



**CUSTÓDIO DAM – THE GEOGENIC CONTRIBUTION TO SEDIMENT  
CHEMICAL COMPOSITION AND THE DETERMINATION OF GEO-  
CHEMICAL REFERENCE VALUES FOR THE LAKES OF SE OF IRON  
QUADRANGLE - MG – BRAZIL**

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**ABSTRACT**

In the South-eastern portion of the Iron Quadrangle, MG, Brazil, there are several dams, which were constructed by mining and steel companies. The Custodio dam is located in the Itacolomi State Park - an Environmental Protection Area at Ouro Preto. In order to assess the impact of constructed reservoirs in the hydrological system of the region, it is necessary to study a lake which can be considered non-contaminated, because the characteristics of the water and sediment of such a lake may be used as reference for other lakes of the region in the assessment of anthropogenic influences. Sediment and water sample data were submitted to Principal Component Analyses in order to assess the geochemical influences of the rocks on the sediment chemical composition, and to assess their geochemical relationship. Upper limit values for As (23.7 mg/kg), Ba (1923 mg/kg), Co (31,8 mg/kg), Cr (157 mg/kg), Cu (53,2 mg/kg), Ni (57,3 mg/kg), Pb (57,3 mg/kg), Rb (213 mg/kg), Sr (116 mg/kg), V (174 mg/kg) and Zn (92,1 mg/kg) are proposed as reference values. A comparison with some international sediment quality guideline values shows that three elements are above the PEL values (As 17 mg/kg, Cr 156 mg/kg and Ni 35,9 mg/kg). As, Cr and Ni are linked to the Banded Iron Formation.

**RESUMO**

Na porção sudeste do Quadrilátero Ferrífero, MG, Brasil, existem várias barragens, que foram construídas por companhias mineradoras e siderúrgicas. A Barragem do Custodio localiza-se no Parque Estadual do Itacolomi - uma área de proteção ambiental em Ouro Preto. Visando avaliar o impacto de reservatórios artificiais no sistema hídrico da região, faz-se necessário estudar um lago que seja considerado não contaminado, porque as características da água e sedimento de um lago como este podem ser usadas como referência para outros lagos da região na avaliação de influências antrópicas. Os dados de análise de água e sedimentos foram submetidos a análise de componentes principais (PCA) visando entender a influência geoquímica das rochas na composição química dos sedimentos, e avaliar a sua relação geoquímica. Valores limites para As (23.7 mg/kg), Ba (1923 mg/kg), Co (31,8 mg/kg), Cr (157 mg/kg), Cu (53,2 mg/kg), Ni (57,3

mg/kg), Pb (57,3 mg/kg), Rb (213 mg/kg), Sr (116 mg/kg), V (174 mg/kg) e Zn (92,1 mg/kg) são propostos como valores de referência. Uma comparação com valores guia de qualidade de sedimentos mostram que dois dos elementos analisados estão acima de PEL (As 17 mg/kg e Ni 35,9 mg/kg). As, Cr e Ni estão intimamente ligados à Formação Ferrífera.

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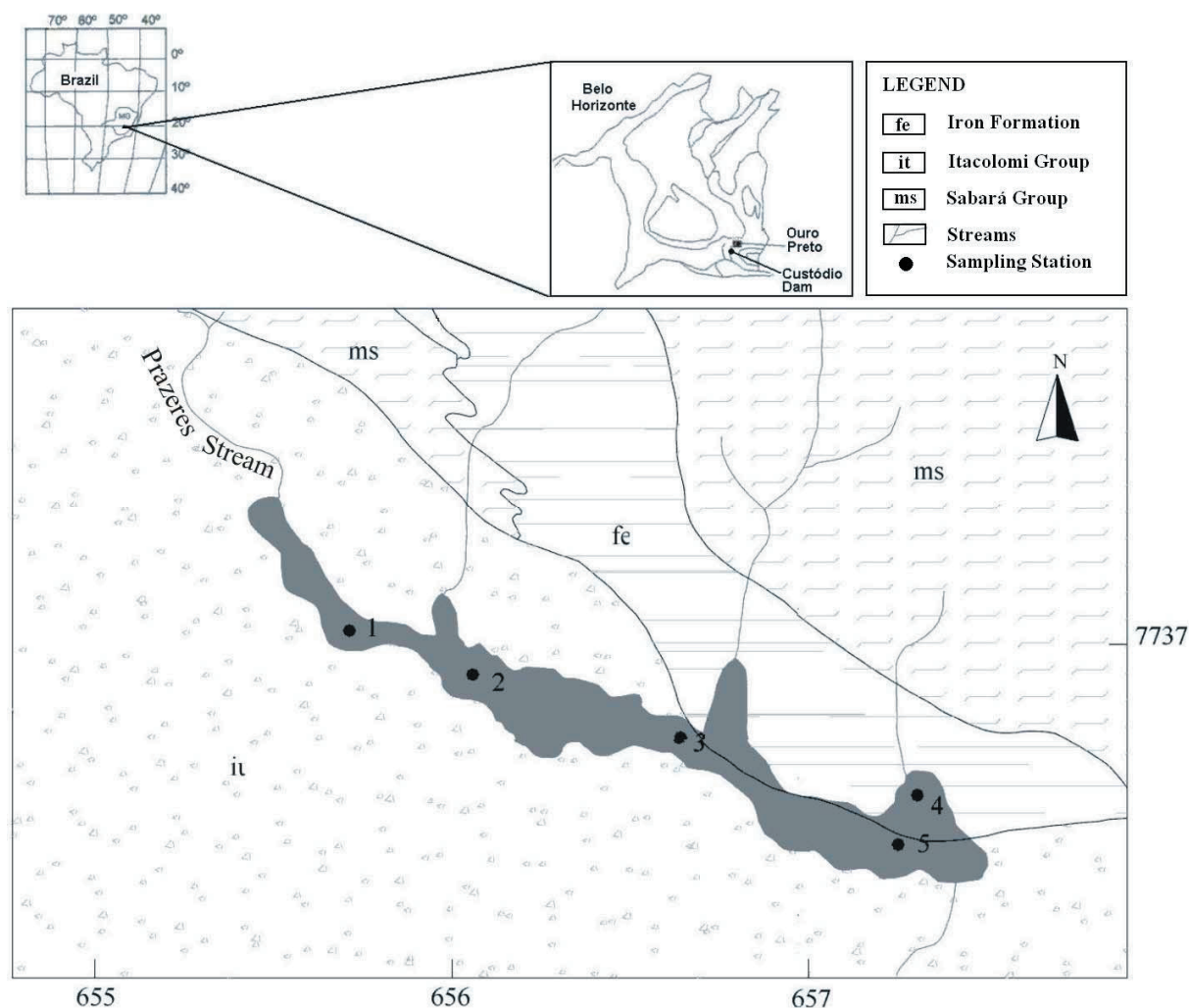
## INTRODUCTION

The eastern part of the Iron Quadrangle (Minas Gerais, Brazil) is characterized by intense metallurgical, steelwork and mining activities. The companies, which operate in the region, built up containment dams with different purposes. Mining companies use them to retain the waste material of their processing plants. Metallurgical and steelwork companies use them to produce electrical energy. It is a well-known fact that the construction of dams causes undesirable impacts in the environment (Horne & Goldman, 1994) and these impacts must be understood in order to minimize the adverse effects. Several works have been carried out in the southeastern part of the Iron Quadrangle, aiming to understand the impact of these dams in the hydrological system of this region (e.g. Basilio *et al.*, 2005; Guimarães, 2005; Pimentel *et al.*, 2003; Pires *et al.*, 2003; Costa *et al.*, 2003; Cruz, 2002; Matsumura, 1999). For a work of this nature it is also necessary to study a lake which can be considered non-contaminated, i.e., with no anthropogenic influences. The characteristics of the water and sediment of such a lake may be used as reference values for other lakes of the region, with similar geology, in the assessment of anthropogenic influences. The knowledge of such reference values for the region is of primary importance in the assessment of environment impact of constructed lakes. The Sediment Enrichment Factor and Geoaccumulation Index (Loska *et al.*, 1993) were normally used in these calculations, but, as pointed out by Moreira & Boaventura (2003), the use of average world values can be misleading. These same authors have proposed the use of local values in order to achieve a more realistic assessment of environmental aspects. The present work aims to apply the methodology proposed by these authors, i.e., using the Custodio dam

as a control area for lakes constructed on domains with similar geology.

The Custodio Dam is located in the Itacolomi State Park (an Environmental Protection Area) in the region of Ouro Preto and Mariana, MG, Brazil (Figure 1). It belongs to Alcan Company and it is used to produce electrical energy. It is formed by the containment of the Prazeres stream and receives water from small water courses from north. Because it is a conservation unit, the region around the Prazeres stream basin is free from anthropogenic influences. Geologically it is in the center-southeast of the Minas Gerais State (Dorr *et al.*, 1957). The western and southwestern part of the Custódio dam basin is formed by quartzites, micaceous-quartzites and phyllite sequences of pre-cambrian ages of the Itacolomi Group. A second part (east and north-east of the dam) is composed by aluminous iron formations associated with the schists of the Sabará Group. The dam receives sediments formed from these rocks, which have great influence on its composition.

According to the Koeppen classification (Strahler & Strahler, 1987), the climate in Ouro Preto surroundings corresponds to the Cwb type - moist continental mid-latitude due to maritime tropical air masses in summer and continental polar air masses in winter. The pluviometry is typical of the tropical regime presenting an average of 1723.6 mm/year. The rainy season is from October to March with 89.6% of the annual precipitation. The dry season (from April to September) represents 10.4% of the annual precipitation (Coelho, 1994). The region of the Ouro Preto County is characterized mild temperatures. The hills surrounding the city (mean altitude around 1200 m) favour low temperatures. The annual mean is 17.4 °C with maximum of 22.6 °C and minimum of 13.1 °C.



**Figure 1:** Localization of the Custódio dam and of the sampling stations.

The main scope of this work is to determine the composition of water and sediment of the Custodio Dam, to determine its origin and to establish reference values especially for heavy metals in sediments for subsequent works in the region.

### METHODOLOGY

Water and sediment samples were collected in March 2002 (rainy season) and September 2002 (dry season) according to climate of the region. The sample stations are shown in Figure 1. They were chosen in order to comply with the water flow in the dam and to have them as equidistant as possible.

Flasks for water sample collection were previously washed with 2.5% nitric solution, followed by rinsing five times with deionised

water and allowed to dry at room temperature (Greenberg *et al.*, 1992). Analyses included physical chemical parameters (pH, Eh, electric conductivity - EC, total dissolved solids - TDS, dissolved oxygen - DO and turbidity), anions ( $\text{HCO}_3^-$ ,  $\text{SO}_4^{2-}$  and  $\text{Cl}^-$ ) cations ( $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ ) and main and trace elements (Al, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Sr, Mo, Cd, Ba, Zr and Y). Samples were collected in 5 stations (Figure 1) at each meter in depth ranging from the surface to the bottom. At station 5, due to the large depth, samples were collected at each 2 meters. For the determination of trace metals samples were filtered with  $0.45 \mu\text{m}$  and preserved with nitric acid (Greenberg *et al.*, 1992) ( $\text{pH} < 2$ ) at  $4^\circ\text{C}$ . Some physical-chemical parameters (pH,  $E_h$ , EC, temperature, salinity and TDS) were measured in-situ with an Ultrameter equipment model 6P from

Myron L Company, Dissolved Oxygen was measured with a WTW Oxi 320, WTW CelloX 325. Equipments were calibrated according to manufacturer instructions. All chemical analyses were conducted according to the Standard Methods for the Examination of Water and Wastewater (Greenberg *et al.*, 1992). Turbidity was measured with a B250 Micronal turbidimeter.  $\text{HCO}_3^-$  and  $\text{Cl}^-$  were determined by titration. Sulfate was obtained by the turbidimetric method. Measurements of the concentration of the main cations and of trace metal contents were achieved using inductively coupled plasma spectrometry optical emission (ICP-OES) from Spectro Company (ICP-OES Spectro Ciros CCD). The results were validated with the NIST 1643d reference material.

Sediment samples were also collected in two campaigns (March and September 2002). At each sampling station three sediment samples were collected with a grabber, taking samples from the upper part of the sediment. At station CST4 it was not collected because, at this point, the water column is direct on the rock. Samples were taken to the laboratory and dried under infrared light (40-50°C). X-Ray Fluorescence determinations of chemical composition were carried out according to Morgenstern *et al.* (2001). For the major element determination, 1 g ( $\pm 0,1$  mg) of the sample was weighted and mixed with 7 g ( $\pm 0,1$  mg) of  $\text{Li}_2\text{B}_4\text{O}_7$  and used at 1200 °C in Pt-Au crucibles for 20 minutes. For the trace element content determinations 4 g ( $\pm 0,1$  mg) of sample were weighed, mixed with 20% wax binder (Hoechst) and compacted with hydraulic press (100 MPa). All analyses were validated with the Buffalo River Sediment 2704 NIST reference material. An amount of 1g of each sample was used for the mineralogical characterization by XRD using a Shimadzu equipment equipped with Co tube ( $\lambda = 1.728 \text{ \AA}$ ). The obtained diagrams were interpreted on the basis of the *Powder Diffraction File* (JPCDS, 1967).

Before carrying out any statistical treatment of the data, tests for fitting

distributions with Normal Probability Chart - NPC (Snedecor & Cochran, 1989) were performed with the Minitab 14 version. These tests were used to check whether the data fit in the normal distribution, and also to check for the presence of outliers. The goodness-of-fit for normality test was checked by the Anderson-Darling test. All the data were submitted to Principal Component Analysis (PCA) (Gardiner, 1997). The procedure was carried out on the whole set of transformed data. In order to minimize the large differences among them, a normalization procedure (Massart *et al.*, 1988) was performed, to obtain the normalized value  $z_{kj}$  according to the equation below:

$$z_{ki} = \frac{y_{ki} - \bar{y}_i}{s_i}$$

where  $y_{ki}$  represents each measured value  $k$  for the element  $i$ ,  $\bar{y}_i$  is the mean value of each measured data for the element  $i$ , and  $s_i$  standard deviation for all measured data for the element  $i$ .

## RESULTS

Sediment at the station CST1 is composed of gravel with little fine particle material. Between this station and the subsequent one there is a physical barrier, which prevents the flow of coarse material, mainly detritic quartz. The sediment mineralogy is composed of quartz, goethite, kaolinite and, as minor constituents, muscovite and gibbsite.

Table 1 displays the chemical analyses of the bottom sediment samples. It is clear that the content of  $\text{SiO}_2$  is higher at station CST1 while  $\text{Al}_2\text{O}_3$ ,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$  and specially  $\text{Fe}_2\text{O}_3$  are lower when compared to the other stations. This is due to the physical barrier that we mentioned above, clearly showing that the coarse material is being accumulated. Each set of content values was plotted in a Normal Probability Chart (NPC), which showed that the material coming from CST1 station is not representative of the sediment, which accumulates in the whole dam. The NPC shows that the CST1 values are outliers



**Table 1:** Chemical composition of sediment samples of Custodio dam. Sampling Station 4 is on solid rock, hence the absence of pertinent data. Cd and Mo were found below de Detection Limit (2 µg/g). Data represent the mean of two measurements.

	Station							
	March 2002)				September 2002			
	CTS1	CST2	CST3	CST5	CST1	CST2	CST3	CST5
	(%)							
SiO <sub>2</sub>	76.7	50.3	43.4	38.8	67.6	46.9	43.4	41.5
Al <sub>2</sub> O <sub>3</sub>	8.11	20.9	25.5	27.7	12.4	22.4	24.9	26.7
Na <sub>2</sub> O	0.093	0.21	0.27	0.27	0.14	0.24	0.28	0.27
K <sub>2</sub> O	1.51	4.16	4.72	5.21	2.36	4.30	4.76	5.63
CaO	0.049	0.058	0.066	0.051	0.051	0.056	0.065	0.052
MgO	0.23	0.53	0.57	0.54	0.32	0.53	0.57	0.58
MnO	0.047	0.078	0.075	0.055	0.059	0.082	0.072	0.057
TiO <sub>2</sub>	0.92	0.95	0.98	0.86	0.95	0.98	1.00	0.82
P <sub>2</sub> O <sub>5</sub>	0.054	0.095	0.13	0.13	0.072	0.11	0.13	0.12
Fe <sub>2</sub> O <sub>3</sub>	6.62	11.2	11.4	11.5	8.40	12.1	11.3	10.8
LOI	6.42	12.7	14.5	16.6	8.57	13.5	14.2	14.2
	(µg/g)							
As	9	19	20	21	15	23	18	18
Ba	422	1094	1412	1575	637	1117	1406	1777
Co	4	26	26	28	17	29	26	31
Cr	72	124	138	149	88	140	138	146
Cu	28	46	32	23	28	44	25	23
Ni	22	48	47	54	33	55	48	46
Pb	23	34	46	50	21	31	44	47
Rb	57	153	171	194	89	160	171	201
Sb	4	6	5	5	4	7	5	5
Sn	3	6	5	5	<2	4	5	6
Sr	20	53	81	94	30	56	82	99
V	58	130	154	164	92	149	155	156
W	<2	3	2	3	<2	<2	3	5
Zn	50	86	72	72	59	86	67	71
Zr	159	237	255	225	198	274	256	228
S	290	376	510	647	350	392	470	515

and, therefore, the statistical treatment was carried out with the CST2, CST3 and CST5 data. Sediment data from each sampling station, for each season, were compared by the Student test (Snedecor & Cochran, 1989) for comparison of means. This test showed that there are no significant differences in the composition of sediments from one season to another. Therefore, average values for each sampling station were used for the statistical study.

The Principal Component Analysis (Table 2) is used to explain the sediment composition and origin. Only the PC, which account cumulatively for about 90% of the total data variation was taken into

consideration (Gardiner, 1997). Factors, which account for a given PC were chosen according to their loadings. Each factor was assigned to the PC in which it presented the highest loading.

The three first components account for 93.0% of the total variability and this is enough to explain the whole variations in composition. PC1 has the eigenvalue of 14.883 and responds for 62.0% of the total variability in the composition. The contributing factors (and their loadings) are Si (-0.248), Al (0.254), Na (0.220), K (0.248), Mn (-0.234), Ba (0.251), Cu (-0.251), Pb (0.244), Rb (0.247), Sr (0.258), V (0.222) and S (0.228). The second component PC2

**Table 2:** Eigenvalues and factor loadings from the Principal Component Analysis of the sediment chemical analytical data of the Custódio Dam.

Component	PC1	PC2	PC3
Eigenvalue	14.883	4.106	3.324
Proportion	0.620	0.171	0.138
Cumulative	0.620	0.791	0.930
SiO <sub>2</sub>	-0.248	-0.135	-0.053
Al <sub>2</sub> O <sub>3</sub>	0.254	0.077	0.047
Na <sub>2</sub> O	0.220	0.035	0.253
K <sub>2</sub> O	0.248	-0.048	-0.135
CaO	-0.073	-0.173	0.484
MgO	0.174	-0.269	0.173
MnO	-0.234	-0.006	0.192
TiO <sub>2</sub>	-0.149	0.183	0.349
P <sub>2</sub> O <sub>5</sub>	0.205	0.098	0.314
Fe <sub>2</sub> O <sub>3</sub>	-0.123	0.411	0.126
As	-0.088	0.444	-0.035
Ba	0.251	-0.082	-0.080
Co	0.106	0.088	-0.391
Cr	0.215	0.242	-0.050
Cu	-0.251	0.033	-0.085
Ni	-0.048	0.471	-0.075
Pb	0.244	-0.046	0.105
Rb	0.247	0.018	-0.159
Sr	0.258	-0.040	0.010
V	0.222	0.212	0.127
Zn	-0.222	0.108	-0.246
LOI	0.203	0.249	0.069
S	0.228	0.151	0.028

has an eigenvalue of 4.106 and responds for 17.1% of the variability. The contributing factors (and their loadings) are Mg (-0.269), Fe (0.411), As (0.444), Cr (0.242), Ni (0.471) and LOI (0.249). Finally the PC3, with an eigenvalue of 3.324 responds for 13.8% of the total variability. It is composed Na (0.253), Ca (0.484), Ti (0.349), P (0.314), Co (0.391), Zn (-0.246) and Zr (0.283). PC1 and PC2 together represent 79.1% of the variability of the composition. The score plot of both components (Figure 2) reveals some interesting patterns. Al, Na, K, Sr, Ba, Rb and Pb form a cluster with higher positive loadings in PC1 compared to PC2. These elements are characteristic of feldspars. Cu, Mn and Si, on the other hand, form a cluster with negative loadings in PC1. For this particular set Pearson's correlation coefficient (*r*) (Snedecor & Cochran, 1989) have been calculated and showed that there

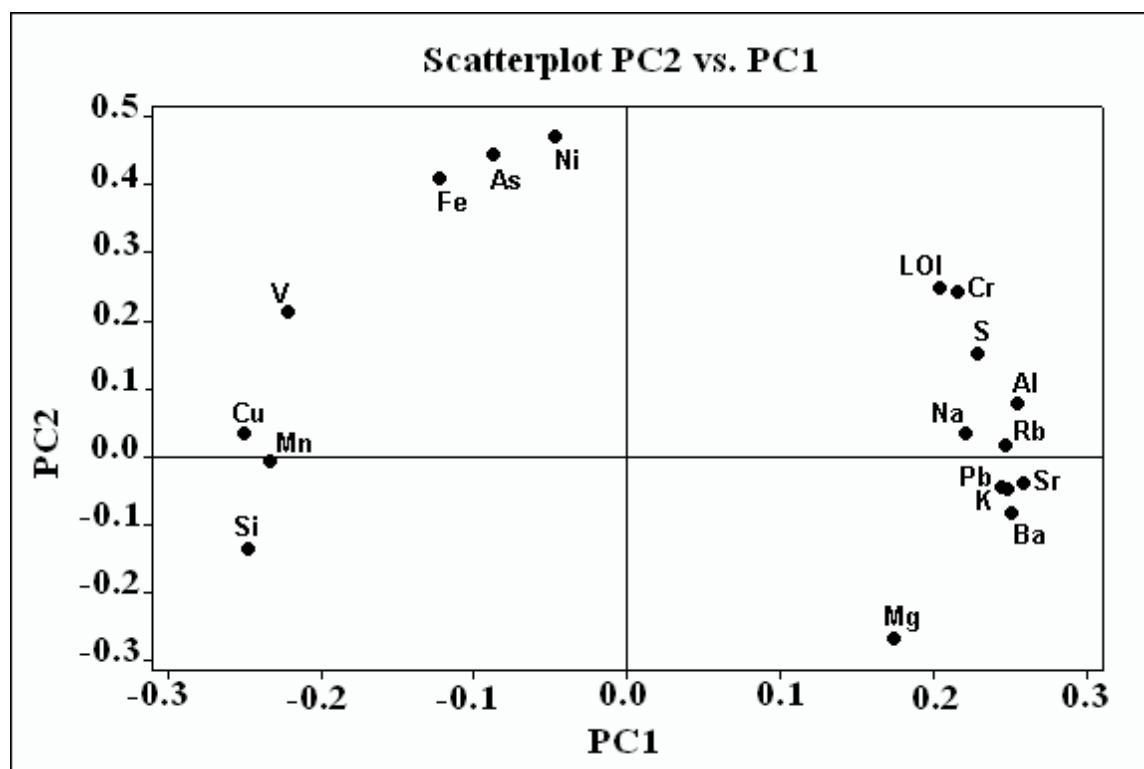
is no correlation between Si and the other two elements. Si represents the contribution of quartz to the total composition, while Mn and Cu (strongly correlated) may represent the contribution of mafic minerals. A third pattern, formed by Fe, As and Ni, can be observed. They have high positive loadings in PC2. Their presence is due to the weathering of the banded iron formation (BIF). V is isolated and may stem from the Banded Iron Formation.

The central problem to establish reference values is to calculate the range within which 95% of the data are. It is expected that the data in an area to be randomly distributed around a central value and values below an upper confidence limit may be considered characteristic of this area. For a normal distribution the upper confidence limit with 95% of probability (UCL95) is calculated adding twice the standard deviation to the mean.

Mean and standard deviation for As, Ba, Co, Cr, Cu, Ni, Pb, Rb, Sr, V and Zn in sediments were calculated using data from stations CST2, CST3 and CST5 (CST1 data are outliers). The proposed baseline reference values are As (23.7 mg/kg), Ba (1923 mg/kg), Co (31,8 mg/kg), Cr (157 mg/kg), Cu (53,2 mg/kg), Ni (57,3 mg/kg), Pb (57,3 mg/kg), Rb (213 mg/kg), Sr (116 mg/kg), V (174 mg/kg) and Zn (92,1 mg/kg). They are characteristic of this area and may be used as reference values for sediments from lakes constructed on areas with similar geology.

Tables 3a and 3b show the physical chemical parameters for the water in the rainy and dry season of the year 2002 respectively. Contents of Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, Cr, Co, Cu, Cd, Mo, Sr and V are omitted because they fell below the detection limits of the technique (Cl<sup>-</sup> 0.1mg/L; SO<sub>4</sub><sup>2-</sup> 0.1 mg/L; As 0.1 mg/L, Cr 7.0 µg/L and Co 5.0 µg/L; Cu 2.0 µg/L; Cd 4.0 µg/L, Mo 3.9 µg/L, Sr 10 µg/L, Ti 8.0 µg/L, V 3.0 µg/L and Zn 2.3 µg/L). Temperature and turbidity are homogeneously distributed in the water column showing no variation. Temperature

**Figure 2:** Score plot of the two first principal components from chemical analyses of the Custódio dam sediment.



values are significantly higher in the rainy season while turbidity is slightly higher in the rainy season due to material movement. The  $E_h$  values decrease systematically from 4m depth to bottom. This leads to propitious conditions for the release of adsorbed or coprecipitated metals, which are associated to oxihydroxides, to the water column and hence to the environment (Burdige, 1993). This explains the increase in the concentration of Mn, Fe and Ba (Tables 3a and 3b). In spite of being in higher content in sediments at stations 3 and 5 K is homogeneously distributed in the whole water body, which means that at those stations it is not being released to water. In general this water body may be as Class I according the Brazilian legislation (Res. CONAMA 357 de 17/05/2005).

A comparison of the obtained values with the available Sediment Quality Guidelines (Smith *et al.*, 1996 ; Long & Morgan, 1991 ; MacDonald *et al.*, 2001) is interesting. These values were introduced in order to provide a way to evaluate the quality

of a given sediment. Of particular interest are the Threshold Effect Level (TEL) and Probable Effect Level (PEL), which are well established for As (5.9, 17), Pb (35, 91.3), Cu (35.7, 197), Cr (37.5, 90), Ni( 18, 35.9) and Zn (123, 315). Values are given in mg/kg. As, Cr and Ni are above the PEL, while Cu and Pb are below PEL and above TEL. Only Zn is below TEL.

## CONCLUSION

The geogenic nature of the sediment of Custodio dam occurrences allowed the proposition of baseline values for lacustrine sediments with similar geological origin. The PCA shows that As, Cr and Ni stem from the BIF. A comparison of the obtained values with the available Sediment Quality Guidelines, introduced in order to provide a way to evaluate the quality of a given sediment showed that those of particular interest are the Threshold Effect Level (TEL) and Probable Effect

**Table 3a:** Physical chemical parameters of the water from Custodio dam (April 2002).

Station	Prof (m)	T (°C)	pH	E <sub>h</sub> (mV)	EC (µS/cm)	Turb (FTU)	OD	TDS	(mg/L)			(µg/L)						
									Na <sup>+</sup>	K <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	HCO <sub>3</sub>	Al	Fe	Mn	Ni	Ba
CST1	0	23.4	7.09	424	8.39	2.0	6.27	5.41	0.32	0.19	0.22	0.46	8.84	6.6	42.3	1.4	7.8	2.3
	1	23.4	7.08	420	8.40	2.0	4.59	5.42	0.37	0.16	0.78	0.42	8.11	12.5	127	1.2	5.0	3.2
	2	23.2	7.04	413	8.37	2.0	4.47	5.40	0.36	0.20	0.66	0.41	11.1	10.6	112	1.0	2.6	2.7
	3	23.0	7.01	416	8.35	2.0	4.39	5.39	0.37	0.18	0.37	0.41	8.84	15.0	120	1.4	<2.6	2.8
	4	23.0	6.94	405	8.39	2.0	4.53	5.41	0.43	0.25	0.69	0.41	9.58	19.2	141	1.2	<2.6	2.9
	5	23.0	6.91	418	8.42	2.0	4.55	5.44	0.35	0.17	0.64	0.40	10.3	11.2	134	2.2	<2.6	2.9
	6	22.4	6.81	421	9.42	2.0	4.98	6.09	0.42	0.22	0.74	0.49	10.3	26.7	167	10.1	3.7	3.5
	7	21.9	6.81	420	9.82	2.0	5.78	6.36	0.35	0.15	0.77	0.51	11.8	12.2	155	29.3	<2.6	3.5
	8	22.0	6.72	393	10.4	2.0	5.55	6.72	0.47	0.33	0.85	0.52	10.3	24.7	170	52.7	<2.6	4.2
	9	21.5	6.46	343	11.2	3.0	4.02	7.29	0.54	0.70	0.83	0.50	10.3	26.1	118	159	7.7	5.4
CST2	0	23.2	7.00	404	8.41	2.0	6.52	5.42	0.37	0.23	0.65	0.43	11.8	21.3	131	3.2	8.4	2.9
	1	23.8	7.00	399	8.42	2.0	4.98	5.42	0.44	0.28	0.68	0.43	11.8	32.4	156	3.1	6.7	3.1
	2	23.4	7.04	409	8.41	2.0	5.05	5.43	0.37	0.23	0.69	0.43	11.8	21.5	124	2.4	8.0	2.9
	3	22.9	7.04	400	8.41	2.0	5.02	5.43	0.38	0.27	0.65	0.43	11.8	28.8	155	2.7	3.8	2.9
	4	23.4	6.99	407	8.39	2.0	4.50	5.41	0.39	0.28	0.64	0.42	11.8	27.0	150	2.1	<2.6	3.0
	5	22.9	6.91	407	8.45	2.0	4.83	5.45	0.35	0.20	0.64	0.43	11.8	14.3	134	1.1	<2.6	2.8
	6	22.7	6.73	433	8.78	2.0	4.99	5.66	0.42	0.28	0.71	0.44	11.8	44.8	204	12.0	9.5	3.6
	7	22.4	6.53	423	9.58	2.5	4.34	6.20	0.37	0.21	0.74	0.47	11.8	17.5	176	46.4	3.7	3.9
	8	23.5	6.89	399	10.4	2.5	4.61	5.42	0.32	0.20	0.63	0.42	10.3	19.7	132	44.9	4.1	2.7
	9	21.3	6.24	400	10.4	3.0	3.16	6.71	0.38	0.28	0.77	0.49	11.8	34.2	261	118	4.5	4.8
CST3	0	22.7	6.87	429	8.37	2.0	6.30	5.41	0.46	0.32	0.77	0.43	7.37	33.3	157	11.2	<2.6	3.2
	1	23.1	7.01	433	8.38	2.0	5.20	5.41	0.41	0.21	0.70	0.42	7.37	19.7	132	3.6	5.3	2.9
	2	22.8	6.97	429	8.41	2.0	5.12	5.43	0.34	0.16	0.63	0.41	8.84	16.1	117	2.3	<2.6	2.8
	3	22.9	6.95	433	8.40	2.0	4.86	5.42	0.41	0.24	0.72	0.43	8.84	25.3	130	2.1	11.2	3.1
	4	23.1	6.91	437	8.41	2.0	4.90	5.43	0.52	0.26	0.71	0.43	8.84	22.5	142	2.0	5.5	3.5
	5	22.4	6.61	439	8.65	2.0	5.38	5.59	0.42	0.28	0.70	0.44	10.3	13.7	152	6.7	6.5	3.1
	6	22.2	6.45	445	8.95	2.0	4.55	5.79	0.39	0.19	0.72	0.44	10.3	14.1	169	17.4	<2.6	3.6
	7	21.5	6.24	456	9.58	2.0	3.61	6.20	0.42	0.25	0.76	0.45	10.3	20.9	219	65.1	<2.6	4.1
	8	21.3	6.13	468	9.98	3.0	3.16	6.47	0.40	0.23	0.92	0.46	10.3	17.5	239	115	<2.6	6.3
	9	21.2	6.08	438	10.4	3.5	2.43	6.73	0.32	0.16	0.95	0.44	8.84	12.0	252	172	4.6	4.7
	10	21.1	5.98	465	11.2	3.5	1.52	7.29	0.50	0.40	0.79	0.40	10.3	35.8	249	271	6.9	5.6
	11	21.1	5.96	434	11.7	4.0	1.17	7.58	0.42	0.29	0.82	0.44	11.8	26.7	210	358	4.2	6.0
	12	21.2	5.98	381	12.2	4.5	0.72	7.90	0.39	0.29	0.82	0.43	10.3	17.8	192	429	8.1	6.5
13	21.7	6.06	323	14.2	5.0	0.21	9.23	0.38	0.27	0.42	0.42	10.3	20.1	782	541	<2.6	7.5	



Table 3a: (Continuation).

Station	Prof (m)	T (°C)	pH	E <sub>h</sub> (mV)	EC (µS/cm)	Turb (FTU)	OD	TDS	Na <sup>+</sup> (mg/L)	K <sup>+</sup> (mg/L)	Ca <sup>2+</sup> (mg/L)	Mg <sup>2+</sup> (mg/L)	HCO <sub>3</sub> <sup>-</sup> (µg/L)	Al	Fe	Mn (µg/L)	Ni	Ba
CST4	0	23.7	7.11	463	8.37	2.0	6.49	5.43	0.31	0.15	0.63	0.42	7.40	6.3	119	27.0	6.8	2.8
	1	23.1	7.14	465	8.37	2.0	5.40	5.42	0.34	0.18	0.65	0.42	11.8	11.4	111	3.6	<2.6	2.8
	2	22.4	7.13	476	8.35	2.0	5.40	5.41	0.32	0.16	0.68	0.42	10.3	11.1	116	1.6	<2.6	3.3
	3	22.3	7.03	473	8.36	2.0	5.36	5.44	0.33	0.13	0.66	0.42	10.3	12.5	99.8	0.9	3.2	2.9
	4	22.4	6.94	480	8.39	2.0	4.86	5.43	0.38	0.21	0.71	0.43	11.8	17.2	130	1.7	6.5	3.3
	5	22.2	6.63	486	8.60	2.0	4.59	5.62	0.35	0.19	0.71	0.43	11.8	20.7	132	13.0	<2.6	4.4
	6	22.3	6.28	481	8.87	2.0	3.52	5.75	0.33	0.20	0.68	0.43	10.3	10.4	123	46.6	9.2	3.7
	7	22.0	6.08	462	9.23	2.0	2.58	5.98	0.38	0.19	0.70	0.42	10.3	17.9	179	89.5	3.7	4.4
	8	22.2	6.14	479	9.39	3.0	2.38	6.10	0.30	0.17	0.71	0.42	10.3	12.0	208	106	<2.6	4.4
CST5	9	22.1	6.04	473	9.55	3.0	2.38	6.21	0.33	0.21	0.73	0.41	11.8	17.6	230	129	2.6	4.7
	0	22.5	7.01	398	8.37	2.0	6.21	5.56	0.48	0.11	0.34	0.42	8.84	7.4	74.2	5.0	7.3	3.1
	2	22.2	7.04	403	8.37	2.0	5.12	5.48	0.30	0.14	0.64	0.42	8.84	5.7	73.0	1.1	3.0	2.6
	4	22.2	6.90	397	8.35	2.0	4.92	5.49	0.39	0.10	0.61	0.42	8.84	5.2	66.5	1.4	<2.6	2.6
	6	22.0	6.62	409	8.36	2.0	4.43	5.58	0.39	0.10	0.62	0.42	10.3	3.1	61.7	10.7	<2.6	2.8
	8	21.5	6.14	443	8.39	3.0	2.39	6.16	0.28	0.14	0.67	0.42	10.3	5.8	171	104	<2.6	4.9
	10	21.3	6.16	420	8.60	3.0	2.35	6.78	0.28	0.14	0.71	0.43	11.8	4.7	218	21.5	4.2	4.6
	12	21.2	6.15	399	8.87	4.0	1.50	7.40	0.37	0.29	0.72	0.43	10.3	5.1	366	315	<2.6	5.4
14	21.1	6.14	368	9.23	4.0	1.01	7.67	0.37	0.14	0.70	0.41	8.84	3.2	303	378	5.9	5.9	
16	21.0	6.43	276	9.39	7.0	0.92	10.6	0.29	0.18	0.72	0.41	11.8	11.0	450	559	<2.6	7.7	

Table 3b: Physical chemical parameters of the water from Custodio dam (September 2002).

Station	Prof (m)	T (°C)	pH	E <sub>h</sub> (mV)	EC (µS/cm)	Turb (FTU)	OD	TDS	Na <sup>+</sup>	K <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	HCO <sub>3</sub>	Al	Fe	Mn	Ni	Ba				
																			(µg/L)			
CST1	0	19.5	6.93	361	10.5	1.2	4.73	6.90	0.47	0.25	0.86	0.56	10.3	51.4	97.7	7.7	7.6	3.1				
	1	19.5	6.91	363	10.4	1.2	4.72	6.87	0.43	0.21	0.83	0.55	10.3	49.1	118	30.3	<2.6	3.5				
	2	19.8	6.96	358	10.4	1.2	4.66	6.83	0.46	0.25	0.86	0.56	10.3	66.2	157	35.3	5.3	3.8				
	3	19.8	6.92	341	10.4	1.1	4.65	6.85	0.47	0.27	0.85	0.55	8.84	64.9	153	32.4	<2.6	3.6				
	4	19.0	6.82	350	10.5	1.2	4.51	6.95	0.46	0.17	0.83	0.55	7.37	31.4	114	47.2	<2.6	3.7				
	5	18.6	6.86	335	11.9	1.3	4.63	7.86	0.38	0.16	0.96	0.65	8.81	26.5	92.6	61.9	<2.6	3.9				
CST2	0	20.0	6.95	366	10.4	1.0	5.15	6.91	0.41	0.23	0.81	0.56	10.3	43.8	167	77.6	4.8	4.5				
	1	19.8	6.98	366	10.4	1.2	4.92	6.91	0.38	0.16	0.82	0.54	7.37	17.5	56.2	20.4	9.1	2.7				
	2	19.9	6.94	360	10.5	1.2	4.60	6.92	0.49	0.28	0.83	0.56	7.37	42.9	89.7	21.9	7.4	3.2				
	3	19.5	6.95	366	10.4	1.2	4.83	6.90	0.41	0.20	0.80	0.55	8.84	21.0	62.5	21.9	<2.6	2.9				
	4	19.4	7.01	365	10.4	1.2	5.09	6.90	0.43	0.23	0.82	0.56	8.84	27.9	70.5	22.1	<2.6	3.0				
	5	19.5	6.98	366	10.4	1.2	4.24	6.90	0.39	0.17	0.82	0.55	7.37	17.5	56.7	20.4	6.9	2.9				
CST3	6	19.2	6.89	381	10.4	1.3	4.55	6.90	0.37	0.19	0.79	0.55	8.84	10.3	51.0	20.8	4.4	2.7				
	7	19.1	6.91	376	10.5	1.3	3.78	6.89	0.39	0.17	0.80	0.55	8.84	11.5	48.6	20.9	7.3	2.9				
	8	19.2	6.93	363	10.6	1.3	3.08	6.97	0.43	0.26	0.86	0.55	7.37	15.6	56.9	21.1	2.9	2.8				
	9	19.2	6.95	355	10.5	1.3	2.57	6.92	0.37	0.18	0.80	0.55	8.84	10.3	55.3	21.8	<2.6	2.8				
	10	19.6	6.95	312	10.5	3.0	2.62	6.89	0.40	0.20	0.81	0.55	8.84	12.6	61.9	23.6	<2.6	2.8				
	0	19.5	6.93	361	10.5	1.2	4.73	6.90	0.47	0.25	0.86	0.56	10.3	51.4	97.7	7.7	7.6	3.1				
	1	19.5	6.91	363	10.4	1.2	4.72	6.87	0.43	0.21	0.83	0.55	10.3	49.1	118	30.3	<2.6	3.5				
	2	19.8	6.96	358	10.4	1.2	4.66	6.83	0.46	0.25	0.86	0.56	10.3	66.2	157	35.3	5.3	3.8				
	3	19.8	6.92	341	10.4	1.1	4.65	6.85	0.47	0.27	0.85	0.55	8.84	64.9	153	32.4	<2.6	3.6				
	4	19.0	6.82	350	10.5	1.2	4.51	6.95	0.46	0.17	0.83	0.55	7.37	31.4	114	47.2	<2.6	3.7				
5	18.6	6.86	335	11.9	1.3	4.63	7.86	0.38	0.16	0.96	0.65	8.81	26.5	92.6	61.9	<2.6	3.9					
6	19.1	7.67	289	11.8	1.6	4.64	7.81	0.56	0.33	0.99	0.65	10.3	43.8	167	77.6	4.8	4.5					
0	20.0	6.95	366	10.4	1.0	5.15	6.91	0.41	0.23	0.81	0.56	10.3	43.8	167	77.6	4.8	4.5					
1	19.8	6.98	366	10.4	1.2	4.92	6.91	0.38	0.16	0.82	0.54	7.37	17.5	56.2	20.4	9.1	2.7					
2	19.9	6.94	360	10.5	1.2	4.60	6.92	0.49	0.28	0.83	0.56	7.37	42.9	89.7	21.9	7.4	3.2					
3	19.5	6.95	366	10.4	1.2	4.83	6.90	0.41	0.20	0.80	0.55	8.84	21.0	62.5	21.9	<2.6	2.9					
4	19.4	7.01	365	10.4	1.2	5.09	6.90	0.43	0.23	0.82	0.56	8.84	27.9	70.5	22.1	<2.6	3.0					
5	19.5	6.98	366	10.4	1.2	4.24	6.90	0.39	0.17	0.82	0.55	7.37	17.5	56.7	20.4	6.9	2.9					
6	19.7	6.87	360	10.4	1.3	4.71	6.84	0.40	0.20	0.80	0.55	7.37	16.1	53.2	19.6	<2.6	2.8					
7	20.1	6.95	323	10.3	1.4	3.27	6.84	0.40	0.21	0.82	0.54	7.37	17.4	65.0	31.0	<2.6	3.2					
0	19.7	6.09	428	10.3	1.0	5.05	6.77	0.38	0.17	0.76	0.54	8.84	16.0	47.1	9.5	3.9	2.5					
1	19.5	5.95	442	10.2	1.0	4.97	6.79	0.39	0.20	0.74	0.54	8.84	17.2	53.6	8.7	<2.6	2.4					
2	19.4	6.03	436	10.2	1.0	5.08	6.77	0.36	0.15	0.78	0.54	7.37	10.9	35.0	8.5	4.1	2.5					
3	19.3	6.17	425	10.3	1.1	4.93	6.78	0.38	0.18	0.78	0.54	7.37	11.3	42.9	9.7	5.1	2.6					
4	19.2	6.44	409	10.4	1.1	4.81	6.87	0.39	0.20	0.80	0.54	7.37	13.1	48.1	15.1	4.2	2.7					
5	19.1	6.89	384	10.4	1.2	4.92	6.89	0.39	0.18	0.80	0.54	8.84	17.8	58.6	19.3	10.5	2.9					
6	19.2	6.89	381	10.4	1.3	4.55	6.90	0.37	0.19	0.79	0.55	8.84	10.3	51.0	20.8	4.4	2.7					
7	19.1	6.91	376	10.5	1.3	3.78	6.89	0.39	0.17	0.80	0.55	8.84	11.5	48.6	20.9	7.3	2.9					
8	19.2	6.93	363	10.6	1.3	3.08	6.97	0.43	0.26	0.86	0.55	7.37	15.6	56.9	21.1	2.9	2.8					
9	19.2	6.95	355	10.5	1.3	2.57	6.92	0.37	0.18	0.80	0.55	8.84	10.3	55.3	21.8	<2.6	2.8					
10	19.6	6.95	312	10.5	3.0	2.62	6.89	0.40	0.20	0.81	0.55	8.84	12.6	61.9	23.6	<2.6	2.8					
0	19.5	6.93	361	10.5	1.2	4.73	6.90	0.47	0.25	0.86	0.56	10.3	51.4	97.7	7.7	7.6	3.1					
1	19.5	6.91	363	10.4	1.2	4.72	6.87	0.43	0.21	0.83	0.55	10.3	49.1	118	30.3	<2.6	3.5					
2	19.8	6.96	358	10.4	1.2	4.66	6.83	0.46	0.25	0.86	0.56	10.3	66.2	157	35.3	5.3	3.8					
3	19.8	6.92	341	10.4	1.1	4.65	6.85	0.47	0.27	0.85	0.55	8.84	64.9	153	32.4	<2.6	3.6					
4	19.0	6.82	350	10.5	1.2	4.51	6.95	0.46	0.17	0.83	0.55	7.37	31.4	114	47.2	<2.6	3.7					
5	18.6	6.86	335	11.9	1.3	4.63	7.86	0.38	0.16	0.96	0.65	8.81	26.5	92.6	61.9	<2.6	3.9					
6	19.1	7.67	289	11.8	1.6	4.64	7.81	0.56	0.33	0.99	0.65	10.3	43.8	167	77.6	4.8	4.5					
0	20.0	6.95	366	10.4	1.0	5.15	6.91	0.41	0.23	0.81	0.56	10.3	43.8	167	77.6	4.8	4.5					
1	19.8	6.98	366	10.4	1.2	4.92	6.91	0.38	0.16	0.82	0.54	7.37	17.5	56.2	20.4	9.1	2.7					
2	19.9	6.94	360	10.5	1.2	4.60	6.92	0.49	0.28	0.83	0.56	7.37	42.9	89.7	21.9	7.4	3.2					
3	19.5	6.95	366	10.4	1.2	4.83	6.90	0.41	0.20	0.80	0.55	8.84	21.0	62.5	21.9	<2.6	2.9					
4	19.4	7.01	365	10.4	1.2	5.09	6.90	0.43	0.23	0.82	0.56	8.84	27.9	70.5	22.1	<2.6	3.0					
5	19.5	6.98	366	10.4	1.2	4.24	6.90	0.39	0.17	0.82	0.55	7.37	17.5	56.7	20.4	6.9	2.9					
6	19.7	6.87	360	10.4	1.3	4.71	6.84	0.40	0.20	0.80	0.55	7.37	16.1	53.2	19.6	<2.6	2.8					
7	20.1	6.95	323	10.3	1.4	3.27	6.84	0.40	0.21	0.82	0.54	7.37	17.4	65.0	31.0	<2.6	3.2					
0	19.7	6.09	428	10.3	1.0	5.05	6.77	0.38	0.17	0.76	0.54	8.84	16.0	47.1	9.5	3.9	2.5					
1	19.5	5.95	442	10.2	1.0	4.97	6.79	0.39	0.20	0.74	0.54	8.84	17.2	53.6	8.7	<2.6	2.4					
2	19.4	6.03	436	10.2	1.0	5.08	6.77	0.36	0.15	0.78	0.54	7.37	10.9	35.0	8.5	4.1	2.5					
3	19.3	6.17	425	10.3	1.1	4.93	6.78	0.38	0.18	0.78	0.54	7.37	11.3	42.9	9.7	5.1	2.6					
4	19.2	6.44	409	10.4	1.1	4.81	6.87	0.39	0.20	0.80	0.54	7.37	13.1	48.1	15.1	4.2	2.7					
5	19.1	6.89	384	10.4	1.2	4.92	6.89	0.39	0.18	0.80	0.54	8.84	17.8	58.6	19.3	10.5	2.9					
6	19.2	6.89	381	10.4	1.3	4.55	6.90	0.37	0.19	0.79	0.55	8.84	10.3	51.0	20.8	4.4	2.7					
7	19.1	6.91	376	10.5	1.3	3.78	6.89	0.39	0.17	0.80	0.55	8.84	11.5	48.6	20.9	7.3	2.9					
8	19.2	6.93	363	10.6	1.3																	

Table 3b: (Continuation).

Station	Prof (m)	T (°C)	pH	E <sub>h</sub> (mV)	EC (µS/cm)	Turb (FTU)	OD	TDS	Na <sup>+</sup>	K <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	HCO <sub>3</sub>	Al	Fe	Mn (µg/L)	Ni	Ba
CST4	0	19.1	6.75	348	10.2	1.0	5.26	6.76	0.37	0.17	0.79	0.54	7.37	7.2	37.6	7.2	6.1	2.5
	1	19.0	6.79	349	10.3	1.0	4.77	6.77	0.36	0.21	0.79	0.54	7.37	57.9	3.82	6.8	3.3	2.7
	2	19.0	6.77	326	10.2	1.0	4.58	6.78	0.36	0.19	0.79	0.54	7.37	8.8	44.2	5.8	6.4	2.5
	3	18.9	6.82	365	10.3	1.0	3.43	6.81	0.41	0.22	0.79	0.54	8.84	15.8	46.3	5.8	3.8	2.5
	4	19.0	6.85	359	10.3	1.0	2.62	6.79	0.42	0.23	0.80	0.54	7.37	18.9	55.5	5.5	<2.6	2.6
	5	18.8	6.92	344	10.2	1.0	2.39	6.77	0.40	0.21	0.79	0.54	8.84	12.7	48.2	5.6	<2.6	2.5
CST5	6	18.9	7.30	320	10.3	1.2	2.35	6.80	0.41	0.23	0.80	0.54	7.37	17.9	54.2	6.0	3.9	2.6
	0	19.4	6.79	317	10.2	1.0	5.02	6.75	0.43	0.24	0.80	0.54	8.84	16.8	56.6	7.2	<2.6	2.7
	2	19.3	6.76	315	10.2	1.0	4.73	6.74	0.40	0.21	0.79	0.54	7.37	21.3	45.7	6.0	4.2	2.7
	4	19.1	6.79	340	10.2	1.0	2.48	6.75	0.43	0.25	0.79	0.54	7.37	15.5	49.5	4.6	<2.6	2.6
	6	19.2	6.75	334	10.2	1.0	2.36	6.74	0.45	0.26	0.80	0.55	8.84	20.1	55.7	4.5	10.2	2.7
	8	19.2	6.71	338	10.2	1.0	1.61	6.77	0.42	0.23	0.81	0.54	8.84	12.8	44.2	6.1	6.5	2.7
CST5	10	19.2	6.66	320	10.3	1.2	1.23	6.76	0.45	0.25	0.80	0.54	8.84	17.6	52.0	7.9	6.3	2.7
	12	19.3	6.78	329	10.3	3.0	1.08	6.81	0.47	0.25	0.81	0.54	8.84	21.1	79.2	12.6	11.5	2.9
	0	19.1	6.75	348	10.2	1.0	5.26	6.76	0.37	0.17	0.79	0.54	7.37	7.2	37.6	7.2	6.1	2.5
	1	19.0	6.79	349	10.3	1.0	4.77	6.77	0.36	0.21	0.79	0.54	7.37	57.9	3.82	6.8	3.3	2.7
	2	19.0	6.77	326	10.2	1.0	4.58	6.78	0.36	0.19	0.79	0.54	7.37	8.8	44.2	5.8	6.4	2.5
	3	18.9	6.82	365	10.3	1.0	3.43	6.81	0.41	0.22	0.79	0.54	8.84	15.8	46.3	5.8	3.8	2.5
4	19.0	6.85	359	10.3	1.0	2.62	6.79	0.42	0.23	0.80	0.54	7.37	18.9	55.5	5.5	<2.6	2.6	

Level (PEL), which are well established for As (5.9, 17), Pb (35, 91.3), Cu (35.7, 197), Cr (37.5, 90), Ni( 18, 35.9) and Zn (123, 315). Values are given in mg/kg. As, Cr and Ni are above the PEL, while Cu and Pb are below PEL and above TEL. Only Zn is below TEL. This does not mean necessarily that the sediment of Custódio dam stream basin is contaminated, for the geogenic origin of these metals was demonstrated. It means that these values are characteristic of this region. Water analyses show that it is quite clean but any use of these resources must be considered carefully.

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(Footnotes)

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