Implementation of a Hydro-climatic Monitoring Network in the Guapi-Macacu River Basin in Rio de Janeiro, Brazil

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Abstract

Hydrology and water quality are dependent on many factors including climate, soil conditions, land use and land management. However, relative impacts of different land uses on hydrology and water quality are yet to be ascertained and quantified. A hydro-climatic monitoring network was designed and put into place in the Guapi-Macacu basin (1,265 km²) located in Rio de Janeiro (Brazil) within the Atlantic Forest biome. Three sub-watersheds with different land use distributions were selected as test areas where meteorological variables (precipitation, temperature, air humidity), water level together with water quality parameters are being measured. The collected data will be used to model the hydrology and the water quality using the J2000 and J2000-S models respectively.

Keywords: *Hydro-climatic monitoring, hydrology, water quality, modelling, Brazil*

1. Introduction

Hydrometeorological components, land use, soil properties and topography have an important impact on water regime in a drainage basin and together with the activity of organisms also an impact on water quality (Arreghini et al. 2007). However, among these factors, land use changes (e.g. deforestation, agriculture, forestry, urbanisation) can be regarded as the main driving force enhancing the current hydrological and water quality degradation trend.

Changes in land cover and in land use have become recognised over the last decades as important global environmental changes (Turner 2002). Besides having an impact on hydrology and water quality, land use changes are also interrelated with other important environmental issues, such as climate change and carbon cycle, loss of biodiversity, and sustainability of agriculture (Lepers et al. 2005).

Land use is determined by human needs, and the use of natural resources has been a general practice to fulfil such needs. However, by clearing tropical forests, intensifying farmland production, and expanding urban centres the world’s landscapes have experienced a strong environmental degradation (Foley et al. 2005). Temporal and spatial changes in the hydrologic cycle have also a strong influence on sediment and chemical transport, as well as on the variability of chemicals concentration.

Moreover, anthropogenic nutrient inputs, coming from fertiliser to increase agricultural production, have widespread effects on water quality and coastal and freshwater – both surface and groundwater – ecosystems (Foley et al. 2005). Negative impacts of excessive nitrogen loading include algal blooms, impairment of drinking water sources, eutrophication of freshwater ecosystems, hypoxia in coastal marine ecosystems (Nelson 2005).

The Brazilian Mata Atlântica (Atlantic Forest) has undergone, for centuries, serious environmental changes including deforestation, urbanisation and industrialisation. Deforestation has been appointed as an important environmental pressure within the region, since it is estimated that only 5-8% of the original 1million km² tropical forest still exists (BMBF 2002). Moreover, this tropical forest is not only important for carbon sequestration but is also considered as one of the world biodiversity "hot spots", which means that the region hosts a great variety of biological species.

Environmental monitoring can be defined as the observation in time of selected parameters to describe a system. This basic understanding of a system is necessary to identify changes and be able to propose ameliorative measures.

According to Brazilian Institute of Geography and Statistics (IBGE 2011) the calculated population and GDP growth rate in the most relevant municipality (Cachoeiras de Macacu) within the basin for the period 2000-2007 were of 1.3% and 7.7%, respectively. These growth rates represent further pressures on the water quantity and quality to the study region: the Guapi-Macacu basin (GMB). Flügel (2007) identifies the main consequences of such pressures:

(1) A growing population demands increasing food production but simultaneously rural and urban areas compete for increasing water supply.
(2) Expensive water diversion is required to sustain and even extend irrigation agriculture to alleviate poverty and improve livelihoods in rural areas.
(3) Fast growing cities need increasingly more water for their growing population and industrialized economic development.
(4) The worldwide recognised necessity to reserve water for the environment is becoming a further priority.

2. Research Area

The GMB is located within the state of Rio de Janeiro (Brazil), in the north east of the Guanabara Bay and the city Rio de Janeiro (Figure 1). It has a drainage area of around 1,265 km² and elevation ranges from the coastal plain until the mountain range Serra dos Órgãos at 2,250 m.a.s.l. (Fidalgo et al. 2009). The major streams, the Macacu and Guapiaçu Rivers, drain parts of the NE-SW trending Serra dos Órgãos, belonging to the northern part of the mountain range Serra do Mar. The Guanabara Bay and the river valleys of the GMB can be seen as a trench located between the horsts of the Serra dos Órgãos and the coastal shield. Moreover, the mountain range of the watershed covers species-rich relicts of the Atlantic Forest (Mata Atlântica).

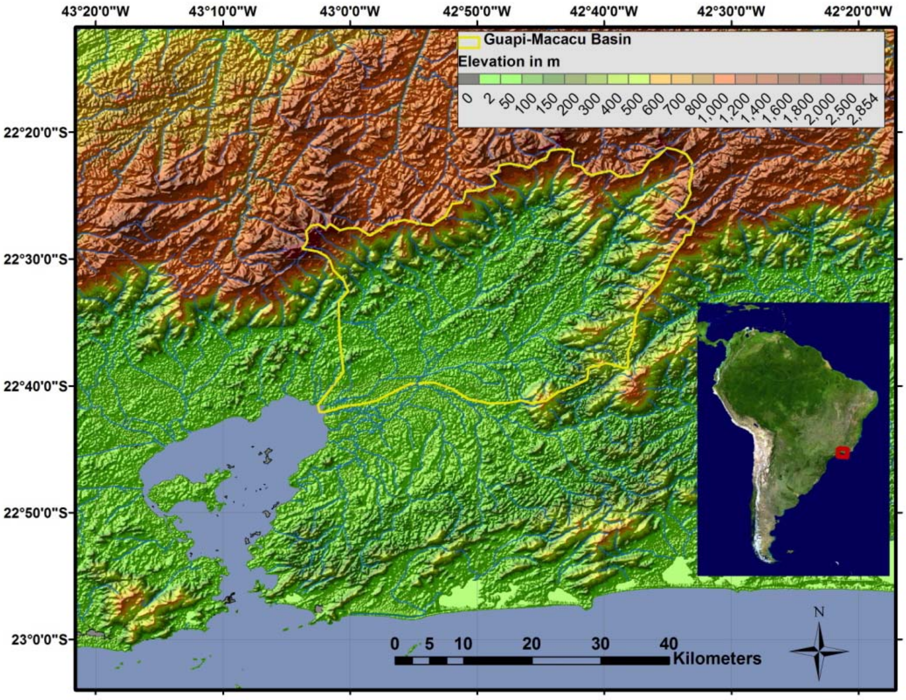

Figure 1: The yellow polygon shows the placement of the research area, the Guapi-Macacu watershed in Brazil (Data source: USGS/NASA SRTM by Jarvis et al. 2008 and Blue Marple Satellite Image by NASA 2002).

The regional climate varies within the basin. The plain coastal area in the southwest of the watershed shows higher temperatures and lower precipitation rates compared to the mountain range in the northeast. For instance, Rio de Janeiro (5 m.a.s.l.) representing the coastal weathering shows an annual average temperature of 22.6 °C and 1093 mm rain per year, while Nova Friburgo (856 m.a.s.l.), located in the mountainous region, has an annual mean temperature of 17.9°C and precipitation of 1,246 mm (after FAOCLIM, in Nehren 2008). The mean annual precipitation within the watershed varies between 1,200mm and 2,750mm (ANA 2011). The distribution over the year shows a maximum in the summer months from November until March and a minimum in the winter season (cf. Figure 2).

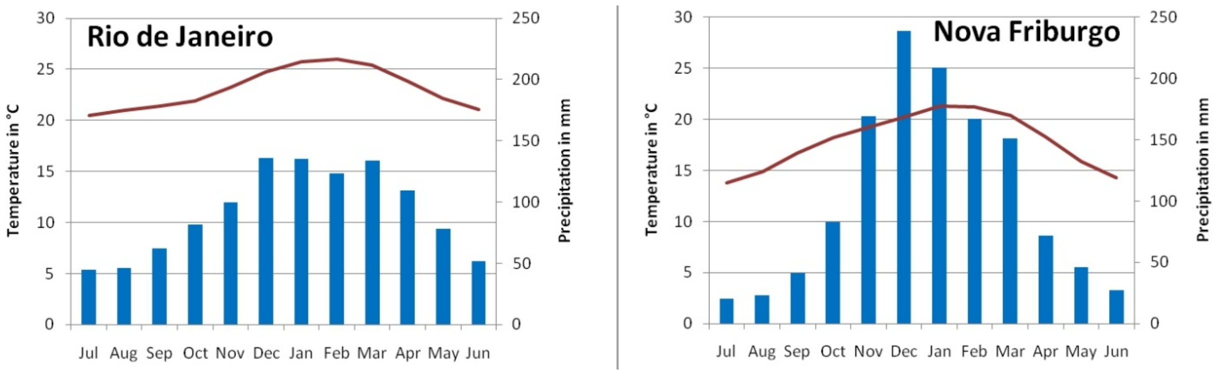

Figure 2: Yearly mean temperature (red line) and monthly precipitation (blue bar) at the weather stations Rio de Janeiro (5 m.a.s.l.) and Nova Friburgo (856 m.a.s.l.) (FAOCLIM, 2011).

The total population living within the basin is of 106,000 inhabitants. However, this basin plays an important role in the region since it supplies around 2.5 million people from the municipalities of Niterói, São Gonçalo, Paquetá and parts of Itaboraí with drinking water (Projeto Macacu 2010). Currently, the biggest petrochemical complex of Brazil (COMPERJ) is being constructed in the lower part of the basin. The expected social and environmental impacts are enormous: demographic explosion, urban and peri-urban growth, water consumption increase, and land use changes.

The dominant land use within the basin is forest (49%), followed by pasture (42%) and arable land (5%). The presence of urban areas is low (3%) being Cachoeiras de Macacu, Papucaia and Japuíba the biggest urban settlements. Other land use types in the watershed with lower proportions are mangrove and highland pasture (Fidalgo et al. 2009). This basin has many fragments of Atlantic Forest, including official Areas of Environmental Conservation.

Besides the alluvial sediments (Fluvisols) in the flood plain area of the GMB, the main soil types are Cambisols in the mountainous areas and Ferralsols in the lowland area. In the downstream area gleyic soils have developed due to periodical seasonal flooding (cf. Figure 3, Lumbreras 2010). Typical for tropical regions is the profound weathering of the substrate, controlled by climate factors, especially high humidity and temperatures. Due to the processes of ferralization and desilication, silicum compounds and cations such as Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} can be leached out. Such soils show a low cation exchange capacity (CEC) and therefore a poor nutrient content level (Scheffer & Schachtschabel 2010).

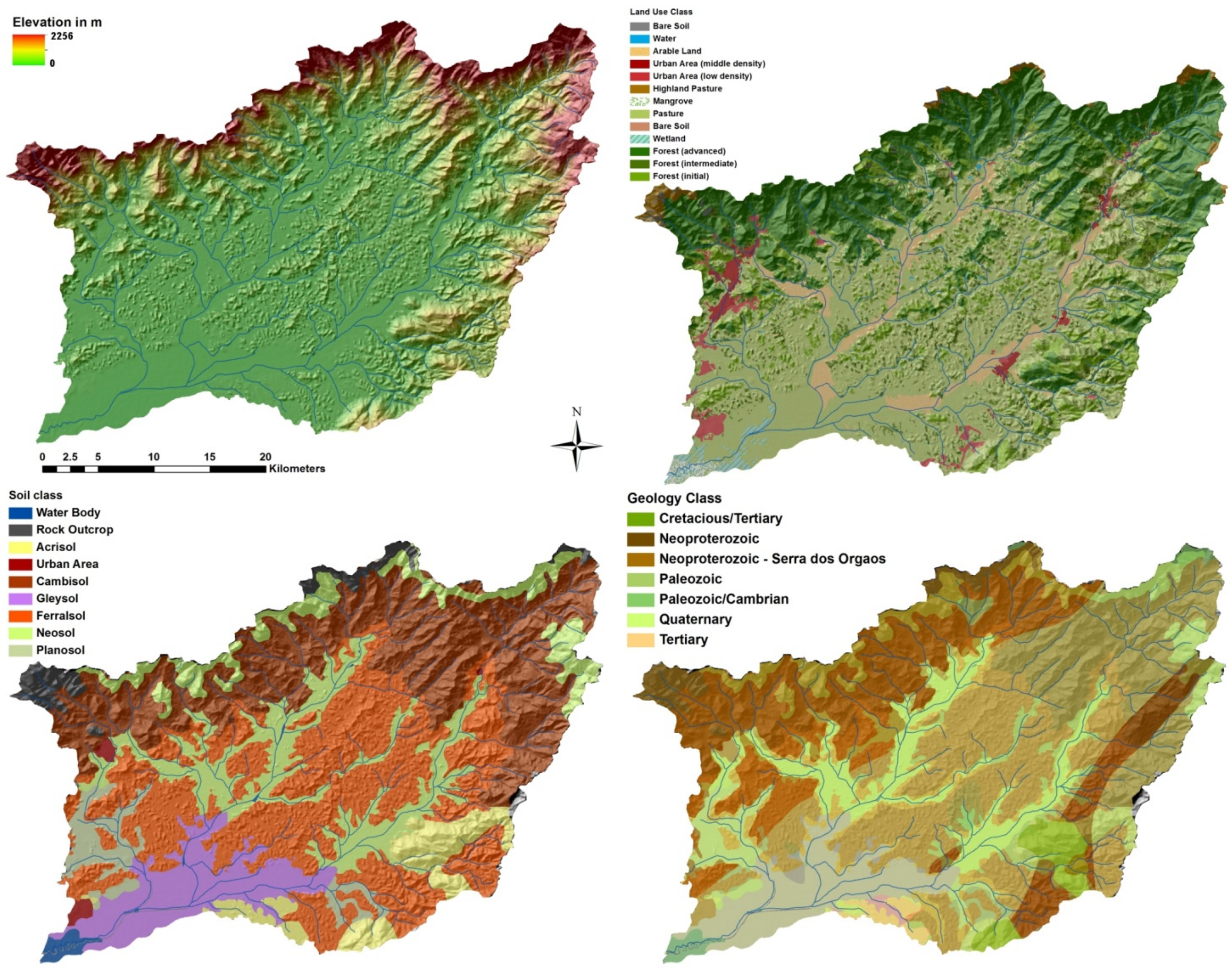

Figure 3: Overview of the different environmental conditions of the Guapi-Macacu watershed. Top left: Elevation (Source: Fidalgo et al. 2009), top right: land use classification (source: Embrapa 2008), bottom left: soil classes (Lumbreras 2010) and bottom right: geology classes (Projeto Macacu 2010).

3. Methods

Hydro-climatic and water quality monitoring is paramount to understand systematically the physical and chemical processes occurring within a watershed. Moreover, within the management cycle monitoring represents the basis upon which decisions are to be made. Strobl and Robillard (2008) define as crucial the identification of clear objectives and statistically acceptable assumptions while designing a monitoring network to avoid the “data rich but information poor” syndrome identified by Ward et al. (1986). In this paper, the main goal of the instrumented monitoring network is “to provide accurate meteorological, hydrological and water quality information as a basis to model the impacts of land use on hydrology and water quality”.

a. Sub-basins Selection

Three sub-basins were selected according to the most representative land uses of the whole GMB (see Table 1): Manuel Alexandre (MA), Batatal and Caboclo. The rationale behind was to monitor a sub-basin for each of the aforementioned most relevant land uses: forest, pasture, and agriculture. Together these uses account for almost 95% of the total area of the watershed (for location of the sub-basins compare Figure 4).

The sub-basins were also selected based on information gathered through field trips and expertise information provided by agricultural extensionists and local planners. Furthermore, logistical constraints such as ‘ease of access’ and ‘protection from vandalism’ were also taken into consideration.

The Manuel Alexandre River was selected as “background area” (Arreghini et al. 2007) or “reference basin” due to the predominance of forest and the low impact of human activities within the sub-catchment. In Caboclo forest is also the dominant use but according to the information provided by the director of the extension services in the region (EMATER) the agriculture practiced in this watershed is more intensive and the percentage of cultivated surface is also higher than the average for the GMB. Last, the Batatal sub-basin presents a mixture of the most relevant land uses with a higher proportion of forest followed by pasture. The size of the sub-basins fluctuates from 12.5 km² (Caboclo) to 32 km² (Batatal).

Table 1: Land use percentages and surface of the selected sub-basin and the GMB

Basin	Surface [km²]	Land Use [%]					
		Pasture	Arable land	Forest (Initial)	Forest (Intermediate)	Forest (Advanced)	Others
Batatal	31.8	23.7	3.1	23.9	28.8	20.5	-
Caboclo	12.5	7.5	8.9	1.2	6.2	76.2	0.1
MA	18.5	0.5	-	2.9	2.3	83.8	10.5
GMB	1,263.6	41.4	4.4	8.0	11.9	28.9	5.4

b. Meteorology

The available meteorological data for the region varies according to the required parameter. For instance, the density of the rain-gauge network consists of five active and six inactive stations (latter providing historical data) which corresponds to the LAWA recommendation (DVWK, 1994) and is higher than the one suggested by Schaake (1981). However, the network’s density monitoring of other meteorological variables (temperature, humidity, radiation, wind) is much lower. There are only three stations near the basin with historical data and four other new automatic stations also nearby (not within the basin) with information from the last five years.

None of the existing meteorological stations were located within the selected sub-basins. Therefore, meteorological stations in two of the three selected sub-basins (Batatal and Manuel Alexandre) were installed in order to better understand and describe the hydrological processes taking place (e.g. precipitation, evapotranspiration). Since the State Environmental Protection Agency (INEA) has two active rain-gauges in the neighbourhood of the Caboclo sub-basin, which are assumed to have similar climatic behaviour, no station was installed there. The installed stations measure relative humidity, air temperature (hourly) and precipitation (every ten minutes). Moreover, an extra meteorological station was installed in the middle part of the GMB to also monitor, besides the aforementioned variables, radiation, soil temperature as well as wind speed and direction. This information will be used to regionalise the modelling results for the whole GMB.

c. Hydrology

One of the main goals of the study is to understand the hydrological response of GMB to climate factors (e.g. precipitation, evapotranspiration) as well as to different environmental conditions. Therefore, a hydrometric monitoring network consisting of a water level logger within each of the three test sub-watersheds was implemented. The installed sensors measure the water level on a frequency of ten minutes. Every two months discharge is measured manually with a current meter in order to calculate the rating curve. The location of the installed water level logger stations is shown in figure 4. The information collected by the meteorological stations will be used to build a relationship between the climate variables and the levels registered.

d. Water Quality

Water quality in a catchment is highly variable both in space and time because the driving processes (e.g. precipitation, pollution sources, discharge) vary spatially and temporary (Walton and Hunter 2009). Measured water quality data at any point in the stream reflects an integration of upstream processes. Therefore, unless a catchment is small enough for the hydrological processes to be homogeneous and the data is continuous, monitoring data alone is insufficient to isolate the different water quality processes (Walton & Hunter, 2009).

Thus, an ideal water quality monitoring network should include multiple sites, each one of them monitoring small homogenous sub-watersheds on a continuous basis. In practice, most water quality monitoring data is both non-representative and non-continuous. Logical and financial constraints limit the number of monitoring stations while accessibility defines often the site locations (Walton & Hunter, 2009).

A water quality network was designed to monitor the three selected sub-watersheds and also other sampling points within the GMB. Although the sub-watersheds are not small enough to be homogeneous in relationship to soil type, land use, climate, etc. their size allows an increase in the spatial resolution of the water quality monitoring network. The monitoring concept within the sub-watersheds was to measure in up-, middle, and downstream to assess the water quality evolution from up- to downstream. However, in Manuel Alexandre, due to the accessibility and a more homogenous land use, only one sampling site at the outlet of the watershed was selected. As mentioned before, this site will be taken as reference or background since the upstream main land use is almost exclusively forest.

Domestic wastewater within the GMB is directly discharged into the streams. Until now, there is no information available on the load discharged into the water bodies. Therefore, to estimate influence of wastewater on water quality two sampling points were added. These sampling points are located before and after Cachoeiras de Macacu, the most important urban settlement of the GMB.

In addition, another site was selected at the Guapiaçu River short after an intensive crop production area and where an existing INEA streamflow measuring station is located. This station will provide data for the regionalisation of the modelling results for the whole GMB. Last, another sampling site was located where the Drinking Water and Wastewater State Company (CEDAE) (see Figure 4) has a small dam to divert water to a pumping station to provide almost 2.5 million people with drinking water. This point was chosen since historical measured water quality data is available.

The monitoring network includes 11 sampling sites (see Table 2 and Figure 4) and the following parameters are being measured:

- Electrical conductivity (EC), pH, dissolved oxygen (DO), and temperature using a multi-parameter sampler Hanna (HI9828), *in situ*
- Turbidity using a Hach Lange Turbidimeter 2100P ISO, *in situ*
- Nitrate ($N-NO_3^-$), nitrite ($N-NO_2^-$), ammonia ($N-NH_4^-$), total nitrogen (TN), ortho-phosphate ($P-PO_4^-$) and total phosphorous (TP) using a Hach Lange DR2800 spectrophotometer at the laboratory.
- Total Dissolved Solids (TDS) and Total Suspended Solis (TSS) based on the gravimetric method (APHA 2005)
- Cations using ICP

Table 2: Water sampling locations in GMB

Site Code	Name
MA	Manuel Alexandre
CN	Caboclo Nascente (Upstream)

CM	Caboclo Meio (Middle-stream)
CB	Caboclo Baixo (Downstream)
BN	Batatal Nascente (Upstream)
BM	Batatal Meio (Middle-stream)
BB	Batatal Baixo (Downstream)
MACN	Macacu Nascente (Upstream)
MACB	Macacu Baixo (Downstream)
G	Guapiaçu
CEDAE	CEDAE

The measuring frequency is a vital variable while designing a monitoring network. As mentioned before, there is an ideal monitoring frequency which allows representing with statistical confidence the variability of the selected parameters. However, logistical and financial constraints often oblige monitoring programmes to reduce this frequency. In the implemented water quality network the parameters are measured *in situ* and water samples are collected to be analysed at the laboratory on a bi-monthly basis. This frequency will help to understand the seasonal changes taking place at the GMB.

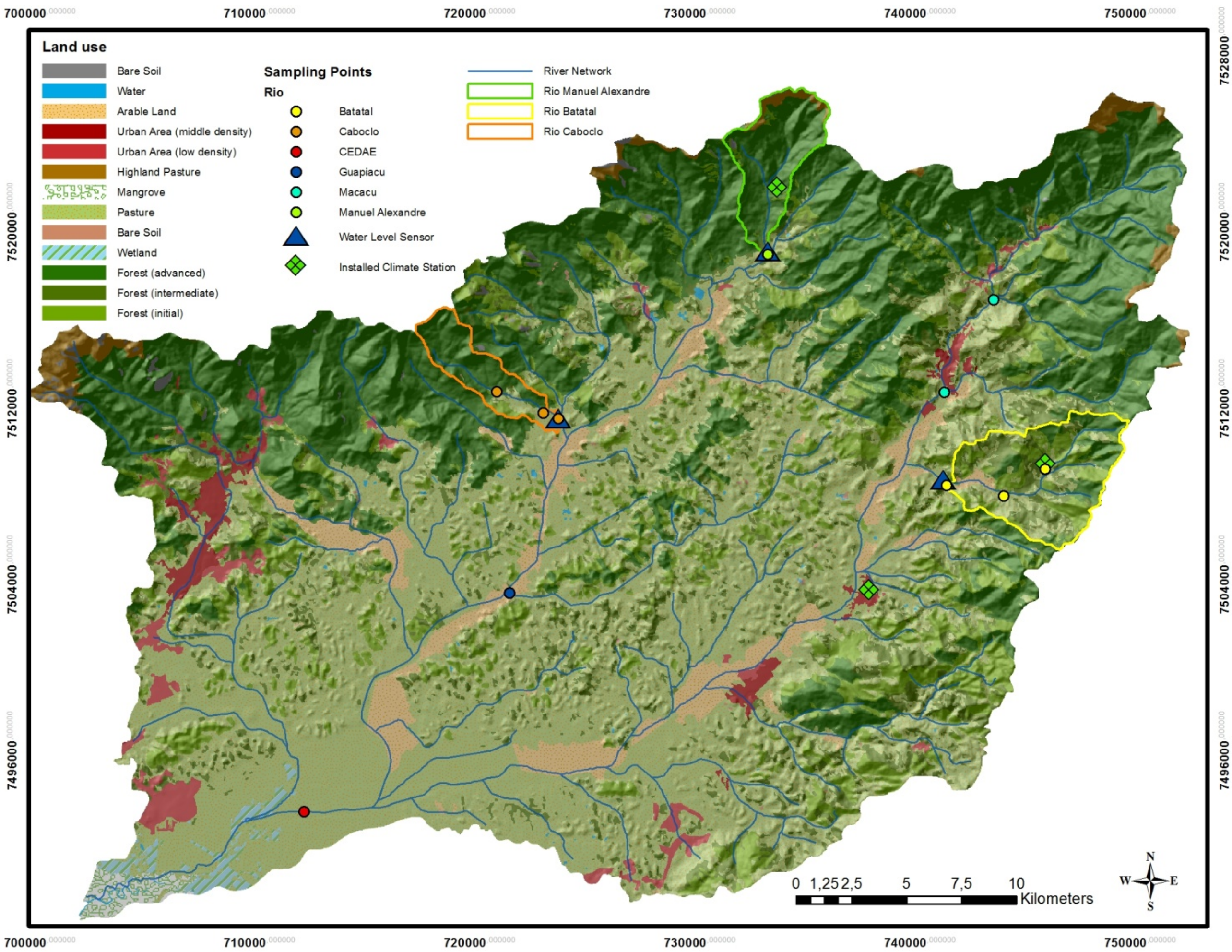

Figure 4: Monitoring network in the Guapi-Macacu basin (Corrego Alegre/UTM Zone 23S). Besides the instrumentation of the sub-basins Batatal (yellow), Caboclo (orange) and Manuel Alexandre (green) four sampling points are located within the main rivers and one climate station close to the Macacu river.

e. Modelling concept

A physically-based and fully distributed hydrological model (J2000) developed by Krause (2001) to understand and describe the hydrological processes taking place at the basin level was applied in this study. J2000 was designed for dynamic simulations of water transport in meso- to macro-scale river basins (Krause 2001). The water pathways are calculated on the basis of the Hydrological Response Units (HRUs). HRUs are computational units with homogeneous land use and pedotopogeological characteristics controlling the water dynamics (Flügel 1996). The spatial distribution concept of HRUs provides the possibility to simulate land use changes, even on the field scale. For this study the environmental conditions of the GMB (land use, topography, geology, soil type) (see Figure 3) were taken into account to generate the HRUs. Due to a topological routing scheme (Staudenrausch 2001) the lateral water transport processes can be simulated between the HRUs until the reach of the river.

Fink et al. (2007) worked on the enhancement of the J2000 into the J2000-S model to widen the scope of hydrological simulation to the area of water quality. J2000-S is a further development of the J2000 model combined with nutrient transport routines of the semi-distributive Soil Water Assessment Tool (SWAT) (Arnold et al. 1998). The models work within the Java-based modelling framework JAMS (Jena Adaptable Modeling System; Kralisch & Krause 2006; Fink et al. 2007). The modular and object orientated structure of the modelling system allows a customised selection or adaptation of the components, like for example the choice between different evapotranspiration equations or modifications depending on data availability.

The first step was the hydro-climatic data, water quality and spatial data acquisition. Historical time series are needed to calibrate and validate the models. The Brazilian National Water Agency (ANA) provides precipitation and water level data (ANA 2011). INEA is responsible for the maintenance and the administration of the monitoring network within the GMB. On the other hand, the National Meteorological Service (INMET) has six further climate stations with different length of time series close to the GMB, but free access is only available for three stations. Due to the lack of discharge information in the lower part of the GMB, it is not possible to validate the modelling results for the whole basin. Hence the discharge information available at the lowest stations for each of the main rivers (Guapiaçu and Macacu) will be modelled and then extrapolated for the whole GMB.

The modelling concept will follow two main approaches. On one hand, the models will be calibrated and validated for the Macacu and Guapiaçu rivers using the observed runoff at the mentioned gauge stations from INEA. On the other hand, hydrology and nitrogen transport of the three test sub-catchments will be modelled based on the information obtained through the monitoring network. The modelling will be done for these smaller basins with a higher temporal and spatial resolution to better understand the hydrological dynamics as well as the water quality processes in the region. The simulation of the test basins allows a comparison of the performance of the two approaches.

f. Model input data and parameterisation

The spatial distribution concept needs the following input data to delineate the HRUs: a digital elevation model (DEM) to derive elevation, slope and aspect, as well as soil, hydrogeology and land use types. Following data were used in this study: a) 30m x 30m DEM (Fidalgo et al. 2009), b) 1:250,000 soil map (Lumbreras 2010), c) 1:50,000 land use map (Fidalgo et al. 2008), d) 1:250,000 geology map from the Projeto Macacu (Projeto Macacu 2010).

The hydro-climatic input data consist of precipitation, climate variables and discharge. Climate data requirements to calculate evapotranspiration depend on the equation used for this purpose. Furthermore, observed runoff is needed to calibrate and validate the model.

J2000 and J2000-S put special focus on the modelling of soil water balance of the unsaturated soil zone. Hence regarding soil characteristics at least physical soil attributes like depth, texture and bulk density are needed to delineate soil conductivity, sum of field and air capacity per each decimeter of the soil profile.

These parameters are necessary to calculate the amount of water infiltration, interflow and percolation. In this study the soil parameters were derived from soil analysis data performed by the Projeto Macacu (2010) as well as data from SOTERLAC Database (Dijkshoorn et al. 2005).

For the nitrogen transport modelling, J2000-S requires further data like land use management practices (e.g. crops, crop rotation, fertilisation, tillage, harvesting), as well as information about organic carbon content and bulk density of every soil horizon to calculate nitrogen transformation processes in the soil zone

4. Initial Results and Discussion

The measured hydro-climatic data from each sub-watershed shows a different behaviour regarding precipitation rates as well as the water level response dynamic (see Figure 5).

At first sight, all rivers show a response to the rain events within the respective catchment. Differences between the three rivers can be seen in the base level height, in the dynamic of water level rise and fall as well as in the amplitude. The base level height of Manuel Alexandre River (green line) is higher than the other two rivers. The highest rain rate events occurred in the Manuel Alexandre sub-basin, with a ten-minute maximum of 18.3 mm. The hydrological response can be seen in the form of direct rise in water level of 0.5m, after one hour and 20 minutes. On the other hand, precipitation rates within the Batatal sub-basin are much lower as well as the water level's response. Even though there is no precipitation information yet for Caboclo (INEA uploads the rain-gauge data every 6 months) it can be assumed that rain events occurred during the same time by observing the water level dynamic which shows the highest amplitude (around one meter) followed by Manuel Alexandre, whereas Batatal reflects a much lower dynamic. This behaviour may be explained through the narrowness of the Caboclo basin which provokes a much faster and sensitive hydrological response to precipitation events while the Manuel Alexandre catchment has more side valleys. In contrast, in the Batatal sub-basin hydrological response seems to be delayed due to the greater extension of the basin and the presence of side valleys (cf. Figure 5).

The different water level responses can be explained through the land use types. From the 25th until 28th of April rainfall occurred in all test sub-basins. Although the Manuel Alexandre and the Caboclo basins have similar topographic features the observed changes of water level were higher in Caboclo as in Manuel Alexandre. This fact may be due to the hydrological buffer function of forest (Mark & Dickinson 2008) in Manuel Alexandre. However, more research and longer time series are needed to underline these assumptions.

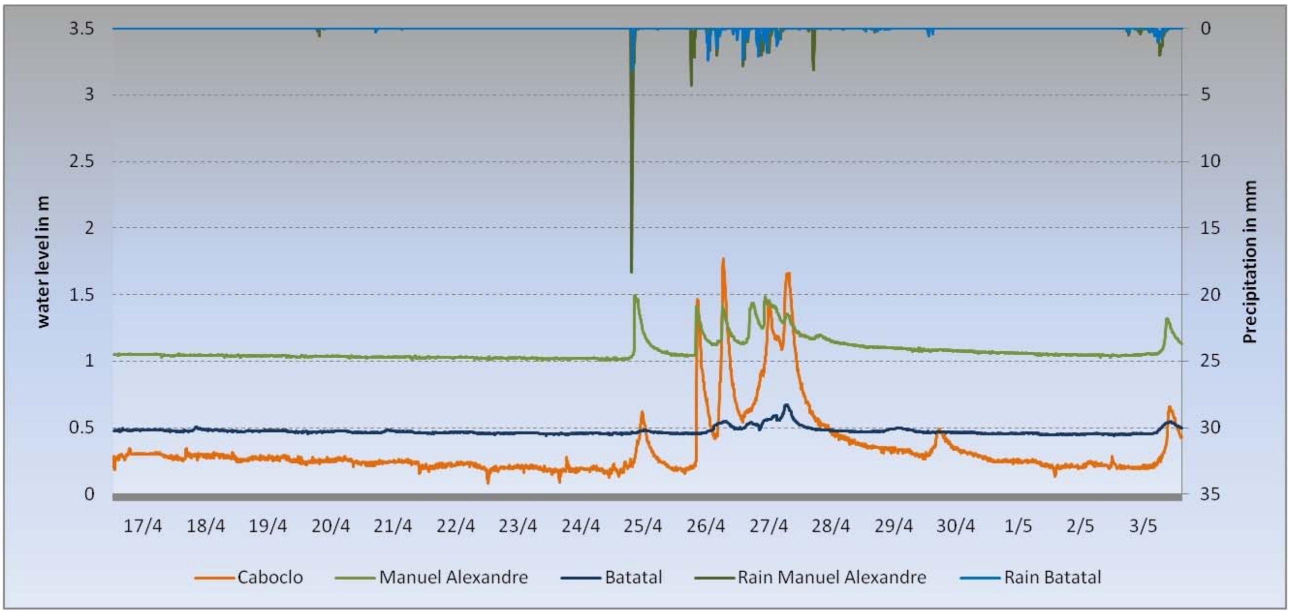

Figure 5: Water level at the measuring stations of Batatal (blue line), Caboclo (orange line) and Manuel Alexandre (green line) and precipitation of the climate stations in the catchment of Manuel Alexandre (dark green bars) and Batatal (blue bars) from 16th of April 2011 until 3rd of May 2011.

The first results of the water quality monitoring are also available. The median was used instead of the average since several authors (e.g. Arreghini et al. 2007, Edmunds et al. 2003) appoint it as more robust and less prone to be affected by outliers. The water quality measurements (presented in Table 3) from the monitoring network show that downstream sampling points in each sub-watershed as well as in the GMB present higher electrical conductivity values. All sampling points present higher DO values than what is required by the Brazilian National Environmental Council (CONAMA) (>6,0 mg·l^{-1}) being CEDAE the lowest one (6.1 mg·l^{-1}). Furthermore, in all sampling points the values of TDS are higher than the ones measured for TSS which may indicate that the source of runoff is mainly baseflow and interflow (Brinkmann 1983).

Table 3: Main physical and chemical variables measured at the sampling sites in GMB

Site		TSS	TDS	TP	TN	DO	EC
		[mg·l^{-1}]	[mg·l^{-1}]	[mg·l^{-1}]	[mg·l^{-1}]	[mg·l^{-1}]	[µS·cm^{-1}]
MA	Median	1.4	21.6	0.02	0.31	8.4	13.0
	Min	0	4.4	0.01	0.30	6.4	7.7
	Max	5.6	53.6	0.04	0.74	15.2	20.7
	N	6	6	4	3	7	7
CN	Median	1	30.4	0.03	0.40	8.9	21.7
	Min	0.4	0.4	0.01	0.25	7.4	17.0
	Max	7.2	76.8	0.08	1.00	15.3	24.0
	N	6	6	4	3	7	7
CM	Median	2	44.9	0.02	0.38	9.3	25.0
	Min	0	7.2	0.01	0.32	8.7	20.0
	Max	10.8	59.6	0.04	0.59	18.4	30.7
	N	6	6	4	3	7	7
CB	Median	2.2	45.1	0.06	0.93	9.2	32.3
	Min	0	13.6	0.04	0.74	8.5	24.0
	Max	17.6	72.4	0.08	1.23	18.4	39.3
	N	6	6	4	3	7	7
BN	Median	0.8	11.3	0.03	0.51	8.5	16.7
	Min	0	0.0	0.01	0.17	3.5	11.0
	Max	2.4	52.4	0.03	0.75	16.7	22.0
	N	6	6	4	3	7	7
BM	Median	0.6	22.9	0.02	0.12	8.8	19.3
	Min	0	7.2	0.01	0.03	5.5	13.0
	Max	4.4	48.0	0.02	0.44	16.9	21.3
	N	6	6	4	3	7	7
BB	Median	3	30.4	0.03	0.70	7.9	25.0
	Min	0	1.6	0.02	0.05	2.8	13.3
	Max	12	48.0	0.05	0.71	17.5	27.0
	N	6	6	4	3	7	7
MACN	Median	0.4	32.9	0.02	0.25	7.9	19.0
	Min	0	9.6	0.01	0.08	2.9	15.0
	Max	8.4	50.8	0.09	1.77	17.7	74.0
	N	6	6	4	4	7	7
MACB	Median	3	36.2	0.03	1.11	8.2	33.0
	Min	0.8	17.2	0.01	0.27	6.6	27.0
	Max	28	58.4	0.06	2.68	13.2	185.0
	N	6	6	4	4	7	7
G	Median	12.12	35.2	0.08	0.86	8.7	30.5
	Min	0	15.4	0.02	0.31	7.3	24.0
	Max	27.2	59.6	0.10	1.54	16.2	33.7
	N	6	6	4	4	7	6
CEDAE	Median	24.2	58.6	0.07	1.20	6.1	36.0
	Min	0	4.8	0.06	0.48	5.5	32.0
	Max	57.6	109.2	0.10	3.70	10.4	42.7
	N	6	6	4	3	7	7

TSS = Total Suspended Solids, TDS = Total Dissolved Solids, TP = Total Phosphorous, TN = Total Nitrogen, DO = Dissolved Oxygen, EC = Electrical Conductivity. Refer to codes for the stations (Table 2)

Moreover, the points located at the outlets or lower parts of the watersheds show relative higher values of TSS which may be explained through erosion taking place at the basin. In the case of nutrients the values are relatively low if compared to what is established by the Brazilian law. However, the influence from agriculture and urban settlements can be identified since the lower sampling sites show higher values of TN and slightly of TP as well.

5. Conclusion

The monitoring network was designed to provide accurate information as the basis for the hydrological and nitrogen modelling. The first results show heterogeneous hydrologic responses within the selected sub-basins. This may be explained through the topography as well as the land coverage. However, these hypotheses are yet to be ascertained with the longer time series and the support of the hydrological modelling. On the other hand, water quality shows already different parameter values at the 11 sampling points. The influence of agriculture and urban settlements has already been captured by the monitoring network. Nevertheless, still more data is needed to better describe with a higher confidence how the system behaves. Data from agriculture management is yet to be collected to gain understanding about the processes affecting water quality.

The monitoring network design intends to isolate the influence of land use on the hydrological and water quality response. However, due to the heterogeneity of the GMB it was not possible to define a test sub-basin for only one land use. Therefore, it is now necessary to couple other methods to reduce uncertainties during the modelling. The physically based model parameterisation will help to achieve this task. Studies like the one from Walton and Hunter (2009) are also helpful using other tools (model calibration) to isolate the impact of different land uses.

The calibrated models will be physically based management tools which will help regional water planners to adapt to future more demanding conditions. The construction of the COMPERJ is expected to have a relevant impact on water consumption but also on crop production and water resources pollution. CEDAE is using the water from this basin to supply 2.5 million people with drinking water. The models can give information on the quantity and quality of water which could serve for cost planning purposes. Moreover, the impact of climate change, different land production practices or future land use changes on water resources can be assessed using the models.

Based on the results coming from the modelling the monitoring network can be adapted (see the monitoring cycle UN/ECE 2000) to continue to provide valuable information and according to the objectives. The binomial monitoring/modelling can be a powerful tool to achieve an understanding hydro-chemical processes and a sustainable management of water resources.

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