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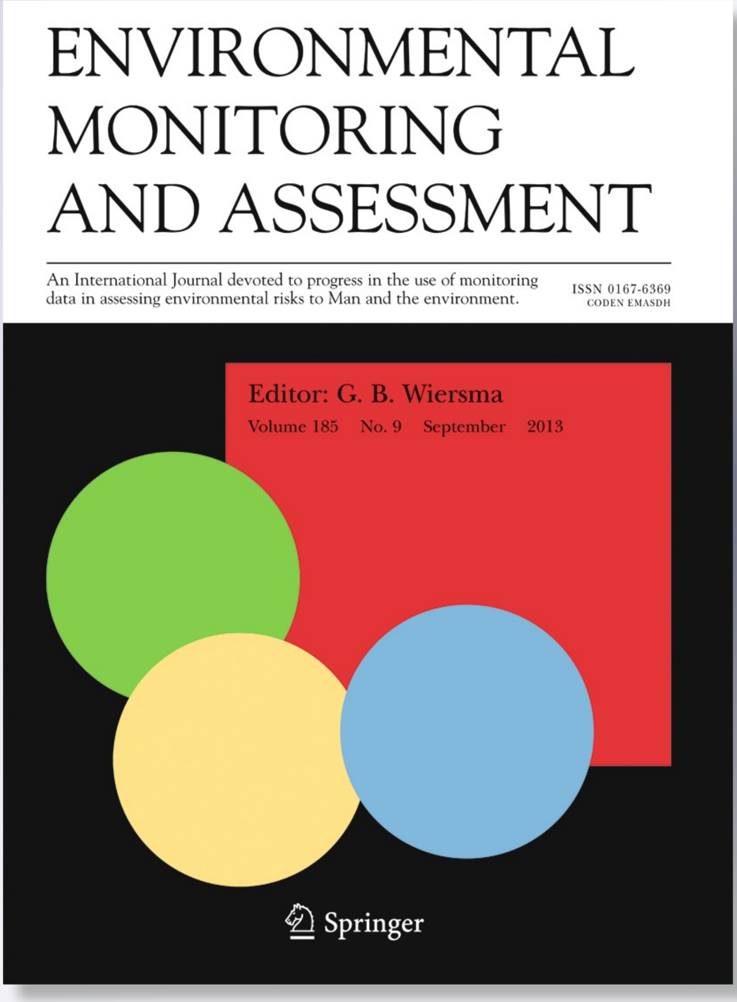

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Evaluation of the impacts of road runoff in a Mediterranean reservoir in Portugal

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Abstract Road runoff is a linear diffuse source of pollution, with very specific characteristics. This study intends to improve the understanding of road runoff impacts in water bodies in Portugal. The chosen case study is S. Domingos reservoir catchment. The study analyzed land uses, the presence of pollution sources, and gathered temporal water quality data and performed site measurements and sample collection. The water quality data for the reservoir was provided by the national water quality monitoring system from the Portuguese Water Institute. The parameters selected were TSS, COD, NO_3^-, Cl^-, and Cu. The results obtained revealed that the presence of IP6 highway at S. Domingos catchment affects the water quality; however, the impacts are not significant due to the high dilution effect of the reservoir volume. Agriculture, the main land use of the catchment, is responsible for introducing pollutants such as TSS, Cl^-, COD, N, and P in the local water streams and at the reservoir. TSS, COD, and Cu are pollutants generated by the road. The success of the study was very much dependent on the availability of 12 years of historic water quality data for S. Domingos reservoir, and the use of the moving average method. Taking into consideration the high variability of hydrological variables in Mediterranean climates, the concentration of pollutants in the water bodies must always be assessed in a significant time period.

Keywords Impact assessment · Diffuse pollution · Road runoff · Water quality

Introduction

Road runoff is a linear diffuse source of pollution, with very specific pollutants characteristics and type of discharge in the environment. The major constituents of road runoff are dissolved and suspended solids, organic compounds, hydrocarbons, nutrients, and heavy metals (Huang et al. 2005; Kayhanian et al. 2007; Karlaviciene et al. 2009; Sansalone and Buchberger 1997). The amount and the quality of stormwater runoff depend on several factors such as its origin and climate (Eriksson et al. 2007; Goldyn et al. 2009; Waara and Färm 2008).

Unlike point source pollution, stormwater has an irregular pattern with a variability of pollutants concentrations between runoff events due to the random nature of rainfall (Hvivted-Jacobsen et al. 2010). The occurrence of high concentrations of contaminants in relatively short periods of time and during the initial flow volume is often observed, known as the first flush phenomenon (Brix et al. 2010; Hvivted-Jacobsen et al. 2010; Sansalone and Buchberger 1997).

Depending on the characteristics of the runoff event, the receiving environment, the road, and the

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drainage system, road runoff can exert an acute and/or chronic impact on the chemical quality and ecological status of the receiving water body (Crabtree et al. 2008; Opher and Friedler 2008). Research made in USA by the Environmental Protection Agency estimated that 4 % of the impacts in wet lands and rivers, 7 % in coastal waters and lakes, and 11 % of the impacts in estuaries were caused by urban runoff (FHWA 1996). Several studies investigated the characteristics of road runoff (e.g., Drapper et al. 2000; Maltby et al. 1995) and their impact in receiving water bodies with different sizes and hydrological characteristics (e.g., Meland et al. 2010; Nabelkova et al. 2005 and 2012; Pitt 2001).

The evaluation of the impacts caused by road runoff in receiving water bodies remains a complex issue that needs to take into account the variability of discharge volume and quality, as well as the discharge location and characteristics of receiving water body. Based on specific studies, Forman and Alexander (1998) established a spatial scale for road runoff impacts both upstream and downstream the discharge, being the latter the most relevant. Accordingly to these authors, road runoff pollutants would be a problem to aquatic ecosystems within 50 m downstream; hydrological effects can take place within 200 to 1,000 m; and sediments up to more than 1,000 m downstream the discharge.

Typical water quality responses to road runoff includes increased levels of heavy metals, salinity, turbidity, and dissolved oxygen; sometimes these changes tend to be temporary and localized (Brix et al. 2010; Forman and Alexander 1998). Nabelkova et al. (2012) found the presence of the heavy metals mercury (Hg), zinc (Zn), copper (Cu), nickel (Ni), cadmium (Cd), chromium (Cr), and lead (Pb) in urban streams from three different sized watersheds (4, 11, and 135 km^2) in the Czech Republic. All of them included residential areas; therefore, the impact from highway runoff could not be clearly detected.

Protection of water quality that in the past was focused on reducing point pollution discharges (Brix et al. 2010) is now based also on the regulation and management of non-point or diffuse source discharges including stormwater runoff. Examples are the USA law from 1987, named the "Clean Water Act" and, in Europe, the Water Framework Directive (WFD) dated from the year 2000, which incorporates the need to control both diffuse and point pollution sources.

Some road runoff pollutants, like polycyclic aromatic hydrocarbons, organic matter, and the metals Zn, Cu, Ni, Cr, Pb, and Cd are currently identified in the WFD as priority pollutants. This means that they are persistent, have ecotoxicological effects and may accumulate in biological tissues, resulting in ecological damages (European Commission 2000).

Monitoring the road runoff and the receiving water characteristics is the most accurate methodology for the evaluation of impacts, particularly if high amount of water quality data, representing different hydrological conditions, is available. Nevertheless, this approach requires time and a significant investment in human and material resources; therefore, usually the monitoring work cannot be as intensive as desired. Seilheimer et al. (2007), Nabelkova et al. (2012), and Hedrick et al. (2010) are examples of studies reported on the literature that used in situ water quality monitoring in order to evaluate the impacts of road runoff discharge in water bodies: either in their biotic communities or directly on water quality alteration.

In Portugal, the understanding of road runoff characteristics has been growing since the late 1990s (Barbosa and Hvitved-Jacobsen 1999), based on research and monitoring studies of road runoff in several sites within the country. A recent national research established total suspended solids (TSS), chemical oxygen demand (COD), Fe, Zn, and Cu as key pollutants to be evaluated in Portugal, because they are present in high concentrations and/or they overpass national law standards for wastewater discharge (Barbosa et al. 2011). Note that in Portugal there is no legislation concerning road runoff pollution discharge.

In spite of this knowledge, it is still not clear when and how a significant level of impacts in local water bodies receiving road runoff should be expected. One factor of uncertainty, among others of difficult evaluation, is the high hydrological variability, typical for Mediterranean climates. The discharge of stormwater with high concentrations of pollutants may be of high concern after the dry season, when the receiving water bodies have low volume and are, therefore, more sensitive to pollution. In Portugal several water courses only have flow during the wet season, and some keep water flowing just during rain events of considerable volume.

This study intends to improve the understanding of road runoff impacts in water bodies in Portugal.

The choice of the case study was based in these assumptions: having a water mass receiving road runoff that in spite of volume variations has a permanent water pool, and the availability of water quality data. For this purpose the authors selected a road monitored in the years 2005 and 2006 (IP6 highway) that is placed in the watershed of a small water reservoir, located in Central Portugal. This road was constructed during the period between 2002 and 2004. S. Domingos reservoir is used for abstraction of water for human consumption and has historical water quality data from the national water quality monitoring system controlled by the Portuguese Water Institute.

Methodology

Since the resources for gathering data through field work and laboratory analysis were limited, the approach was based in both the collection of existing data and complementary field monitoring work. An analysis of all data allowed an understanding of each pollutant origin.

The data was gathered through the activities hereafter mentioned:

1. Collection of information on land use and identification of pollution sources at the study catchment.
2. Gathering historical data for the S. Domingos reservoir containing water quality series from before and after the IP6 construction.
3. Field work for confirmation of the land use, observation, measurements, and collection of samples from the small creek that runs through IP6, receives the road runoff, and discharges in the S. Domingos reservoir.

The field work took place in two different dates, during the wet season. The dates were selected taking into consideration the occurrence of considerable rainfall in the days/weeks before and a good possibility for rain in the day of the field work itself. The dates were the 8th of March 2010 and the 11th of November 2011; in this last date the volume of rainfall during the work allowed sampling of the IP6 road runoff.

The IP6 road runoff quality was characterized by Barbosa et al. (2006) through 47 runoff water samples taken during eight complete rainfall events. It is not expected presently any significant variation in concentrations, taking into consideration that the annual average daily traffic was of 6,539, 6,466, and 6,100 vehicles, respectively for the years 2005, 2010, and 2011 (Barbosa et al. 2006; Estradas de Portugal 2012).

After gathering all the information, these data was processed and analyzed. The analysis was based in the following steps:

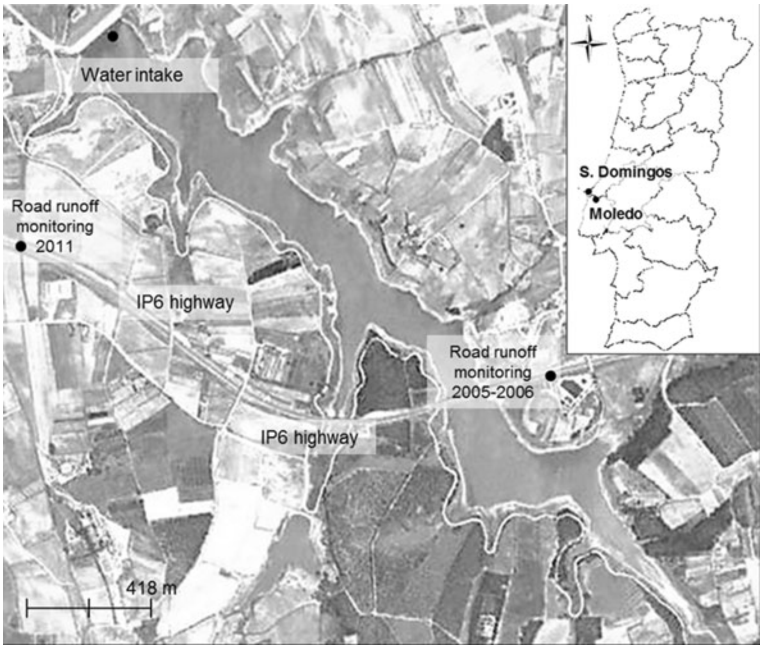

Fig. 1 The study site, S. Domingos reservoir watershed, in Peniche, Portugal

1. Comparison between the concentrations of selected water quality parameters in the reservoir, in the creek and in the IP6 runoff.
2. Simple linear correlations between the precipitation volume and the water quality data of the reservoir.
3. Analysis of the temporal evolution of water quality at S. Domingos reservoir, including the periods before, during and after the construction of IP6 road.

Because the road runoff characterization dated from September 2005 to February 2006, and the creek was sampled in March 2010 and in November 2011, it was necessary to get water quality data for the reservoir for a compatible period of the year; the choice was to take information from the months from September to March, for the years from 2005 to 2010. Data for 2011 was still not available at the time of this work.

Case study characterization

The case study site, the S. Domingos reservoir watershed, is located near Peniche, 100 km to the North from Lisbon. The watershed has an area of 39.4 km^2 and is crossed by a 5.7-km-long section of the IP6 highway. Figure 1 presents the location of the site, the aerial photo of the catchment, and the origin of the precipitation data, Moledo meteorological station (Table 1).

Taking into consideration that reservoir water is used for human consumption, road runoff treatment systems were constructed to control the pollution (COBA 2001). However, a small extension of the road (290 m, corresponding to a paved area of 4,350 m^2) drains, without treatment, to the Azenha da Petinga creek that flows into the S. Domingos reservoir, whose characteristics are presented in Table 2 (DGRAH 1981).

The land use of the studied watershed was characterized in GIS using Corine 2006 land cover (Caetano et al. 2009) and was confirmed with orthophotomaps and field survey. Table 1 includes information on the relative area for each identified land use, and of main pollutants loads associated with each of them.

Table 1 Land uses at the study catchment (percentage and area) and main pollutants associated

Land use	% in the watershed	Area (km^2)	Main pollutants associated (Burton and Pitt 2002)
Agriculture	66.4	26.16	N, P, Cl$^-$, TSS
Forest	28.6	11.27	N
Urban areas (IP6 highway included)	3.8	1.50	COD, BOD$_5$, heavy metals, TSS
Water bodies	1.2	0.47	–

Precipitation data from the nearest monitoring station Moledo, located 6 km far from S. Domingos reservoir (Fig. 1), for the years 1999 to 2009 shows a high variation of the total volume of rainfall each year. Figure 2 illustrates how these values varied between 400.5 and 892.8 mm by year. The Mediterranean climate is also characterized by a pronounced interannual precipitation variation, with months of much less precipitation compared to others from the wet season; this discrepancy is depicted in Fig. 3, which represents the average monthly precipitation, and explains the high variations expected in the water bodies flow and volume.

Azenha da Petinga creek is an ephemeral water course. The discharge was measured in the field twice, under different hydrological conditions. The data is presented in Table 3.

Presentation and discussion of the results

Water quality data

Resume of available water quality data

At this stage of this study designed to evaluate the impacts of IP6 highway runoff discharge in S. Domingos reservoir, an analysis of the available water quality data was done. Table 4 presents a resume of the existing information. Figure 4 supports Table 4, by representing graphically the relative location of the water quality data.

Taking into consideration the limitations of water quality data and the importance of some water quality

Table 2 S. Domingos reservoir characteristics (DRA-LVT 2001; SNIRH 2010)

Total storage capacity (m^3)	$7,900\times10^3$
Effective storage (m^3)	$7,548\times10^3$
Sill elevation (m)	42.5
Minimum operating level (m)	22
Reservoir area (ha)	96
Time of concentration (h)	2.8
Curve number	83.3

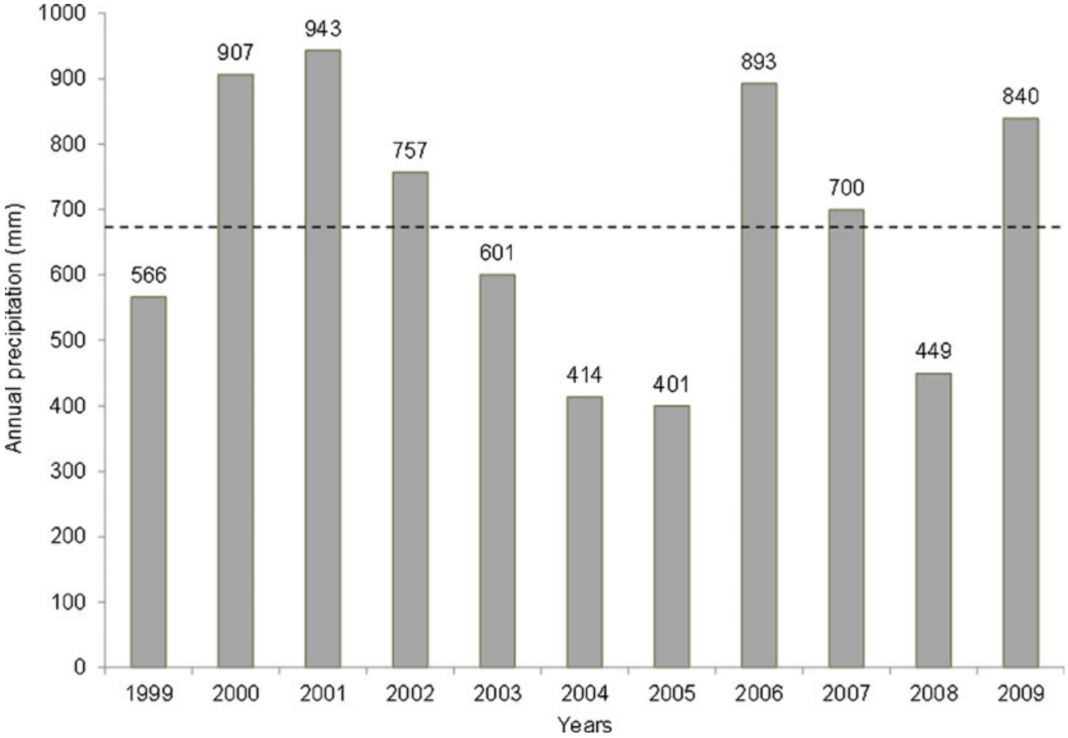

Fig. 2 Annual precipitation in Moledo station for the period between 1999 and 2009. The *line* represents the total average (679 mm) (SNIRH 2010)

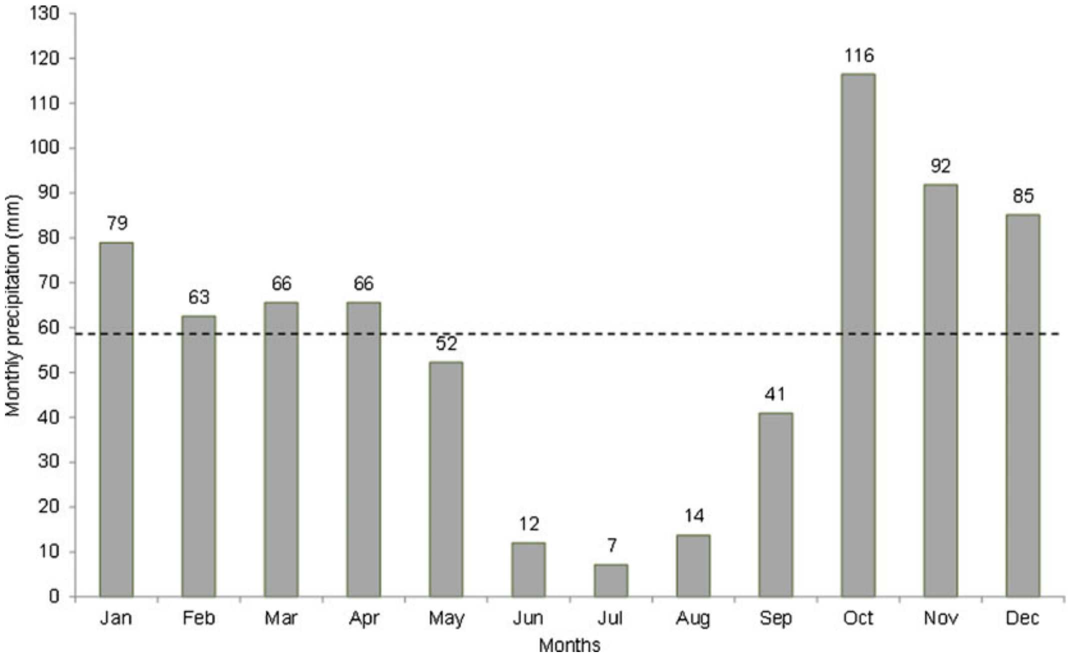

Fig. 3 Average monthly precipitation in Moledo station for the period between 1999 and 2009. Monthly averaged precipitation is 58 mm (*dashed line*) and standard deviation is 34 mm SNIRH (2010)

Table 3 Characteristics of the Azenha da Petinga creek measured in the field in different hydrologic conditions

Characteristics	8th March 2010	11th November 2011
Water height (m)	0.06	0.15
Flow area (m^2)	0.0252	0.1280
Velocity (m/s)	0.126	0.685
Flow (l/s)	3.2	87.7

parameters that represent the pollution sources at stake (road runoff and agriculture), it was considered necessary to make a selection of the relevant parameters for this evaluation. The following water quality parameters have been chosen: conductivity, chlorides (Cl^-), TSS, COD, nitrates (NO_3^-) (or Kjeldhal-N for the case of Azenha da Petinga creek, March 2010), Total-P, and Cu.

IP6 runoff

The IP6 runoff quality data was provided by a previous monitoring study carried on the place presented in Fig. 1 (Barbosa et al. 2006). The field monitoring equipment used consisted of a rain gauge, a flowmeter (ISCO 730 Bubbler flow module and a Thel-Mar volumetric weir, installed on a 400-mm pipe), and an automatic water sampler (ISCO 6700, with eight bottles, each of 1.8 l) working in synchronization (Barbosa et al. 2006).

Between September and October 2005 and February 2006, eight different rainfall events were monitored and 47 runoff samples collected. The sampling routine was trigged either by the precipitation or by the runoff flow. A maximum of eight samples were collected during each event that had an average duration of approximately 2 h.

The quality parameters pH, temperature, conductivity, and salinity were measured in situ using a Yellow Springs multi-parametric probe (YSI556MPS). The parameters measured at the laboratory were: total hardness, Zn, Cu, Pb, Cd, Cr, TSS, Cl^-, NO_3^-, and COD. In a few samples biochemical oxygen demand (BOD_5), oil, and grease and total hydrocarbons were also measured.

Data from both Barbosa et al. (2006) and the presented study are presented in Table 5. Data from the presented study represents background pollution. It is confirmed by the fact that the concentrations are, except for COD and Zn, close or below the lowest

Table 4 Description of the available water quality data

Water body	Dates	Source of data	Available water quality data	No. samples	Comments
IP 6 runoff	2005–2006	Barbosa et al. (2006)	pH; T; Cond; Salinity; Tot. Hard.; TSS; COD; Cl^-; NO_3^-; Zn; Cu; Pb; Cd; Cr (BOD_5; Oil and Grease; Tot. Hyd.)	47	Data based on automatic sampling during 8 rain events
	2011	Field work	pH; T; Cond; Salinity; Tot. Hard.; TSS; COD; Cl^-; NO_3^-; Tot-P; Zn; Cu;	1	Represent background pollution; taken within a rainfall event of 5.7 mm
Az. da Petinga creek	2010	Field work	pH; T; Cond; Tot. Hard.; TSS; COD; TOC; Cl^-; Tot-P; N-Kjeldahl; Oil and Grease; Tot. Hyd.; Fe; Zn; Cu; Pb; Cr; Cd	2	R1 and R3 in Fig. 2
	2011	Field work	pH; T; Cond; Salinity; Tot. Hard.; TSS; COD; Cl^-; NO_3^-; Tot-P; Zn; Cu	2	R1 and R3 in Fig. 2
S. Domingos reservoir	1999–2010	SNIRH	pH; Cond; Tot. Hard.; TSS; COD; TOC; Cl^-; NO_3^-; Tot-P; BOD_5; N-Kjeldahl; Oil and Grease; Tot. Hyd.; Fe; Zn; Cu; Pb; Cr; Cd; Hg	71–155	Cu is the parameter with less samples analyzed (71) and TSS has the higher amount of samples (155)
	2010	Field work	pH; T; Cond; Salinity; Tot. Hard.; TSS; COD; Cl^-; NO_3^-; Tot-P; Fe; Zn; Cu;	1	P3 in Fig. 2
	2011	Field work	pH; T; Cond; Salinity; Tot. Hard.; TSS; COD; Cl^-; NO_3^-; Tot-P; Zn; Cu	3 (at different sites)	P1, P2, and P3 in Fig. 2

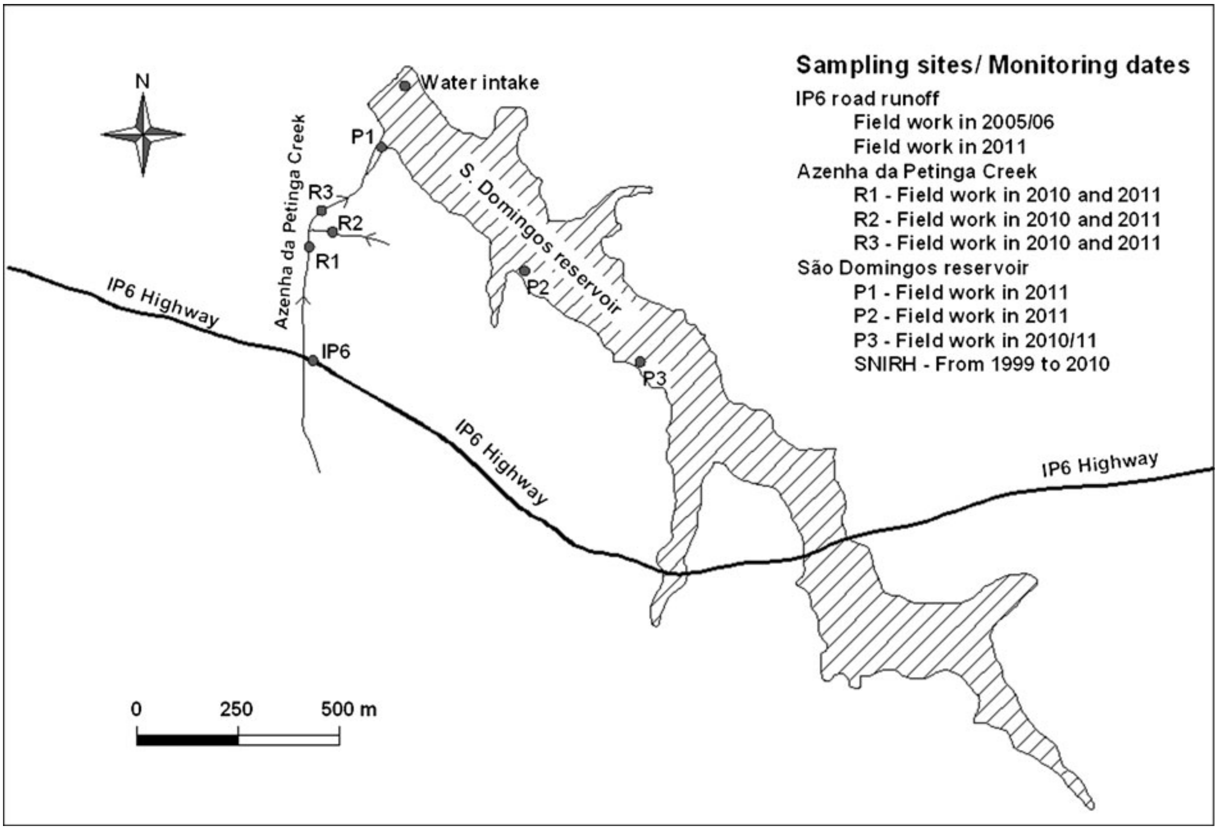

Fig. 4 Graphical representation of the relative location of the water quality data

concentrations measured in 2005/2006. Taking into consideration the little traffic volume change from 2005/2006 up to 2010/2011, it is expected that the information from road runoff obtained in the past still remains appropriate.

Azenha da Petinga creek

The watershed of Azenha da Petinga creek has an area of 2.85 km^2 and its land use is mainly agriculture with the road representing 1.5 % of total area. The water quality data was characterized by samples collected during field work in March 2010 and in November 2011. The collection sites are identified by R1 as the local receiving IP6 runoff, R2 representing the irrigation channel flowing to the creek, and R3 as the confluent point between the creek and a channel. The flow, flow area, and water height of the stream (Table 3) were measured at the sampling point R3.

The pH, temperature, conductivity, and salinity were measured at the field using a Yellow Springs multi-parametric water probe (YSI556MPS). The collected samples were placed in plastic or glass bottles and refrigerated. The samples were transported to laboratories for analysis.

Taking into consideration the results from the first sampling (March 2010) and the will to better characterize agriculture sources in the second field trip, the set of parameters analyzed were slightly different. For both dates (March 2010 and November 2011) the following analyses were conducted: TSS, total hardness, Cl$^-$, COD, total phosphorus (Total-P), and the heavy metals Zn and Cu. For the 2010 sample, oil and grease, total hydrocarbons, total organic carbon (TOC), Kjeldahl nitrogen, Pb, Cr, Cd, and iron (Fe) were measured as well. For the samples taken in 2011, nitrates were measured instead of N-Kjeldahl.

The results are presented in Table 6. Oil and grease and total hydrocarbons results (samples from 2010) were always below the detection limit, 2 mg/L; Cr was not detected.

Table 5 IP6 runoff water quality results from 2005 to 2006 (Barbosa et al. 2006) and from November 2011

Parameters	Results from 2005 to 2006 (Barbosa et al. 2006)					Present study from Nov. 2011
	No. samples	Min	Max	Average	SD	
pH. 25 °C	47	4.43	7.52	6.5	0.68	8.44
Conductivity (μS/cm)	47	132.0	722.0	384.3	145.5	47.0
Salinity (mg/L)	47	19.0	350.0	182.7	75.4	30.0
Cl$^-$ (mg/L)	47	4.2	53.0	35.0	14.0	3.5
TSS (mg/L)	47	11.0	1,800.0	235.6	358.4	8.0
Tot. hard. (mgCaCO$_3$/L)	47	71.0	569.0	159.2	80.7	20.0
COD (mg/L)	47	4.0	690.0	173.3	179.7	40.0
BOD$_5$ (mg/L)	20	1.0	20.0	8.1	5.6	NA
NO$_3^-$ (mg/L)	30	0.3	9.0	4.8	2.3	0.5
Oil and grease (mg/L)	8	0.0	1.0	0.5	0.4	NA
Tot. hydr. (mg/L)	6	0.1	0.7	0.3	0.3	NA
Zn (μg/L)	47	6.7	510.0	77.0	80.4	131.0
Cu (μg/L)	47	3.0	137.0	32.0	26.4	ND
Pb (μg/L)	47	1.0	17.2	9.5	17.2	NA
Cd (μg/L)	30	<3.0	7.0	1.0	1.0	NA
Cr (μg/L)	30	<10.0	13.0	8.0	13.0	NA

ND: non detected

NA: not analyzed

The results from November 2011 express the conditions of intense precipitation and flow at the study catchment; as there is no information for that specific day, online meteorological data was used. It indicated

Table 6 Results from field monitoring in March 2010 and November 2011

Parameters	March 2010			November 2011		
	R1	R2	R3	R1	R2	R3
Temp. (°C)	13.0	13.3	13.0	16.4	16.5	16.4
pH, 25 °C	7.94	8.19	8.07	8.26	8.59	8.79
Cond. (μS/cm)	1,964.0	2,328.0	1,976.0	420.0	879.0	689.0
Salinity (mg/L)	1,320.0	1,570.0	1,330.0	240.0	520.0	410.0
Cl$^-$ (mg/L)	370.0	320.0	340.0	82.1	160.4	144.2
Tot. Hard. (mgCaCO$_3$/L)	622.0	485.0	626.0	224.0	392.0	260.0
TSS (mg/L)	260.0	25.0	26.0	1,220.0	1,248.0	1,212.0
COD (mg/L)	34.0	93.0	<30.0	198.0	119.0	103.0
TOC (mg/L)	16.0	16.0	14.0	NA	NA	NA
N-Kjeldahl (mgN/L)	2.3	4.5	2.9	NA	NA	NA
NO$_3^-$ (mg/L)	NA	NA	NA	69.4	145.9	146.8
Total-P (mg/L)	<0.50	<0.50	<0.50	1.10	0.70	1.00
Fe (mg/L)	7.4	1.2	3.0	NA	NA	NA
Zn (μg/L)	<81.0	ND	<81.0	ND	220.0	224.0
Cu (μg/L)	<15.0	<15.0	<15.0	37.6	48.8	45.4
Pb (μg/L)	71.0	67.0	73.0	NA	NA	NA
Cd (μg/L)	1.5	1.3	1.3	NA	NA	NA

ND non detected, *NA* not analyzed

that for the 11th November, there was no precipitation between 6 am and 9 am, and there was 5.7 mm between 9 am and 12 am. The field work took place between 10 am and 12:30 am, during which it rained continuously. The presence of very high TSS values, compared to 2010, should express the turbulence and washing out of soil and associated pollutants. On the other hand, the dilution effect was much more significant (flow 27 times higher in 2011, compared to 2010) which should be the explanation for the lower concentrations of several pollutants. Nevertheless, it is observed that the pollution transported by the ditch (R2) is considerable concerning indicators of agriculture activity (N and P). The increase in Total-P from

Table 7 Annual average of the concentrations of the selected parameters, annual precipitation, and annual storage volume in S. Domingos reservoir: Ave stands for the average, SD for the standard deviation, and *n* for the number of samples (SNIRH 2010)

		TSS (mg/L)	COD (mg/L)	Cl^- (mg/L)	Cu (μg/L)	NO_3^- (mg/L)	Total-P (mg/L)	Annual precipitation (mm)	Annual storage volume (dam^3)
1999	Ave	9.7	20.9	75.6	1.8	3.5	0.06	566.1	4,255.6
	SD	5.23	5.87	5.35	0.75	1.82	0.02		
	n	12	12	12	6	8	12		
2000	Ave	17.8	23.1	77.8	2.5	5.7	0.08	906.5	2,568.1
	SD	30.02	5.76	22.04	1.05	4.19	0.05		
	n	12	12	12	6	11	12		
2001	Ave	13.0	17.3	47.4	2.8	12.1	0.14	943.4	6,868.2
	SD	19.62	4.10	13.92	1.47	7.81	0.11		
	n	12	12	12	6	12	12		
2002	Ave	4.2	19.0	62.2	1.8	4.5	0.07	757.0	4,744.8
	SD	1.62	5.29	4.65	0.45	2.65	0.04		
	n	12	12	12	5	10	12		
2003	Ave	6.4	18.3	65.3	4.2	8.7	0.08	600.5	6,702.5
	SD	4.17	5.47	6.02	2.14	5.43	0.05		
	n	12	12	12	6	12	12		
2004	Ave	5.7	25.9	72.1	2.7	6.2	0.05	414.2	5,672.4
	SD	2.69	7.31	5.58	0.82	4.07	0.02		
	n	12	12	12	6	9	8		
2005	Ave	9.5	34.9	87.6	3.0	4.0	0.10	400.5	2,223.4
	SD	5.24	8.56	12.81	2.00	4.10	0.06		
	n	20	12	11	6	9	12		
2006	Ave	19.2	31.1	80.0	3.0	13.7	0.13	892.8	2,724.9
	SD	18.10	7.73	26.44	0.89	10.00	0.09		
	n	12	12	12	6	7	11		
2007	Ave	12.4	32.4	51.3	4.8	13.0	0.15	699.6	5,404.0
	SD	7.02	7.12	12.69	2.71	4.48	0.07		
	n	12	12	10	6	5	12		
2008	Ave	9.8	29.5	64.2	4.5	1.8	0.12	449.4	3,454.6
	SD	5.03	5.01	5.49	3.56	0.78	0.04		
	n	12	11	12	6	6	12		
2009	Ave	13.6	35.4	71.3	3.7	10.5	0.10	839.6	3,063.3
	SD	5.99	6.92	5.14	1.80	6.62	0.02		
	n	12	12	12	6	5	4		
2010	Ave	10.2	27.6	63.8	2.6	6.6	0.05	NA	5,886.1
	SD	3.51	3.90	5.91	0.93	5.26	0.04		
	n	15	12	13	6	18	6		
Total	Ave	10.87	26.26	68.28	3.14	7.25	0.10	–	–
	n	155	143	142	71	111	124	–	–

NA not available

2010 to 2011 is noticeable; this agrees with the field observation of increased agriculture activity near Azenha da Petinga creek.

S. Domingos reservoir

The available water quality data for S. Domingos reservoir was provided by the national water quality monitoring system from the Portuguese Water Institute (National System of Water Resources Information, SNIRH). The data represents sampling at the water reservoir intake, collected at 30–50 cm below the water surface.

A very broad range of water quality parameters were considered in a preliminary study of the water quality. Due to their significance and availability, the parameters selected for analysis were TSS, COD, chlorides, Cu, nitrates, and Total-P, available for the period from 1999 to 2010 on a monthly basis. This time length includes the periods before, during, and after the construction of the road. Table 7 presents this data.

The water quality of the reservoir complies with the Portuguese regulation for surface water abstracting for human consumption. Comparing with the results from other lakes and reservoirs, the concentrations for some common parameters such as COD, Cl^-, Total-P, and NO_3^- are in the same order of magnitude although these other water bodies have different hydromorphological and climate characteristics (Cid et al. 2011; Ghumman 2011; Justus 2009).

Water samples from S. Domingos reservoir, collected during the field monitoring work in March 2010 and November 2011, provided some extra data. The procedures in the field and the water quality parameters analyzed in the laboratory were the same as described in Section 2.2.2 for the Azenha da Petinga creek. The results are presented in Table 8.

The values from 2011 enable a fair understanding of the dilution effect in the reservoir water mass on the pollutants transported by the Azenha da Petinga creek. Comparing the concentrations of Tables 7 and 8, both representing surface water sampling, it is seen that near the confluence of stream discharge (P2) the values are

Table 8 Water quality at S. Domingos reservoir: results from field monitoring in March 2010 and in November 2011

Parameters	March 2010 (P3)	November 2011		
		At Az. Petinga confluence (P1)	Downstream from Az. Petinga confluence (P2)	Site sampled in March 2010 (P3)
Temp. (°C)	12.9	16.8	16.8	16.6
pH, 25 °C	8.28	8.79	8.80	8.72
Conductivity (μS/cm)	527.5	582.0	506.0	513.0
Salinity (mg/L)	300.0	300.0	300.0	300.0
Cl^- (mg/L)	63.0	116.0	113.5	113.0
Tot. hard. ($mgCaCO_3$/L)	198.0	208.0	188.0	190.0
TSS (mg/L)	23.0	396.0	10.0	18.0
COD (mg/L)	<30.0	63.0	63.0	39.0
TOC (mg/L)	14.0	NA	NA	NA
N-Kjeldahl (mg/L)	1.5	NA	NA	NA
NO_3^- (mg/L)	NA	75.5	33.6	27.8
Total-P (mg P/L)	<0.5	0.4	0.2	0.2
Oil and grease (mg/L)	<2.0	NA	NA	NA
Tot. hydr. (mg/L)	<2.0	NA	NA	NA
Zn (μg/L)	ND	10.9	ND	ND
Cu (μg/L)	ND	<LQ	ND	ND
Pb (μg/L)	19.0	NA	NA	NA
Cd (μg/L)	<0.6	NA	NA	NA
Cr (μg/L)	ND	NA	NA	NA
Fe (mg/L)	0.7	NA	NA	NA

ND non detected, *NA* not analyzed

much higher, which is expected. For instance, Total-P is of 0.2 mg/l near the edge of the reservoir (P2 and P3) and the average concentration in S. Domingos reservoir for 12 years is of 0.1 mg/l.

Discussion of the results

Comparison between the reservoir, the creek, and the road runoff water quality

A comparison between the reservoir, the creek, and the road runoff water quality was made. Figure 5 presents the average concentrations of the selected parameters in these places. The S. Domingos reservoir water quality stands for the period between September and March (from 2005 to 2010). The Azenha da Petinga creek quality data is the average from the field work results (2010 and 2011 samples), and the IP6 runoff was provided by Barbosa et al. (2006).

Analyzing Fig. 5, it is possible to observe a dilution in the reservoir of all pollutants. The creek water quality shows the importance of agriculture as a source of pollution (TSS, Cl^-, NO_3^-, and Total-P). On the other hand, it is obvious that the IP6 highway runoff contributes with relevant concentrations of COD and Cu, which agrees with the most recent national research on the key pollutants for road runoff in Portugal (Barbosa et al. 2011)

Temporal evolution of S. Domingos reservoir water quality

The correlation between the precipitation volume and the water quality at the reservoir did not reveal significant results, even when using cumulative precipitation data (e.g., for 2 days up to 2 months). This must be due to dilution effects on the water mass, since the ratio between the precipitation and the reservoir volumes is very low. For instance, the highest precipitation volume for 2 months was 470 mm corresponding to approximately 3 % of the total volume of the S. Domingos reservoir (7,548 dam^3).

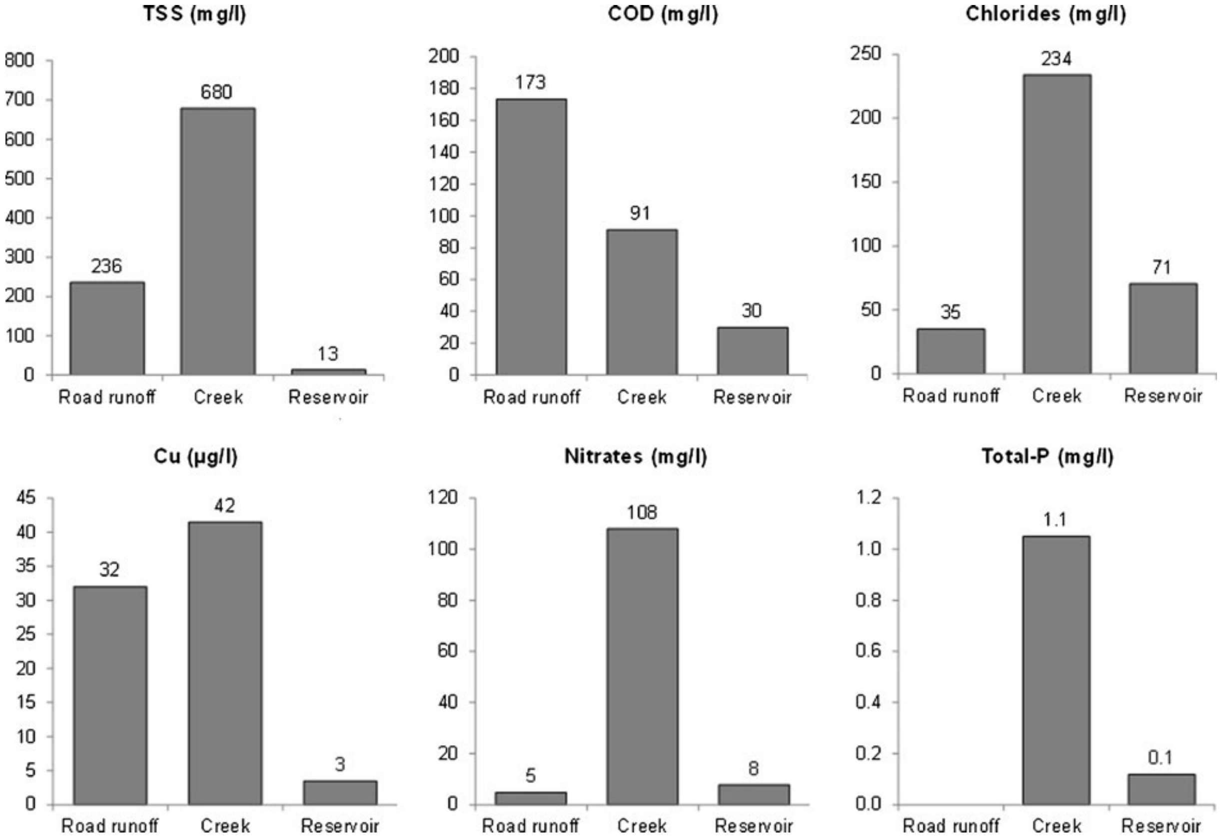

Fig. 5 Average concentrations of TSS, COD, chlorides, Cu, nitrates, and Total-P in the reservoir (SNIRH 2010), in the creek and in the IP6 runoff (Barbosa et al. 2006)

The evaluation of the water quality variability in the reservoir was made considering the periods before, during, and after the construction of IP6 road. Since the reservoir volume, that affects pollutants' concentrations, is a result of the annual precipitation, it is relevant to analyze the average precipitation for these three periods. The values are, respectively, of 805, 591, and 656 mm for the periods before, during, and after IP6 construction, showing clearly that the construction period was dryer than the others.

The available data was averaged to obtain annual concentrations of TSS, COD, chlorides, Cu, nitrates, and Total-P that are presented in Table 7. Some parameters were monitored less than 12 months per year. Despite this fact, at least three values from different months (e.g., hydrological conditions) were used in the average calculation.

An analysis of the moving average of the data was made in order to identify temporal trends in the water quality concentrations. This procedure allows the reduction of the inter-seasonal variations preserving the long-term trends (Facco et al. 2009). This type of methodology is mainly used to identify the relative influence of a known factor in climate changes, producing more reliable predictions (Ducharne 2008; Of 2009; Zhang et al. 2012), which validates its use in this case study. Several lengths of the moving window were set to highlight a possible

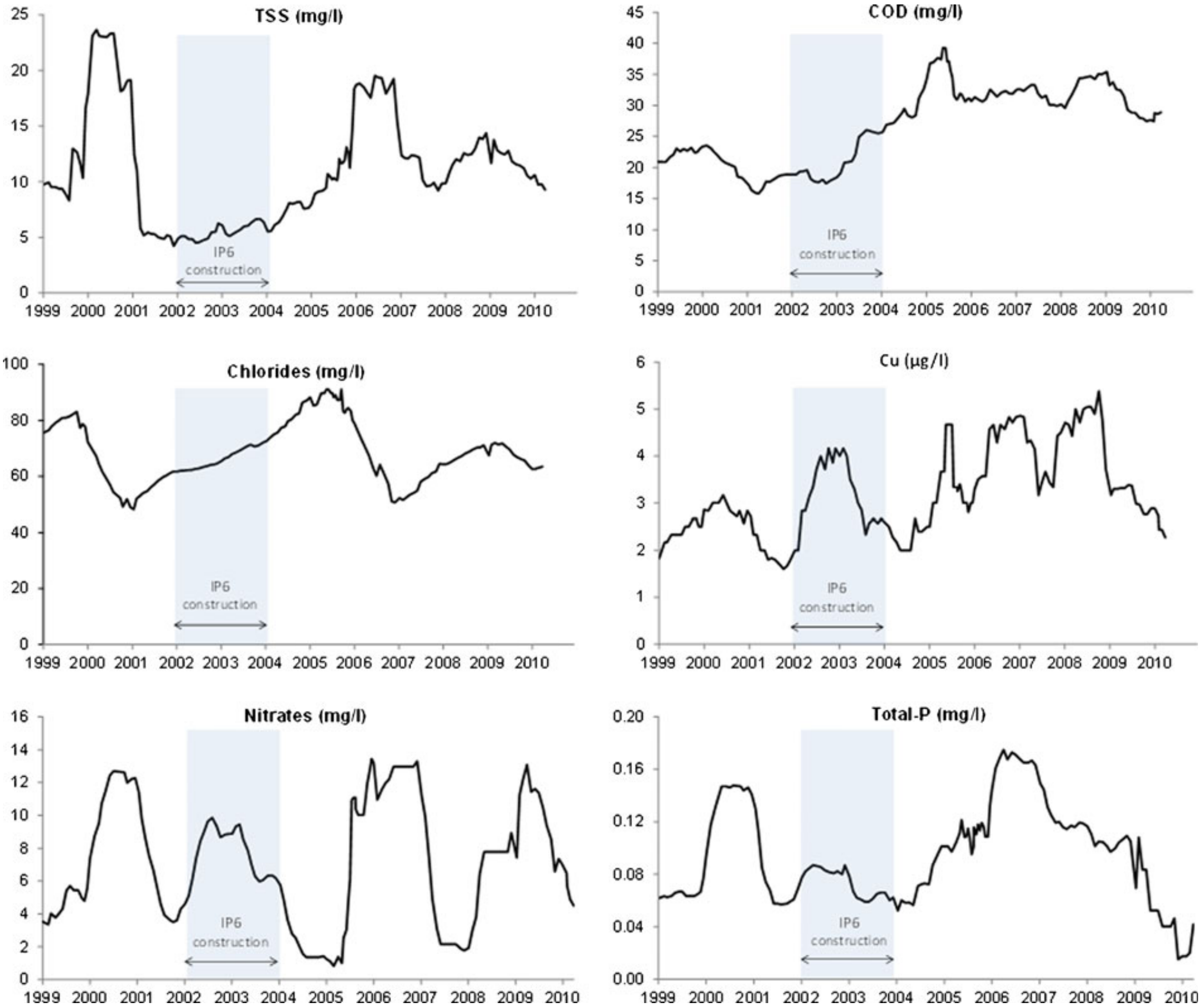

Fig. 6 Annual moving average for TSS, COD, Cl$^-$, Cu, NO$_3$$^-$, and Total-P concentrations in S. Domingos reservoir during the period between 1999 to 2010 (SNIRH 2010). The *shadowed area* represents the period of construction of the IP6

tendency. The results, obtained with an annual moving window, are represented in Fig. 6 in which the shadow area represents the period of construction of the IP6.

In order to evaluate the possible influence of the IP6 construction, the S. Domingos reservoir quality data was grouped in three different periods: before the construction of the IP6 (1999 to 2002), during it (2002 to 2004), and at the road operation period (2004 to 2010). The results are presented in Fig. 7.

As a reference, the Portuguese law recommends the following maximum limits for the water used a source of human consumption: 25 mg/l for TSS, 30 mg/l for COD, 200 mg/l for chlorides, 20 mg/l for Cu, and 25 mg/l for nitrates. Figure 7 confirms that these limits are respected in all periods.

Analyzing Figs. 6 and 7, it is clear that the IP6 road runoff affects the quality of S. Domingos reservoir in what respects the pollutants COD and Cu. This assumption is supported by the fact that COD and Cu, parameters related to traffic pollution, had an increase of 51.6 and 45.5 %, respectively, after the road construction. It was not found a pattern for the TSS and chlorides concentrations during the analyzed period. TSS is, as well, a key pollutant in road runoff in Portugal and is also generated by agriculture activities that take place in 66.4 % of the watershed area. The fact that the construction period had low annual precipitation explains the lower TSS concentrations from 2002 to 2004. These results agree with the spatial scale indicated by Forman and Alexander (1998) for road runoff impacts in water bodies (IP6 discharge is locates approximately 700 m upstream the reservoir).

The sources of chlorides are the ocean and agriculture, and it is known that the IP6 pavement accumulates chlorides (Table 5). This variable is affected by atmospheric conditions like wind, air temperatures, and pressures; by the use of agricultural products; and by their washed out

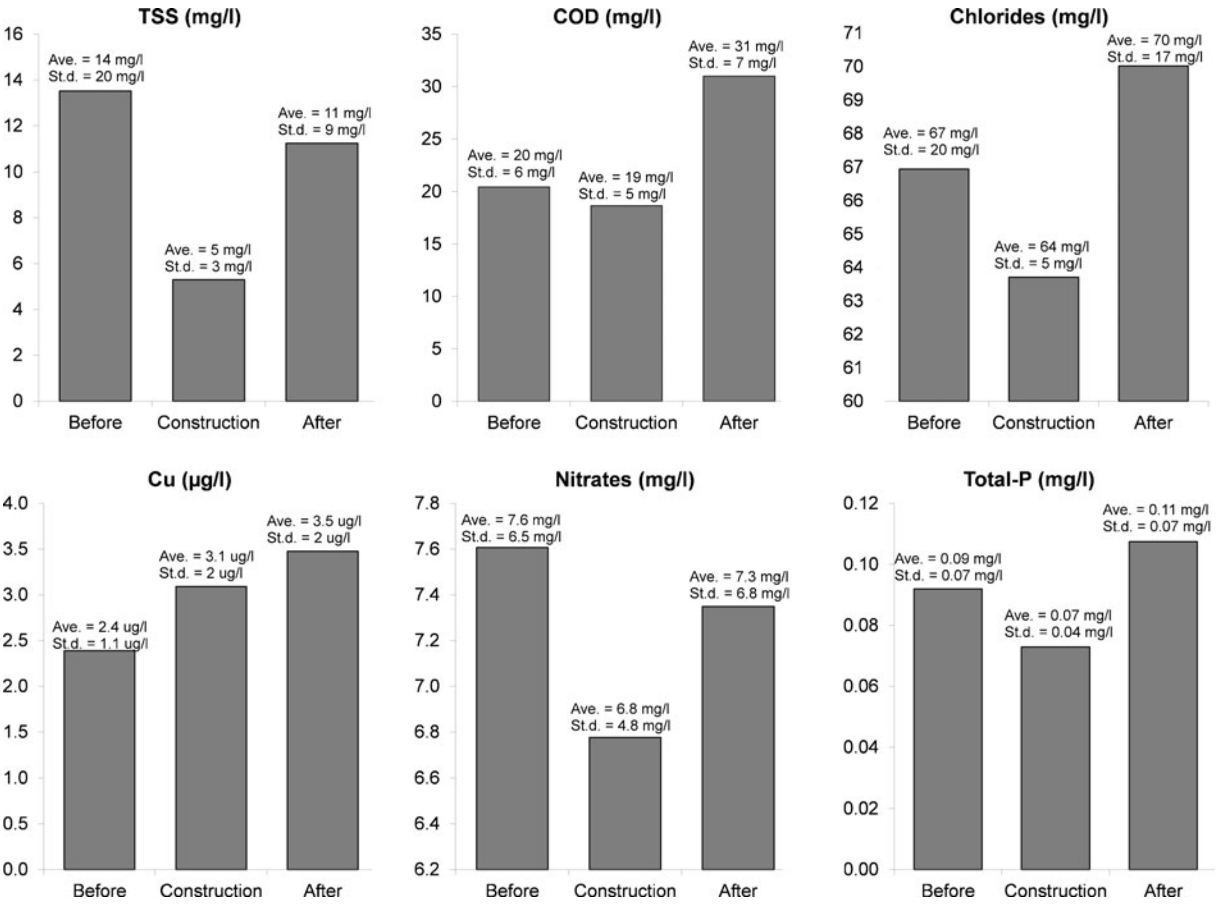

Fig. 7 Average concentrations of TSS, COD, Cl^-, Cu, NO_3^-, and Total-P in the S. Domingos reservoir before the construction of the IP6, during it, and at the road operation period

either by artificial irrigation or precipitation. Therefore it is difficult to find a pattern for chlorides concentrations.

The relative lower nitrates and Total-P concentrations observed during IP6 construction should be a result of lower precipitation at the catchment during these years. For the periods before and after the road construction, the concentrations are similar and are likely to be affected from small variations in agricultural activity and precipitation pattern among others.

Conclusions

The objective of the study was fulfilled and it was possible to conclude that the presence of the IP6 highway at S. Domingos catchment affects the water quality at the reservoir. Although the impacts are not significant due to the high dilution effect of the reservoir volume, it should be clear that some of the typical pollutants for road runoff—like heavy metals—are cumulative and may cause long-term impacts. It should be borne in mind, as well, that even nonmeasurable concentrations of certain elements may cause alterations in the ecological status of the water—this aspect was not included in the study. Agriculture, the main land use of the catchment (66 % of the total area), is responsible for introducing pollutants such as TSS, Cl^-, COD, N, and P in the local water streams and at the reservoir. TSS, COD, and Cu are generated both by the road and the agriculture.

The dilution effect caused by the reservoir volume may hide the presence of pollutants, and the success of this study was very much dependent on the availability of 12 years of historic water quality data for S. Domingos reservoir, and the use of the moving average method. Analysis of concentrations of pollutants in the water must always be assessed taking into consideration hydrological variables and the pollution sources. Such variations in Mediterranean climates are very high. In the case study, for instance, the flow variability at Azenha da Petinga creek, in two monitoring dates was of a factor of 27. This creek, like many streams and rivers in Mediterranean countries, does not have flow at all during the dry season; this variability makes it very vulnerable to pollution, and at the same time may hide the presence of pollutants.

Water quality impacts may be seen in an increase of pollutant concentrations or in more subtle effects, such as decreases in the ecological status of the water body—even if changes in water quality do not affect its uses, as was the case.

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