PHYSICO-CHEMICAL FEATURES OF MAJOR AMAZONIAN WATER TYPOLOGIES: SUBSIDIES FOR THE IMPROVEMENT OF RIVER CLASSIFICATION

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ABSTRACT

Physico-chemistry of water provides important parameters for quantifying biogeochemical cycles and establishing management options in river systems and wetlands. Pre-Columbian populations categorized Amazonian rivers by the color of their waters, and both native and colonial inhabitants of the Amazon knew that water color was related to specific ecological properties such as fish richness or soil fertility. The first scientific classification of Amazonian water bodies was elaborated in the 1950s by Sioli (1956a; 1956b). He used water color, transparency, pH and electrical conductance to explain limnological characteristics of the large Amazonian rivers. The innovative aspect of his classification was the correlation of these characteristics to the geological and geomorphological properties of the river catchments, an approach used today in landscape ecology. This simplified classification has dominated until today the scientific discussion about limnology and ecology of the Amazon basin, but Sioli's classification was based only on a very limited data base. After his studies the situation has changed dramatically. The National Amazonian Research Institute – INPA has conducted many limnological studies and hosted high-level, national and international limnological projects, such as the cooperation with the Max-Planck-Institute for Limnology in Plön, Germany and the CAMREX expeditions of the University of Seattle. The aim of this paper is to discuss some new insights into the limnological classification of Amazonian rivers and streams. From literature we collected some preliminary data available on hydrochemistry of rivers and streams. In addition we collected water samples in the course of four field surveys during the periods of 27th October - 3th November 2009, 1th - 7th March 2010, 26th September - 3th October 2010, and 3th - 12th Dezember 2010 around the middle and lower area of the Jutaí, Tefé, Juruá and Tapajós river basins, respectively. The transparency values were measured using the Secchi disk, and the electrical conductivity, pH, and Dissolved Oxygen values were measured in the field using WTW instruments. In the laboratory of the INPA in Manaus (Brazil) the water samples were analyzed to obtain the values of the major cations and major anions, as well as the values of water colour, Turbidity, Total Suspended Solids, PO_4, P_{tot}, NH_4, NO_3, N_{tot} and Si. All the analyses were carried out by standard methods and the data was analysed with Minitab 14.

Keywords: Amazonian Region, Water Types, River Ecology.

1 INTRODUCTION AND METHODS

Physico-chemistry of water provides important parameters for quantifying biogeochemical cycles and establishing management options in river systems and wetlands. Pre-Columbian populations categorized Amazonian rivers by the color of their waters, and both native and colonial inhabitants of the Amazon knew that water color was related to specific ecological properties such as fish richness or soil fertility (Junk et al., 2011). The first scientific classification of Amazonian water bodies was elaborated in the 1950s by Sioli (1956a). He used water color, transparency, pH and electrical conductance to explain limnological characteristics of the large Amazonian rivers. The innovative aspect of his classification was the correlation of these characteristics to the geological and geomorphological properties of the river catchments, an approach used today in landscape ecology**.** This simplified classification has dominated until today the scientific discussion about limnology and ecology of the Amazon basin, but Sioli's classification was based only on a very limited data base. After his studies the situation has changed dramatically. The National Amazon Research Institute – INPA has conducted many limnological studies and hosted high-level, national and international limnological projects, such as the cooperation with the Max-Planck-Institute for Limnology in Plön, Germany and the CAMREX expeditions of the University of Seattle. The aim of this paper is to discuss some new insights into the limnological classification of Amazonian rivers and streams. From literature we collected some preliminary data available on hydrochemistry of rivers and streams. In addition we collected water samples in the course of four field surveys during the periods of 27th October - 3th November 2009, 1th - 7th March 2010, 26th September - 3th October 2010, and 3th - 12th December 2010 around the middle and lower area of the Jutaí, Tefé, Juruá and Tapajós river basins, respectively. The transparency values were measured using the Secchi disk, and the electrical conductivity, pH, and Dissolved Oxygen values were measured in the field using WTW instruments. In the laboratory of the INPA in Manaus (Brazil) the water samples were analyzed to obtain the values of the major cations and major anions, as well as the values of water color, Turbidity, Total Suspended Solids, PO_4, P_{tot}, NH_4, NO_3, N_{tot} and Si. All the analyses were carried out by standard methods (APHA et al., 2005) and the data was analyzed with Minitab 14.

2 RESULTS AND DISCUSSION

In Table 1 are presented the mean physico-chemical results of the analyzed water samples that were taken from some colorless streams (lower Tapajós basin) and Tapajós, Cuparí, Jutai, Tefé and Juruá rivers. The physico-chemical characteristics of the Tefé and Juruá rivers are similar to the classic/typical black and white waters, respectively (Furch and Junk 1997). The Tapajós River is characterized by having intermediate conditions between the white and black waters (Junk and Howard-Williams 1984). An intermediate and transitional pattern is also observed in the Jutai River. The colorless streams of the lower Tapajós basin show very acidic conditions and poverty in electrolytes resembling the classic black waters, with the exception of the color value which is very low in this type of clear water streams.

Table 1. Average physico-chemical characteristics of Tapajós, Jutaí, Tefé and Juruá river waters (modified from Ríos-Villamizar et al., 2014)

Parameter	Tapajós	Jutai	Tefé	Juruá
pH	6.56	5.96	5.03	7.27
Electric conductivity (µS/cm)	14.33	8.71	7.36	191.14
Total Suspended Solids (mg/L)	10.56	46.56	7.90	51.42
Ca (mg/L)	0.52	0.54	0.71	32.55
Mg (mg/L)	0.26	0.15	0.22	4.42
Na (mg/L)	1.50	1.21	0.40	10.19
Total P (mg/L)	0.010	0.079	0.03	0.080
Total N (mg/L)	0.35	0.49	0.24	0.39
SO_4 (mg/L)	0.30	0.61	4.20	2.56
Color (mg Pt/L)	4.02	62.78	54.90	41.61
Cl (mg/L)	0.53	1.28	0.85	4.75

Others authors such as Silva et al. (2011) already observed colour values in the Tapajós river water around five times higher than the value of this study, similarly to the values observed in the Jufari river water, which is considered one of the Negro River's tributaries showing the highest poverty of dissolved substances (Santos et al., 1984). We also observed similarities between the Jufari and Tapajós River mainly in terms of the variables Cl and total Fe. On the other hand, the values of the variables pH, Ca, K and NH_4 are similar between Jufari River and the colorless streams of the lower Tapajós basin. However, the results of the Cuparí River, a Tapajós River's right bank tributary, are higher than usually are found in the Tapajós basin and the Amazon region itself.

In contrast to the Amazonian black waters which show pH-values below 5.0 and electrical conductivity below 25 µS cm^{-1}, the typical Amazonian white waters are characterized as carbonate waters according to Furch and Junk (1997), indicating richness in carbonates and calcium, pH above 6.5 and electrical conductivity above 40 µS cm^{-1}. On the other hand, Sioli's observations of clear waters were based at the lower Tapajós and Arapiuns (Sioli 1956a; Sioli 1956b). Both rivers show typical high transparency because they are Ria lakes without major current, where sediments brought in by the rivers became quickly deposited. They do not represent the physico chemical conditions of the channels of these rivers, but those of Ria-lakes, which have been built in the large mouth bays of the black and clearwater tributaries of the Amazon River by the damming back of the river water because of the raise in sea-level after the last glacial period. Transparency of the Tapajós-water increases from 85 cm at Itaituba on Transamazon Highway to 245 cm at Santarém, 280 km far. The other parameters do not show major changes. We may assume that sediment load of the Tapajós has increased since Sioli's time because of increased erosion as a result of

increased land use. But this certainly will happen in the future in other transparent rivers and streams, pointing out the limited value of transparency for river classification.
Furthermore, annual data sets show for some rivers considerable seasonal fluctuations in physico-chemical parameters, which makes difficult to relate these characteristics to a specific water type, as shown for the Branco River and tributaries (Figure 1).

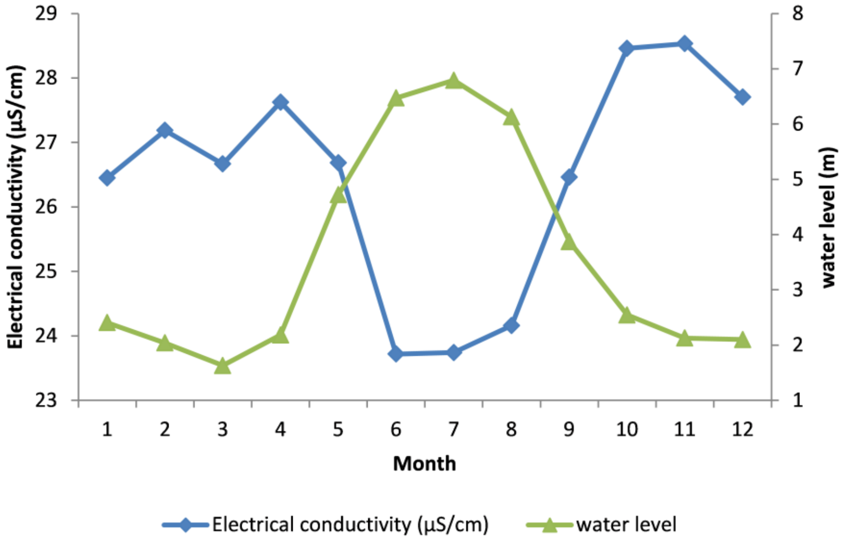

Figure 1. Electrical conductivity and water level variations in the Branco River, 2003-2009 (Ríos-Villamizar et al., 2014)

A preliminary multivariate analysis (Figure 2) indicated that the first three principal components account for over 65% of the variability in the data set. According to the first component, the more important variables were the major anions, HCO_3, electrical conductivity, major cations and pH. Accounting to the second component in terms of importance are the total N, eq% Mg, eq% Na, water colour, eq% SO_4 and eq% K. The third component is constituted by eq% HCO_3, eq% Cl, transparency and total P.

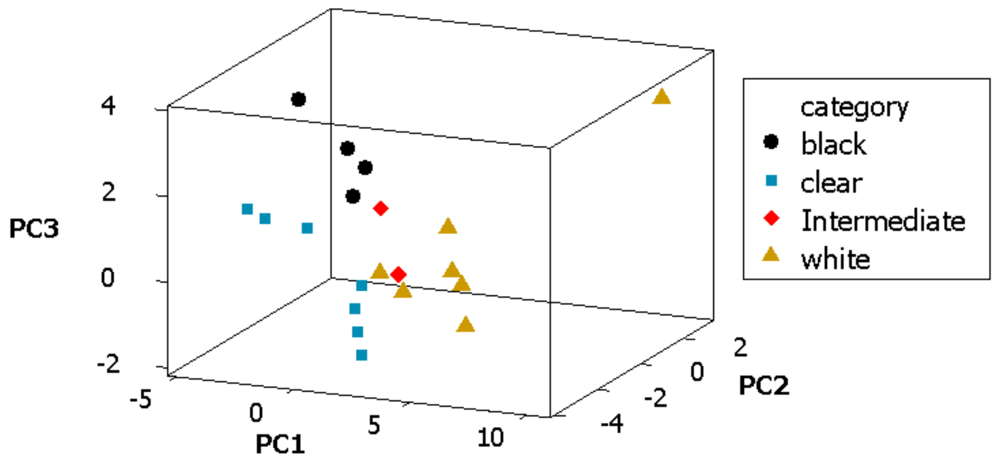

Figure 2. Scores plot of the PCA for the first three components (Ríos-Villamizar et al., 2014)

The river and stream data used in the analysis (by water type) are as follows: Blackwater Rivers (such as Negro and Tefé); Clearwater Rivers (such as Tapajós, Branco, Araguaia, Guaporé, and colorless streams at lower Tapajós River); Whitewater Rivers (such as Solimões/Amazonas, Juruá, Cuparí and Tocantins), and finally the intermediate rivers, such as Jutaí and Bóia (Leenheer and Santos 1980; Santos 1983; Stallard and Edmond 1983; Junk and Howard-Williams 1984; Santos et al., 1984; Furch and Junk 1997; Richey et al., 2008; Ríos-Villamizar et al., 2014; INAU, unpubl. data).
Ríos-Villamizar et al., (2012) categorized several rivers and streams using the relationship between the distribution of alkali and alkaline-earth metals (each one of the four major cations - %) and the transparency

of some Amazonian rivers and streams. They observed that the distribution of alkali and alkaline-earth metals allows distinguishing well the three classical water types and to categorize others rivers that occupy intermediate positions with a transitional character such as Jutaí and Bóia rivers.

Along the Amazon Basin, we can find waters whose chemical characteristics do not match with the optical attributes according with Sioli's classification. The Copatana River, a lower Jutaí river's left bank tributary, exhibit optical appearance of blackwater rivers, nonetheless, it shares water quality features such as electrical conductivity, hardness, pH, and nutrient status, with whitewater rivers (Figure 3). As indicated by Junk et al. (2011), in Roraima State, many tributaries of the Branco River transport a high load of suspended matter and have the appearance of whitewater rivers, however, chemical characteristics of these rivers show that they generally have low nutrient status and a closer relationship to clearwater rivers. These examples point out once again the difficulties arising when river typologies are given generalized designations (Geisler and Schneider 1976).

Figure 3. The Copatana river, a lower Jutaí river's left bank tributary (photograph of E.A. Ríos-Villamizar)

Nowadays, road construction in the Amazon allows access to low-order Rivers in remote areas that were previously inaccessible during the Sioli's and other limnologist's time. Some areas of the archaic/Pre-Cambrian shields show a large and small-scale geological complexity which is reflected by large hydrochemical variability as shown by the hydrochemical transect South to North from Cuiabá to Manaus, among others (Furch and Junk 1980). The geology of the pre-Andean zone is also rather heterogeneous with large old sedimentation areas (paleo-varzeas) of different ages. These sediments are strongly weathered, but still contain a higher bioelement content than the tertiary sediments of the central Amazon basin and the soils on the archaic shields.

3 CONCLUSIONS

The importance of the total amount and relationship of alkali and alkali-earth metals and carbonates can be considered as an essential chemical attribute for the classification of Amazonian water types. The rivers of the Sioli's clear water type have their upper catchments in the Central Brazilian and Guiana archaic/Pre-Cambrian shields and are characterized by pH-values that vary between 5.0 and 7.0, electrical conductivity is in the range of 10-50 $\mu S\ cm^{-1}$, the water transparency can reach up to 300 cm. Transparency values less than 100 cm are also common in these rivers. Nevertheless, we consider the total amount and relation of alkali and alkali-earth metals and carbonates as a more stable and stronger parameter for the water classification than the transparency. The combination of several parameters such as the amount and relationship between alkali, alkali-earth metals, and major anions, as well as electrical conductivity, pH, total N, water colour, suspended sediment load and total P allow to distinguish the three classical water types (white, black and clear) and other water bodies with intermediate position. The distribution of alkali and alkaline-earth metals and major anions is especially useful for the distinction of whitewater, blackwater and clearwater categories. Higher variability is shown by water bodies that not fit inside these three classic categories.

4 ACKNOWLEDGMENTS

We thank the Nuclei Excellency Support Projects (PRONEX), INPA/Max-Planck project, and the Ecology, Monitoring and Sustainable Use of Wetlands Group (MAUA-INCT-ADAPTA/INPA), as well as the Instituto Nacional de Ciência e Tecnologia em Áreas Úmidas (INCT-INAU-UFMT) and "CAPES/CNPq – IEL Nacional – Brasil" for financial support. We also thank the personnel of the environmental chemistry laboratory at INPA (CPCRH - Recursos Hidricos/CDAM/INPA) for assistance with laboratory analyses.

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