doi:10.2166/wpt.2012.044

Assessment of sanitary infrastructures and polluting loads in Pojuca river (Brazil)

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Abstract

This study was carried out to quantitatively and qualitatively investigate sources of water pollution in Pojuca river basin, in order to define ameliorative interventions.

The basin of Pojuca river is located in Recôncavo Norte region, immediately northwards from Salvador da Bahia, capital city of Bahia State (Brazil). River Pojuca is the main water body of the region and it represents a very important potential source of water to be used for drinking purposes, in order to face the rapidly growing population of Salvador da Bahia Metropolitan Area.

According to previous studies, its quality did not meet the minimum standards set for surface water withdrawn for potabilization treatment in 2000. In the present study, the most polluting activities have been identified as urban sewage discharges. Wastewater management coverage rate ranged between 30 and 90% in a high number of municipalities in the basin. Wastewaters were commonly discharged on the soil or into it (by means of septic and rudimental tanks) and also urban sewage systems, where existing, often did not convey wastewaters to treatment plants.

Polluting loads were estimated according to a methodology elaborated during the study. The estimation was based on the data collected by the authors through field visits and the ones available in the federal databases (updated to year 2007). It allowed to establish that diffuse loads were major than point loads: point discharges were quite rare, whereas pipelines discharging in water bodies and infrastructures such as septic or rudimental tanks were widespread. Treatment plants and septic tanks presented small removal efficiencies of nutrients. This justified also the high organic and microbiological concentrations registered in the river as well as the high content of nutrients.

Water quality could be improved in order to meet standards for drinking purposes by building new wastewater treatment plants or upgrading the existing ones. In particular, in urban areas dynamic systems for wastewater collection and treatment plants should be built, whereas in rural areas scattered households should be provided with septic tanks.

Key words: Brazil, Pojuca river, polluting loads, sanitary infrastructures

INTRODUCTION

Pojuca river basin is located in Recôncavo Norte region, immediately northwards from Salvador da Bahia, capital city of Bahia State (Brazil). Pojuca river is the main water body of the region, its course is about 200 km long and it flows into the Atlantic Ocean.

Pojuca river basin is characterized by a surface equal to about 5,000 km^2 and comprehends 22 municipalities where about 1,000,000 inhabitants live. The most important cities are Feira de Santana, Alagoinhas and Catu; these towns are the most populated in the basin, hosting respectively 556,642, 141,949 and 51,077 inhabitants (IBGE 2011).

doi:10.2166/wpt.2012.044

Salvador da Bahia Metropolitan Area (known as RMS, Região Metropolitana de Salvador) is nowadays characterized by a rapidly growing population. So, the municipality is improving its structures and infrastructures, in particular drinking water supply systems. As well as upgrading water treatment plants and distribution networks, new still available water sources are being identified, because the ones used until 2006 are not likely to be able to satisfy the increasing demand. According to EMBASA and CNEC (1981), Salvador water company planned to use some neighbour rivers to answer the 'ordinary' demand and the water withdrawn from Pojuca river to face the 'extra-ordinary' request. Moreover, according to that project, a high volume of water immediately available for withdrawal should have had to be stored to answer the extra-ordinary demand; therefore, the realization of a 2 km long barrage and an artificial reservoir near the Pojuca river mouth were planned.

In order to improve water quality, polluting activities were to be identified and kept under control. This study aimed at investigating quantitatively and qualitatively water pollution by pointing out the polluting activities, as done for other areas in several studies (Cerqueira *et al*. 2005; Karaer & Küçükballi 2006; Bongartz *et al*. 2007; Girija *et al*. 2007). In particular, this study was developed through three steps:

1. analysis of previous studies on water quality of Pojuca river;
2. identification of impacting activities (mainly urban sewage discharge, because zootechnical and industrial activities were not widespread and no specific information could be collected);
3. evaluation of polluting loads discharged in the river.

WATER QUALITY OF POJUCA RIVER

Pojuca river quality has been monitored since 1960s. Five monitoring campaigns were conducted between 1962 and 1980; they were limited to few sampling points and a small number of parameters (CEPED and CONDER 1983). In particular, in most cases only the content of chlorides and hardness was analysed, probably in order to evaluate the influence on water quality of the oil wells present in the area. Those previous campaigns showed that the quality of Pojuca river significantly varied from one point to another, and downstream it was better than upstream. This is probably due to the flowing of less polluted affluents into the main stream and to the consequent dilution effect. In particular, analyses showed chlorides concentrations higher than the limit set by Resolução CONAMA 357/2005 (250 mg/L; CONAMA 2005) for waters to be subjected to a conventional potabilization treatment (class 2).

Another monitoring campaign was performed in 1996, during the elaboration of the master plans of Recôncavo Norte and Inhambupe basins. These analyses evaluated physical, chemical and microbiological parameters in four sampling points along the main stream of the river. The survey confirmed the improvement of Pojuca river water quality downstream (for example, COD and concentration of total solids, chlorides and total and faecal coliforms decreased downstream), but it also evidenced variations of water quality due to the presence of organic pollutants in the affluents (Governo do Estado da Bahia 1996).

Other two campaigns were carried out in 2000 and 2001 (CRA 2000, 2001), following the directions given by Resolução CONAMA 20/86: those surveys regarded the same monitoring points called PJ-0300, PJ-0400 and PJ-0900 (shown in Figure 1) and the same physical, chemical and microbiological parameters, but they gave different results. Table 1 presents a comparison between the results obtained during 2000 and 2001 campaigns and the limit values set by Resolução CONAMA 357/2005 (CONAMA 2005).

Data reported in Table 1 show that on the whole water quality of Pojuca river worsened between 2000 and 2001. In particular, this worsening is witnessed by the strong decrease of dissolved oxygen

doi:10.2166/wpt.2012.044

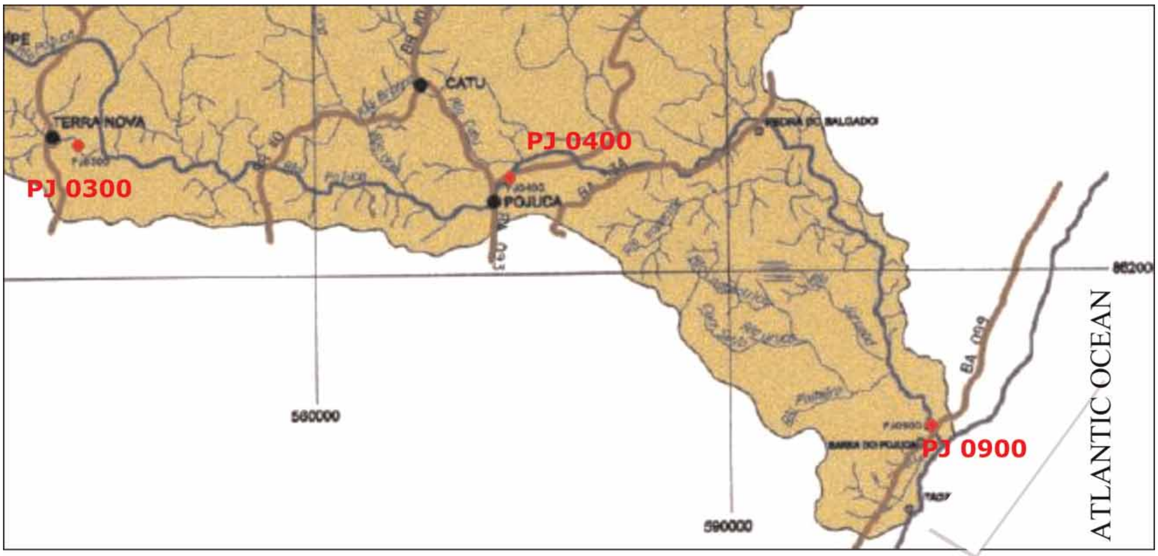

Figure 1 | Location of monitoring points during 2000 and 2001 campaigns (CRA 2000).

concentration that in 2001 was lower than the values prescribed by the law in all the monitoring points. Moreover, the values of BOD_5 and total solids clearly increased between 2000 and 2001: in 2001 these parameters presented concentrations higher than the limits in all the considered points. As regards microbiological parameters, between 2000 and 2001 faecal contamination increased in the upstream stations (PJ-0300 and PJ-0400), whereas it decreased in the station located next to Pojuca river mouth (PJ-0900). Faecal coliforms concentrations were lower than law limits only in the station PJ-0900 during the 2001 monitoring campaign. Furthermore, that monitoring campaign showed a high level of pollution downstream of densely-populated cities like Pojuca and Alagoinhas. The content of metals was analysed, as well: concentrations of cadmium and hexavalent chromium resulted inferior to CONAMA 357/05 limits, respectively equal to 0.001 and 0.05 mg/L. Lead, copper and zinc values were lower than instrumental detection limits (IDLs), respectively equal to 0.015, 0.01 and 0.02 mg/L.

In 2005 another monitoring campaign was performed, but it was limited to the mouth area of Pojuca river, downstream of PJ-0900 (Governo do Estado da Bahia *et al*. 2005). It involved three monitoring points where physical, chemical and microbiological parameters were analysed. Basing on the collected data Pojuca river water quality was judged good in that area.

It was decided to individuate sanitary infrastructures located in Pojuca river basin, aiming to define the causes of the bad water quality of Pojuca river. So, the sanitary infrastructures present in the basin were assessed, their influence on Pojuca river water quality was defined and pollution loads were estimated.

URBAN SEWAGE SYSTEM AND WASTEWATER TREATMENT PLANTS

According to the Brazilian Federal Law No 11, 445/07, urban wastewater must be collected and conveyed to a treatment plant by means of a sewage system and the users should be taxed for this service. The same law mandates also the realization of another network (separated from the previous one) specifically dedicated to storm water runoff, which is generated when precipitation from rain flows over land or impervious surfaces and does not percolate into the ground (Tilley *et al*. 2008). Since storm water is theoretically poor of pollutants, this net should be designed to directly discharge into water-bodies without any treatment.

Table 1 | Comparison between results obtained during 2000 and 2001 campaigns and limit values set by Resolução CONAMA 357/2005 for 'class 2' water bodies (values represented with a bold font do not comply with legislation standards)

Parameter	Unit	CONAMA 357/05 (class 2)	Statistical data	2000			2001		
				PJ-0300	PJ-0400	PJ-0900	PJ-0300	PJ-0400	PJ-0900
Temperature	°C	–	Range	22–27	23–26	23–26	23–24	24–27	26
			Median	24.5	24.5	26.0	23.5	25.5	26.0
pH		From 6 to 9	Range	7.2–7.8	6.7–7.3	7.0–7.5	7.4–7.7	6.6–8.0	7.3–7.6
			Median				7.5	7.2	7.4
DO	mg/L	>5	Range	5.2–7.0	5.9–8.9	5.5–7.5	2.8–6.1	2.5–4.5	3.7–7.6
			Median	5.3	6.7	7.4	4.4	3.5	5.6
Turbidity	NTU	100	Range	20.5–51.7	37.6–95.1	19.4–332.0	9.0–38.6	20.6–49.6	9.1–18.0
			Median	30.1	47.3	76.2	13.8	35.1	13.5
BOD_5	mg/L	5	Range	<2–3	<2–3	<2–4	14	20–21	29.0
			Median	<2	<2	<2		21	
Total solids	mg/L	500[a]	Range	360–380	304–574	<10–254	330–508	424–562	1,392–1,752
			Median	380	378	30	419	493	1,572
Total nitrogen	mg/L	14.7[b]	Range	1.0–1.2	0.2–0.8	0.5–1.2	13.0	<1–4.0	3.0–3.0
			Median	1.2	0.7	0.9			6.5
Total phosphorus	mg/L	0.100	Range	<0.016–0.120	0.016–0,180	0.049–0.180	0.030–0.082	<0.009–0.180	0.048–0.070
			Median	0.112	0.128	0.059	0.056		0.059
Iron	mg/L	0.3	Range	1.39–1.80	0.71–2.42	0.64–6.86	1.30–1.30	1.20–1.40	1.00–1.14
			Median	1.60	2.17	3.60	1.30	1.30	1.07
Chloride	mg/L	250	Range	89.3–119.0	58.7–82.0	60.6–85.0	167.0–257.0	80.0–117.5	130.0–697.0
			Median	95.4	70.3	76.6	212.0	117.5	413.5
Feacal coliforms	N/100 mL	1.0×10^3[c]	Range	2.4×10^3–6.5×10^3	1.5×10^3–6.2×10^3	1.0×10^3–2.0×10^3	2.2×10^4–2.6×10^4	3.8×10^4–2.6×10^5	3.2×10^2–3.9×10^2
			Median	2.5×10^3	3.3×10^3	3.8×10^3	2.4×10^4	1.4×10^5	3.5×10^2

[a]Value referred to total dissolved solids.
[b]Law does not report a limit value for total nitrogen: different limits are given for each nitrogen form.
[c]Limit value to be respected in at least three samples drawn during a year.

The situation of sanitary infrastructures and municipal services (i.e., drinking water supply, urban wastewater collection and treatment and urban solid waste management) in the study area has been defined thanks to the data reported by the 2000 Demographic Census (IBGE 2000), in the section regarding sanitation infrastructures. The survey was then completed by data handed by public or private sanitary management agencies and by the representatives of local administrations interviewed during visits on the field. The most recent available data were referred to year 2007.

Solutions for wastewater catchment adopted by the municipalities in Pojuca River basin can be classified as static (easier) and dynamic (more complex) systems. Static systems include rudimental and septic tanks. Rudimental tanks are pits dug in the ground where sewage is collected; as a pit is full, another is excavated. Dynamic systems include black and storm water networks, usually conveyed separately in Brazil. Storm water is considered unpolluted, therefore it could be discharged directly into water bodies, whereas wastewater pipelines should reach a treatment plant. Actually, many inhabitants abusively connected their sewage to the storm water net, so it could contain as pollutants as the black-water net.

Wastewater treatment plants present in Pojuca river basin were of different types, characterized by various treatment trains. The simplest ones offered only a primary treatment, i.e. a sedimentation sector for the removal of settleable solids, whereas the most complex ones were able to remove also organic matter and nutrients (nitrogen and phosphorous). No activated sludge treatment plants were built, probably due to their high cost and difficult maintenance. In particular, stabilization ponds, anaerobic filters and wetlands were most commonly employed.

Sanitary infrastructures for urban wastewater collection in 2000

The demographic census performed in 2000 covered 99.83% of the population living inside the hydrographic basin of Pojuca river (1,124,083 over 1,131,039 inhabitants). Its results are presented in Table 2.

Infrastructures of urban sewage collection were described in the sanitation section of the census in terms of:

- dynamic (by means of black or stormwater network) or static catchment system (septic or rudimental tanks). Blackwater is the mixture of urine, faeces and flush-water along with anal cleansing water (if anal cleansing is practiced) and/or dry cleansing material (e.g. toilet paper). Blackwater has all of the pathogens of faeces and all of the nutrients of urine, but diluted in flushwater (Tilley *et al*. 2008). In this paper a wider definition of blackwater is adopted, meaning water coming from public and private toilets, including both greywater and blackwater;
- characteristics of black water and storm water networks, if existing (extension, pipes description, number of users, pipeline cartography);
- features of the untreated collected flow discharged directly in water bodies (localization, flow-rate and numbers of inhabitants linked to the pipeline branch responsible of the discharge).

Sanitary infrastructures coverage rate in all the municipalities was higher than 30%, reaching in three cases (in Camaçari, Conceição do Jacuípe e Feira de Santana) values above 90%. Those high percentages were due to the widespread presence of rudimental tanks (i.e. simple holes into the ground): between 30 and 60% of the population living in 12 municipalities and more than 90% of the population in Conceição do Jacuípe were provided with it.

Moreover, the census underlined that the easier (and cheaper) the sanitary installation, the higher its application. As shown in Table 2, septic and rudimental tanks were the most widespread catchment systems, serving the 49.2% of the population living inside the basin, with values ranging between 13.8% in Terra Nova and 89.6% in Conceição do Jacuípe. Direct discharge in ditches and river was not a common practice, adopted only by 3% of the population (values ranging between 0.3% in Coração do Maria and 10.9% in Terra Nova).

Table 2 | Number of inhabitants provided with sanitary installations in each municipality of Pojuca river basin in 2000 (IBGE 2000)

Municipality	No. of inhabitants % on municipality tot.pop.	Total population	Black-water or storm water network	Septic tank	Rudimental tank	Ditch	River, lake or sea	Other discharge	Without sanitary installation
Água Fria	Inh	14,718	109	83	4,668	91	163	52	9,520
	%		0.74	0.57	31.79	0.62	1.11	0.35	64.82
Alagoinhas	Inh	130,095	39,994	22,417	47,182	1,824	1,279	879	16,059
	%		30.85	17.29	36.40	1.41	0.99	0.68	12.39
Amélia Rodrigues	Inh	24,134	420	14,011	4,004	300	77	171	5,074
	%		1.75	58.24	16.64	1.25	0.32	0.71	21.09
Araçás	Inh	11,003	3	25	6,318	20	113	74	4,416
	%		0.03	0.23	57.60	0.18	1.03	0.67	40.26
Aramari	Inh	9,258	353	132	4,123	99	205	74	4,248
	%		3.82	1.43	44.65	1.07	2.22	0.80	46.00
Camaçari	Inh	161,727	65,479	37,245	37,535	2,882	3,223	823	13,477
	%		40.76	23.18	23.36	1.79	2.01	0.51	8.39
Catu	Inh	46,731	24,406	2,002	9,770	1,460	431	1,202	7,303
	%		52.40	4.30	20.98	3.13	0.93	2.58	15.68
Conceição do Jacuípe	Inh	26,194	183	285	23,054	151	10	129	2,228
	%		0,70	1.09	88.53	0.58	0.04	0.50	8.56
Coração de Maria	Inh	23,818	22	115	13,513	60	5	78	9,831
	%		0.09	0.49	57.20	0.25	0.02	0.33	41.61
Feira de Santana	Inh	480,949	164,293	61,533	191,186	10,229	2,930	3,670	43,885
	%		34.39	12.88	40.02	2.14	0.61	0.77	9.19
Irará	Inh	25,163	24	134	14,740	360	0	108	9,696
	%		0.10	0.53	58.81	1.44	0.00	0.43	38.69

Itanagra	Inh	6,370	13	2,192	836	58	15	40	3,155
	%		0.21	34.74	13.25	0.92	0.24	0.63	50.01
Lamarão	Inh	9,523	1,122	35	1,355	365	0	18	6,616
	%		11.80	0.37	14.25	3.84	0.00	0.19	69.56
Mata de São João	Inh	32,568	5,254	2,912	14,987	1,103	501	607	6,730
	%		16.37	9.07	46.70	3.44	1.56	1.89	20.97
Ouriçangas	Inh	7,525	206	40	2,995	71	3	125	4,080
	%		2.74	0.53	39.83	0.94	0.04	1.66	54.26
Pedrão	Inh	6,764	149	90	3.430	86	14	277	2,702
	%		2.21	1.33	50.83	1.27	0.21	4.10	40.04
Pojuca	Inh	26,203	15,770	2,031	2.569	411	284	188	4,847
	%		60.42	7.78	9.84	1.57	1.09	0.72	18.57
Santa Bárbara	Inh	17,933	458	4,489	2.879	402	0	81	9,570
	%		2.56	25.11	16.10	2.25	0.00	0.45	53.53
Santanópolis	Inh	8,644	7	166	3.263	368	22	85	4,723
	%		0.08	1.92	37.79	4.26	0.25	0.98	54.70
São Sebastião do Passé	Inh	39,960	18,222	837	6.850	1,139	1,349	1,015	9,949
	%		46.29	2.13	17.40	2.89	3.43	2.58	25.28
Teodoro Sampaio	Inh	8,884	772	1,691	4.006	163	33	130	2,048
	%		8.73	19.12	45.30	1.84	0.37	1.47	23.16
Terra Nova	Inh	12,875	5,397	27	1.747	815	578	379	3.871
	%		42.12	0.21	13.63	6.36	4.51	2.96	30.21
TOTAL	Inh	1,131,039	342,656	152,492	401,010	22,457	11,235	10,205	184,028
	%		30.48	13.57	35.67	2.00	1.00	0.91	16.37

Water Practice & Technology Vol 7 No 2
doi:10.2166/wpt.2012.044

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In 15 municipalities, piped networks for black- and storm-water served less than 20% of the population. A higher percentage, ranging between 30 and 50%, could be found only in five municipalities. Finally, Catu and Pojuca showed a very high coverage of piped network, having more than 50% of the inhabitants connected.

In 20 municipalities, a small percentage of population (from 1 to 10%) was not provided with either dynamic or static systems, but discharged its wastewater directly in water bodies.

In almost all the municipalities the part of population having no sanitary installation was still considerable: about 16.4% of the basin population, with the minimum percentage (8.5%) registered in Camaçari and the maximum (68.6%) in Lamarão.

Sanitary infrastructures for urban wastewater collection in 2007

The results of 2000 Demographic Census were updated by the authors to year 2007 through specific data provided by the technicians of the municipalities of Pojuca river basin. As above mentioned, the authors had to use data referred to year 2007 because they were the most updated. As shown in Table 3, the overall setting of sanitary infrastructures did not change much during those seven years: only few new plants were built and the sewage system was usually upgraded only to answer to the population growth, leaving the coverage percentage unchanged. The main improvements were carried out in six municipalities: Alagoinhas, Camaçari, Catu, Ouriçangas, Pojuca and Santa Bárbara. A comparison between the number of inhabitants served by a wastewater collection system in 2000 and 2007 is shown in Figure 2, whereas Figure 3 illustrates the enlargement of the collection net in terms of percentage of inhabitants.

Figure 3 shows that the most extensive works were done in Ouriçangas and Santa Bárbara. Here, in 2000 a proper system for wastewater management did not exist as proved by the low coverage percentage, whereas in 2007 almost one third of population was connected to a black-water collection system (see Figure 2). In particular, in 2007 a net served 33.6% of the population in Ouriçangas, whereas in 2000 only 2.5% was reached by that service: so, the percentage of served people increased of 31.1% (i.e. 2,570 inhabitants) between 2000 and 2007. Similarly, in 2007 a net served 38.8% of the population in Santa Bárbara, whereas in 2000 only 2.4% was reached by that service: so, the percentage of served people increased of 36.4% (i.e. 6,904 inhabitants) between 2000 and 2007.

In Alagoinhas, Camaçari, Catu and Pojuca an existing well-developed urban drainage system was enlarged. In Alagoinhas the percentage of served population reached the 38.9% with an increase of 12.3%, i.e. 18,891 inhabitants (in 2000 the 26.52% of the population was connected); in Camaçari the percentage of served population reached the 40.8% with an increase of 9.5%, i.e. 19,952 inhabitants (in 2000 the 31.2% of the population was connected); in Catu the percentage of served population reached the 67.8% with an increase of 22%, i.e. 11,696 inhabitants (in 2000 the 45.8% of the population was connected); in Pojuca the percentage of served population reached the 60.4% with an increase of 19.8%, i.e. 7,668 inhabitants (in 2000 the 40.7% of the population was connected).

The comparison between Tables 2 and 3 shows also that other five municipalities enlarged their urban drainage system in a less significant way: Aramari (6.7%), Conceição do Jacuípe (2.7%), Itanagra (6.7%), Pedrão (1.2%) and Teodoro Sampaio (7%). On the whole, the percentage of the inhabitants in the basin served by sanitary infrastructures increased of 3.3% from 2000 to 2007.

Other considerations emerged from the comparison between 2000 and 2007 data, as well. Also in 2007 in all the municipalities the coverage of sanitary infrastructures was higher than 30%, as registered in 2000, and the municipalities reaching values above 90% were only three (Camaçari, Conceição do Jacuípe e Feira de Santana). These high percentages were due also in 2007 to the widespread presence of rudimental tanks, even if they had often been substituted by piped networks between 2000 and 2007. For example, in Conceição do Jacuípe and Ouriçangas the percentage of

Table 3 | Number of inhabitants provided with sanitary installations in each municipality of Pojuca river basin in 2007

Municipality		Total population	Black-water or storm water network	Septic tank	Rudimental tank	Discharge into ditch	Discharge into river, lake or sea	Other discharge	Without sanitary installation
Água Fria	Inh	14,520	108	82	4,615	90	161	51	9,413
	%		0.74	0.57	31.79	0.62	1.11	0.35	64.82
Alagoinhas	Inh	150,793	58,585	26,076	42,820	2,122	1,488	1,022	16,680
	%		38.85	17.29	28.4	1.41	0.99	0.68	12.39
Amélia Rodrigues	Inh	25,448	444	14,821	4,236	317	81	181	5,367
	%		1.75	58.24	16.64	1.25	0.32	0.71	21.09
Araçás	Inh	12,234	3	28	7,047	22	126	83	4,925
	%		0.03	0.23	57.60	0.18	1.03	0.67	40.26
Aramari	Inh	10,474	1,103	150	3,974	112	233	84	4,818
	%		10.53	1.43	39.94	1.07	2.22	0.80	46.00
Camaçari	Inh	209,621	85,431	48,594	48,972	3,760	4,205	1,074	17,584
	%		40.76	23.18	23.36	1.79	2.01	0.51	8.39
Catu	Inh	53,254	36,102	2,289	2,975	1,669	493	1,374	8,350
	%		67.79	4.30	5.59	3.13	0.93	2.58	15.68
Conceição do Jacuípe	Inh	28,023	999	318	24,900	168	11	144	2,483
	%		3.44	1.09	85.79	0.58	0.04	0.50	8.56
Coração de Maria	Inh	25,926	24	126	14,830	66	5	86	10,789
	%		0.09	0.49	57.20	0.25	0.02	0.33	41.86
Feira de Santana	Inh	603,839	207,664	77,777	241,657	12,929	3,703	4,369	55,470
	%		34.39	12.88	40.02	2.14	0.61	0.77	9.19
Irará	Inh	27,001	26	144	15,880	388	0	116	10,466
	%		0.10	0.53	58.81	1.44	0.00	0.43	38.69
Itanagra	Inh	6,902	14	2,398	915	63	16	44	3,451
	%		0.21	34.74	13.25	0.92	0.24	0.63	50.01
Lamarão	Inh	10,482	1,941	39	795	402	0	20	7,291
	%		18.52	0.37	7.53	3.84	0.00	0.19	69.56
Mata de São João	Inh	36,362	5,953	3,299	16,980	1,250	568	688	7,625
	%		16.37	9.07	46.70	3.44	1.56	1.89	20.97
Ouriçangas	Inh	8,274	2,766	44	756	78	3	138	4,489
	%		33.43	0.53	9.14	0.94	0.04	1.66	54.26
Pedrão	Inh	6,762	233	90	3,353	86	14	278	2,708
	%		3.45	1.33	49.59	1.27	0.21	4.10	40.04

(*Continued.*)

Water Practice & Technology Vol 7 No 2
doi:10.2166/wpt.2012.044

Table 3 | continued

Municipality		Total population	Black-water or storm water network	Septic tank	Rudimental tank	Discharge into ditch	Discharge into river, lake or sea	Other discharge	Without sanitary installation
Pojuca	Inh	38,774	23,428	3,017	3,817	611	422	279	7,201
	%		60.42	7.78	9.84	1.57	1.09	0.72	18.31
Santa Bárbara	Inh	18,998	7,362	4,770	30,059	427	0	86	3,294
	%		38.74	25.11	16.10	2.25	0.00	0.45	17.34
Santanópolis	Inh	8,360	7	161	3,160	356	21	82	4,573
	%		0.08	1.92	37.79	4.26	0.25	0.98	54.70
São Sebastião do Passé	Inh	43,083	19,945	916	7,498	1,247	1,477	1,111	10,890
	%		46.29	2.13	17.40	2.89	3.43	2.58	25.28
Teodoro Sampaio	Inh	8,260	1,299	1,580	3,164	152	31	121	1,913
	%		15.73	19.12	38.3	1.84	0.37	1.47	23.16
Terra Nova	Inh	14,428	6,067	30	1,967	918	651	427	4,359
	%		42.12	0.21	13.63	6.36	4.51	2.96	30.21
TOTAL	Inh	1,361,818	456,504	186,749	484,370	27,233	13,709	11,858	204,139
	%		33.74	13.71	35.57	2.00	1.01	0.87	14.99

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doi:10.2166/wpt.2012.044

doi:10.2166/wpt.2012.044

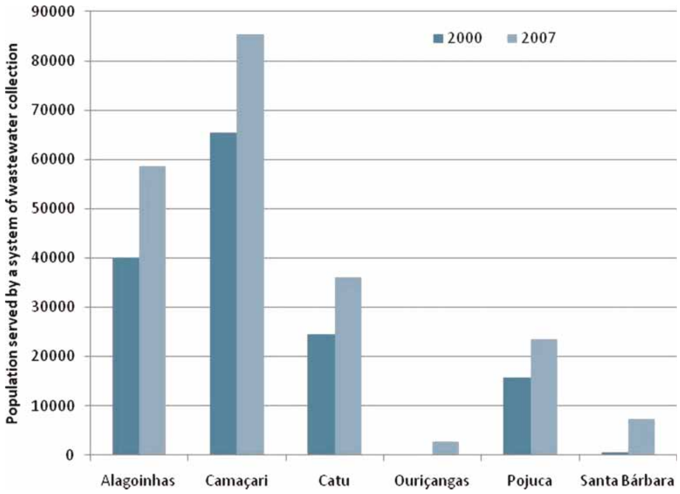

Figure 2 | Comparison between the population served by a system of wastewater collection in 2000 and 2007.

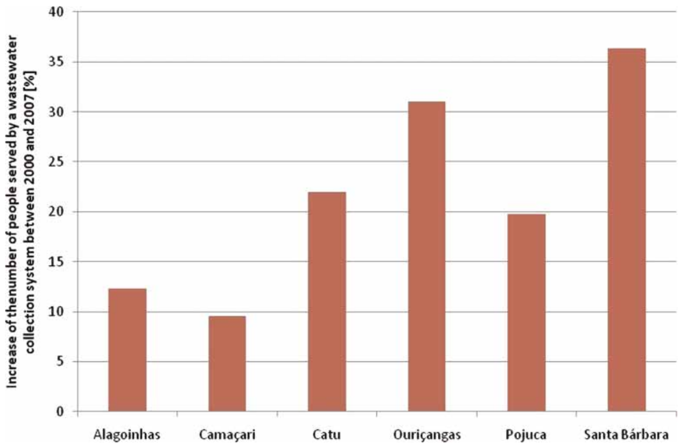

Figure 3 | Enlargement of the wastewater collection system between 2000 and 2007 in terms of percentage of served inhabitants.

rudimental tanks decreased respectively from 88.5 to 85.8% and from 39.8 to 9.1%. Also in 2007, septic and rudimental tanks were the most common catchment systems, serving an unchanged percentage (about 49%) of the population living inside the Pojuca river basin, but the minimum and the maximum coverage percentages slightly decreased, ranging between 7.9% in Lamarão and 86.9% in Conceição do Jacuípe.

No significant changes were appreciated in the practices of discharging wastewater in ditches or in water bodies. In conclusion, the upgrades done between 2000 and 2007 did not cause a great improvement, because on the whole the part of population not provided with any sanitary installation decreased only by 1.4%.

Wastewater treatment plants present in Pojuca river basin

In 2005 the Ministry of Environment and the National Council of Environment issued a law (Resolução CONAMA 357/2005; CONAMA 2005) that fixed the limits for wastewater discharge, as well as defining water-bodies classification.

The accomplishment of this law led to the construction of some wastewater treatment plants, surveyed by the authors during on site visits. Their main features are presented in Table 4. Pojuca river basin municipalities provided with wastewater treatment plants were Pojuca, Catu, Alagoinhas,

Table 4 | Characteristics of urban wastewater treatment plants inside Pojuca river basin

				Theoretical removal efficiency (von Sperling 2005)						
Municipality	**River**	**Treatment**	**Potentiality (inhabitants)**	**BOD_5 (%)**	**COD (%)**	**SS (%)**	**NH_3 (%)**	**N (%)**	**P (%)**	**Total coliforms (log. unit)**
Alaigonhas	Catu river	Sand filter + Anaerobic filter + wetland 'Fonte dos Padres'[a]	2,500	64	N.A	N.A	N.A	57	60	90%[b]
	Catu river	Sand filter + wetland 'Jardim Petrolar'[a]	6,418	88	N.A	N.A	N.A	50	30	86%[b]
Feira de Santana	Pojuca Affluent	Stabilization pond	69,221	75–85	65–80	70–80	<50	<60	<35	1.5
Pojuca	Pojuca river	Primary treatment	About 5,000	30–35	25–35	55–65	<30	<30	<35	<1
	Catu river	Primary treatment	About 5,000	30–35	25–35	55–65	<30	<30	<35	<1
	Catu river	Primary treatment	About 5,000	30–35	25–35	55–65	<30	<30	<35	<1
	Pojuca river	Primary treatment	About 5,000	30–35	25–35	55–65	<30	<30	<35	<1
	Pojuca river	Primary treatment	About 5,000	30–35	25–35	55–65	<30	<30	<35	<1

[a]Removal efficiencies provided by the manager of the treatment plant, obtained through an average of the values registered in January 2007.
[b]Removal efficiencies expressed as percentages.
N.A. = not available.

doi:10.2166/wpt.2012.044

Ouriçangas, Mata de São João, Feira de Santana and Santa Bárbara for an overall number of 13 plants with potentialities varying between 2,500 and 69,221 equivalent inhabitants. Only 10 plants are described in Table 4, due to the absence of precise data referring to the plants in Catu, Ouriçangas, Mata de São João and Santa Bárbara. In Ouriçangas and Santa Bárbara wastewaters were discharged on the ground or treated by means of stabilization ponds built without any scientific design. On the whole, those plants served only 12% of the basin population (i.e., about 163,000 inhabitants).

Data on the effective treatment efficiency of those plants were not available but for the ones in Alagoinhas that were constantly monitored. In Alagoinhas at 'Fonte dos Padres' plant the treatment train was made up of a sand filter, an anaerobic filter and a wetland. At 'Jardim Petrolar' plant only a sand filter and a wetland were working at the time of the survey, but an UASB reactor was under construction. Respectively at 'Fonte dos Padres' and 'Jardim Petrolar' plants the following removal efficiencies were found: BOD_5 64 and 88%, suspended solids 64 and 89%, total nitrogen 57 and 50%, total phosphorous 60 and 30% and faecal coliforms 90 and 85%. The comparison of these results with the theoretical ones showed that 'Fonte dos Padres' plant reached not very high efficiencies in BOD_5 and suspended solids removal, whereas it showed a good behaviour on the nutrients. On the contrary, 'Jardim Petrolar' plant had good BOD_5 and suspended solids removal accompanied by a low treatment efficiency on nutrients. In Feira de Santana only a stabilization pond was serving a small percentage of the population at the time of the survey, but it could have been able to reach good removal efficiencies, according to literature values (von Sperling 2005). Finally, Pojuca represents an interesting case. All the treatment plants were designed as UASB, but they were actually used as primary treatments at the time of the survey. The removal efficiencies reported in Table 1 refer to typical values for primary treatments. It is important to underline that the treatment system initially chosen resulted too complicated to be correctly managed and it was actually used in a more simple way.

ESTIMATION OF POLLUTING LOADS

Polluting loads affecting the water quality of Pojuca river were calculated as the sum of civil loads, generated by the population living in the basin, runoff loads, due to the transportation of polluting agents present on the soil by means of rainwater, and industrial loads, produced by industries located within the basin.

The contribution of runoff and industrial loads to the whole load can be considered very limited. The polluting load deriving from runoff was calculated by the authors in terms of total phosphorus, assuming a production of 100 kg P/km^2/year for urban areas (von Sperling 2005). The contribution deriving from agricultural areas was neglected because fertilizers were not commonly used and so phosphorous runoff could be considered low (von Sperling 2005). As regards industrial loads, 23 industries of medium-large size (with more than 100 employees) were located in the basin of Pojuca river. They were concentrated in the municipalities of Alagoinhas, Pojuca and Conceição do Jacuípe and were mainly involved in the sectors of food and beverage and construction materials. Each of them was provided with a wastewater treatment system, but detailed data about the treatment train and the quality of treated wastewater were not provided, even after several enquiries.

Therefore, attention was principally paid to civil load, representing the main contribution of the overall polluting load.

Method for the estimation of civil polluting loads

Civil polluting load was estimated first calculating the total civil polluting load potentially produced in the 22 municipalities of the basin that was called 'potential load'. Then the 'real load' was estimated

doi:10.2166/wpt.2012.044

considering that a part of the polluting loads was discharged in other neighbouring basins or was subjected to a purification treatment. Main pollutants present in civil loads are BOD_5, COD, total nitrogen, total phosphorus and faecal coliforms; von Sperling (2005) suggested a typical daily per-capita production in Brazil for all pollutants except than for faecal coliforms, for which only a range was provided. So, a value equal to 10^{11} org/inh/d, suggested by good practice, was used by the authors. Those values are presented in Table 5.

The potential load was calculated for each municipality by multiplying the daily per-capita production by the number of inhabitants living in the municipality. Data concerning the presence of sanitary infrastructures for wastewater collection and treatment were used to evaluate the 'real load'. In particular, the categories identified by IBGE and reported in Table 3 were grouped according to three different types of polluting loads: point load, 'direct' diffuse load and 'purified' diffuse load.

As illustrated in Figure 4, the point load was made up of wastewater conveyed in a pipeline and discharged (treated or not) in an exact point of the water body; the 'direct' diffuse load was formed by wastewaters discharged in several points of the water body and not subjected to previous purification processes (for example, wastewater discharged without any treatment in ditches or rivers from several points of the wastewater net, isolated households discharging their wastewater into a ditch, etc.); the 'purified' diffuse load was generated by wastewaters discharged in septic or rudimental tanks or directly on the ground.

The removal efficiency of each kind of infrastructure was considered in order to calculate the 'real load' reaching the river. Removal efficiencies assumed for septic tanks, rudimental tanks and direct discharge on the ground are reported in Table 6, whereas removal efficiencies already shown in Table 4 were adopted for the treatment plants present in the basin.

Table 5 | Daily per-capita production of BOD_5, COD, total nitrogen, total phosphorus and faecal coliforms (von Sperling 2005)

	Per-capita production (g/inh*d)		
Parameter	**Unit**	**Range**	**Typical value**
BOD_5	g/inh/d	40–60	50
COD	g/inh/d	80–120	100
Total nitrogen	gN/inh/d	6.0–10.0	8
Total phosphorus	gP/inh/d	0.7–2.5	1
Faecal coliforms	org/inh/d	10^9–10^{12}	10^{11}[a]

[a]Datum not provided by von Sperling (2005), but adopted by the authors.

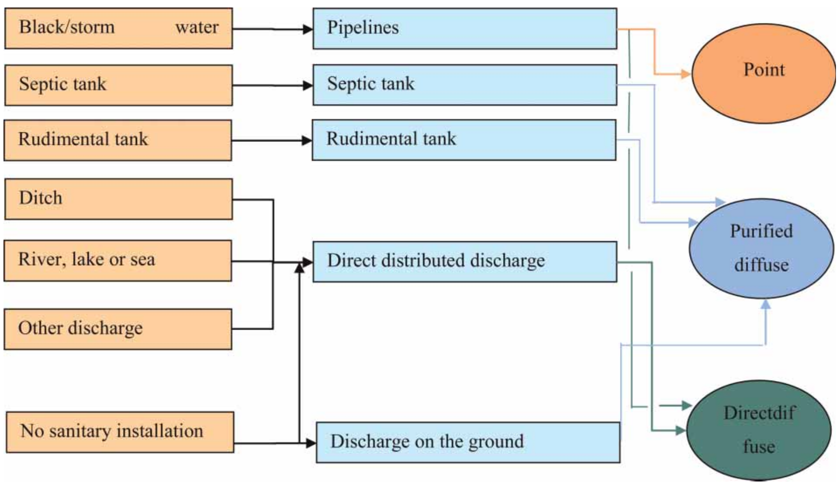

Figure 4 | Scheme used to calculate the civil polluting load discharged in Pojuca river basin.

doi:10.2166/wpt.2012.044

Table 6 | Removal efficiencies of septic tanks, rudimental tanks and discharge on the ground (von Sperling 2005, modified)

	Medium range of removal efficiences					Assumed removal efficiences values				
Systems	BOD_5 (%)	COD (%)	N_t (%)	P_t (%)	Total coli. (log unit)	BOD_5 (%)	COD (%)	N_t (%)	P_t (%)	Total coli. (log unit)
Septic tank + infiltration	90–98	85–95	>65	>50	4.0–5.0	94	90	65	50	4.5
Discharge on the ground	90–99	85–95	>75	>85	3.0–5.0	95	90	75	85	4.0
Rudimental tank	85–98	80–93	>65	>50	4.0–5.0	92	87	65	50	4.5

The 'real load' was estimated by multiplying the potential load (calculated for each kind of infrastructure in each municipality) by the related removal efficiencies.

Estimation of 2007 civil polluting loads

Civil polluting loads were calculated basing on the population living in Pojuca river basin and on the data concerning sanitary installations coverage in 2007. Evaluated loads are presented in Table 7.

Nine out of twenty-two municipalities forming Pojuca river basin did not present point loads: wastewater pipelines often discharged in several points and did not convey wastewaters to treatment plants. Moreover, as observed at paragraph 3.3, septic and rudimental tanks were the most common wastewater disposal systems; so, the whole amount of 'purified' diffuse load was significant.

As concerns discharged quantities, the maximum point load was registered in Catu, where a pipeline discharged waters collected and untreated in a single point.

The maximum 'direct' diffuse load was observed in Alagoinhas. This city was provided with two highly efficient treatment plants and other facilities were under construction, but a significant part of collected wastewaters was discharged untreated in several points at the moment of the survey.

The maximum 'purified' diffuse load was registered in Feira de Santana, where about 60% of the population was provided with septic or rudimental tanks. Here also a big treatment plant was located, but it could serve only about the 11% of the population of the town.

Therefore, it stands to reason that each municipality has proper characteristics, producing different impacts on Pojuca river water quality.

The civil polluting loads estimated for year 2007 can be considered still valid nowadays as the last population census updated to 2010 (IBGE 2011) reports quite the same number of total inhabitants in Pojuca river basin (Table 8).

CONCLUSIONS

This study was carried out to investigate quantitatively and qualitatively water pollution in Pojuca river and point out the polluting activities of the basin, in order to define ameliorative interventions.

Most polluting activities were mainly made up of urban sewage discharge. Wastewater management coverage rate usually lies between 30 and 90% in the municipalities of the basin. Wastewaters were commonly discharged on the soil or into it (by means of septic and rudimental tanks). Moreover, the separation of black waters and storm waters was not respected and treatment plants were present only in seven municipalities and were characterized by treatment trains often able to reach low removal efficiencies. Also urban sewage systems did not frequently convey wastewaters to treatment plants: in many cases they discharged directly in water bodies at several points of discharge. As financial resources were available, they were used to build structures for sewage collection. On the contrary,

doi:10.2166/wpt.2012.044

Table 7 | Polluting loads discharged in Pojuca river and its affluents in 2007

			Load				
Municipality	**Population**	**Load type**	**BOD_5 (kg/d)**	**COD (kg/d)**	**N_{tot} (kg/d)**	**P_{tot} (kg/d)**	**Total Col. (org/d)**
Água Fria	14,520	Point	0.80	1.59	0.13	0.02	1.59E + 12
		Direct diffuse	6.92	13.83	1.11	0.14	1.38E + 13
		Purified diffuse	4.32	17.27	3.45	0.26	1.73E + 14
Alagoinhas	150,793	Point	38.83	128.36	25.47	4.49	9.31E + 13
		Point	45.13	100.00	8.68	1.01	2.50E + 14
		Direct diffuse	2,623.96	5,247.93	419.83	52.48	5.25E + 15
		Purified diffuse	279.93	939.09	217.24	36.27	8.11E + 15
Amelia Rodrigues	25,448	Direct diffuse	12.40	24.81	1.98	0.25	2.48E + 13
		Purified diffuse	2.10	8.41	1.68	0.13	8.41E + 13
Araçás	12,234	Point	0.17	0.33	0.03	0.00	3.35E + 11
		Direct diffuse	8.41	16.82	1.35	0.17	1.68E + 13
		Purified diffuse	33.35	112.97	23.98	3.78	9.26E + 14
Aramari	10,474	Point	55.16	110.32	8.83	1.10	1.10E + 14
		Direct diffuse	20.83	41.65	3.33	0.42	4.17E + 13
		Purified diffuse	20.97	72.43	15.35	2.27	6.13E + 14
Camaçari	1,067	Diffuso diretto	53.33	106.66	8.53	1.07	1.07E + 14
Catu	209,621	Point	1,805.10	4,315.28	345.22	43.15	4.32E + 15
		Direct diffuse	352.54	705.09	56.41	7.05	7.05E + 14
		Purified diffuse	30.86	109.93	24.41	3.36	1.01E + 15
Conceição do Jacuípe	28,023	Point	49.96	99.92	7.99	1.00	9.99E + 13
		Direct diffuse	15.04	30.08	2.41	0.30	3.01E + 13
		Purified diffuse	104.22	342.88	73.72	12.71	2.70E + 15
Coração do Maria	25,926	Direct diffuse	11.64	23.27	1.86	0.23	2.33E + 13
		Purified diffuse	86.54	301.43	63.35	9.09	2.57E + 15
Feira de Santana	603,839	Point	103.83	280.35	37.38	7.27	1.04E + 15
		Direct diffuse	886.68	2,185.22	259.54	47.15	6.48E + 15
		Purified diffuse	437.95	1,458.29	328.51	55.52	1.22E + 16
Irarà	27,001	Direct diffuse	38.96	77.91	6.23	0.78	7.79E + 13
		Purified diffuse	89.45	309.86	65.26	9.54	2.62E + 15
Itanagra	6,902	Direct diffuse	3.12	6.24	0.50	0.06	6.24E + 12
		Purified diffuse	1.97	7.33	1.54	0.17	6.90E + 13
Lamarão	10,482	Direct diffuse	51.15	102.30	8.18	1.02	1.02E + 14
		Purified diffuse	5.44	20.90	4.25	0.40	2.01E + 14
Mata do São João	36,362	Point	129.34	270.27	21.62	3.47	3.86E + 14
		Direct diffuse	48.27	96.54	7.72	0.97	9.65E + 13
		Purified diffuse	5.21	20.79	4.16	0.32	2.07E + 14
Ouriçangâs	8,274	Point	8.30	27.66	7.74	1.38	2.77E + 14
		Direct diffuse	30.30	60.59	4.85	0.61	6.06E + 13
		Purified diffuse	12.49	47.63	9.71	0.96	4.54E + 14
Pedrão	6,762	Direct diffuse	34.48	68.95	5.52	0.69	6.90E + 13
		Purified diffuse	20.26	70.79	14.90	2.12	6.07E + 14
Pojuca	38,774	Point	158.14	327.99	26.24	4.22	4.69E + 14
		Point	158.14	327.99	26.24	4.22	4.69E + 14
		Point	158.14	327.99	26.24	4.22	4.69E + 14
		Point	158.14	327.99	26.24	4.22	4.69E + 14
		Point	158.14	327.99	26.24	4.22	4.69E + 14
		Direct diffuse	142.25	284.50	22.76	2.85	2.85E + 14
		Purified diffuse	38.49	136.46	30.47	4.27	1.25E + 15
Santa Barbara	18,998	Point	18.40	73.62	14.72	1.10	7.36E + 14
		Direct diffuse	22.13	44.26	3.54	0.44	4.43E + 13
		Purified diffuse	19.16	65.70	16.04	2.58	6.13E + 14

(*Continued.*)

Table 7 | continued

Municipality	Population	Load type	Load BOD$_5$ (kg/d)	COD (kg/d)	N_{tot} (kg/d)	P_{tot} (kg/d)	Total Col. (org/d)
Santanópolis	8,360	Direct diffuse	32.95	65.90	5.27	0.66	6.59E + 13
		Purified diffuse	17.69	62.82	13.20	1.78	5.52E + 14
São Sebastião do Passe	43,083	Direct diffuse	47.48	94.96	7.60	0.95	9.50E + 13
		Purified diffuse	0.54	2.17	0.43	0.03	2.17E + 13
Teodoro Sampaio	8,260	Point	6.50	12.99	1.04	0.13	1.30E + 13
		Direct diffuse	78.93	40.91	3.27	0.41	4.09E + 13
		Purified diffuse	21.91	75.01	16.90	2.64	6.55E + 14
Terra Nova	14,428	Point	60.77	121.54	9.72	1.22	1.22E + 14
		Point	121.54	243.08	19.45	2.43	2.43E + 14
		Direct diffuse	268.88	537.76	43.02	5.38	5.38E + 14
		Purified diffuse	14.02	50.13	10.44	1.36	4.42E + 14

Table 8 | Number of inhabitants in Pojuca river basin in 2010 (IBGE 2011) and the estimated 2007 values

Municipality	Inhabs.2007 (est.)	Inhabs.2010
Água Fria	14,520	15,731
Alagoinhas	150,793	141,949
Amélia Rodrigues	25,448	25,190
Araçás	12,234	11,561
Aramari	10,474	10,036
Camaçari	209,621	242,970
Catu	53,254	51,077
Conceição do Jacuípe	28,023	30,123
Coração de Maria	25,926	22,401
Feira de Santana	603,839	556,642
Irará	27,001	27,466
Itanagra	6,902	7,598
Lamarão	10,482	9,560
Mata de São João	36,362	40,183
Ouriçangas	8,274	8,298
Pedrão	6,762	6,876
Pojuca	38,774	33,066
Santa Bárbara	18,998	19,064
Santanópolis	8,360	8,776
São Sebastião do Passé	43,083	42,153
Teodoro Sampaio	8,260	7,895
Terra Nova	14,428	12,803
Total	1,361,818	1,331,418

the construction of treatment plants was not seen as a priority, although their importance was beginning to be understood, according to the principle of 'out of sight, out of mind'.

The estimation of polluting loads allowed to establish that diffuse loads were higher than point loads: point discharges were quite rare, whereas pipelines, discharging in water bodies, and infrastructures, such as septic or rudimental tanks, were widespread. Treatment plants and septic tanks presented not very high removal efficiencies of nutrients (in some cases lower than 30%). This justified also the high organic and microbiological concentrations registered in Pojuca river basin as well as the high content of nutrients.

Water quality could be improved up to law prescriptions to be used for drinking purposes by realizing new treatment plants or upgrading the existing ones. First of all present infrastructures currently in bad conditions should be restored. Then, the coverage rate should be increased in order to satisfactory serve the population, inefficient treatment plants should be upgraded or new infrastructures should be built (Ujang 2006).

In particular, in urban areas point loads should be treated by means of plants using technologies easy to be managed and guaranteeing good performances. It is important to adopt an approach that is appropriate in terms of protection of water quality, based on specific economical, institutional, technological and climatic conditions of the basin (Oliveira & von Sperling 2008). Alagoinhas municipality represented a positive example: here, secondary treatments, like anaerobic filters, were followed by post-treatments, such as wetlands. As registered also by Oliveira & von Sperling (2008), these technologies were widespread and well-known in Bahia and other Brazilian states. But it has to be underlined that plants removal efficiencies depend not only from the design, but also from operation and maintenance.

In rural areas significant point loads were not identified during the surveys. Settlements were mainly made up of a little number of households, often located at great distance from each other. The building of networks is not appropriate for the rural context: it would imply high costs and a complex management. Scattered households should instead be provided with septic tanks, receiving wastewaters from residential areas or individual households. This technology is characterized by quite good removal efficiencies and can be easily operated. Also in this case, it has to be highlighted that correct operation and maintenance are necessary for guaranteeing good removal efficiencies of pollutants.

The responsibility to implement the proposed interventions should lay on the entities already responsible for the treatment of wastewater in the municipalities involved in the study. They usually are multiutility companies, partially or totally supported by municipal funds, serving the municipality they are located in or more than one municipality. The operational control over the plants should be conducted by the multiutilities themselves, whereas periodic control aiming at verifying the compliance with Country and Federal laws should be carried out by the Secreteria de Recursos Hydricos (SEMARH) of the Government of Bahia.

The results of this study has been used to implement a decision support system, which will be illustrated in a further paper, aimed at elaborating a master plan for the use of Pojuca river as drinking water source for the metropolitan city of Salvador and as water source for industrial and agricultural activities in the basin.

ACKNOWLEDGEMENTS

The authors would like to give special thanks to the experts of Università dell'Insubria& Università di Pavia (Italy) and Universidade Federal da Bahia (Brazil) who contributed their expertise to get the results presented in this paper. Moreover, the authors thank Regione Lombardia (Italy) and Secretaria Estadual do Meio Ambiente do Estado da Bahia (Brazil) that gave financial support to the study.

AUTHORING

Carlo Collivignarelli coordinated the study; Valentina de Felice and Veronica di Bella carried out data collection and analysis; Sabrina Sorlini, Vincenzo Torretta and Mentore Vaccari supervised the data analysis and the paper drafting.

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