SURFACE WATER QUALITY PARAMETERS IN AN IRON MINE REGION, QUADRILÁTERO FERRÍFERO, MINAS GERAIS, BRAZIL.

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ABSTRACT

This paper describes the analyses of quality parameters in water samples downstream of two iron mines in the Gulaxo do Norte river system northwest of Mariana, Minas Gerais. Besides pH, E_H, electric conductivity, total dissolved solids, the main cations, Na, K, Ca, Mg, trace elements like Fe, Mn, and Al and some heavy metals (Cd, Ni, Cr, Zn, As, Pb, and Co) were analyzed. The water samples were dominated by bicarbonate, sodium, sulfate, calcium, magnesium and potassium. They can be classified as bicarbonate and sodium rich water. Enriched concentrations of iron and manganese were only observed where predatory gold exploitation were done by garimpos and where supergenic alteration of the itabirites (canga) have occured. Iron and manganese background values were sometimes higher than the limits established by CONAMA.

Key words: water quality, hydrogeochemistry, iron mining

INTRODUCTION

In the east part of the Quadrilátero Ferrífero region (Minas Gerais, Brazil) there are wide iron ore deposits. The fluvial systems of the region are part of the Doce river hydrographic basin. Several small rivers flow on mineralized rock units.

The Gualaxo do Norte river system (Fig.1) is the main object of this study. Its springs are located near Antônio Pereira and Bento Rodrigues districts, northwest of Mariana city (Fig.1). This region is characterized by an intense iron mining activity (Timbopeba, Germano and Alegria). Besides of the iron mines, the area is marked by extensive manganese and gold occurrence and by predatory exploitation (*garimpo*) activity. The Gualaxo do Norte river springs are located in the supracrustal rock domain, represented by quartzites, itabirites (Banded Iron Formation) and phyllites of the Minas supergroup. The medium course of the Gualaxo do Norte river is located in the Archean metamorphic complex rocks (gneiss and metabasics) and in the schists and quartzites of the Greenstone Belt Rio das Velhas.

The Timbopeba mine exploits the iron ore since1984. The reserves are estimated around 213 millions of tons of hematite. At that time the exploitation was expected to last 35 years (mine rapport research, *in* Endo, 1983). The Germano mine was exploited since 1973 to 1995 when the ore reserves were exhausted. After this, itabirite in the Alegria mine began to be exploited, whose reserves were estimated around 160 millions of tons (Matsumura, 1999).

Two main types of waste are released in these mines: 1) rocks not containing ore material produced in the iron exploitation inside or around the mine. This waste is disposed in artificial piles drained by artificial drains; 2) mud effluents which comes from the iron processing plant. It is rich in iron oxides, NaOH, sulfates and amines, the latter being used in the ore processing. The residual mud and waters are stocked in two tailing dams. The first one is a contention dam (Timbopeba - TPBT) where the deposition of the major part of the suspension solids takes place. The water flows to the second dam (Natividade - TPBN) which is responsible by the contention and by the regulation of the water flow during the winter and summer. The water from this dam, together with the water from "Doutor" and "Manso" streams, (Antônio Pereira region) flows into the Gualaxo1 sub-basin (Fig. 1). The mine waters and the residual mud derived from the Germano and Alegria mines flow to the Germano dam and the aqueous fraction flow to the Santarém sedimentation dam, near Bento Rodrigues district. The Santarém river flows into the Gualaxo 2 sub-basin (Fig.1).

The general aim of this study was the physical-chemical characterization of the Gualaxo do Norte basin between its springs and the Carmo river, near Barra Longa city. During this work we focused on the iron mine contribution to the water quality in a region intensely affected by mineral exploitation. We tried to identify water parameter anomalies and its respective sources (natural or anthropogenic). The Timbopeba mine region was studied in more detail.

METHODOLOGY

The surface water monitoring of the Gualaxo river included the determination of water quality parameters (pH, E_H, electric conductivity (EC), salinity, total dissolved solids (TDS) and turbidity); anions (HCO_3^-, SO_4^{2-} and Cl^-) and main cations (Na^+, K^+, Ca^{2+} and Mg^{2+}); trace elements (Mn, Fe and Al) and heavy metals (Cd, Ni, Cr, Zn, As, Pb and Co).

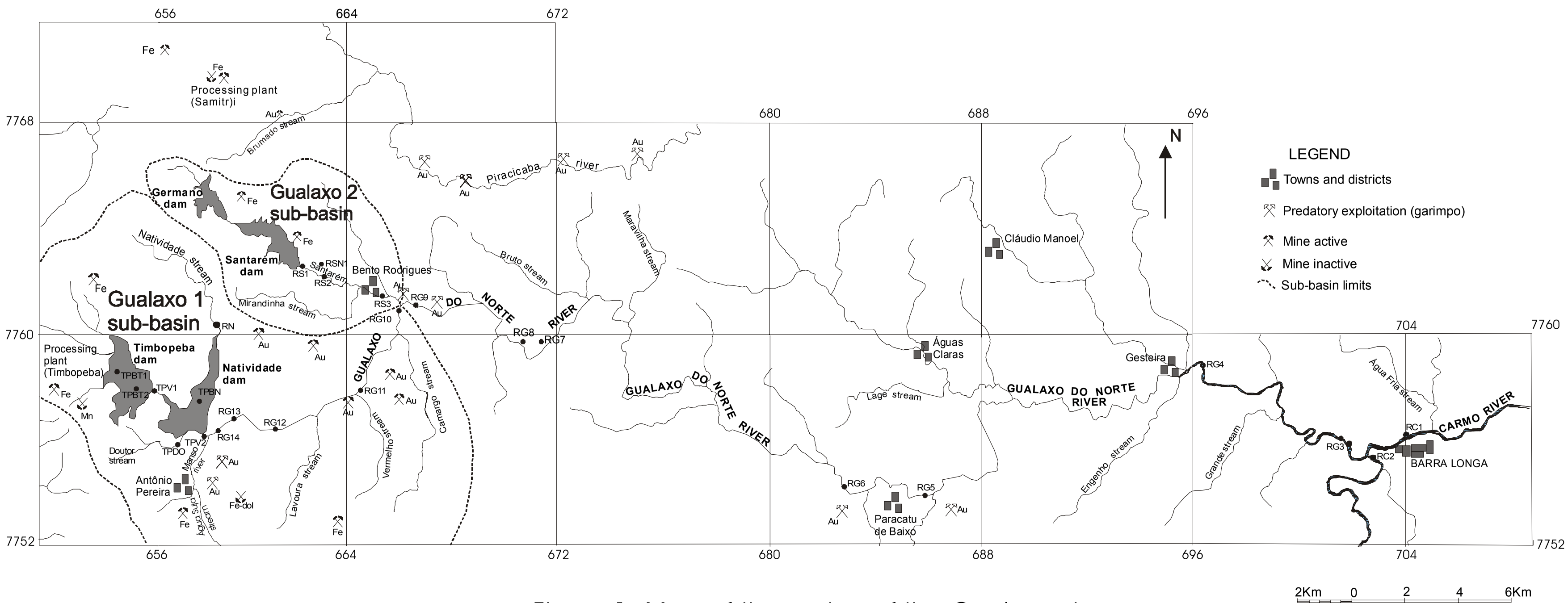


Figure 1: Map of the region of the Gualaxo do Norte river, southeastern Quadrilátero Ferrífero, Minas Gerais state (Brazil)

Two main sampling campaigns were accomplished. To detect maximum possible chemical variations during dry/wet periods, samples were collected by the end of the dry season (winter), when maximum concentrations were expected, and by the end of the rainy season (summer), when maximum dilution was expected. 18 samples were collected, including sources, non-affected small rivers, artificial drains in the mine sterile piles, dams and the Natividade, Doutor, Manso, Santarém, Gualaxo do Norte and Carmo streams in August/1999 (restricted to the Timbopeba mine). 17 samples were collected in January/2000 (wet period) and 26 samples in June/2000 (dry period) from the Gualaxo do Norte basin system.

Some physico-chemical parameters (pH, EC, temperature, salinity and TDS) were measured in-situ with a multiparameter portable equipment. All the chemical analyses were accomplished according to the Standard Methods for the Examination of Water and Wastewater (APHA, 1992). Turbidity was measured by a Micronal turbiditymeter B250. Measurements of E_H were made by a Daniel cell in the laboratory. HCO_3^- and Cl^- were determinated by titration and sulfate by turbidimetry (APHA B4500). Measurements of the concentration of the main cations (Na^+, Ca^{2+}, K^+, Mg^{2+}) were accomplished by Varian AA475 Atomic Absorption Spectrometry equipment. Heavy metals (As, Cr, Ni, Co, Cd, Pb and Zn) and some trace elements (Fe, Al and Mn) contents were obtained using inductively coupled plasma spectrometry (ICP) according to Standard Methods.

DISCUSSION OF RESULTS

Water quality parameters

Water turbidity in the Timbopeba mine area showed values varying from 0.1 to 46.5 FTU. The largest values were observed in the Serragem river (TPS1) and in the Timbopeba dam (TPBT1). Probably, this was due to a rise in the suspended solids which were carried to the Serragem stream. These solids are mobilized as a consequence of the mine operation which, together with the mud (ore processing), flows into the dam. However, the spillway showed low values for turbidity (TPV1=5.6 FTU; TPV2=0.6 FTU).

In the Gualaxo do Norte river, during the dry period, the turbidity values varied from 1.2 to 26 FTU. During the rain period it varied from 1.1 to 43 FTU. These results were in accordance to the fact that during the rain period, larger quantities of solids were carried in suspension by the natural and artificial water drains. These results showed that the contention dams are efficient for the sedimentation of the suspended solids.

In general, the pH values of the water samples were around 7. Inside the Timbopeba mine the pH varied between 6.2 and 7.5 (average 6.8). In the Gualaxo do Norte river the pH varied from 6.1 to 7.6 (average 7.2).

E_H indicated more oxidizing conditions in the dry period inside the Timbopeba mine, with values varying from 0.727 and 0.841 V (average 0,765 V). The maximum value was measured in the Timbopeba dam. The average for the E_H values in the Gualaxo do Norte river was about 0.27 in the rain period and 0.478 in the dry period. There was a decrease of the E_H in the rain period.

The sample RS1 (drain of the Santarém tailing dam) presented 0.2% of salinity in the dry period. The remaining samples showed values varying from 0 to 0.1%

In the Timbopeba mine, EC and TDS showed low values in the springs and in the artificial drains (Table 1). In the Timbopeba dam, a significant increase in these values was observed, and they decreased continuously downstream. The results suggest that there was a significant loss of dissolved solids from the dams to the Gualaxo river.

It was observed that the difference of the EC and TDS between the dry and wet period were negligible in the Gualaxo 2 sub-basin. Probably the water had more solids dissolved in dry period but the water volume was smaller. Some anomalous values (Table 2) were observed (Santarém dam drain) in the dry period but they did not affect the Gualaxo do Norte river because the volume of water that was released from the dam was too small.

In the Gualaxo 1 sub-basin, the EC and TDS decreased significantly ongoing from the dry period to the wet one with values showing a mean decrease of 50%.

The Timbopeba dam effluents presented anomalous values. These effluents flow into the Gualaxo 1 sub-basin. It is possible to say that the Timbopeba dam is the main source of rise of the EC and TDS values in the Gualaxo do Norte river during the dry season, while in the wet season the contribution from the Santarém and Timbopeba dams become important.

Anions

In the Gualaxo do Norte river HCO_3^- and SO_4^{2-} were the dominant anions. Chlorides were below the detection limit of the method. Table 4 displays their avarage concentration.

Alkalinity and sulfates

In the Timbopeba mine, the HCO_3^- concentrations varied from 8.0 to 10.0 mg/L upstream the dam (drains and spring). In the Timbopeba dam the HCO_3^- concentration showed a higher level 86.6 mg/L (TPBT1) during the year. Ongoing to the Gualaxo river this concentration was lowered due to dilution.

In general, during the dry season, the largest HCO_3^- values were observed for the samples of the Gualaxo 1 sub-basin, whose main water source is the Timbopeba mine area. An anomalous value of (105 mg/L) was observed in the drain of the Santarem dam (RS1). In the next station downstream RS2 a value of 46.12 mg/L was observed. The Santarém dam water level was very low in the dry season and the water discharge for the Santarém dam was minimum or not observed. Then the HCO_3^- contribution was very low from the Santarém stream to the Gualaxo 2 sub-basin. Therefore in the dry season the HCO_3^- values of the Gualaxo river was controlled mainly by the Gualaxo 1 sub-basin which was influenced by the Timbopeba mine.

In the wet period, the HCO_3^- concentration decreased around 50% in the Gualaxo 1 sub-basin due to the dilution caused by the increase in the water volume. In the Gualaxo 2 sub-basin, the HCO_3^- remained relatively constant (Figures 2a and 2b). In the wet period the water contribution of the Santarém dam was important and resulted in 50% more HCO_3^- in the Gualaxo 2 sub-basin.

Before receiving the Timbopeba dam the spring and drain waters showed SO_4^{2-} concentrations which varied between 1.71 to 3.05 mg/L. In the dam SO_4^{2-} concentration was 27.6mg/L (TPBT1) and it remained constant until the Natividade dam where it decreased (TPV2=17.4 mg/L).

Table 1: Water quality parameters (EC, TDS, HCO_3^-, SO_4^{--}, Na, K, Ca, Mg, Mn, Fe and Al average concentrations) in the Timbopeba region and the Gualaxo 1 and 2 sub-basins during the dry and wet season.

	[1]Spring	[2]Drains	[3]Timbopeba dam	[4]Nativida-de dam	Manso stream	Natividade stream	[5]Gualaxo 1 sub-basin	[6]Spring	[7]Santarém river	[8]Gualaxo 2	[9]Carmo river
TDS dry (mg/L)	6	33.5	103.67	81	63	61.2	81.2	25.24	126.67	54.78	44,5
TDS wet (mg/L)	-	-	-	54	-	4	32.8	13	108.33	42.78	45
EC dry (µS/cm)	14.8	70.75	218.67	171.32	86.3	89.35	170.82	51.12	258.3	116.62	97.75
EC wet (µS/cm)	-	-	-	112.2	-	7.7	73.24	27.95	215.67	90.09	97.45
$HCO3^-$ dry (mg/L)	8.5	27.4	86.6	78.59	39.29	47.08	66.35	17.42	65.33	47.03	26.26
$HCO3^-$ wet (mg/L)	-	-	-	57	17.93	6.41	38.67	12.81	84.54	36.78	30.1
SO_4^{2-} dry (mg/L)	2.1	2.37	26.92	14.06	3.66	1.86	8.92	2.13	41.47	4.41	9.24
SO_4^{2-} wet (mg/L)	-	-	-	9.97	1.94	5.77	3.4	1.71	108.94	4.03	5.95
Na^+ dry (mg/L)	0.23	0.88	28.99	19.02	2.12	0.14	9.99	1.63	17.55	8.88	5.41
Na^+ wet (mg/L)	-	-	-	19.62	7.5	0.2	5.06	0.19	48.36	12.68	10.17
Mg^{2+} dry (mg/L)	0.35	2.37	26.92	10.15	3.18	3.69	4.55	1.21	2.37	3.89	1.44
Mg^{2+} wet (mg/L)	-	-	-	2.8	0.83	0.23	2.27	0.79	0.53	1.45	1.61
Ca^{2+} dry (mg/L)	0.69	1.49	2.86	5.52	3.97	4.62	8.13	2.4	6.58	5.47	3.65
Ca^{2+} wet (mg/L)	-	-	-	2.36	1.15	0.76	1.69	0.95	2.66	1.61	1.66

K^+ dry (mg/L)	0.17	0.47	1.61	1.13	0.73	0.24	1.25	1.53	1.77	1.07	1.39
K^+ wet (mg/L)	-	-	-	0.86	0.31	0.45	0.43	0.08	1.06	0.63	0.86
Fe dry (mg/L)	0.11	4.6	0.99	0.09	20	0.14	1.96	0.41	0.43	3.71	1.65
Fe wet (mg/L)	-	-	-	<0.05	0.19	0.19	0.08	0.12	0.28	0.18	0.14
Mn dry (mg/L)	<0.02	0.88	2.13	0.23	1.94	0.21	O.33	0.01	0.14	0.98	0.13
Mn wet (mg/L)	-	-	-	0.19	0.12	0.1	0.08	0.03	0.02	0.08	0.02
Al dry (mg/L)	<0.05	0.3	0.14	0.06	2.99	<0.05	0.34	0.11	0.08	1.11	0.75
Al wet (mg/L)	-	-	-	<0.05	0.08	<0.05	<0.05	<0.05	<0.05	0.09	0.05

[1] springs: amostras TPN1, TPN2, TPN3 (Timbopeba mine springs)
[2] drains: samples TPD1, TPD2, TPD3 (waste rock piles drains in the Timbopeba mine)
[3]Timbopeba dam: TPBT1, TPBT2, TPV1
[4]Natividade dam:TPBN, TPV2
[5]Gualaxo 1 sub-basin: samples RG14, RG13, RG12, RG11, RG10
[6] Gualaxo 2 sub-basin springs: amostras RSN1, RSN2, RG4N, RG6N
[7]Santarém river: RS1, RS2, RS3
[8]Gualaxo 2 sub-basin: RG9, RG8, RG7, RG6, RG5, RG4, RG3,
[9]Carmo river: RC1, RC2

Table 2: Average electrical conductivity and total dissolved solids of the Santarém river waters.

Samples	TDS dry season (mg/L)	TDS wet season (mg/L)	EC dry season (µS/cm)	EC wet season (µS/cm)
RS1	232	97	464	227
RS2	94	125	197,7	205
RS3	54	103	113,2	215

In the Gualaxo 1 sub-basin, SO_4^{2-} concentration decreased approx. 50%, comparing the dry and wet season values. In both seasons a continuous trend was observed that suggests the lowering of sulfate concentration from Natividade dam downstream. During the dry season in the Gualaxo 2 sub-basin, there was an anomalous SO_4^{2-} concentration only in the spillway of the Santarém dam (RS1=106 mg/L). In the rainy season a decrease in the SO_4^{2-} concentration was observed in the Santarem stream.

It can be concluded that the Timbopeba dam released effluents with high SO_4^{2-} and HCO_3 concentrations for the Gualaxo 1 sub-basin during the dry and wet seasons. The Santarém dam contained high SO_4^{2-} and HCO_3^- concentrations because of the small volume of water present. The effluents of the Santarém dam were released for the Gualaxo 2 sub-basin during the wet period.

Metals

In the Gualaxo do Norte river water, Na^+ was the main cation followed by Ca^{2+}, K^+ and Mg^{2+}.

Sodium

In the Timbopeba mine the Na^+ varied between 0.17 to 1.74 mg/L upstream the dam (drains and springs). The TPS2 sample (mud from ore processing) presented an anomalous value of 95.4 mg/L. In the Timbopeba dam the concentration of this element was kept constant (approx. 28.9 mg/L) lowering across the dam and in the spillway (TPV2=16.3 mg/L).

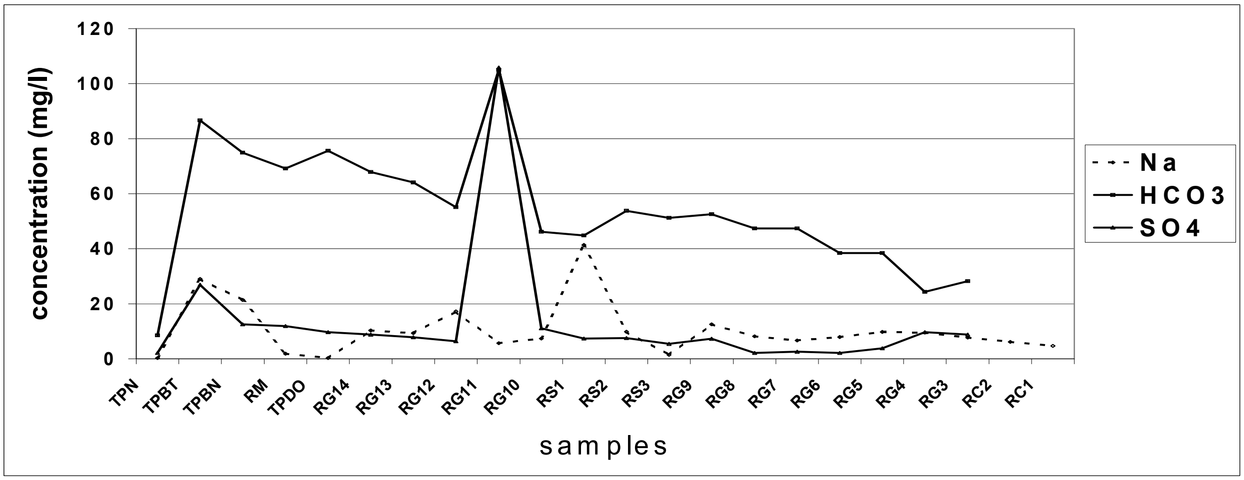
In the Gualaxo 1 sub-basin the Na^+ concentration was higher in the dry season, except in the Rio Manso station. This stream did not received any effluent coming from the mine. The Na^+ values decreased downstream from the Natividade dam in both seasons. During the dry season in the Gualaxo 2 sub-basin an anomalous Na^+ concentration was observed near the Santarem dam spillway (RS1= 41.4 mg/L). Therefore, the Na+ value in the Santarém stream is low (RS3 = 1.42mg/L because the low water volume observed.
In the wet season, there was a continuum decrease of the Na+ concentration for downstream in the Santarém stream (Fig. 2a and 2b). In this season, the Na+ concentration in the Santarém stream was around 12 mg/L.

Potassium

In the Timbopeba mine, the K^+ concentration varied between 0.04 to 0.55mg/L upstream of the processing plant. In the Timbopeba dam a larger K^+ concentration was registered (TPV1=1,75mg/l). In the Natividade drain the water contained 0.86 mg/L K^+. There was low variation in the K^+ concentration although the spring station values were lower when compared with the stations affected by effluents.

Considering all the Gualaxo do Norte river extension, the K^+ concentrations varied from 0.35 to 4.01mg/L during the dry season and from 0.01 to 1.12 mg/L during the wet season. In the dry season two anomalous values were observed: RSN2 = 4.01 mg/L and RS1 = 3.40mg/L.

A)



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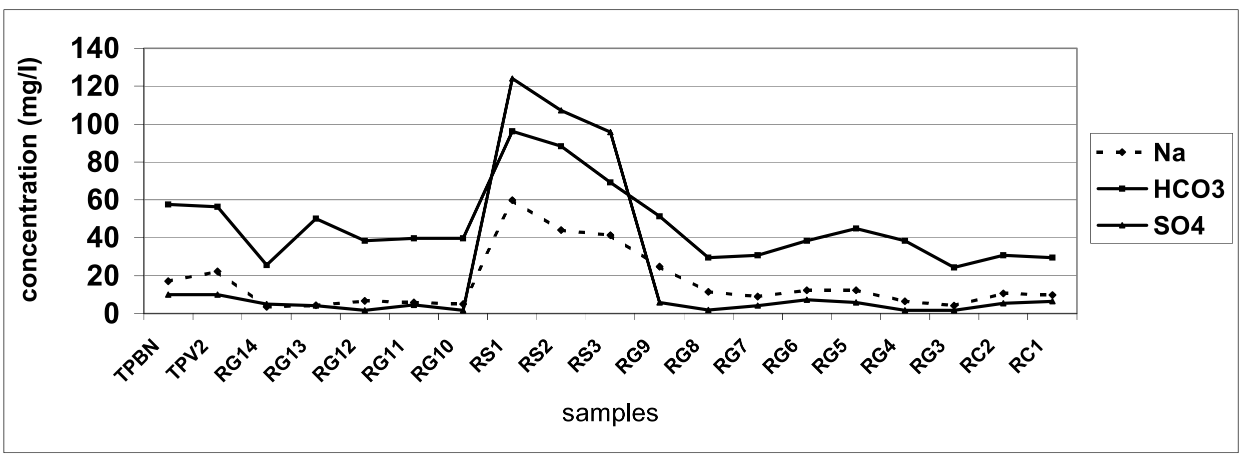

Figure 2: Distribution of sodium, bicarbonate (alkalinity) and sulfate in the Gualaxo do Norte river from Timbopeba mine region to downstream during dry (a) and wet (b) season. The highest concentration values represent the waters of Timbopeba tailing dam (RG11; dry season) and of the Santarém dam spillway (RS1, RS2 and RS3; wet season).

Magnesium

In the Timbopeba mine, the Mg^{2+} concentrations varied between 0.14 and 2.95 mg/L upstream of the Timbopeba dam (pile drains and springs) and between 3.09 and 5.01mg/L downstream including the dams and the Gualaxo river.

Gandarela formation dolomites (Minas supergroup, Fig. 1) was observed in the region south of the Frazão mountain. The Natividade stream and dam are located in this area. Part of the Gandarela formation was covered by the Timbopeba dam. This situation can explain the larger Mg^{2+} concentrations in the Timbopeba and Natividade dams samples. The magnesium solubilization was probably facilitated by the high HCO^-_3 concentration.
Considering all the extension of the Gualaxo do Norte river, the Mg^{2+} concentration varied from 0.41 to 6.97mg/L during the dry season and of 0.23 to 3.65 during the rainy season. Because of the dolomite formations the Mg^{2+} concentrations were higher in the Gualaxo 1 sub-basin. The samples RG7 (6.98 mg/L) and RG9 (6.56mg/L), belonging to the Gualaxo 2 sub-basin, were two exceptions.

Calcium

In the Timbopeba mine, the Ca^{2+} concentration varied from 0.63 to 3.42mg/L upstream of the Timbopeba dam. The value of 3.42 mg/L represented a sample from a waste pile drain (TPD3: Ventura waste pile drain). From the Timbopeba dam downstream, the Ca^{2+} concentration was constant around 3 mg/L. The main contribution for the calcium concentration was the solubilization of calcium-bearing minerals present in the Gandarela formation. The Ca^{2+} concentration of the mud released by the processing iron plant was essentially lower.

Considering all the extension of the Gualaxo do Norte river, the Ca^{2+} varied from 1.42 to 9.27mg/L during the dry and from 0.69 to 2.87 during the wet season. In the dry season, the higher Ca^{2+} concentrations were observed in the Gualaxo 1 sub-basin because of the natural contribution from de Gandarela formation (one exception was the sample RS1 (8.86 mg/l) from the Rio Santarem).

Using standard correlation diagrams, the different nature of the waters analyzed can been demonstrated (Fig. 3). For example, alkalinity versus EC showed a good positive correlation for nearly all samples with a clear separation in different fields due to the different sources of the samples. The same was true for correlation diagrams, alkalinity versus (Ca+Mg) and alkalinity versus Na (Fig. 3).

Aluminum

In the Timbopeba mine, the greatest part of the samples showed aluminum concentrations below the detection limit (Al<0,05 mg/l). The largest anomaly was detected in the TPS1 sample from the Serragem stream (1.07 mg/L) and in the mud of the processing plant after the mud flow in the Serragem stream (TPS2=14 mg/L). In the Timbopeba dam, the highest concentration was detected in the sediment-bearing part of the dam (TPBT1=0,12mg/l).

In the Gualaxo do Norte river, the Al concentration varied from <0.05 to 3.33 mg/L during the dry season and from <0.05 to 0.25 during the wet season. There was a positive correlation between the iron and aluminum values.

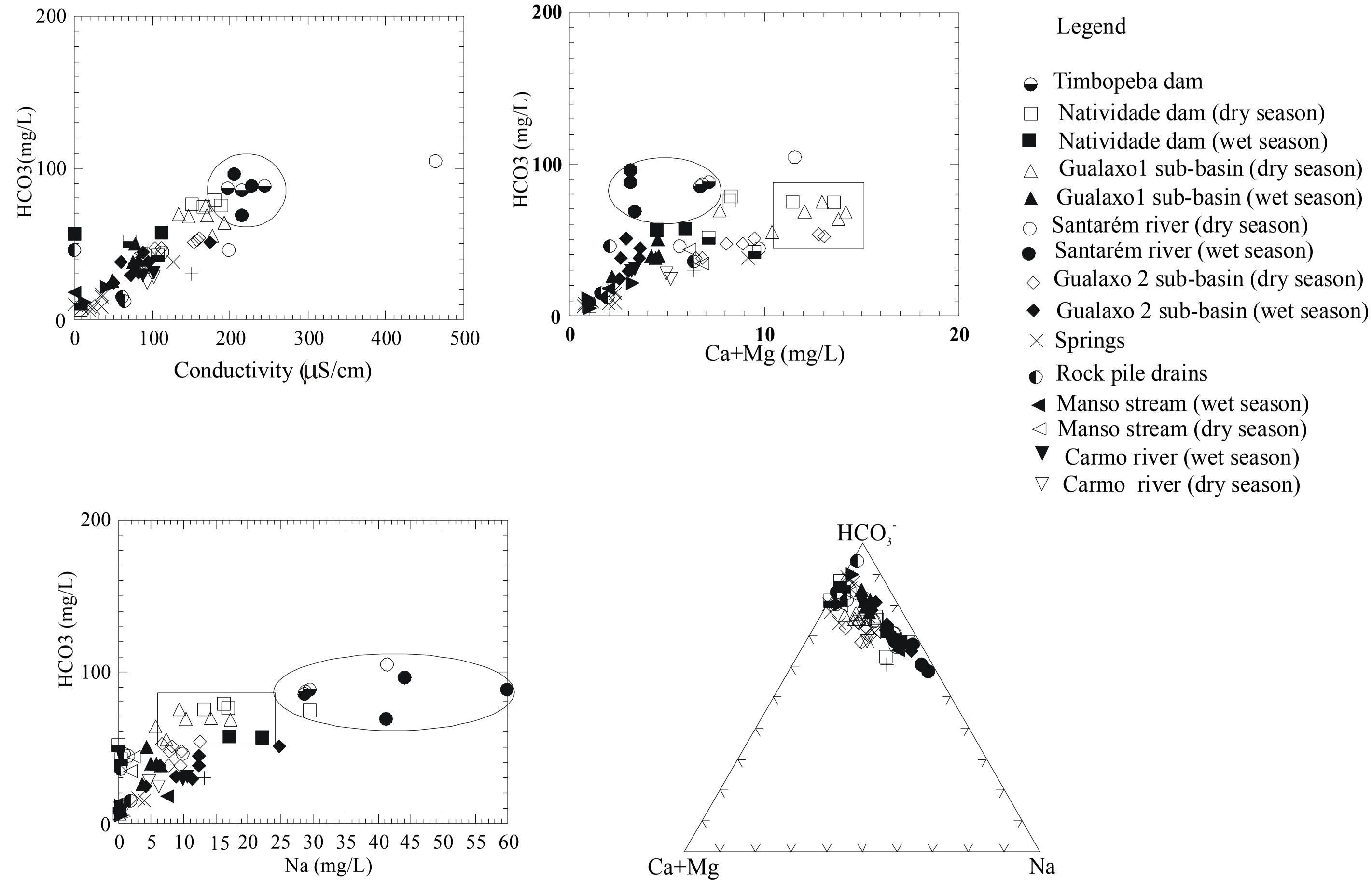

Figure 3: General correlations diagrams using alkalinity from the 1999/2000 collecting campaigns in the Gualaxo do Norte basin:

Diagrams: A) HCO3 X conductivity; (B) HCO3 X Ca+Mg; (C) HCO3 X Na
D) HCO3 X Ca+Mg X Na

Iron

In the Timbopeba mine, the Fe concentrations varied from <0.05 to 98.4mg/L. Anomalies were detected in the samples from the Serragem pile drain (TPD3=11.4 mg/l) and in the mud which flows into the Santarém stream (TPS1=98.4 mg/L). In the Timbopeba dam highest concentrations observed were 2.42 mg/L (TPBT1). Data from microbiological analyses obtained from CVRD (Companhia Vale do Rio Doce) indicated 49.000.000 *Gallionella* (iron bacteria) and a concentration of other bacteria, that was so high that it could not be counted. It is assumed that part of the iron which comes from the plant was being precipitated by these bacteria. The reason is that the effluents downstream the dam showed only low concentration of iron.

Considering the whole extension of the Gualaxo do Norte river the Fe concentrations varied from <0.05 to 8.23 mg/l in the dry season and from <0.05 to 0.31 in the rainy season. The concentrations of Fe in the wet season are below the maximum limit allowed by brazilian legislation (CONAMA - Conselho Nacional de Meio Ambiente) for class 2 water (0.3 mg/L). However, in most samples of the dry season, the contents of soluble iron was several times higher.

Anomalies has been observed in areas with intense prospector activities (RM=20 mg/L; RG6=8.23 mg/L; RG8=5.92 mg/L; RG14=5.25 mg/L) (Fig. 4). The Manso river (RM) drains itabiritic rock formations and it is likely that the predatory *garimpo* activity was the main source for the release of iron to the aquatic system. However, it must be pointed out that even in the springs the content of soluble iron was higher than the maximum limits.

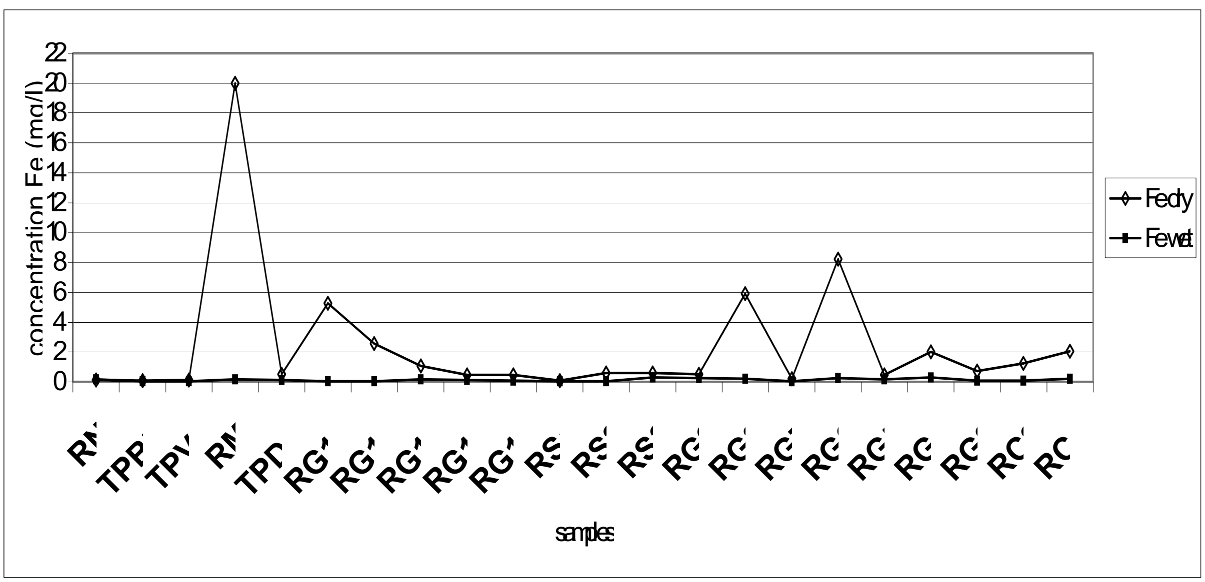

Figure 4: Distribution of iron in the Gualaxo do Norte river from Timbopeba mine region to downstream during dry and wet season

Manganese

The springs upstreams of the Timbopeba mine showed Mn concentrations which were below the limit of detection of the analytical method (<0.02 mg/L). Anomalies have been observed in the samples from the Serragem pile drain (TPD1=3.08 mg/L) and from Timbopeba dam (TPBT2=2.32 mg/L). These high levels of Mn might have contributions from the Serragem stream through its waste rock pile and also from the plant, which, in former times, had processed manganese rich iron ores. Downstream, the Natividade dam spillway released effluents to the Gualaxo river. The Mn content in these effluents are higher (TPV1=0.33 mg/L) than the maximum concentration allowed by Brazilian legislation (0.1mg/L).

The Manso river showed anomalous Mn concentrations in the dry season (RM=1.1 mg/L; 2.79 mg/L) and apparently indicate the source of Mn in the Gualaxo 1 sub-basin. (TP14=1.2 mg/L; 0.64 mg/L). Here, the Mn is associated with the paragenesis of the itabiritic rocks, which are the source of the prospecting activities.

Considering the whole extension of the Gualaxo do Norte river, the manganese concentrations varied from <0.02 to 3.73 mg/L during the dry season and from <0.02 to 0.33mg/L during the rainy season. During the wet season two stations showed Mn concentrations which were above the maximum level of 0.1 mg/L allowed by Brazilian legislation (TPV=0.33 mg/L; TPDO=0.19 mg/L).

During the dry season the vast majority of the samples showed Mn levels which were above the maximum value allowed by Brazilian legislation. The exception was a sample from the spring. Anomalies were observed at RG5=3.73mg/L; RG8=1.7mg/L and RG6=0.95mg/L in addition to TPDO and RM, discussed above (Fig. 5).

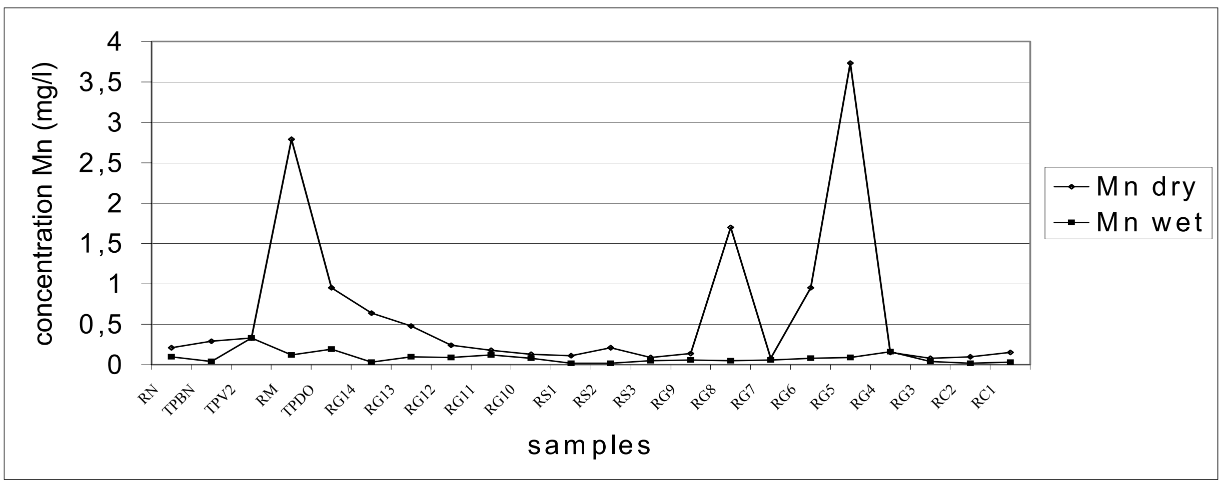

Figure 5: Distribution of manganese in the Gualaxo do Norte river from Timbopeba mine region to downstream during dry and wet season.

Heavy metals

The following heavy metals were analyzed in the Timbopeba mine: As, Cr, Ni, Co, Cd, Pb and Zn. The vast majority of samples showed concentrations below the detection limits of the methodology used (As<0.05 mg/L; Cr<0.02 mg/L; Ni< 0.02 mg/L; Co<0.01 mg/L; Cd<0.001 mg/L; Pb<0.02 mg/L, Zn<0.01 mg/l), and consequently below the maximum level allowed by legislation. The sample from Serragem stream showed concentrations slightly above or near the detection limit of the methods used after receiving the waste from the ore processing (As<0,05 mg/L; Cr= 0,03 mg/L; Ni=0,02 mg/L; Co=0,01 mg/L; Cd=0,037 mg/L; Pb=0,15 mg/L; Zn=0,06 mg/L).

In the Gualaxo river, the greatest part of the samples showed heavy metal concentrations lower than the detection limit. The exceptions were Zn with a maximum value of 0.08 mg/L (TPV2) during the dry period and 0.05 mg/L (RG12) during the wet season. Cd was determined with an anomalous concentration in the Manso river (RM = 0.003 mg/L) during the dry season. This Cd value is three times the legislation limit.

CONCLUSION

The main ions present in the Gualaxo do Norte river were bicarbonte (HCO_3^-), sodium (Na^+), sulfate (SO_4^{2-}), calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^+). The water of the region can be classified like bicarbonate and sodium rich waters.

The hydrogeochemistry observed suggests that the main anthropogenic source of contamination were the iron mines and predatory gold exploitation (garimpo). The iron mines were responsible for bicarbonate, sodium and sulfate anomalous values which resulted from the iron mine processing plants (ore flotation). For example, during the dry season (2000), the main source of bicarbonate, sodium and sulfate to the Gualaxo do Norte river were the Timbopeba tailing dam effluents (Gualaxo 1 sub-basin) because there was only a small volume of water leaving the Santarém tailing dam (Gualaxo 2 sub-basin) from the Santarém stream.

Positives correlations were observed between salinity, EC, TDS and alkalinity. Bicarbonate rich water resulted in the precipitation of calcium and magnesium carbonates (Bernardo 1989). These elements were disposable in the system by the Gandarela formation near the Timbopeba mine (highest observed values). On the other hand, sodium stayed in solution due its high solubility.

Sodium and EC anomalies observed in the Gualaxo river were important in the water quality control for irrigation uses. In general, the waters showed low Na concentration and low salinization risk. The Santarém stream water had the greatest risk if used for soils with low permeability.

The results showed that there were no high anomalous concentrations of Fe and Mn derived from the iron mine effluents to the Gualaxo do Norte river. The main anomalies were associated with the itabirites and their supergenic alteration (canga) and which were mobilized by the gold predatory exploitation. The aluminum concentration was positively related with iron.

The region is characterized by Fe and Mn background values higher than the limits established by CONAMA. At some stations the Fe concentrations were also high in spring waters.

Heavy metal anomalies were observed in the water which came out from the Timbopeba processing plant (Cd, Pb and Zn). In the Gualaxo river system, there was observed a Cd anomaly only in the Manso stream, near Antônio Pereira.

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