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Surface water quality in Portugal during a drought period

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Abstract

A severe drought starting during the hydrological year 1991/92 has been affecting water resource availability in Portugal with 1993 being one of the driest in the last 60 years. The accumulated precipitation for 1992/93 was 70–50% of the mean of previous years with values lower than 40% in some areas in the south of the country. River flow was below normal mean values, with minimums of 1 and 7% in some watersheds in the south, where total storage volumes of only 20% of maximum capacity were registered. Since water quality could be seriously affected by reduced flow and storage, a study to ascertain possible relationships was undertaken. As part of this study, based upon the existing Water Quality Network, fifteen reservoirs, representative of different regions were selected, and analytical data on water quality parameters that are significant for each station collected since 1989 were evaluated. In addition to considering the variability of specific parameters, a water quality index was also used. A significant correlation between water quality parameters and storage volume was not established. Preventive measures on point sources of pollution, no irrigation of agricultural crops and reduction of transported pollution from upstream may in part explain these findings.

Keywords: Water quality; Drought; Water quality index

1. Introduction

The occurrence of droughts in several regions has lead to several studies on their impact, mostly on water availability or water shortage in regard to public needs. In few cases, if any, the impact of water shortage on its quality has been considered.

A severe drought has, and is affecting water resource availability in Portugal. The drought started in the last part of 1991, and the accumulated precipitation up to June 1993 compares with the driest periods for the last 60 years [1]. Currently (June, 1993) the accumulated precipitation, is 50–70% of the mean of previous years, with values lower then 40% in some areas of the south and over 80% in the northern region. The river flow, also below normal values, was, by the end of the first semester of 1993, 20% to 31% of the mean for the whole country, but 1 and 7% in some rivers of the south. In reservoirs, the total storage volume represents 62% accounting for the whole country and, again in the south, smaller percentages are found — values lower than 20%

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of the total capacity of some reservoirs were registered. The mean variation of the stored volumes is negative, being −14% in the regions most severely affected by reduced precipitation [2].

Considering that important reductions in river flows and in stored volumes of reservoirs could impact on the quality of the water, it was decided to carry out a study, drawing on the existing Water Quality Network to assess, at least monthly, trends in water quality taking account of the existing data (since 1989) for the same stations. For this study, 42 sampling stations were selected, which are considered representative of the major river basins of the country, 15 of which were located in reservoirs used for different purposes (Fig. 1). In this paper a preliminary study of the possible influence of very low stored volumes in 14 of the selected reservoirs is presented.

2. Methods

The reservoirs selected are situated in the northern region (Salamonde, Crestuma-Lever, Pocinho e Miranda) where precipitation was highest; in the most affected Alentejo region of the south (Divôr, Roxo, Sta Clara, Caia, Lucefecit, Monte Novo e Vigia); and in the Algarve region, also in the south, but in which the drought was less severe (Beliche, Arade e Bravura). The characteristics of the reservoirs are presented in Table 1. In this table are also included the stored volumes by the end of January, March and June, as well the percentage of the gross capacity they represent. The only reservoir selected in the central region of Portugal did not prove adequate for this type of study due to its water management system.

Samples were collected from January 1993 onwards, either monthly or every 2 weeks, at 50 cm deep, using the same harmonised procedures as for the Water Quality Network, transported and stored alike [3]. The analyses were performed by the laboratories engaged in the Water Quality Network since 1989, with the exception of the samples from the Alentejo reservoirs for which a different laboratory conducted the analysis from April 93 onwards. Since this new laboratory had previously participated in intercalibration exercises having obtained good results, in this study it was decided to consider the data provided.

The water quality parameters selected included those that were being found as determining the actual water quality in each station. The selection of determinants took account of the requirements related to the establishment of a water quality index (WQI) which is a modification [4] of the one proposed and used in Scotland [5]. The parameters selected were: temperature, pH, conductivity (Cond.), total suspended solids (TSS), percentage dissolved oxygen (OD), chemical oxygen demand (COD), biochemical oxygen demand (BOD), ammonia, nitrates, phosphates and fecal coliforms.

3. Pollution sources

The main pollution problems so far identified in Portugal are oxygen-demanding wastes from municipal and agro-industrial point sources. Fecal contamination, once widespread, is now less often detected due to recent improvements in urban waste treatment. Fertilizer and pesticide use, animal feedlots run-off and scattered small industries are diffuse polluters whose contribution has seldom been assessed, but is likely to be important in some areas. Heavy metals and other dangerous substance contamination exists in the more industrialized areas along the coast of Portugal, and in some small river basins in the interior of the country.

For the reservoirs included in this study, it can be assumed that all of them are affected by diffuse sources (mainly agriculture or small industrial plants and piggeries). For most there is also urban waste pollution in the drainage basin, in particular in Crestuma-Lever, Roxo, Caia, Lucefecit, Monte Novo, Vigia e Bravura. Large piggeries are located in the drainage area of Roxo, Caia, Lucefecit, Vigia e Bravura but, in most cases, some effluent treatment is installed. Olive oil extraction plants are a source of seasonal pollution in the Alentejo region. In the Roxo there is heavy metal contamination, since a large mine is located upstream on one of its tributaries.

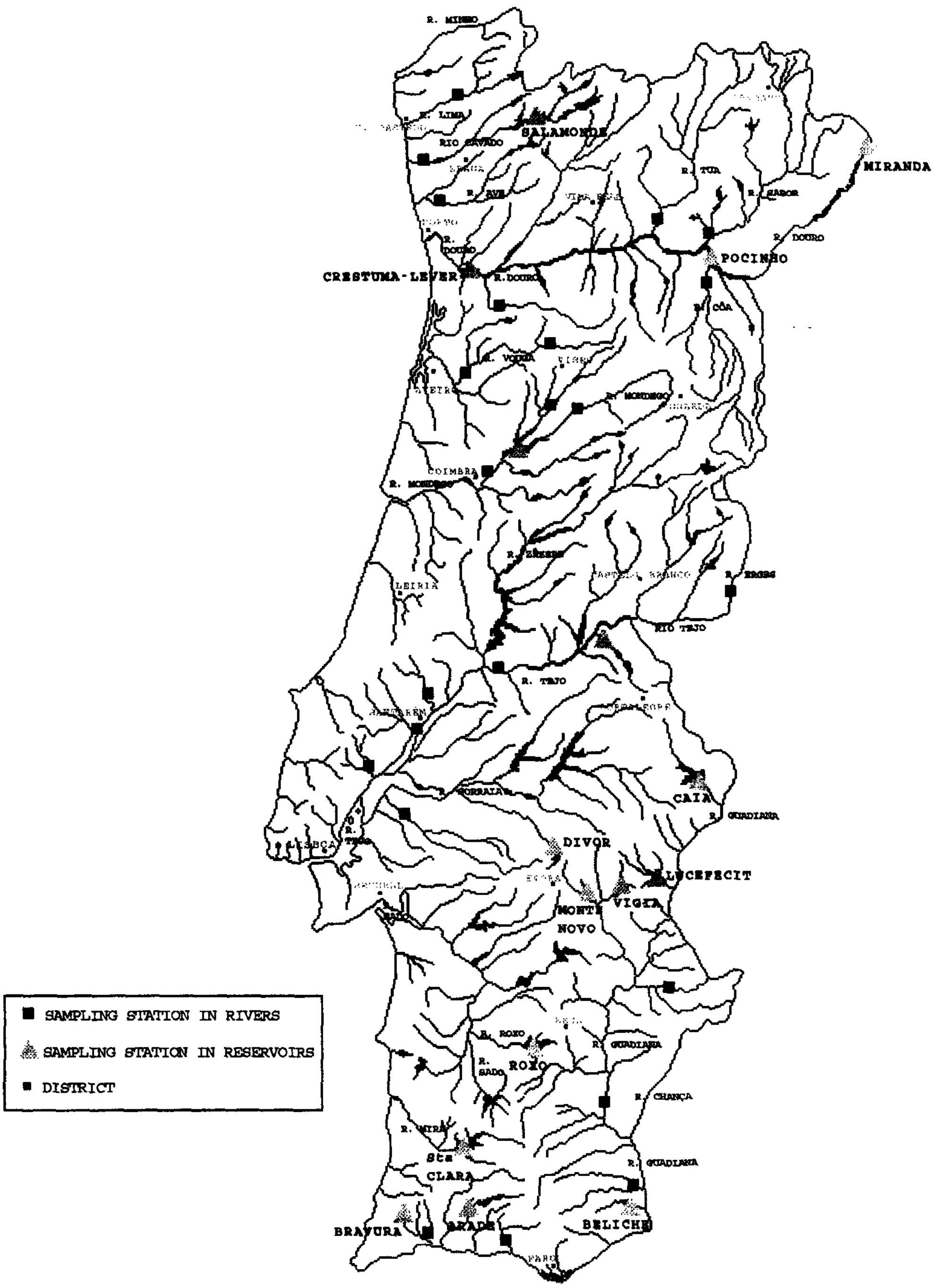

Fig. 1. Sampling stations.

Table 1
Characteristics of the reservoirs

Reservoir year of completion	River location (district)	Area (ha)	Gross capacity [A] (hm^3)	Net capacity (hm^3)	Storage Volume (1993) Jan (hm^3) % of [A]	Mar (hm^3) % of [A]	Jun (hm^3) % of [A]	Purpose
Salamonde	Cávado	242.0	63.0	56.8	53.00	44.00	33.00	Hydroelectric
1953	Braga				84.1	69.8	52.4	
Crestuma-lever	Douro	1420.0	109.0	20.8	107.42	108.74	106.77	Hydroelectric
1985	Porto				98.6	99.8	98.0	Navigation
Pocinho	Douro	830.0	81.0	—	79.50	78.99	66.70	Hydroelectric
1982	Guarda				98.1	97.5	82.3	Navigation
Miranda	Douro	121.0	27.8	6.4	25.75	25.51	24.22	Hydroelectric
1961	Brangança				92.6	91.8	87.1	
Divor	Divor	239.0	12.0	11.9	2.27	2.09	1.56	Irrigation
1965	Évora				18.9	17.4	13.0	Water supply
Roxo	Roxo	1378.0	96.3	89.5	19.03	19.30	18.35	Irrigation
1968	Beja				19.8	20.7	19.1	Water supply
Sta Clara	Mira	1986.0	485.0	240.0	305.05	307.15	295.26	Irrigation
1968	Beja				62.9	63.3	60.9	Water supply
Caia	Caia	1970.0	203.0	192.3	53.83	55.59	54.50	Irrigation
1967	Portalegre				26.5	27.4	26.8	Water supply
Lucefecit	Lucefecit	169.0	10.0	9.8	1.73	1.91	2.00	Irrigation
1982	Évora				17.3	19.1	20.0	Water supply
Monte Novo	Degebe	277.0	15.3	14.8	5.50	5.20	5.00	Irrigation
1982	Évora				35.9	34.0	32.7	Water supply
Vigia	Vale Vasco	262.0	17.0	16.1	3.70	3.77	3.74	Irrigation
1981	Évora				21.8	22.2	22.0	Water supply
Beliche	Beliche	292.0	48.0	48.0	32.00	34.00	34.00	Irrigation
1986	Faro				66.7	70.8	70.8	Water supply
Arade	Arade	182.0	28.4	27.3	8.04	12.10	11.01	Irrigation
1955	Faro				28.3	42.6	38.8	Hydroelectric
Bravura	Odeáxere	285.0	34.8	32.3	14.63	17.68	16.30	Irrigation
1958	Faro				42.0	50.8	49.8	Water supply Hydroelectric

4. Results and discussion

Table 2 presents the extreme values (Min/Max) and the median for all stations and determinants obtained during the first semester of 1993. The data confirms previous conclusions on the existing pollution and its level for each reservoir (Fig. 2). Water quality (assessed on a parameter by parameter classification) is good to fair in the reservoirs from the north (Salamonde, Crestuma-Lever, Pocinho and Miranda), and in those from the south where important point sources of pollution do not exist, or their impact is minimized (Sta Clara, Beliche and Bravura); occasionally in some of these there is a slight deterioration of quality that does not persist. In the remaining reservoirs of the Alentejo region, the water quality is poor or attains levels of high pollution, mainly due to oxygen-consuming substances. The increase in temperature from the spring months onwards is a natural phenomena, and somewhat high values of TSS are mainly due to erosion in the watershed. The WQI leads to similar conclusions, though it should be noted that this index penalizes the bad quality (Table 3 and Fig. 3). The WQI also highlights the large variability in water quality. WQI values over 90 correspond to very good quality, between 70 and

Table 2
Data on water quality from January to June 1993

Reservoir	Temp. (°C) Min. Max Median (n)	pH (μS/cm.20°C) Min. Max Median (n)	Cond. (mg/l) Min. Max Median (n)	Tss (mg O_2/l) Min. Max Median (n)	BOD (mg O_2/l) Min. Max Median (n)	COD (% Sat.) Min. Max Median (n)	DO (mg NH_4/l) Min. Max Median (n)	Ammonia (mg NO_3/l) Min. Max Median (n)	Nitrates (mg P_2O_5/l) Min. Max Median (n)	Phosphates (Col/100 ml) Min. Max Median (n)	Fecal coliforms Min. Max. Median (n)
Salamonde	8.5 18.5	6.9 7.5	20 55	2,8 5.6	0.7 2.2	3.2 6.5	88 109	< 0.01 0.08	< 2.2 8.9	< 0.23	< 20 50
	9.5 (6)	7.1 (6)	23 (6)	4.1 (6)	1.2 (5)	4.0 (6)	102 (6)	0.02 (6)	2.2 (6)	— (6)	20 (5)
Crestuma-Lever	7.0 14.5	6.9 7.9	160 200	4.4 16.0	1.1 3.8	4.4 10.0	74 121	< 0.01 0.10	< 2.2 6.1	< 0.23	0.22 650
	12.0 (6)	7.2 (6)	191 (6)	4.4 (4)	1.4 (5)	4.8 (6)	90 (6)	0.02 (5)	3.7 (6)	0.23 (6)	285 (6)
Pocinho	8.0 20.0	7.5 8.5	285 490	2.0 5.2	0.9 3.2	4.0 8.0	69 111	< 0.01 0.20	< 2.2 11.0	0.25 0.5	< 20
	12.8 (6)	7.7 (6)	285 (6)	4.8 (6)	2.8 (5)	7.2 (5)	80 (6)	0.02 (6)	3.5 (6)	0.38 (6)	— (6)
Miranda	3.5 17.0	7.4 8.1	312 498	2.4 10.8	2.7 3.9	3.6 13.6	30 82	0.03 0.9	< 2.2 9.0	0.50 1.2	< 20 680
	12.5 (6)	8.0 (6)	463 (6)	7.2 (6)	3.2 (5)	11.2 (5)	69 (6)	0.28 (6)	3.6 (6)	0.58 (6)	200 (6)
Divor	8.0 17.0	7.9 8.3	285 424	2.8 71.0	5.5 13.5	38.9 66.3	90 102	0.05 0.6	< 0.1 1.2	< 0.02 0.24	0 240
	11.8 (6)	8.1 (6)	343 (6)	23.7 (6)	7.9 (5)	44.4 (6)	94 (3)	0.08 (6)	0.2 (6)	0.11 (6)	0 (5)
Roxo	9.0 23.0	8.0 8.2	1106 1461	8.4 14.0	3.5 9.0	17.2 24.5	84 105	< 0.02 0.29	0.4 6.1	< 0.02 0.06	350
	11.0 (5)	8.2 (5)	1148 (5)	11.2 (5)	3.6 (4)	20.0 (5)	93 (4)	0.08 (5)	4.6 (5)	0.05 (5)	5 (5)
Sta Clara	12.0 16.0	7.2 8.0	209 244	1.6 18.0	1.4 2.1	9.1 11.7	77 90	0.03 0.05	0.0 0.6	< 0.02	0
	12.5 (4)	7.4 (4)	212 (4)	2.4 (3)	1.8 (2)	9.9 (3)	87 (4)	0.03 (4)	0.3 (4)	— (4)	— (4)
Caia	8.0 15.0	7.5 9.1	253 759	2.2 10.0	2.4 12.0	21.5 36.	71 94	0.06 0.42	0.0 2.4	< 0.02	0 79
	11.5 (6)	8.2 (6)	260 (6)	4.1 (6)	3.4 (4)	23.2 (6)	83 (3)	0.15 (6)	1.2 (6)	0.04 (6)	35 (6)
Lucefecit	8.0 17.0	7.7 8.8	426 668	2.0 8.0	1.5 12.0	21.2 39.7	79 111	0.72 1.5	0.7 2.1	< 0.02	0 490
	12.0 (6)	8.3 (6)	552 (6)	6.5 (6)	2.7 (5)	29.8 (6)	92 (3)	0.41 (6)	1.3 (6)	0.05 (6)	0 (5)
Monte Novo	10.0 24.5	7.6 8.9	364 478	3.2 15.6	2.4 8.0	23.5 43.3	54 98	0.34 1.15	0.2 2.3	< 0.02	0 13
	14.5 (6)	7.9 (6)	373 (6)	6.0 (6)	2.7 (5)	34.8 (6)	54 (3)	0.34 (6)	1.0 (6)	0.09 (6)	0 (6)
Vigia	9.0 17.0	7.8 9.1	322 406	4.0 7.0	2.2 9.0	22.4 40.7	87 105	0.05 0.54	0.1 1.5	< 0.02	0 27
	11.5 (6)	8.1 (6)	363 (6)	5.5 (6)	3.5 (5)	25.0 (6)	96 (3)	0.15 (6)	0.7 (6)	0.07 (6)	0 (5)
Beliche	13.5 23.0	7.4 8.9	141 160	0.6 22.8	0.3 1.3	4.0 10.9	88 111	< 0.01 0.06	0.5 2.5	< 0.02	0 130
	16.5 (9)	7.9 (10)	146 (10)	2.8 (10)	0.9 (10)	7.1 (10)	103 (9)	0.01 (10)	1.8 (10)	0.02 (10)	1 (8)
Arade	12.0 23.5	7.2 8.6	302 431	0.4 100	0.5 2.4	7.1 16.5	79 110	0.02 0.0	4.5 8.6	< 0.02	0 49
	17.5 (10)	7.7 (10)	356 (10)	15.0 (10)	1.1 (10)	13.1 (10)	100 (10)	0.02 (10)	5.6 (10)	0.13 (10)	2 (9)
Bravura	11.5 23.5	7.1 8.4	222 314	1.2 12.4	0.7 1.5	7.1 8.4	84 111	< 0.01	3.0 4.8	< 0.02	0 11
	17.8 (9)	7.7 (10)	227 (10)	3.6 (10)	1.0 (10)	10.1 (10)	101 (9)	0.02 (10)	4.1 (10)	0.05 (10)	4 (9)

n = number of determinations.

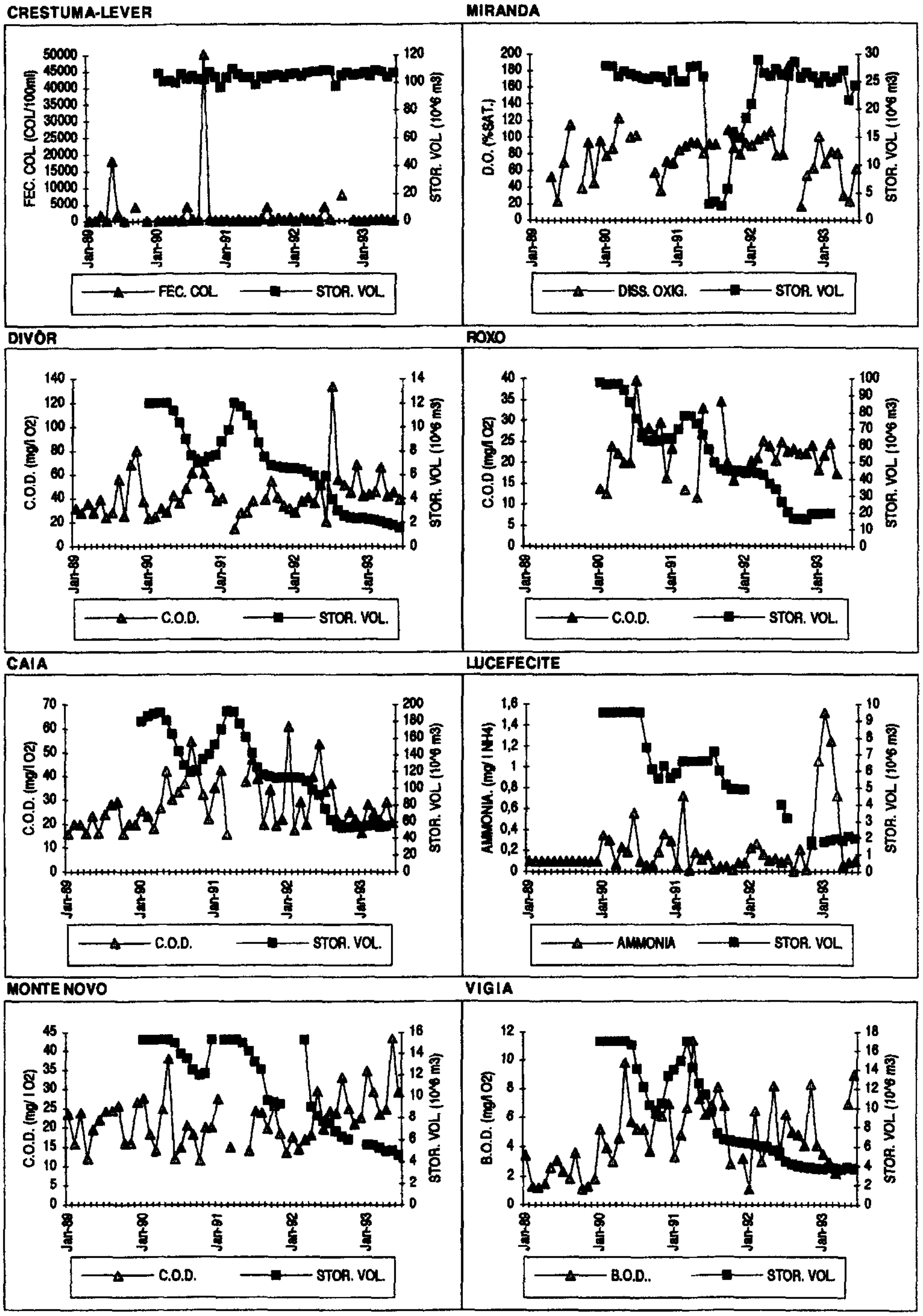

Fig. 2. Selected water quality parameters and stored volumes in reservoirs.

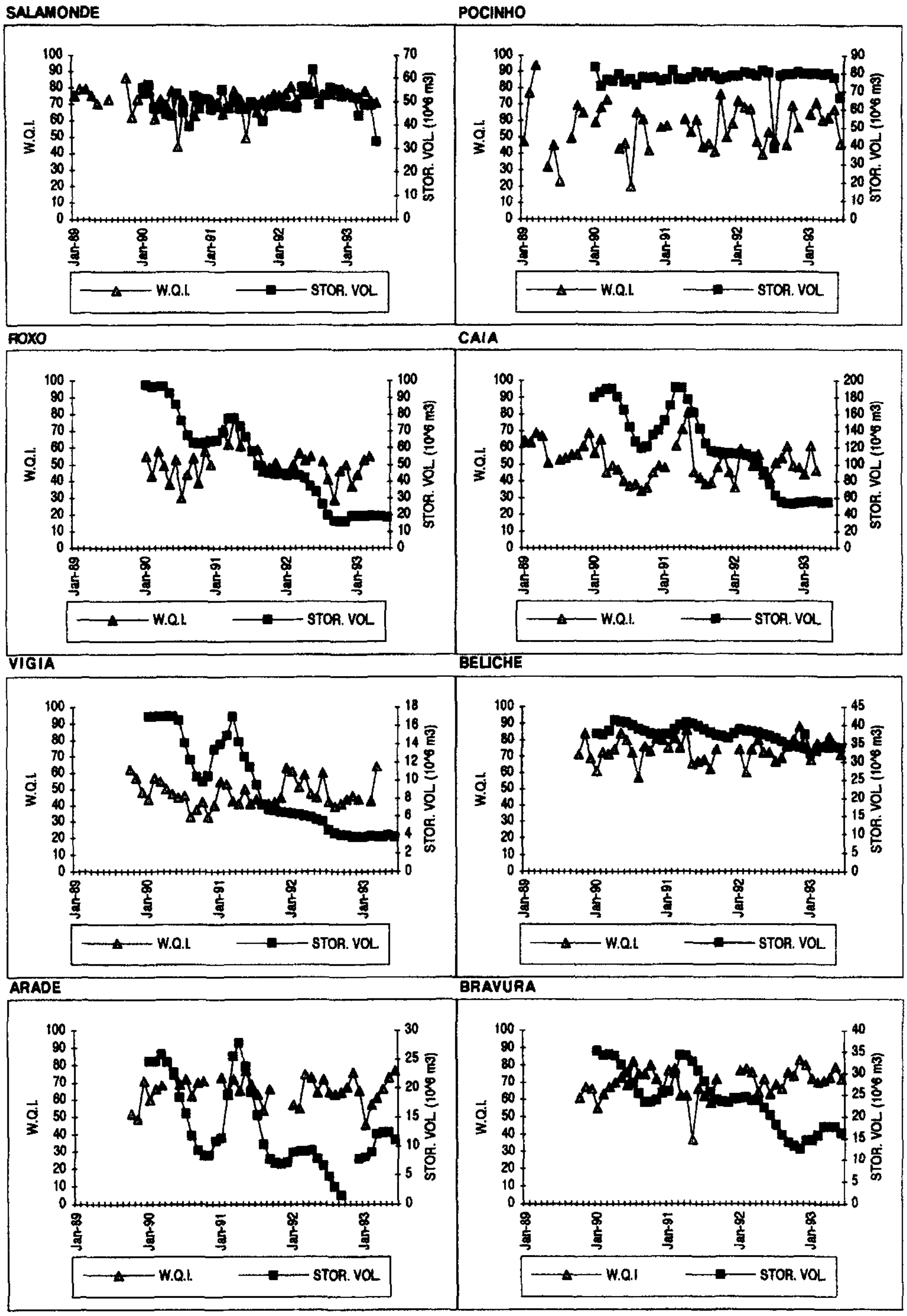

Fig. 3. Selected WQI and stored volumes in reservoirs.

Table 3
Water quality index (WQI) from January to June 1993

Reservoir	January	February	March	April	May	June
Salamonde	77	—[a]	74	78	72	71
Crestuma-Lever	72	64	70	62	72	56
Pocinho	64	66	61	62	67	46
Miranda	53	52	48	26	33	52
Divor	32	42	35	—[a]	—[a]	—[a]
Roxo	44	53	55	—[a]	—[a]	—[a]
Sta Clara	68	73	77	—[a]	—[a]	—[a]
Caia	44	53	55	—[a]	—[a]	—[a]
Lucefecit	—[a]	50	40	—[a]	—[a]	—[a]
Monte Novo	29	34	57	—[a]	—[a]	—[a]
Vigia	—[a]	43	64	—[a]	—[a]	—[a]
Beliche	68	78	76	82	77	71
Arade	46	57	61	66	73	77
Bravura	72	70	71	73	79	72

[a]No suitable data available.

90 to good, between 50 and 70 to poor, between 20 and 50 to highly polluted water, and < 20 to extremely polluted.

The statistical analysis [6] for possible correlations between concentrations and time or storage volume since 1989 did not highlight any significant relationships when considering either actual data or log transformed data. The same conclusion was reached when the statistical analysis was performed separately year by year. The same statistical studies were applied to the WQI and the same conclusions were obtained.

These findings may be explained, in part at least, by the reduced inflows and the consequent low transport of pollutants, by the smaller contribution of diffuse sources in particular due to restrictions in irrigation and other water uses and, finally, to measures taken to reduce the inputs from the most important point sources of pollution. Investigations are under way to clarify these preliminary conclusions.

In spite of the fact that no statistically significant correlation was found, there seems to be a tendency towards further deterioration of water quality in those reservoirs in which the quality is poor. This hypothesis may or may not be confirmed by data from the next months.

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References

[1] F. Espírito Santo, Vigilância e caracterização das secas: a teoria do caos e previsão a longo prazo. Simpósio sobre Catastrofes Naturais. LNEC, Lisbon, 1993.

[2] M.A.R. Lacerda, Alguns elementos para a caracterização da seca. Simpósio sobre Catastrofes Naturais. LNEC, Lisbon, 1993.

[3] M.C. Barros, A rede de qualidade da água da DGRN. 1°Congresso da Agua. APRH, Lisbon, 1992.

[4] M.C. Barros, M.J.R. dos Santos and A.P. Mano, Ensaios de aplicação de Indices de Qualidade da água. DGRN, Lisbon, 1992.

[5] SDD. Development of a Water Quality Index. Appl. Res. Dev. Report ARD 3. Scottish Development Department, Edinburgh, 1976.

[6] R.M. Hirsch, J.R. Slack and R.A. Smith, Techniques of trend analysis for monthly water quality data. Water Resource Res., 18 (1982) 107–121.