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FLUVIAL WATER QUALITY IN A KARST RIVER BASIN, SOUTHERN BRAZIL

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INTRODUCTION

In natural environments water quality is influenced by physical and biological factors: climatic (temperature, humidity, insolation, wind, precipitation), geologic (lithology and structure), pedologic (soil taxons and soil cover patterns), vegetation (kind and state). The contribution of groundwater, meteoric water and evaporation in drier conditions have also influence in fluvial water quality too.

In addition to natural factors, the various human activities (agricultural, urban-industrial, mining and energy) affect the aquatic environment and alter the water composition. This is evident in more artificialized river basins, where natural systems have been deeply transformed.

Stream flow variations also produce changes in the composition of fluvial waters. Considering chemical changes, salts concentrations can decrease with the increasing of the stream flow rate. Stream flow increases may also raise the levels of materials in suspension in the water: silt, clay, organic and fecal matters, waste, etc.

When aquifer contributions to fluvial waters are more significant, the water tends to present a chemical composition that varies less than in streams that are straightly linked with rainfalls, because groundwater is relatively protected from external factors and therefore it has greater chemical and thermal stability (Allan, 1995).

For the reasons cited above, it is very important to record changes in the quality of fluvial waters associated with pluviometry and changes in stream flows. Considering these factors, the main objective with this paper is to understand and define the relationships between changes in stream flows and changes in some parameters of the Capivari stream's water. With this, we expect to find indicators about the degree of land degradation over the High Capivari watershed.

ENVIRONMENTAL FEATURES

This study was carried out at the Capivari watershed. This basin belongs to the Ribeira River basin, which covers an area of 28.306 km^2 and is the largest basin of the Atlantic Ocean in Southern Brazil. The Capivari Basin is located over the Southern Brazilian Plateau in the State of Paraná, at heights that range from 700m to 1,200m above sea level.

This watershed is situated about 20 km from Curitiba, the largest city in Southern Brazil. The basin's area is about 125.19 km^2 (12,519 ha), with a very irregular shape and can be divided into two major sub-basins, corresponding to its major streams: the Capivari and the Bacaetava streams (Figure 1).

According to MINEROPAR (2001), the following geological formations are present in the basin: Setuva Group - composed by gneisses, schists and quartz-mica schists; Capiru Formation of the Açungui Group - consisting predominantly of dolomitic metacarbonates, phyllites and quartzites, and secondarily by graphitic phyllites, and metasiltstone metamarls; basic intrusive rocks of the Jurassic-Cretaceous - diabase dikes.

Figure 1. Location of the State of Paraná, Brazil.

The lithological diversity and geological structures have implications in the movement of groundwater. According to Lisboa (1997), subvertical and vertical diabase dikes that are raincoats and are little fractured cut the metamorphic complex forming hidrogeological barriers, like dams or individual cells. These cells have in their center packages of Açungui carbonate, which are porous, permeable and topographically lower, and are also limited by phyllite and quartzite crests.

Water dynamics in karst areas is also unusual. Rain water or irrigation systems water may reach groundwater easily through conduits or sinks that are usual in this landscape and that can mean a permanent risk of aquifer pollution, as observed by Fritzsons et.al. (2001).

VEGETATION AND LAND USE

The natural vegetation corresponds to the original area of Araucaria forest (Mixed Ombrophylous Forest) or forest with Araucaria (*Araucaria angustifolia*). This araucaria tree is endemic of the Brazilian Southern Plateau and of the Misiones Plateau in Argentina. More than 50% of the basin is occupied by trees and shrub formations, including species that are remnants of native forests and bracatinga reforestations. Bracatinga (*Mimosa Scabrella*) is a characteristic tree from this region.

In the area that was studied, uncultivated fields are common and, with less spatial representation, there is land used for construction, agriculture and limestone mining. Agriculture has become smallholder crops of maize and beans and vegetables that supply Curitiba's metropolitan region. More recent studies have been carried out in this basin and as a result it is possible to conclude that there were no major changes in land use during this time.

Limestone mining is an economically important activity in the region, but it causes serious environmental problems because it leaves large areas with no protection by vegetation, as well as large amounts of exposed soil that eventually flow into the rivers.

CLIMATE

According to Köppen-Geiger climate classification system, the region climate is Cfb (Kottek et al. 2006). It is defined as: Maritime Temperate climate, average temperature in the coldest month below 18 degrees Celsius (mesothermal), and frequent frosts in winter. Fresh summers with average temperature in the warmest month under 22 ºC and with no dry season (IAPAR , 2008).

The estimated average annual rainfall is 1,404 mm (KARST PROJECT, 1998) and erosivity, established by Hudson (1961) as the ability of rain to cause erosion, was estimated by Fritzsons (2003) as being moderate to strong, according to Carvalho's classification (1994).

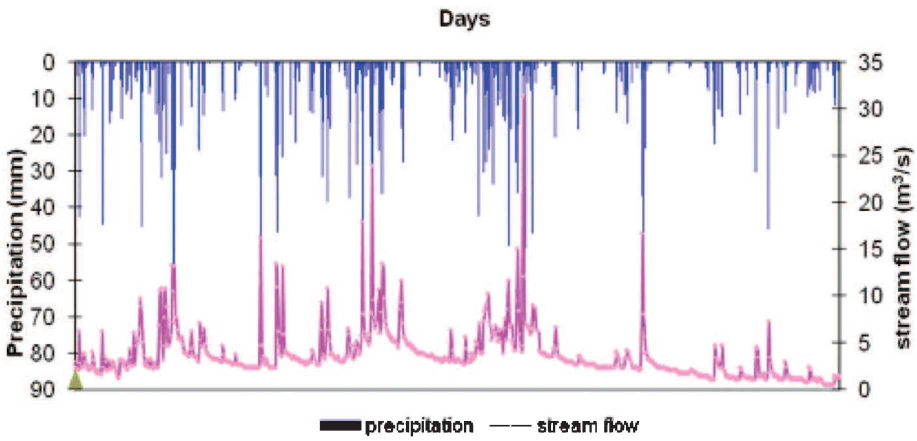
The average of real evapotranspiration (ETR), according to Morton´s method, is equal to 1,040.6 mm /

year and the surplus water, represented by the average annual runoff, is only 363 mm (PROJECT KARST, 1998). This surplus represents the average annual amount of water available to be infiltrated into the soil and drained from the soil surface, to feed the aquifer and rivers too (infiltration and runoff).

AVERAGE RATE OF THE BASIN'S FLOW

Nevertheless, the average of stream flow that comes from direct precipitation to the Upper Capivari basin lies between 50 and 54%. This means that approximately 50% of precipitated water becomes superficial flow, while the other 50% is evaporated or infiltrated. Thus, we conclude that for the Upper Capivari basin, the medium surface runoff is very high, thus partially justifying the rapid response of the flow that is directly linked with precipitation (Figure 2).

Figure 2. Daily stream flow and rainfall of years 1997, 1998 and 1999.



This behavior can be explained by the relatively high altitude, relative higher average air humidity and the consequent lower rate of evaporation, presence of shallow soils and by rugged topography that is typical of areas with a predominance of low permeability rocks.

METHODS

There are several ways to work with data related to water quality and for this work we used width multivariate analyses: Descriptive Statistical Analysis and Principal Component Analysis. The objective with principal component analysis is to rewrite the coordinates of the samples in another axis system that is more convenient for data analysis, Moita (1998). Principal component analysis provides the tools to identify the most important variables in the space of principal components. The characteristics of the principal components can be highlighted: a) can be analyzed separately due to orthogonality, serving to interpret the weight of the original variables in the combination of the most important principal components b) may be used to view the whole sample only the graph of first two principal components, which hold most of the statistical information.

The data used in this study were obtained at the São Dimas water treatment station (ETA), located in the rural municipality of Colombo. We identified and worked with two kinds of data: daily data collected from nature water from January 1998 through December 1999, and daily stream flow data in the same period, both obtained at the Chácara da Luz station (DNAEE, Code: 8129100), about 200 m downstream of the ETA.

We had 696 sampling days of water quality: alkalinity, turbidity, organic matter (mg / L of O2 uptake at acidic pH), pH and true color. The organic matter content was determined indirectly by measuring the amount of oxygen needed to oxidize the organic matter present in the sample.

At the ETA, usually 15 water samples were collected each day and the highest and lowest values were the highest and lowest values found in the day. The highest medium values were computed through an arithmetic average with the highest values found along the days, and the same way the medium lowest value was obtained. The medium value was found through an arithmetic average with all the values obtained in that day.

For the statistical analysis we used the Statigraphics software, Centurion version. Initially, PCA (principal components analyses) was applied to a matrix formed by all the 695 samples and 13 variables.

RESULTS

The statistical summary below shows the values for the parameters (Table 1). It may be noted that the variation range of all parameters is very high, including stream flow, which shows a high diversity in the quality of stream water.

Table 1. Descriptive statistics

	Alkalinity (mg / L)	Maximum color (HU)	Medium color (HU)	Minimum color (HU)	Organic matter (mg / L)	Maximum pH	Medium pH	Minimum pH	Maximum turbidity (NTU)	Medium turbidity (NTU)	Minimum turbidity (NTU)	Stream flow (m^3/s)
Average	92,3	216,6	167,6	118,2	4,4	8,3	8,2	8,1	46,9	29,2	18,1	3,7
Deviation	13,00	293,27	198,33	118,19	1,81	0,22	0,19	0,22	61,06	33,80	16,58	2,76
Coefficient of variation	14,1%	135,4%	118,3%	99,9%	41,5%	2,7%	2,4%	2,7%	130,0%	115,6%	91,4%	74,6%
Minimum	32,0	35,0	10,8	4,5	2,2	6,2	7,15	6,9	5,3	4,6	4,0	0,46
Maximum	110,0	2000,0	1400,0	1200,0	11,9	10,0	9,2	8,8	270,0	201,8	170,0	31,27
Range	78,0	1965,0	1389,2	1195,5	9,7	3,8	2,05	1,9	264,7	197,2	166,0	30,81

In this basin precipitation triggers erosive processes that eventually carry solid and organic matter into fluvial waters. These materials, mobilized by erosion, change the water colors and may reach, in the case of heavy rainfalls, values of Hazen unities higher than 2000 HU. Mining activities disturb large areas and expose earthen materials, so erosion and the subsequent transport of sediments to surface waters can be a major concern (Figure 3).

Figure 3. Exploitation of limestone

Moreover, there are several dirt roads in the rivers' neighborhoods with no proper protection for the riparian forest. During heavy rainfalls some roads are flooded (Fig. 4). This fact is common not only in Brazil, according to Daniels et al. (2010), and research that has been done in the USA has shown that 90 percent of the sediments that end up in that nation's waters from forested lands are associated with improperly designed and maintained roads.

The deposition of materials over river beds carried by the rain waters can cause siltation and ecological disturbances, burying small animals, plants or fish eggs, destroying them by suffocation and also the shelters needed for playback and can cause damage to fish and other aquatic animals too, especially for the benthic animals (Branco, 1987).

Figure 4. Flooded road

Changes in stream water color can occur by mineral or vegetable contaminations. It can be promoted by metallic substances, such as iron or manganese, humic substances, tannins, algae, aquatic plants, protozoa, organic and inorganic waste from industries as mining, refining, explosives, pulp and paper and chemical, among others. In environmental terms, the main effect of color change and turbidity in an aquatic environment is to reduce the penetration of sunlight and the consequent decrease of algae photosynthetic rate, lowering water oxygenation, mainly in streams with low turbulence (Branco, 1987). For natural waters, colors range from 0 to 200 HU (Hazen units). Those waters that are above this value normally belong to swamp or marsh environments with high organic matter contents (Porto et al. 1991). For the medium color we found medium values of 168 HU, but with a great range of variation: from 10 to 1400.

The pH of natural waters oscillates between 6 and 8.5, and lower values occur only in waters with high organic contents and the highest values occur in eutrophic, brackish groundwater and salt lakes (Chapman, Kimstack, 1992). In this study we observed a high average (8.3) which is not usual in Brazil, because most of the Brazilian waters show tendency to have smaller values, from neutral to acidic values. This fact can be explained by geological karstic substrata that influence the groundwater quality, and also by the exposure of uncovered mounds of rock powder (Figure 5).

Figure 5. Limestone deposits

The alkalinity of surface waters in Brazil rarely exceeds 500 mg-CaCO3.L-1 (Bittencourt; Hindi, 2000). Waters with low alkalinity (<24 mg / L as CaCO3) have low buffering capacity and therefore are susceptible to pH changes (Chapman; Kimstack, 1992). Some fish are very sensitive to changes in alkalinity, especially in their larval stage (Rojas Rochar, 2004). In this work we found values of alkalinity of 92.3, but with a large amplitude variation. Alkalinity rises in the same way as pH and in general, it follows pH. Fritzsons at al. (2009) observed that when fluvial waters are collected downstream over limestone open pits, alkalinity and pH were higher when compared with other upstream places, and this was clear even considering the changes in stream flow.

The result of principal components for eleven variables shows that two of them (maximum alkalinity and color) have "Eigen values" greater than one, accounting for 82.5% of the total variance. So, considering the statistical point of view, they are more important.

The chart with the components weights (Figure 6) reveals that:

1. Color (maximum, minimum and average), turbidity (maximum, minimum and average), organic matter and flow are positively correlated, because when the rate flow increases, also increase color, turbidity and organic matter. This happens for the reasons given above.

2. Alkalinity and pH (maximum, minimum and average) are negatively correlated with color (maximum, minimum and average), turbidity (maximum, minimum and average), organic matter and flow. So, when the flow rises, pH and alkalinity decrease. Thus, when there is heavy rainfall, or after it, there is an increase of stream flow and also in the dilution coefficient, which decreases pH and alkalinity. However, we have to consider that rainfall also triggers the erosion process.

3. The pH is correlated positively with alkalinity, that is, the more the water becomes alkaline, higher is the pH.

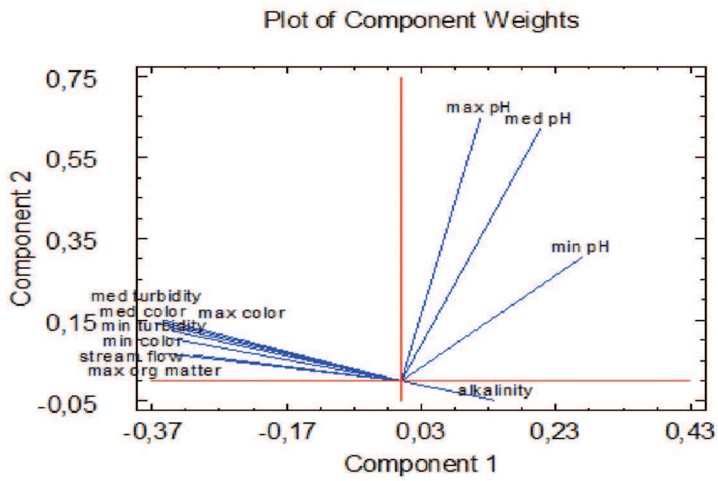


Figure 6. Chart of components weights

CONCLUSIONS

We concluded that in the study area water quality is strongly dependent on the variation of stream flows. So, due to the high coefficient of parameter variation, it becomes clear that sampling of water quality in this stream should be done frequently, especially during rainfall periods, because of the severe impairment of water quality during the changes of volumetric stream flow.

When stream flow is lower, water has high values for pH and alkalinity. When there are heavy rainy days, also increase the stream flow, turbidity and color values.

This fact makes evident the relative decrease of the contribution of the karst aquifer during periods of high flows, once the Capivari stream is strongly dependent on rainfall, in spite of the regulatory factor on fluvial flows exerted by the contributions by the karst aquifer.

Through the principal components analysis we found that in this watershed, turbidity, color, organic matter and flow are closely related, which indicates that rainfall triggers erosion too, with the an input of solid and organic matters to the river system.

We observed that in this basin there are many weak places that need to be repaired: the riparian forest is not enough to protect the fluvial waters, many roads are located beside rivers and the mining activities are leaving areas with bare soil. Considering these problems it is clear that we must implement effective land use planning and increase the riparian forest which, in Brazil, is protected by law.

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