detected and quantified in a significant number of samples, and were observed in concentrations higher than the limits of the referred Portuguese law. Fe is not among the road runoff metals with more toxic effects, but was selected for the last motive.

The variables selected to represent climatic factors were, for each monitored event: Rain depth (Rain Dp); Rain duration (Rain Dr); Rain intensity (Rain Int) and antecedent dry period (ADP). For each quartile of each event (based on the % of runoff volume) the average flow (l/s) and the % of each pollutant mass transported were calculated.

The data analysis was conducted with Excel® and Statistica® tools. The latter was mostly utilized for the multivariate exploratory analysis using Clusters and Principal Component Analysis. To perform the Cluster analysis the variables were standardized, in order to avoid the distortion of the results by the values characteristics.

Results

Characterization of the sites based on climatic variables

To distinguish the climate characteristics of each monitoring site, two meteorological stations were chosen (a minimum series of 20 years was considered for all the parameters) [9]. Fig. 1 showed the variability of the average annual precipitation. The annual precipitation volume for A1 is 1100 mm and for A22 it is 560 mm. For the months of the monitoring period when samples were collected (April, May and June for A1 and January, February and March for A22), the average monthly evaporation was 144 mm and 88 mm for A1 and A22, respectively. During those periods, the average temperature was 17.6ºC for A1 and 12.3ºC for A22.

Table 1 shows the climatic variables for all events; with the exception of event 4 for A22, and event 7 for A1. For the event 7 of A1 a problem occurred with the equipment and the precipitation data was not well characterized. Event 4, in the case of A22, was disregarded because the collection of samples did not cover all the flow. It is known that the definition of a rainfall event has to be in accordance to the use of the data; it can be of few hours to 3 days (e.g., [8]). For this study, the rain events were defined as independence when the period between rain events was longer than the concentration time of the watershed.

Fig. 2 presents the results for the calculations of the average flow (Qm) for each quartile of each event – defined based on 25 % fractions of the event volume.

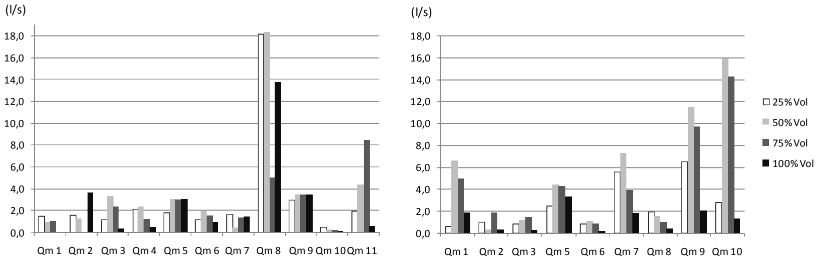

Fig. 2. Average flow (Qm) in each quartile of each of the monitored events at A1 (11 events) and A22 (9 events, due to the exclusion of event 4).

Table 1. Characterization of the precipitation events.

Site	Event	Rain Dp (mm)	Rain Dr (hours)	Rain Int (mm/h)	Run. Coef.	ADP (days)
A1	1	4.6	2.0	2.3	0.04	3*
	2	2.2	0.6	3.8	0.05	4.4
	3	2.8	1.3	2.2	0.15	0.2
	4	2.8	0.8	3.4	0.08	0.8
	5	2.4	0.8	3.2	0.22	0.2
	6	11.2	9.1	1.2	0.29	0.3
	8	16.2	2.8	5.7	0.24	14*
	9	4.2	1.1	3.9	0.15	12.7
	10	3.2	0.3	12.8	0.28	0.7
	11	2.8	0.9	3.1	0.12	1.5
Average (n=10)		**5.2**	**2.0**	**4.2**	**0.16**	**3.6**
A22	1	5.2	3.1	1.7	0.30	10.5
	2	1.8	2.7	0.7	0.14	1.9
	3	1.0	0.8	1.2	0.29	3.6
	5	4.8	2.4	2.0	0.56	1.8
	6	1.4	1.0	1.4	0.18	0.7
	7	8.0	2.8	2.9	0.42	0.9
	8	1.0	0.2	6.0	0.71	0.2
	9	1.4	2.1	0.7	2.00**	2.7
	10	3.4	3.1	1.1	1.00	20.4
Average (n=9)		**3.1**	**2.0**	**2.0**	**0.45**	4.7

*Value estimated based on national data [9] and monitoring records.

** Value inconsistent (probably due to wrong flow measurement) and not considered for the average calculation.

Characterizations of the pollutant concentrations and loads at the two sites

Table 2 presents a characterization of the SMC, pollutant load and maximum observed concentration for the selected parameters. The flow of the event 7 for A1 was estimated based on comparisons of the rainfall data from the local meteorological records [9] with similar rainfall events, with correspondent flow measurements monitored during the study. Table 3 presents the percentage of samples with concentrations of TSS, COD and Fe that exceed the level for discharge of the Decree-Law 236/98. It states also the number of samples (n) for each case.

Fig. 3 and Fig. 4 show the evaluation of the first-flush effect for the TSS, COD, Cu and Fe, for A1 and A22 highways, respectively. Fig. 5 and Fig. 6 illustrate the percentage of mass of TSS, COD, Cu and Fe that is transported in each quartile of the volume for each event, respectively for the case of A1 and of A22.

Table 2. Characterization of A1 and A22 road runoff for sellected pollutants.

Parameters and roads	A1 (11 events)			A22 (9 events)		
	SMC (mg/l)	Max. (mg/l)	Poll. Load (kg/ha/yr)	SMC (mg/l)	Max. (mg/l)	Poll. Load (kg/ha/yr)
TSS	22.2	350.0	5956	52.4	220.0	2937
TOC	22.7	72.0	2624	18.4	38.0	1028
COD	81.9	330.0	9475	38.3	226.0	2147
Cu	0.02	0.051	2.3	0.03	0.046	1.4
Fe	0.35	7.192	40.2	1.9	6.627	108.7
N-Kjel	2.0	5.0	230	2.7	10.0	152

Table 3. Percentage of samples of TSS, COD and Fe that exceed the level for discharge of the Decree-Law 236/98.

% and number samples for each case	A1	A22	Level for discharge Decree-Law
TSS	11% (n=71)	30% (n=65)	150 mg/l
COD	13% (n=71)	1.3% (n=75)	60 mg/l
Fe	6% (n=73)	41% (n=76)	2 mg/l

Multivariate Statistical Analysis and Linear Regressions

Cluster analysis showed that the Rain Dp and the ADP are the climatic variables closer to the variables describing the pollutants, for both highways.

The TSS and the Cu, especially their mass, evidenced a closer connection to the Rain Dp; the COD and the TOC EMC and maximum concentrations were closer to the ADP. N-Kjel was the only pollutant included in the same cluster as the Rain Int, for both case studies. The Principal Component Analysis performed did not add further information.

Simple linear regressions were established between the climatic variables and the variables describing the pollutants. The results were in agreement with the evidences from the multivariate exploratory analysis. The presence of pollutants was more correlated with the Rain Dp for A1 and, for A2, with the ADP – especially for COD and TOC. The coefficients of determination (r^2) ranged between 0.507 and 0.833. The lowest respected to N-Kjel correlation with the Rain Int at A1; the highest r^2 concerned ADP and TOC, at A22.

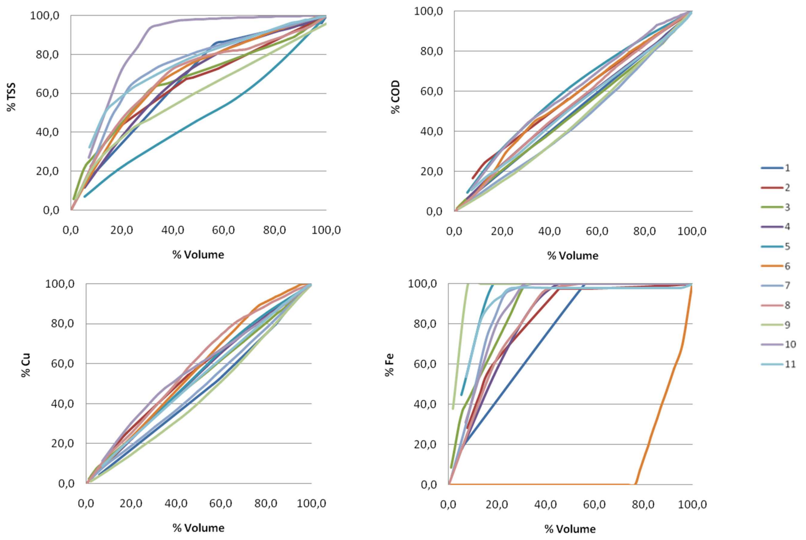

Fig. 3. First flush evaluation for TSS, COD, Cu and Fe for A1 highway.

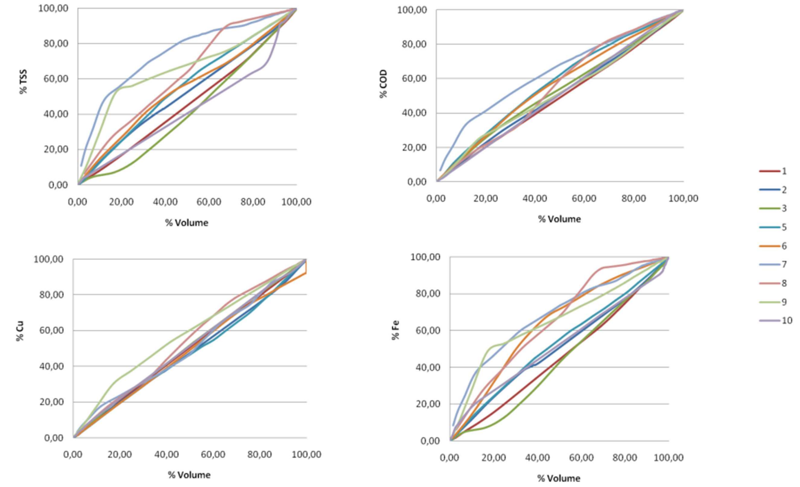

Fig. 4. First flush evaluation for TSS, COD, Cu and Fe for A22 highway.

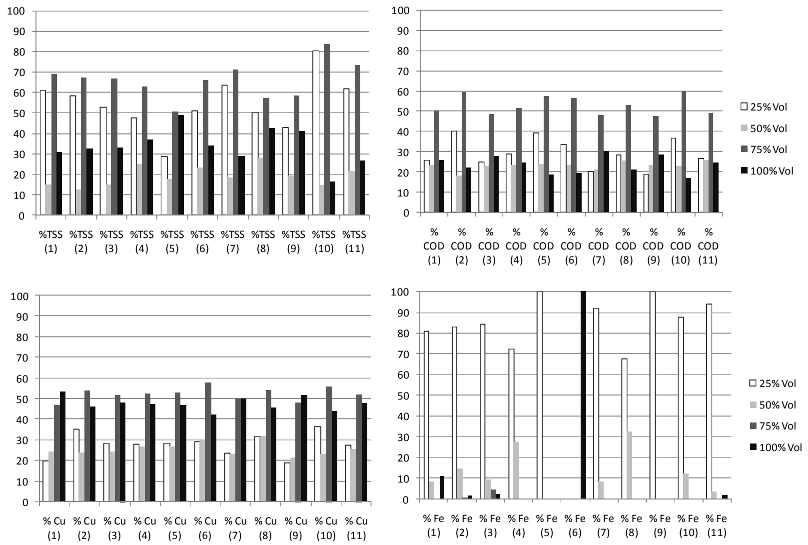

Fig. 5. % of mass of TSS, COD, Cu and Fe transported in each quartile of the monitored events at A1.

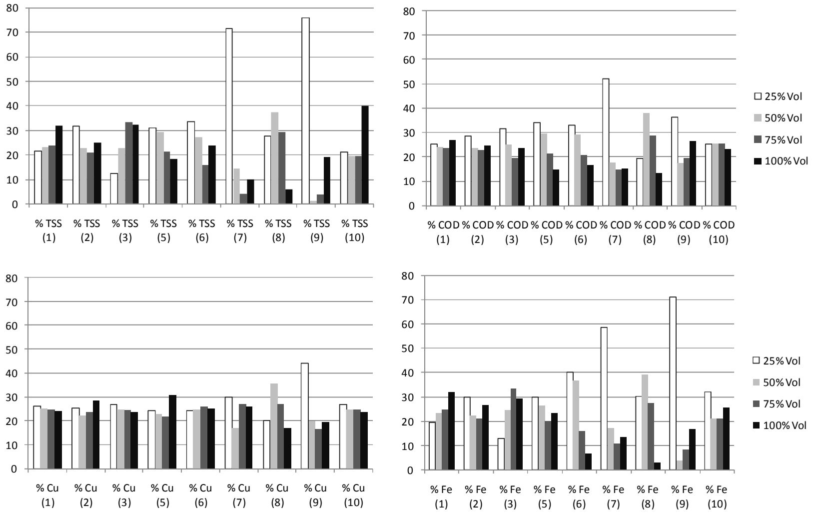

Fig. 6. % of mass of TSS, COD, Cu and Fe transported in each quartile of the monitored events at A22.

Discussion

It is clear the different climatic characteristics for the two sites analyzed (Table 1). The ADP in average is higher for A22 (4.7 days, compared to 3.7 days in A1). The average Rain Dp, on the contrary, higher at A1 site (5.2 mm against 3.1 mm).

These were the two variables showing a closer association to the presence of pollutants in highway runoff for both cases, in agreement with the variable that is stronger for each site. Other authors reached to exactly the same conclusions [5] or these variables are among the ones showing relevance [7]. In average the runoff coefficient is much higher for A22 than for A1 which should be a result of a smaller drainage area and lower temperature for the monitored period. Table 2 data gives evidences that, although for most pollutants A1 is responsible for higher annual loads than A22, the latter may have maximum concentrations almost as high as A1 (or higher, for the case of N-Kjel). Table 3 supports this assumption.

The results concerning the first-flush evaluation (Fig. 3 and Fig. 4) showed for COD and Cu similar curves for each case study, with a slight first-flush effect. For the case of the TSS there are more variations among the events, and the first-flush effect seems more enhanced. The curves for the Fe case are similar to the TSS, for highway A22; for A1 the pattern is sharper; most of the events show a quick first-flush effect.

Comparing the average flow (Fig. 2) and the relative mass of pollutant transported in each quartile of each event (Fig. 5 and Fig. 6), it is clear the absence of direct relations among these variables, for any of the case studies. For instance, A22 has a % of transport of Cu and TOC homogeneous along the event, not showing any response to the higher average intensity for the second and third quartile of the event’s volume.

The characteristics of the catchment (area, slope and concentration time) should be, at least in part, responsible for these observations.

Conclusions

The objective of the study undertaken was not to further explore the analysis of two case studies or quantifying relationships among variables, but to gather evidences concerning the role of climatic variables in controlling the pollutant potential of roads. It is also considered that the amount of data is not sufficient for characterization of all seasons, which may provide rain depths, intensities and interevent dry periods with different characteristics. Therefore, the conclusions that can be made are of a broader sort – but considered to be very relevant in assessing and controlling the impacts of road runoff.

There is evidence that in Portugal a special focus should be placed on controlling TSS, COD and Fe in road runoff, due to at least two of the following reasons: high EMC; high maximum concentrations and potential for first-flush occurrence. Highways located in more arid areas of the country (with longer ADP) are more likely to produce acute impacts in short time durations, because of their potential to discharge higher concentrations of these pollutants.

It should be referred that the runoff from the two studied road catchments are discharged into treatment systems; therefore none of them should cause environmental impacts.

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