ISBN 978-85-5953-031-5
https://doi.org/10.26626/978-85-5953-031-5.2018B001

Water Resources Management

Takako Matsumura-Tundisi
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(Editors)

EDITORA
SCIENZA

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W3242 Water Resources Management / Takako Matsumura-Tundisi, José Galizia Tundisi (Editors). São Carlos, 2018.

248 p.

ISBN 978-85-5953-031-5

https://doi.org/10.26626/978-85-5953-031-5.2018B001

1. Limnology. 2. Water management technology. 3. Aquatic biodiversity. 4. Pollution control. I. Org. II. Título.

CDD 570

Editoração, Revisão e E-pub:

Rua Juca Sabino, 21 – São Carlos, SP

(16) 3364-3346 | (16) 9 9285-3689

www.editorascienza.com.br

gustavo@editorascienza.com

Acknowledgements

The Editors acknowledge the finantial support of FAPESP for this publication (Process: 2016/18658-0), the Brazilian Academy of Sciences (ABC) and the Inter American Network of Academies of Science (IANAS) which provided support for the SÃO PAULO ADVANCED SCHOOL ON INTEGRATED WATER RESOURCES MANAGEMENT and for this book.

Contents

Foreword

One of the priorities of the Water Program of the Interamerican Network of Academies of Sciences (IANAS) is contributing to and organizing capacity building activities for future scientists, managers, and policy-makers on water resource management. Transmitting knowledge to future generations is part of the mission of IANAS as the Science Academies of the Americas are concentrated on aiding national governments and institutions in the respective countries in introducing improved water resource management practices to guarantee the rational and sustainable exploitation of this resource in all of the Americas and especially in developing countries.

This special course, “Sao Paulo Advanced School on Integrated Water Resources Management” organized by the International Institute of Ecology (IIE) of Brazil and supported by the Foundation of Support for Research of the State of Sao Paulo (FAPESP) brought together 100Msc. or PhD students from different institutional origins, universities, NGO´s, government and water companies, who were all specialists in different aspects of water resources from 24 different countries of Latin America, North America and Africa. Top global scientists from UNESCO, universities and IANAS, all specialists from diverse fields of water resource management: water ecosystems, limnology, urban water management, and more were involved as professors. Current special topics on water management such as the relationship between water and other resources (energy, agriculture and food security, mineral extraction), waste water reuse and improvement of treatment systems, the management of actual global water quality problems, the importance of the water and sustainable development goals and more were presented in the two weeks.

This course not only had a very rich formative objective but also promoted international cooperation between students and professors which is of utmost importance in a changing world with great needs for new global initiatives in developing effective strategies for improving water management. There was active interchange on new research methodologies and applications.

The new knowledge gained by this international group of young professionals in water resources will help form an up to date scientific and managerial approach to their work and undoubtedly bring multiplying effects to deal with future water resource problems internationally and to achieve considerable improvements in access and sanitation as oriented in the Sustainability Development Goal 6 in their countries.

This publication is the expression of this active interchange between participants of the Course and includes research papers from students and scientists.

Prof. Katherine Vammen

Chairwoman-Water Comittee InterAmerican

Network of Academy of Science (IANAS)

Preface

From 1st to 15th of September 2017, 100 MsC and Ph.D students from 21 countries, participated in São Carlos, São Paulo State, Brazil of an Advanced Course in Integrated Water Resources Development sponsored fully by the São Paulo Research Foundation (FAPESP). The aim of this course was to promote a complete overview and systemic approach to the management of water resources a critical trouble of the 21st Century. Eleven specialists from Brazil, Colombia, Poland, Venezuela and the Director of The UNESCO International Hydrological Program, participated as lectures of this process in Limnology and Aquatic Ecosystems to the Management of Water Resources. Scientific and Technological approaches were developed.

The Course consisted of lectures, discussions, field work, and a poster exhibition in the Final Day.

This book is a contribution of the students and research workers that participated in the event, and it is one of the products of the training activity.

We are extremely indebted to SABESP that provided photos, and registered all lectures and field work.

Other sponsors were Imobiliária Cardinalli, Latina, Airship Brazil, Distribuidora Modenutti, all from São Carlos.

Hotel Nacional Inn was an extremely important support for the course since provided adequate facilities, very good accommodation and recreation sites.

This training activity was undoubtedly only possible with the full support of FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo) to which Dr. Takako Matsumura-Tundisi the course coordinator is extremely indebted. (FAPESP – Process Nº 2016/18658-0.

This was also a joint activity of IANAS (Inter-American Network of Academies of Science) and Brazilian Academy of Sciences (BAS).

Dr. Takako Matsumura Tundisi

Dr. José Galizia Tundisi

Editors

https://doi.org/10.26626/978-85-5953-031-5.2018C001

Diatoms as Indicators of Anthropogenic Changes in Water Quality in Mucheke and Shagashe Rivers, Masvingo, Zimbabwe

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Abstract

The most widely used method of water quality assessment, physical and chemical variables assessment is less reliable compared to the use of biological methods such as diatom assemblages. The objective of this study was to (1) assess response of diatom assemblages to anthropogenic changes in water quality in two rivers that drain an urban area in Masvingo, Zimbabwe, (2) test the applicability of the Trophic diatom index (TDI) and Pampean diatom index (PDI) in assessing water quality in the study area. Water quality sampling and benthic diatom community data were collected in May to July 2012 from nine sampling stations in the Mucheke and Shagashe Rivers, Zimbabwe.The data were subjected to canonical correspondence analysis (CCA) to determine environmental gradients along which the diatom species were distributed. Diatom-based biotic indices i.e. the TDI and PDI were used to determine the ecological status of study streams in relation to human-induced stressors. Pearson's correlation was used to determine the relationship between the calculated index scores and measured physical and chemical water quality data. Two-way ANOVA was used to compare these correlation values among sampling stations. The PDI and TDI scores on all the sampling sites showed significant correlations with physical and chemical variables. Thus, the indices proved useful in providing an indication of the quality of the investigated waters. No significant differences in physical and chemical variables were recorded between the three sampling periods. Diatom community structure closely reflected this gradient, with communities from polluted sampling stations (U1, U2, U3, U4 and U5) being different from other communities. Polluted sampling stations were associated with pollution tolerant species such as *Diatoma vulgaris, Nitzschia palea, Fragilaria biceps, Achnanthes exigua* and *Cymatopleura solea*. Diatoms communities demonstrated potential for acting as indicators of changes in water quality due to organic and industrial pollution and are therefore recommended for use in research and monitoring of water bodies by relevant governmental and non-governmental organizations in Zimbabwe.

Keywords: diatoms, biological monitoring, pollution, water quality, diatom indices.

Introduction

The success of human civilization is largely due to our skills as ecosystem engineers (KIM; WEAVER, 1994). Although these engineering activities are primarily directed towards achieving some specific purposes (e.g. industrial production), most have major indirect and unintended effects on ecosystems (TANNER, 2001). Freshwater ecosystems are among the most endangered ecosystems in the world and the decline in freshwater biodiversity is far greater than in most affected terrestrial ecosystems (DUDGEON *et al.*, 2006). Disposal of human waste has now become one of the greatest challenges of urbanization in both developed and developing countries (BERE, 2007; BEYENE *et al.*, 2010). This problem is more severe in developing countries like Zimbabwe where rapid urbanization, coupled with rapid population growth, is not matched by associated technical standards for systems such as sewage treatment, collection of garbage and urban drainage due to economic problems and socio-political bewilderments (DUBE; SWATUK, 2002; BERE; MANGADZE, 2014; MANGADZE *et al.*, 2016; MWEDZI *et al.*, 2016). In such instances, waterways are used for disposal of sewage and industrial effluent leading to problems such as the eutrophication and organic pollution (HARPER, 1992; BERE, 2007).

Two threads of basic approaches to the assessment of water quality deterioration in streams run through the literature; physical and chemical methods and biological methods (BERE; TUNDISI, 2010). Physical and chemical methods provide, at best, a fragmented overview of the state of aquatic systems, as sporadic or periodic sampling cannot reflect fluxes of effluent discharge (TAYLOR *et al.*, 2007b). The chemistry at any given time is a snapshot of the water quality at the time of sampling ignoring temporal variation of water quality variables that is usually high in streams (TAYLOR *et al.*, 2007b). In contrast, biological monitoring(the theory behind which decoding environmental change information enshrined in biota) gives a time-integrated indication of the water quality components because of the capacity of reflecting conditions that are not present at the time of sample collection and analysis (KARR, 1981; TAYLOR *et al.*, 2007b). Biological monitoring is a fast and cost effective approach for assessing the effects of environmental stressors, making it a particularly essential tool for the management of rivers in developing countries (ROUND, 1991).

Benthic diatoms are amongst the commonly used biological indicators because they offer several advantages compared to other potential biological indicators like fish, macro invertebrates and plants (HARDING *et al.*, 2005; BERE, TUNDISI, 2010; SMOL; STOERMER, 2010). Diatoms, a type of uni-cellular algae, have a short developmental cycle (a few hours to several days), depending on species and environmental conditions, a rich species composition and wide distribution thus making them ideal for bio-monitoring (RIMET, BOUCHEZ, 2011). Changes in water chemistry will inhibit the multiplication of some species, while supporting that of others (tolerant species), thus the percentage composition of certain species within a community will be changed (WERNER, 1977). Diatoms are sensitive to changes in nutrient concentrations i.e. growth response is directly affected by changes in prevailing nutrient concentrations and light availability (ROUND, 1991; SMOL, STOERMER, 2010; WOOD *et al.*, 2016). Each taxon has a specific optimum and tolerance for nutrients such as phosphate and nitrogen, and this is usually quantifiable. While diatoms collectively show a broad range of tolerance along a gradient of changes in water quality, individual species have specific water chemistry requirements (SMOL, STOERMER, 2010; HARDING, TAYLOR, 2011). Up to 70% of what happens to water quality can be reflected in diatom assemblages (TAYLOR *et al.*, 2007a). Although over the last few decades a number of biological monitoring methods have been developed for the assessment of water quality in streams, these have rarely been applied in Africa, especially in Zimbabwe (PHIRI *et al.*, 2007; BERE; MANGADZE, 2014; MANGADZE *et al.*, 2015, 2016). For instance, diatom-based water quality assessment protocols have been developed and used extensively elsewhere but with little use in Zimbabwe.

Isolated cases where attempts have been made to assess water quality using diatoms rely heavily on information from other countries. However, there is evidence that this information is less successful when applied in other areas (PIPP, 2002). This is due not only to the floristic differences and occurrence of endemics among regions, but also to the environmental differences that modify species responses to water-quality characteristics (POTAPOVA, CHARLES, 2002; TAYLOR *et al.*, 2007b). The first objective of the present study was to assess response of diatom assemblages to anthropogenic changes in water quality in two rivers that drain an urban area in south-eastern Zimbabwe. The second objective was to test the applicability of PDI and TDI in assessing water quality in the study area. In particular, we asked: (1) to what extent observed changes in water quality reflect themselves in diatom communities in the study streams and (2) to what extend PDI and TDI metrics detect changes in water quality in the study streams. We hypothesised that diatom communities are capable of reflecting changes in water quality, with PDI and TDI metrics being sensitive to water quality changes in the study region because of occurrence of ubiquitous taxa that probably have similar environmental tolerances to those recorded for these two indices.

Materials and Methods

Study area

The area under study is located in the southern parts of Zimbabwe (Figure 1) in the Runde catchment area. The two study rivers, Mucheke and Shagashe, fall in a subtropical steppe/low-latitude semi-arid climatic region were the average temperature and rainfall patterns are 19.4°C and 623 mm per annum. Headwaters of the study rivers fall mainly within an agricultural area where crop production and animal husbandry is practiced. From the agricultural area, the streams pass through urban area of the city of Masvingo, a medium-sized city with a population of 88 554 (Zimbabwe National Statistics Agency – ZNSA) located at the confluence of these rivers. Due to rapid population growth, that is not matched by upgrading of systems such as sewage treatment, collection of garbage and urban drainage due to economic problems and socio-political bewilderments, the capacity of municipal sewage treatment facilities has been exceeded. Poor maintenance and breakdowns of these facilities is also very common because of the financial constrains currently facing the municipality. Options that are available for sewage treatment such as biological nutrient removal plants, conventional stabilization ponds, septic tanks and blair latrines are not being exploited to combat eutrophication because of the nation's economic and social problems (MAPIRA, 2011). Therefore, the study streams receive untreated or semi-treated effluent from sewage treatment plants and bust sewage pipes as well as other diffuse sources as they pass thorough the city.

Nine sampling sites were established along the two rivers: two sites (R1 and R2) in the relatively less impacted agricultural and forested headwaters to act as reference sites; five sites (U1, U2, U3, U4 and U5) in the polluted urban area; and two sites (D1 and D2) in downstream area after the urban area where water quality is expected to improve due to river self-purification capacity (BERE, 2007). The rational for choosing the sampling sites was to obtain a pollution gradient of all the stream systems from relatively unpolluted agricultural headwaters to highly polluted urban downstream sites. Monthly samplings of diatom and water quality were conducted from may to july

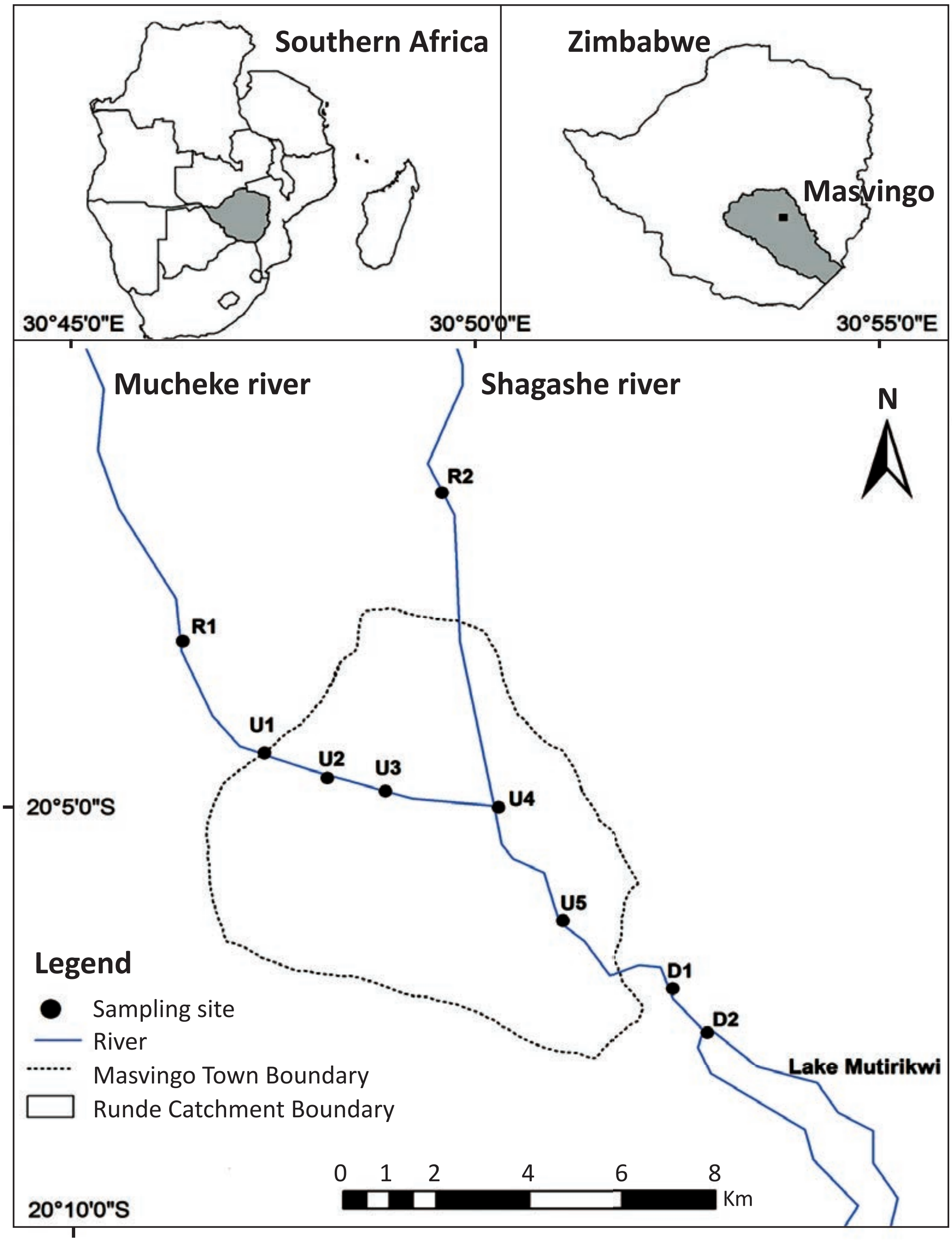

Figure 1 – The location of the Mucheke and Shagashe rivers showing the location of the sampling stations (R1 and R2 = reference sites; U1-U5 = urban sites; D1 and D2 = downstream sites).

2012. The dry season was chosen to avoid variable effects of the rainy season such as great variations in water level and velocity, floods and inundations. These variations affect the growth, development of diatoms and the relative abundance of different species (ROUND, 1991).

Water quality sampling and analysis

At each site, dissolved oxygen (DO), electrical conductivity, specific conductivity, nitrate (NO_3), ammonium, ammonia, chloride, total dissolved solids (TDS), salinity and pH were measured using a portable meter (YSI professional plus, Yellowstone. USA).

Epilithic diatom sampling

At each site, epilithic diatoms were sampled by brushing stones with a tooth brush following (HARDING *et al.*, 2005). Prior to sampling of epilithic surfaces, all substrata were gently shaken in the stream water to remove any loosely attached sediments and non-epilithic diatoms. At least five pebble-to-cobble (5-15 cm), sized stones were randomly collected along each sampling stretch, brushed and the resulting diatom suspensions were pooled to form a single sample which was then put in a labeled plastic container. The dislodged material was decanted into a sample bottle and preserved using formalin to be identified in the laboratory.

In the laboratory, sub-samples of the diatom suspensions were cleaned of organic material using wet combustion with concentrated sulphuric acid and hydrogen peroxide and mounted in Naphrax (Northern Biological supplies Ltd., UK, RI = 1.74) following Biggs and Kilroy (2000). Three replicate slides were prepared for each sample. A total of 300-650 valves per sample (based on counting efficiency determination method by Pappas and Stoermer (1996) were identified and counted using a compound microscope (× 1000; Nilcon, Alphaphot 2, Type YS2-H, China). The diatoms were identified to species level based mainly on studies from South Africa (TAYLOR *et al.*, 2007a); studies from other tropical regions were consulted when necessary e.g. (METZELTIN, LANGE-BERTALOT, 1998).

Indices calculation

The PDI and TDI were calculated following Gómez and Licursi (2001) and Kelly *et al.* (2001) respectively. The PDI values range from 0 to 4 as follows: 0–0.5 (very good), > 0.5-1.5 (good), > 1.5–2 (acceptable); > 2–3 = bad and > 3–4 (very bad) water quality.Values for the TDI range from 1 (very low nutrient concentrations) to 5 (very high nutrient concentrations). The percentage pollution tolerance taxa is then calculated as a measure of the reliability of the trophic diatom index. Different categories are drawn out from the percentage values to come up with an interpretation of the proportion of count composed of taxa tolerant to organic pollution.

Statistical analysis

A two-way analysis of variance (Two-Way ANOVA) with Tukey's post hoc HSD tests was used to compare means of physical and chemical variables among the three sampling station categories and between the three sampling periods. Pearson's correlation was used to determine the relationship between the calculated index scores (TDI and PDI) and measured physical and chemical water quality data. One-way ANOVA was used to compare the PDI and TDI scores among sampling stations.

Multivariate data analyses were performed on the diatom community data to explore the main gradients of floristic variation and to detect and visualize similarities in diatom samples. Preliminary detrended correspondence analysis (DCA) was applied on diatom data set to determine the length of the gradient. The DCA revealed that the gradient was greater than three standard deviation units, justifying the use of unimodial ordination techniques (ter Braak and Verdonschot, 1995). Thus, canonical correspondence analysis (CCA) was performed to relate diatom community structure to simultaneous effects of predictor environmental variables, and to explore the relationship amongst and between species and predictor variables. Preliminary CCA identified collinear variables and selected a subset on inspection of variance inflation factors (VIF < 20); (Ter Braak and Smilauer, 2002). Monte Carlo permutation tests (999 unrestricted permutations, $p \leq 0.05$) were used to test the significance of the axis and determine if the selected environmental variables could explain nearly as much variation in the diatom community structure as all the environmental variables combined. DCA and CCAs were performed using CANOCO version 4.5 (TER BRAAK; SMILAUER, 2002). All other statistical tests were performed with Palaeontological Statistics Software (PAST) Version 2.16 (Hammer *et al.*, 2001).

Physical and chemical variables

The values of the physiochemical variables recorded in the Mucheke and Shagashe River during this study are summarized in Table 1. A total of 10 environmental variables were analyzed. Generally, water quality deteriorated at sites that were at or near discharge points along the two rivers (Table 1). Conductivity and TDS were significantly high in U2, U5 and D1 compared to.R1, R2 and D2 (ANOVA, $P < 0.05$). There were no significant differences in pH and salinity among sampling stations (ANOVA, $P > 0.05$). Ammonia, ammonium, NO_3 specific conductance and Cl were significantly high in urban sampling stations (U1-U5) (ANOVA, $P < 0.05$), while DO was significantly low in the same (ANOVA, $P > 0.05$) compared to the reference and downstream sites.

Diatom indices

The PDI and TDI scores based on all the site categories showed significant correlations ($P < 0.05$) with physical and chemical variables (Table 2). Significant differences (ANOVA, $P < 0.05$) in the PDI scores based on different site categories were recorded, with reference sites R1 and R2 classified as good. Downstream sites D1 and D2 were generally classified as acceptable and good respectively, while urban sites U1, U2, U3, U4 and U5 were classified as bad.

Similarly, significant differences (ANOVA, $P < 0.05$) in the TDI scores

Table 1 – Means (± SD) (n = 3) of physical and chemical variables recorded during the three sampling trips (May to July 2012) for all the sites (R1-D2).

Variables	Site								
	R1	R2	U1	U2	U3	U4	U5	D1	D2
Ammonia (mg/l)	0.01 ± 0.01^a	0.02 ± 0.2^a	0.2 ± 0.02^b	0.5 ± 0.01^c	0.1 ± 0.04^b	0.2 ± 0.03^b	0.04 ± 0.01^a	0.01 ± 0.1^a	0.01 ± 0.01^a
Ammonium (mg/l)	0.7 ± 0.2^b	0.4 ± 0.4^a	0.6 ± 0.7^b	1.6 ± 0.5^c	0.9 ± 0.4^b	2.3 ± 2.1^c	0.7 ± 0.6^b	0.4 ± 0.2^a	0.2 ± 0.2^a
Cl (mg/l)	1.4 ± 1.3^a	1.4 ± 1.2^a	5.9 ± 2.6^b	24.5 ± 4.8^c	21.8 ± 1.4^c	23.5 ± 1.4^c	10.6 ± 2.6^b	11.9 ± 5.2^b	10.2 ± 5.9^b
Conductivity(µS.cm)	111.9 ± 18.1^a	174.3 ± 133.5^a	355.3 ± 34.3^b	552 ± 126.7^b	238.2 ± 93.1^c	258.4 ± 126.5^c	348.9 ± 83.1^b	401.9 ± 127.3^b	116.8 ± 11.9^a
Dissolved oxygen (mg/l)	6.8 ± 1.3^c	6.4 ± 2.2^c	4.7 ± 0.7^b	2.8 ± 1.9^a	3.4 ± 2.2^a	3.6 ± 2.4^b	4.8 ± 1.9^b	5.6 ± 0.3^b	6.1 ± 0.7^c
NO_3 (mg/l)	0.2 ± 0.1^a	0.5 ± 0.2^a	0.9 ± 0.2^b	1.3 ± 0.1^b	2.5 ± 1.4^c	0.9 ± 0.2^b	0.7 ± 0.4^b	0.8 ± 0.4^b	0.1 ± 0.1^a
pH	8.2 ± 0.2	7.5 ± 0.1	7.7 ± 0.1	8.4 ± 0.1	7.7 ± 0.2	7.8 ± 0.3	8 ± 0.7	7.7 ± 0.2	7.7 ± 0.1
Salinity (ppt)	0.1 ± 0.01	0.3 ± 0.4	0.3 ± 0.03	0.3 ± 0.1	0.5 ± 0.5	0.2 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.1 ± 0.01
Specific conductance (µS.cm)	123.2 ± 20.8^a	189.8 ± 150.9^b	564.1 ± 11.7^c	626.6 ± 132.9^c	319.6 ± 52.1^c	356.4 ± 132.6^c	510.1 ± 164.2^c	548.1 ± 148.2^c	134.7 ± 5.5^a
Total dissolved solfids (mg/l)	80 ± 13.5^a	123.3 ± 98.1^b	340.4 ± 39.2^c	407.2 ± 86.5^c	210.7 ± 31.5^b	231.4 ± 86.7^b	332 ± 106.4^c	346.2 ± 87.8^c	88.8 ± 1.6^a

Different letters denote significant differences obtained through Tukey's post hoc comparison test.

based on different site categories were recorded (Figure 3). Reference sites (R1 and R2) as well as downstream sites (D1 and D2) had low percentage pollution tolerant taxa (below 20 %), which means they were free from significant organic pollution (Figure 3). Urban sites generally had high percentage pollution tolerant taxa (above 20 %; Figure 3) indicating some evidence of organic pollution and in some cases (sites U3, U4 and U5) organic pollution was likely to be contributing significantly to eutrophication. Correlations between the PDI scores and physical and chemical variables were also generally lower compared to those between the TDI scores and physical and chemical variables.

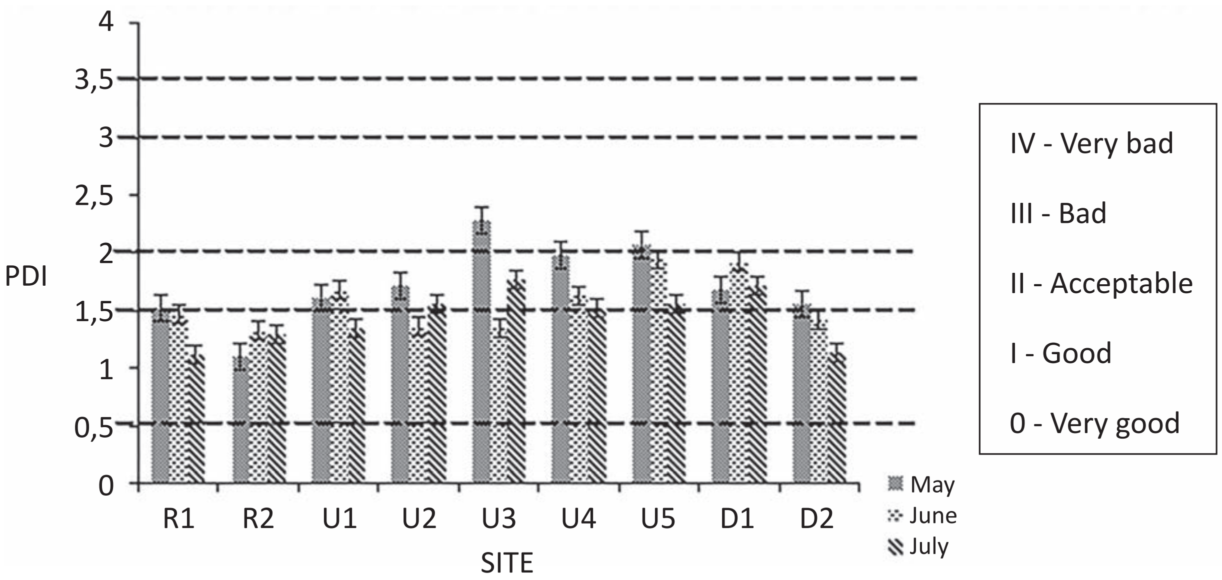

Figure 2 – The Pampean diatom index (PDI) scores recorded at sites along the Mucheke and Shagashe rivers for the study period (may to june).

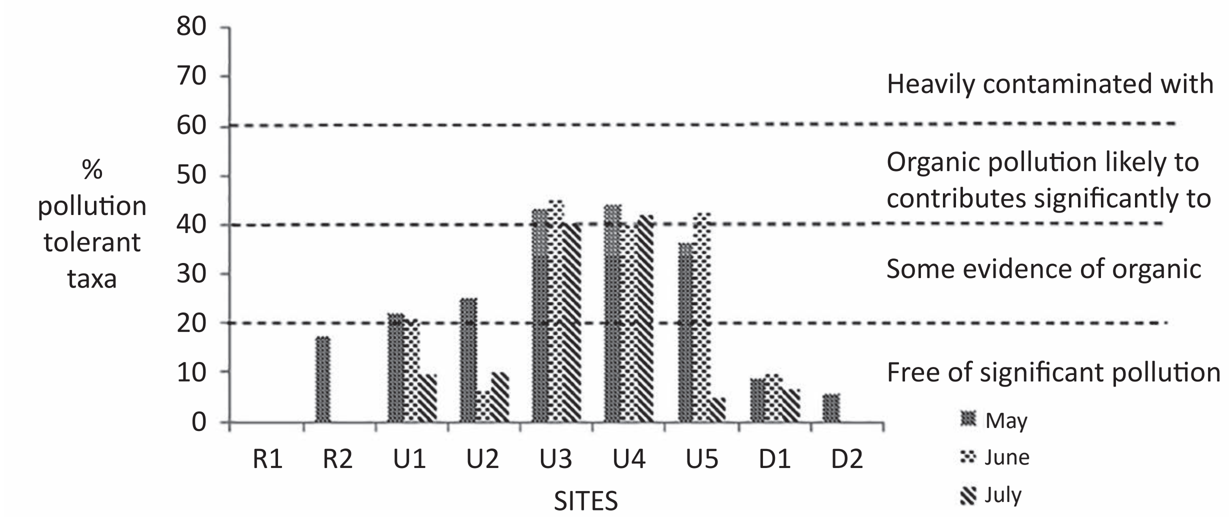

Figure 3 – Percentage pollution tolerant taxa from the nine sampling sites.

Table 2 – Pearson`s correlation between diatom indices and environmental variables.

Parameter	Metric	
	TDI	PDI
Ammonia (mg/l)	0.34	-0.16
Ammonium (mg/l)	0.48	0.2
Cl (mg/l)	0.16	0.07
Conductivity (µS.cm)	0.31	0.29
Dissolved oxygen (mg/l)	-0.18	-0.03
NO3 (mg/l)	-0.09	-0.2
pH	-0.2	0.07
Salinity (ppt)	0.48	-0.1
Total dissolved solids (mg/l)	0.41	0.38

Community composition

A total of 39 diatom species belonging to 25 genera were identified in all nine sampling sites (Table 3). Species composition in terms of species richness, species diversity, dominance and evenness is in the same range for reference and downstream sites compared to urban sites.

The results of CCA are presented in Figure 4. The first four axes of the selected exploratory variables accounted for 79.9% of the total variance in the community data (Table 2). Axis 1 and 2 significantly explained 26.4 % and 16.3%, respectively, of the diatom species variance (Table 2; Monte Carlo unrestricted permutation, *P* < 0.05). CCA Axes 1 and 2 separated the sites into 3 groups. The first group consisted of less polluted sites R1 and R2 that were positively associated with the first axis. Diatom species characterising these sites include species such as *Achnanthidium minutissimum*, *Aulacoseira distans*, *Encyonema silesiacum*, *Encyonopsis minuta*, *Cymatopleura solea*, *Eunotia flexuosa Diploneis subovalis*, *Cymbella kappii*, *Eunotia flexuosa*, *Fragilaria nanana*, *Rhopalodia gibba*, *Diadesmis confervacea*, *Brachysira neoexilis*, *Gomphonema laticollum*,*Cymatopleura solea*,*Pinnularia acrosphaeria*, *Gomphonema minitum*, *Pinnularia subcapitata* and *Staurosirella pinnata.* The second group consisted of highly polluted sites (U1-U5) that were negatively associated with the first and positively associated with the second axis, respectively (Figure 4). These sites were associated with high ammonium, ammonia and nitrate levels. Diatom species characterising these sites include species such as *Fragilaria biceps*, *Fragilaria ulna*, *Rhoicosphenia abbreviate*, *Cyclotella meneghiniana*, *Nitzschia palea*, *Gomphonema parvulum*, *Cyclotella spp*, *Pinnularia confirma*, *Pinnularia viridiformis.* This group of species was associated with high levels of ammonia, ammonium and nitrate as compared to the rest of the species. The third group consisted of medium polluted sites D1 and D2 that were negatively associated with the first and second axis. These sites were associated with high salinity and pH levels. Nutrient levels were generally low compared to those of sites U1-U5. Sites D1and D2 wereassociated *Pleurosigma* *elongatum, Tabellaria flocculosa, Sellaphora stroemii, Sellaphora seminulum, Planothidium frequentissimum, Nitzschia frustulum, Gomphonema insigne, Fallacia monoculata, Achnanthes exigua* and *Diatoma vulgaris.*

Table 3 – Mean values of species richness, diversity, dominance and evenness.

	Site								
	R1	**R2**	**U1**	**U2**	**U3**	**U4**	**U5**	**D1**	**D2**
Speciesrichness	8 ± 1	10 ± 2	8 ± 1	10 ± 0	7 ± 1	5 ± 1	6 ± 2	10 ± 2	9 ± 2
Shannondiversity	1.6 ± 1.8	2.1 ± 0.1	1.9 ± 0.3	2.1 ± 0.04	1.8 ± 0.2	1.5 ± 0.1	1.5 ± 0.4	1.8 ± 0.3	1.8 ± 0.2
Dominance	0.3 ± 0.1	0.1 ± 0.02	0.2 ± 0.1	0.1 ± 0.01	0.2 ± 0.03	0.2 ± 0.03	0.3 ± 0.1	0.3 ± 0.1	0.2 ± 0.04
Evenness	0.6 ± 0.1	0.8 ± 0.05	0.8 ± 0.1	0.8 ± 0.03	0.9 ± 0.05	0.8 ± 0.05	0.7 ± 0.1	0.6 ± 0.2	0.7 ± 0.02

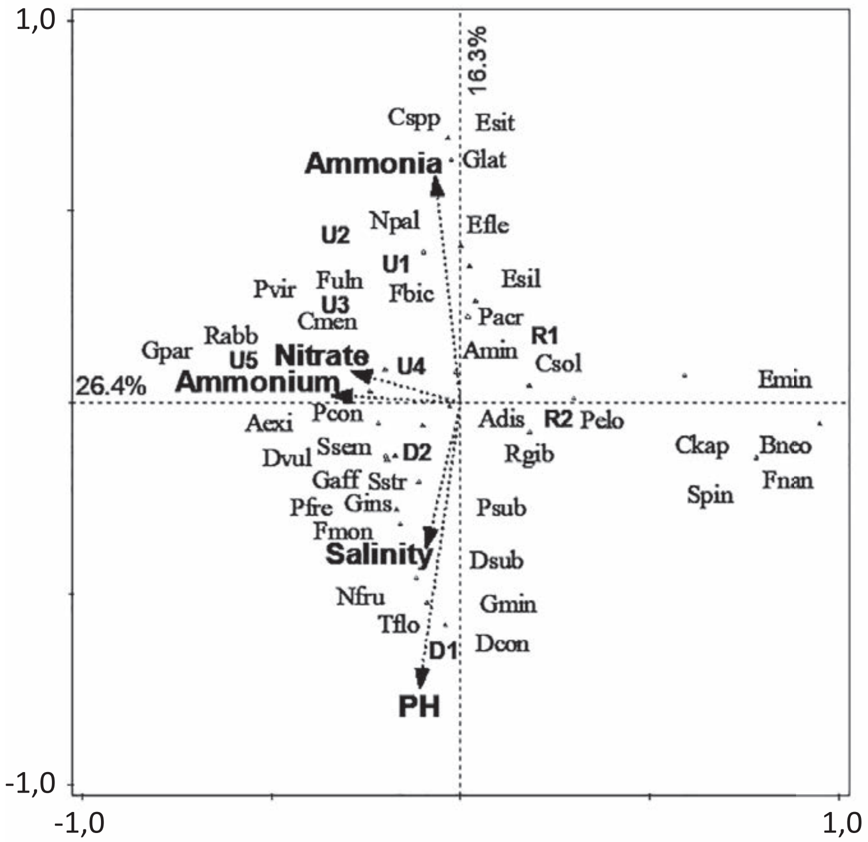

Figure 7 – Ordination diagram based on canonical correspondence analysis (CCA) of diatom species composition in nine sampling sites in respect with six environmental variables.

Table 4 – Diatom species codes used in the canonical correspondence analysis.

Species	Code
Achnanthes exigua	Aexi
Achnanthidium minutissimum	Amin
Aulacoseira distans	Adis
Brachysira neoexilis	Bneo
Cyclotella meneghiniana	Cmen
Cyclotella species	Cspp
Cymatopleura solea	Csol
Cymbella kappii	Ckap
Diadesmis confervacea	Dcon
Diatoma vulgaris	Dvul
Diploneis subovalis	Dsub
Encyonopsis minuta	Emin
Encyonema silesiacum	Esil
Encyonema sitesiam	Esit
Eunotia flexuosa	Efle
Fallacia monoculata	Fmon
Fragilaria biceps	Fbic
Fragilaria nanana	Fnan
Fragilaria ulna	Fuln
Gomphonema affine	Gaff

Species	Code
Gomphonema insigne	Gins
Gomphonema laticollum	Glat
Gomphonema minutum	Gmin
Gomphonema parvulum	Gpar
Nitzschia frustulum	Nfru
Nitzschia palea	Npal
Nitzschia reversa	Nrev
Pinnularia acrosphaeria	Pacr
Pinnularia confirma	Pcon
Pinnularia subcapitata	Psub
Pinnularia viridiformis	Pvir
Planothidium frequentissimum	Pfre
Pleurosigma elongatum	Pelo
Rhoicosphenia abbreviata	Rabb
Rhopalodia gibba	Rgib
Sellaphora seminulum	Ssem
Sellaphora stroemii	Sstr
Staurosirella pinnata	Spin
Tabellaria flocculosa	Tflo

Discussion

Water quality

The results of the physical and chemical variables in the study showed that pollution levels, especially organic pollution and eutrophication, differed among the sites sampled (Table 1). Conductivity, ammonium, ammonia, chloride and nitrate were significantly higher in sites that were near or at a pollution point in the urban areas.Industrial, domestic and sewage effluent disposals are the main causes of decrease in the water quality along the Mucheke and Shagashe River system. These high levels of nutrients are associated with deterioration of water quality and eventually lead to eutrophication and changes in diatom species composition (BERE, 2010).

Diatom community structure in relation to environmental variables

Diatom community structure and composition closely followed the observed changes in pollution levels, with less polluted sites R1 and R2 being associated with diatom communities that were different from highly polluted sites U1, U2, U3, U4 and U5. Cluster analysis of sampling stations based on epilithic diatom communities in streams of the Mucheke and Shagashe river clearly reflected the effects of pollution (Figure 2). The epilithic algal communities in this study were primarily affected by organic pollution and nutrient concentrations in the streams resulting from urban runoff as confirmed by the findings of Beyene *et al.* (2010). Diatoms have an important role in biological monitoring of lotic systems as they have shown capacity to respond to changes in water quality. Ammonia, Ammonium, salinity, pH and nitrate were found to be important in structuring benthic diatom communities in the study area (Figure 4). Other studies have also shown that nutrients (ammonia, ammonium and nitrate)are the primary drivers of periphyton community structure and biomass (BIGGS, THOMSEN, 1995; JOWETT, BIGGS, 1997). Nonetheless, a review of literature carried out by (SAROS, FRITZ, 2000) showed that salinity may influence nutrient availability to primary producers, as well as nutrient requirements and uptake by diatoms. pH exerts a direct physiological stress on diatoms (GENSEMER, 1991), and also strongly influences other water chemistry variables (SIGG, STUMM, 1981). Based on the CCA (Figure 4), sites that were relatively more polluted had pollution tolerant species such as *Nitzschia palea, Gomphonema parvulum, Cyclotella spp, Pinnularia confirma* and *Pinnularia viridiformis.* These species are known to be resistant to heavy metal and organic pollution (ROUND, 1991; BERE, TUNDISI, 2010). Whereas, reference sites R1 and R2 were characterized by low pollution tolerant species such as *Fragilaria nanana, Rhopalodia gibba, Diadesmis confervacea, Brachysira neoexilis, Gomphonema laticollum,Cymatopleura solea,Pinnularia acrosphaeria, Gomphonema minitum, Pinnularia subcapitata* and *Staurosirella pinnata.*These species are mainly found in oligo- to mesotrophic water with moderate conductivity (VAN DAM *et al.*, 1994; BERE, TUNDISI, 2011).

Applicability of TDI and PDI to the study area

The significant correlations between TDI and PDI index values and physical and chemical characteristics of streams recorded in this study indicate that these indices may be used to reflect general changes in water quality of rivers and streams of Zimbabwe (Table 2). Values of the TDI and PDI indices showed significant differences between reference sites R1 and R2 and heavily polluted urban sites U1-U5 (Figures 2 and 3). This is supported by (Bate *et al.*, 2004) who found that most dominant diatom species found in South African rivers were already recorded in international studies. Thus, most foreign diatom indices may be used in the study area as they are based on the ecology of widely distributed or cosmopolitan taxa. In conclusion, it can be said that the PDI and TDI are applicable to the study area. Diatoms have an important role in biological monitoring of lotic systems as they have shown capacity to respond to changes in water quality.

Conclusion

In conclusion, organic and industrial effluent has a great effect on the water quality of Mucheke and Shagashe Rivers as shown by the physical and chemical variables of the two rivers. Changes in the assemblages of diatom species are also evident of changes in water quality along the rivers, thus a relationship between diatoms and water quality. Diatoms have an important role in biological monitoring of lotic systems as they has shown capacity to respond to changes in water quality. Biological monitoring of water quality using diatoms is a reliable method for water quality assessment and should therefore be adapted in research and by relevant government organizations.

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https://doi.org/10.26626/978-85-5953-031-5.2018C002

Analysis of Surface and Ground Water Samples in the Environs of Gold Mines Linked to Lead Poisoning Incident in Niger State, Nigeria

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Abstract

Nine water samples were collected from wells, boreholes and ponds around gold mining sites in Rafi Local Government Area (LGA) of Niger State, Nigeria affected by artisanal gold mining activities and where the deaths of over 28 children were recorded. The water samples were analyzed to determine their concentrations of potentially toxic metals using linear sweep anodic stripping voltammetry (LSASV). The Pb concentrations in the water sample was in the range 50.15 µg/L-5916 µg/L. These values are above the WHO permissible limit of 10 µg/L for Pb in potable water. The concentrations of Cu in the water samples were found to be within limits and was in the range 0.002 µg/L-679 µg/L. Other parameters determined and their results were pH (6.28-8.65), total dissolved solids (40 mg/L-760 mg/L), electrical conductivity (81 µS/cm -1517 µS.cm), temperature (29.6°C-36.6°C), acidity; (3.86 mg $CaCO_3$/L-19.28 mg $CaCO_3$/L), alkalinity; (13.73 mg $CaCO_3$/L-114.45 mg $CaCO_3$/L) and hardness; (0.12 mg $CaCO_3$/L-4.30 mg $CaCO_3$/L). The results show that Pb poisoning may have been responsible for the deaths of these children in parts of Rafi LGA of Niger State.

Keywords: gold mining, heavy metal pollution, lead poisoning, water, voltammetry.

Introduction

Mining of solid minerals has been identified as a major source of potentially toxic metals in the environment because metal ores may contain potentially toxic metals (PTM) as well as essential elements (AROGUNJO, 2007).The main threats to human health from heavy metals are associated with exposure to lead, copper, cadmium, mercury as well as arsenic. These metals may enter the human body through inhalation of dust, consumption of contaminated drinking water and ingestion of food plants grown in contaminated soils (MARTINEZ-FINLEY *et al.*, 2012; JAN *et al.*, 2015).

Artisanal mining operations are known to be the common methods of extraction of minerals from the earth, especially in developing countries where it is adopted in rural areas (VEIGA, 2003; SNEHA *et al.,* 2012). Mining activities have been reported to have adverse effects on water resources and farmlands (ADEGBOYE, 2013) and this could lead to accumulation of PTM in such water bodies.Artisanal gold mining has long been practiced in Nigeria and around the world. For almost a century, parts of Kebbi, Niger and Zamfara States in Northern Nigeria have become hubs for illegal artisanal miners, who use crude methods to extract gold from ores by various processing methods (MINING AFRICA, 2017). These activities often impact negatively on the environment resulting in land degradation, pollution of soil, plants, water bodies and air. Gold mining operations are particularly dangerous as miners use mercury to form amalgams with the metal of interest followed by washing with water. Thus water bodies such as rivers, ponds and lakes used in processing the ore are severely polluted. Water pollution around mining areas has been reported to contain high concentrations of PTM which bioconcentrate in aquatic organismsand eventually biomagnifies along the food chain (NIRMAL *et al.,* 2011).

The worst Pb poisoning incident in modern history took place in Zamfara State in 2010 and led to the deaths of over 400 children under 5 years of age. Despite the efforts of development, laws and regulatory enforcements to control the activities, Pb contamination of the environment arising from artisanal mining continues to afflict large numbers of children in several parts of northern Nigeria. In 2015 several deaths were recorded in Madaka district in Rafi LGA of Niger State and this was attributed to Pb poisoning arising from the artisanal mining and processing of gold ores. Blood Pb levels of children affected were 17 to 22 times higher than the acceptable limit of 10 μg/mL. A similar incident leading to the deaths of several children occurred in 2010 in Anka LGA of Zamfara State. The Pb and Cu levels of water samples collected from ponds, streams and boreholes in Dareta and Abare showed very high concentrations of Pb (OKIEI *et al.*, 2016). This was the motivation for carrying out this study on water samples collected from Madaka, Rafi Local Government Area (LGA) of Niger state.

The objective of this study was to determine the concentration of toxic metals present in surface and ground water samples collected from Rafi LGA of Niger State using electrochemical method. The physicochemical parameters such as pH, TDS, EC, temperature, acidity, alkalinity, hardness of the water samples were also determined.

Materials and Methods

Collection of Samples and Preservation

Samples of water were collected from Maigiro and Kawo in Rafi LGA, Niger State, northern Nigeria in May, 2016. About 500 mL of water samples were collected in precleaned plastic bottles in duplicate. Duplicate sample for water collected was acidified using 2 mL of concentrated nitric acid (Sigma-Aldrich), stoppered and kept in polythene bags for heavy metal analysis. Water samples (not acidified) were also filled to the brim of some plastic bottles, stopperedand kept in dark polythene bags. Both acidified and un-acidified samples were transported to the laboratory and stored in the refrigerator at 4°C for further analysis. Coordinates of all sampling points were recorded using the Garmin GPS 72 Handheld global positioning system (GPS). Depths of the wells, ponds and boreholes were also measured.

Digestion of Water Samples

50 mL of eachacidified water sample wasmeasured into a conical flask, heated and allowed to evaporate to 25 mL. The digested sample was filtered and made up to 50 mL with deionized water and stored in air tight pre-cleaned plastic bottle.

Voltammetric Measurements for Heavy Metals

A Basi-Epsilon potentiostat/galvanostat was used in the voltammetric determination of heavy metals in the water samples. Glassy carbon (3.0 mm diameter) was used as the working electrode, Ag/AgCl as reference while platinum electrode (1.6 mm diameter) served as the auxiliary electrode. The working electrode and the auxiliary electrode were thoroughly cleaned by polishing them with alumina, rinsed with deionized water and air dried before each determination.

Calibration Curve

Stock standard solution of each metal salt was prepared by dissolving weighed amount of the salt [0.1598 g of Pb $(NO_3)_2$ and 0.3929 g of $CuSO_4 \times 5H_2O$] separately in 100 mL of deionized water to give 1000 ppm of Pband Cu respectively. Serial dilutions were done to get working concentrations of 4000 ppb, 2000 ppb, 1000 ppb and 500 ppb for Pb and copper Cu respectively using 0.1 M acetate buffer, pH 4.50 containing 50 mM nitric acid (HNO_3), 0.2 M potassium nitrate (KNO_3), and 80 ppm mercury (II) nitrate $Hg(NO_3)_2$. Thestandard solutions were used to obtain the calibration curve. 10 mL each of the standard solution of each metal salt was transferred to the electrochemical cell and purged with nitrogen for 10 min. The pre-concentration of the metal in the standard solution was carried out at –900 mV for 120 s with stirring and after a quiet time of 30 s, the stripping process was carried out by scanning the potential from –900 mV to 200 mV using a scan rate of 20 mV/s. Peak currents for lead and copper were observed at –495 mV and –19.4 mV respectively.

Analysis of Water Samples for Heavy Metals

5 mL of the digested water sample was transferred into the electrochemical cell and 5 mL of the buffer solution was added and mixed thoroughly. The solution was purged with nitrogen for 10 min. and pre-concentration and stripping were carried out as described for the standard solutions. The peak current obtained at –495 mV or –19.4mV was used to obtain the concentrations of lead or copper respectively in the samples.

Determination of Physico-chemical Parameters of the Water Samples

The temperature, pH, TDS and EC were determined using a multiprobe meter (Hanna HI 98129 Combo waterproof). The determinations were carried out on site. Acidity, alkalinity and total hardness were carried out on filtered raw water samples using the methods of the American Public Health Association (APHA, 1998).

Results

The location of Niger state and the sampling stations in Rafi LGA are shown in Fig. 1. Fig. 2 and 4 show the overlay of the voltammograms obtained for standard solutions of Pb and Cu. Plots of values of peak current against Pb or Cu concentrations are presented in Fig. 3 and 5. Fig. 6 is an example of a voltammogram obtained for water sample (MAIG/W/5). The coordinates of the sampling sites in Rafi LGA, the concentrations of lead and copper as well as the physico-chemical parameters of the water samples are presented in Table 1.

The results in Table 1 show that Cu was detected in 8 water samples from Rafi LGA. These levels ranged from 50 µg/L-679 µg/L. The maximum permissible limit for copper is 2000 µg/L (WHO, 2003). Hence the levels of Cu in these water samples are within safe limit for potable water.

Table 1 also shows the levels of Pb in the water samples from sites in Rafi LGA. Pb was not detected in sampleMAD/W/2 but eight (8) of the water samples had significant levels of Pb in the range 50.5 µg/L-5916.39 µg/L. The permissible limit for Pb in potable water for adults is 10 µg/L (WHO, 2011) and 5 µg/L for children (CDC, 2017).

Ponds and borehole exhibited slightly alkaline pH values which were within the WHO limit of 6.3-8.65. Temperature of the water samples was in the range 29.6ºC-36.6ºC and conductivity of the water samples ranged from 81 µS/mL-1517 µS/mL. Electrical conductivity (EC) is a good measure of dissolved solids. It is an important criterion in determining the suitability of a body of water for irrigation (KUMAR; PAL, 2012). Values of EC ranged from 81 µS/mL-1517 µS/mL.

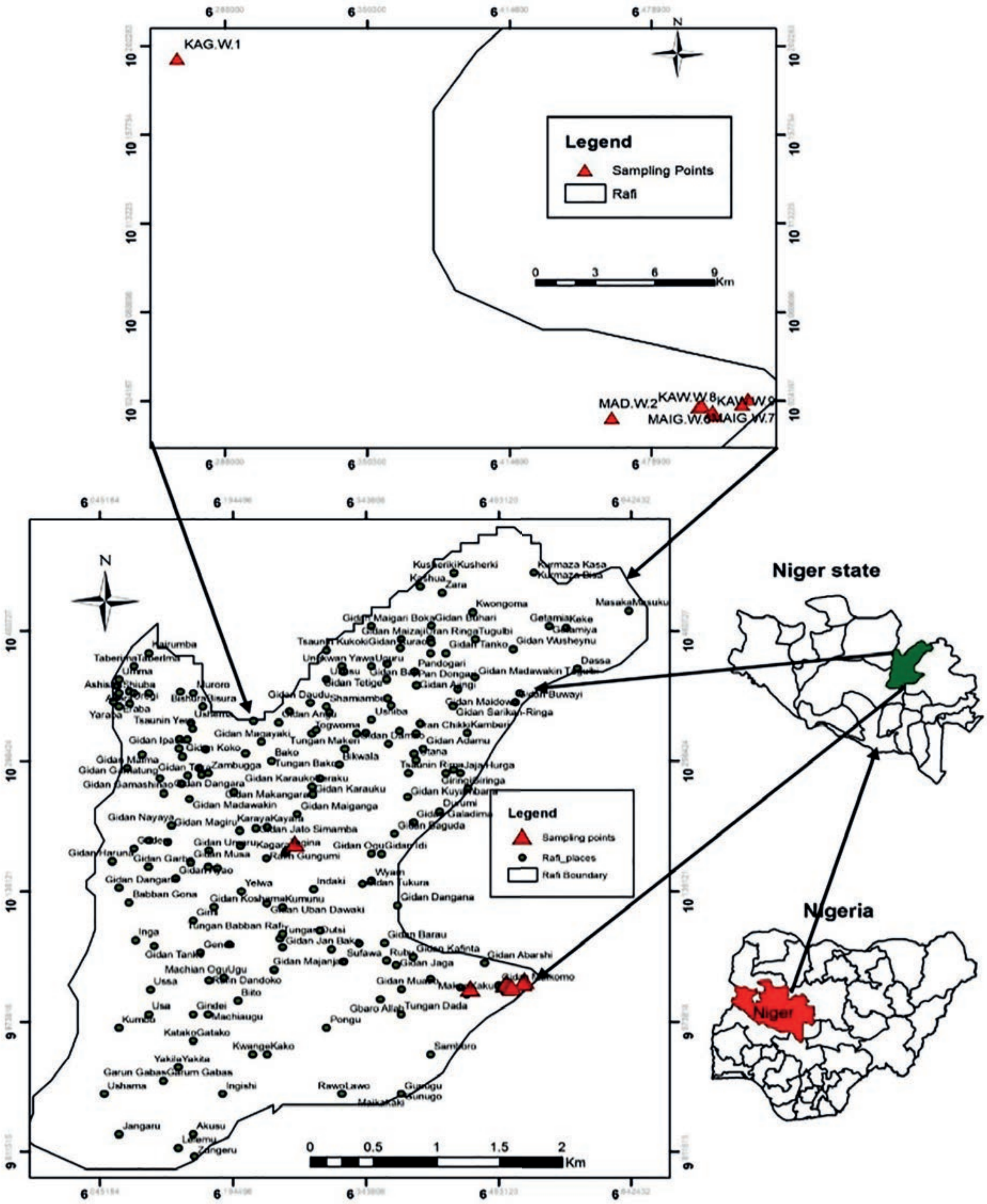

Figure 1 – Composite map of Nigeria showing sampling points inRafi Local Government Area in Niger state.

Table 1 – Coordinates of samples, concentrations of Pb and Cu and physico-chemical parameters of water samples collected from in Rafi Local Government Area of Niger State.

Sample Identity	Source	Coordinates	Heavy metal concentrations (µg/L) of water samples using LSSV		Physico-Chemical parameters								
			Pb	Cu	Depth (meters)	pH	TDS (ppm)	EC (µS/cm)	Temp. (^{0}C)	Acidity (mg CaCO3/L)	Alkalinity (mg CaCO3/L)	Hardness (mg CaCO3/L)
KAG/W/1	Well (Control)	N 1011.459 E 006 15.519	50.5 ± 2.34	Not detected	10.45	6.74	124	283	29.6	6.75 ± 0.07	36.95 ± 0.14	0.54 ± 0.14
MAD/W/2	Borehole	N 10 00.561 E 006 27.407	Not Detected	202.09 ± 3.89	660	6.88	760	1517	33.3	3.86 ± 0.14	103.33 ± 0.47	4.3 ± 0.07
MAIG/W/3	Borehole	N10 01.309 E 006 30.826	80 ± 3.11	166.73 ± 4.45	720	6.39	238	472	32.8	12.53 ± 0.02	48.72 ± 0.48	1.52 ± 0.04
MAIG/W/4	Washing Pond	N10 00.166 E 006 32.049	5916.39 ± 8.97	679.96 ± 2.34	0.15	7.03	405	808	36.6	19.28 ± 0.1	114.45 ± 0.06	0.12 ± 0.03
MAIG/W/5	Pond	N10 00.153 E 006 32.017	146.48 ± 3.91	167.6 ± 2.16	0.40	6.12	94	194	35.2	14.46 ± 0.09	28.78 ± 1.10	0.7 ± 0.11
MAIG/W/6	Pond	N10 00.191 E 006 32.081	70.35 ± 1.25	228.82 ± 3.55	0.45	6.93	242	484	35.7	10.6 ± 0	55.59 ± 0.14	1.5 ± 0.2
MAIG/W/7	Mine	N10 00.213 E 006 30. 734	229.39 ± 5.89	374.00 ± 2.98	1.67	6.65	125	249	31.8	3.86 ± 0.05	20.27 ± 0.24	0.56 ± 0
MAIG/W/8	Borehole	N10 00.677 E 006 30. 248	245.94 ± 6.15	233.86 ± 5.44	720	6.51	140	280	30.8	14.46 ± 0.04	59.84 ± 0.11	0.98 ± 0.01
KAW/W/9	Pond	N10 00.604 E 006 30. 294	280.03 ± 4.76	564.05 ± 5.79	3.60	6.37	40	81	32.2	3.86 ± 0.01	13.73 ± 0.02	0.16 ± 0.03

TDS= Total dissolved solids, EC= Electrical conductivity

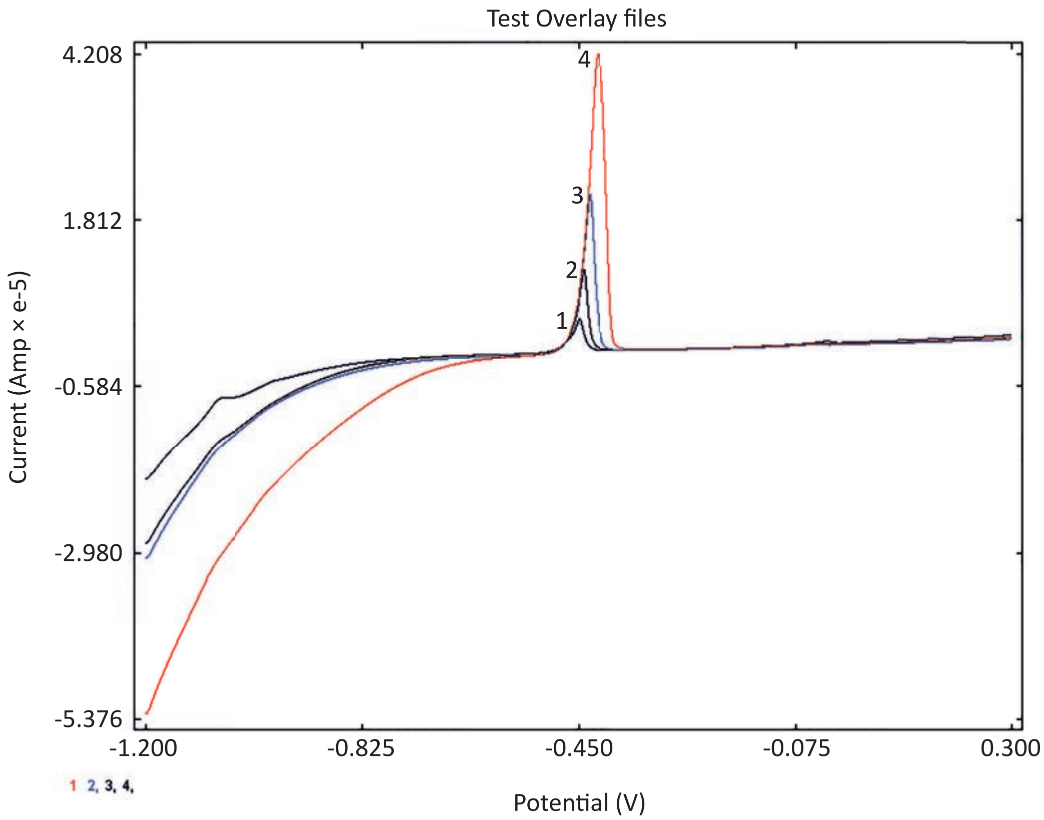

Figure 2 – Overlay of voltammograms obtained for the determination of Pb in0.1M acetate buffer containing 80 ppm $Hg(NO_3)_2$ and 0.2 M KNO_3 at pH 4.5) (Pb concentration: 500 ppb (1), 1000 ppb (2), 2000 ppb (3), 4000 ppb (4).

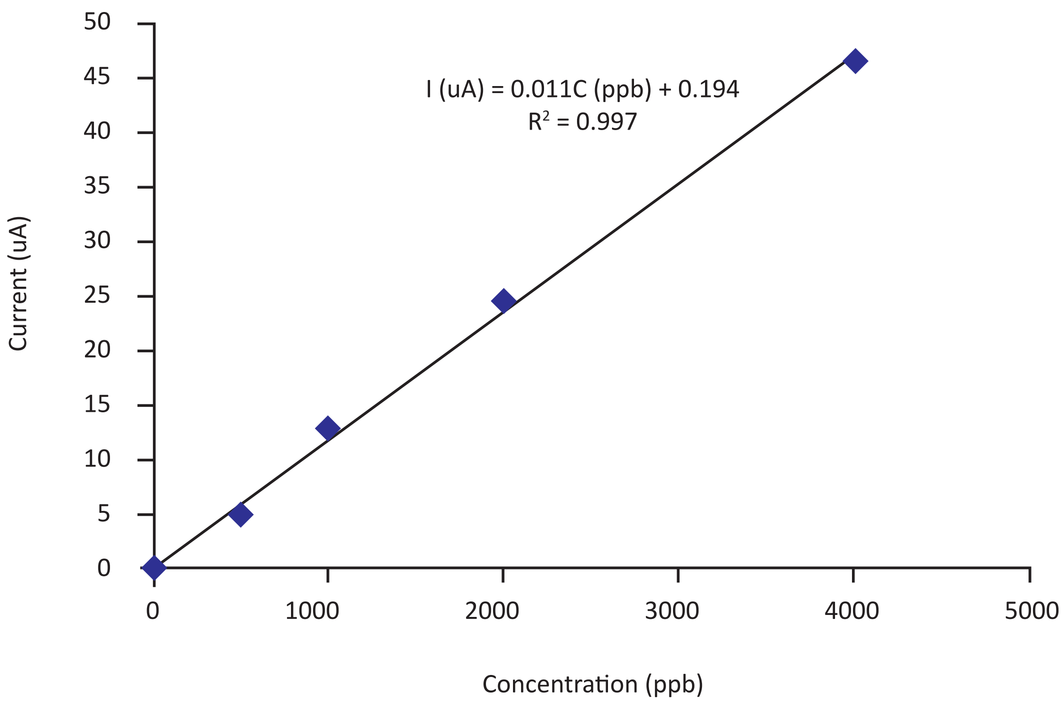

Figure 3 – Lead (Pb) LSSV standard calibration curve: A plot of peak current against Pb concentration in background solution. (Pb concentration: 1 = 500 ppb, 2 = 1000 ppb, 3 = 2000 ppb, 4 = 4000 ppb).

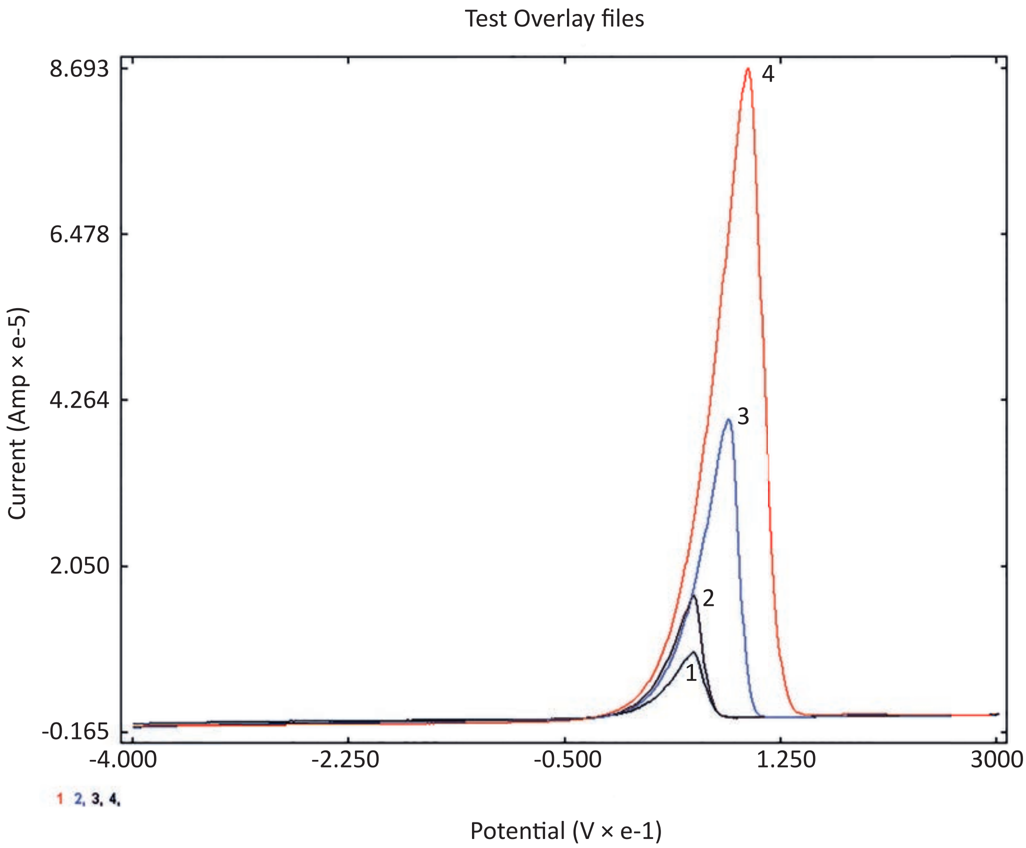

Figure 4 – Overlay of voltammograms obtained for the determination of Cu in 0.1 M acetate buffer containing 80 ppm $Hg(NO_3)_2$ and 0.2 M KNO_3 at pH 4.5) (Pb concentration: 500 ppb (1), 1000 ppb (2), 2000 ppb (3), 4000 ppb (4).

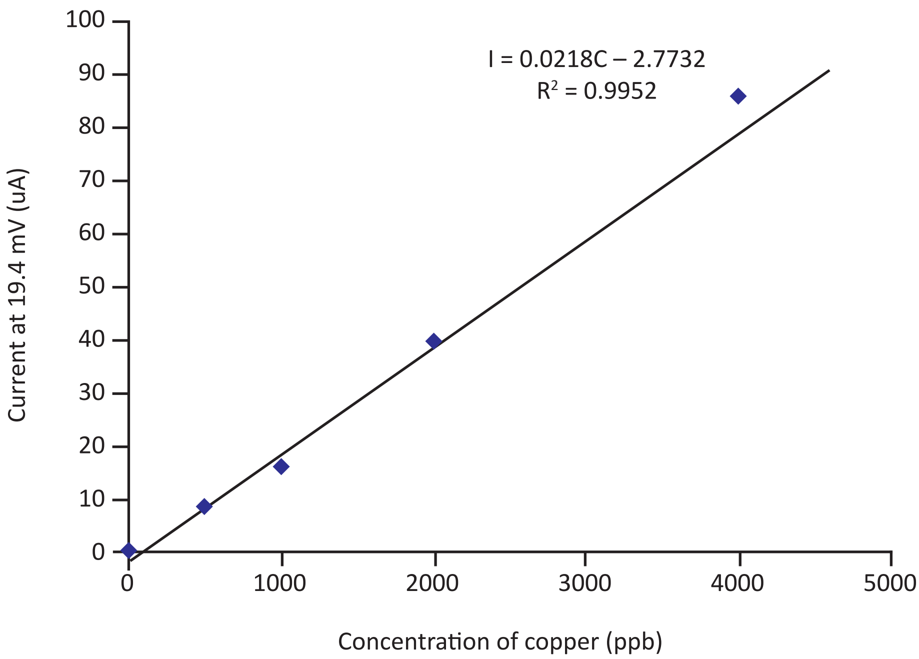

Figure 5 – Calibration plot of peak currents at 19.4 mV against Cu concentration in 0.1 M acetate buffer pH, 4.50 containing 80 ppm $Hg(NO_3)_2$ and 0.2 M KNO_3.

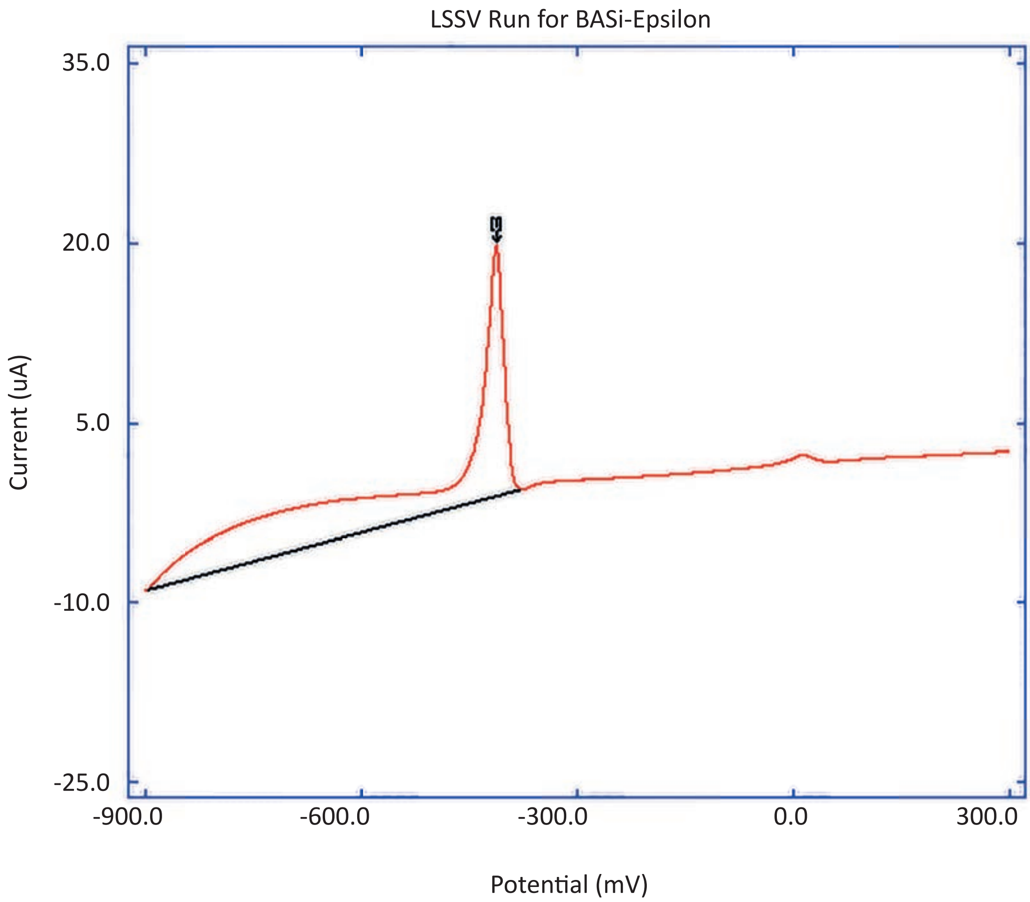

Figure 6 – Voltammogram of water sample MAIG/W/5.

Discussion

Water samples from Rafi LGA were found to be contaminated by Pb and Cu. The results presented in Table 1 show Pb and Cu contents of the water samples from three boreholes, MAD/W/2, MAIG/W/3 and MAIG/W/8 in Madaka and Maigiro. Pb was not detected in the water sample from the borehole MAD/W/2 but water sample MAIG/W/3 and MAIG/W/8 had Pb levels of80µg/L and 245µg/L respectively. The borehole in Madaka community is 660 meters deep and is situated about 60 kilometers from Kawo and Maigiro where Pb poisoning was reported. This shows that the groundwater aquifer has not been affected by the artisanal mining operations in Kawo and Maigiro. Hence water from this borehole may be safe for human consumption. It must be noted that no death was recorded in Madaka. The borehole in Madakais about 660 meters deep and covered.

Water sample KAG/W/1 obtained from an open well at the Local Government Hospitalin Kagarawas found to contain 50µg/L of Pb. The detection of Pb in the water sample from this well located 400 km from mining site is not readily explainable but it is probable that miners who visited the hospital for medical assistance washed their hands or clothes with water from this well. The waste water, contaminated with Pb may have drained into the open well. The lack of covering for this well at the hospital significantly puts it at high risk of cross contamination from miners from highly contaminated communities.

The levels of Pb found in the washing ponds were high. The levels found in the ponds MAIG/W/4, MAIG/W/5, MAIG/W/6 and KAW/W/9 were 5916 µg/L, 146 µg/L, 70 µg/L and 280 µg/L respectively. MAIG/W/4 which had the highest lead value in all samples collected exceeded the maximum permissible limit by WHO (10 µg/l) over 590 times (WHO, 2011). This sample was collected from the largest pond where ground gold ore was washed during the floatation process involved in separation of the ore.Domestic animals in these communities sometimes consume this wateras nomadic farming is highly practiced in this region. This could have accounted for the deaths of domestic animals in this community (AKO *et al.*, 2014). In rural Nigeria, it is not uncommon to find animals and humans drinking water from the same source. Thus, there could be an analogy between human exposures to that of domestic animals. Sample MAIG/W/7 obtained from the water body near the mine had Pb concentration of 229 µg/L. This value is over 20 times lower than sample MAIG/W/4 water obtained from the washing pond. Thus excavation of the ore may pose a lesser risk to the community than water bodies such as ponds used for separation of the gold from the ore.

The process of obtaining gold from the ore after excavation starts from crushing the main ore to pebbles which helps to increase the surface area. Second stage involves the grinding of the pebbles into fine particles which further increases the surface area. This is normally carried out in the homes of miners by women and children. It explains the greater risk of exposure of women and infants to Pb. Infants ingest the ores when they suck their hands or eat with unwashed hands. In addition to exposure through water, exposure also occurs through inhalation in the first and second stages of ore processing. It has been shown that inhalation or ingesting of contaminated soil, dust, air, or water near mining sites, eating contaminated food grown on soil containing lead or food covered with lead-containing dust could result in lead toxicity (NABILAH, 2014). Third stage which is washing of the fine particles of the ore leads to dissolution of the complexed Pb and hence becomes available in the water bodies used for its washing as evidenced in the high value of Pb (5916 µg/l) in MAIG/W/4 obtained from the main washing pond in Maigiro. Water from the borehole MAD/W/2 sampled in this study did not contain lead which suggests that the pollution most likely remains confined to areas where processing had taken place and has not spread throughout the groundwater aquifer. This also suggests water bodies which are covered are likely to be less contaminated and will be more suitable for drinking in these communities.

There is limited information on indirect sources of exposure in this area, however a recent study reported a prevalence rate of 100% was reported in kidney and liver samples from cattle slaughtered in Sokoto Central abattoir (BALA *et al.,* 2012).

No mines were observed in Maigirobut inhabitants of this town travel to Kawo to excavate gold-containing ores. As mentioned above, three stages are involved in ore processing and could all result in the pollution of the environment.

There are limited studies on the newly emerged problems of mining in Niger state, though, the dangers of Pb poisoning through this relatively new economic activity in the state emphasize the risk to the health of the community. Socioeconomic factors associated with this problem could be non-availability of pipe borne water, overcrowding, poverty, negligence, lack of awareness and unemployment.

Children are especially prone to the adverse effects of Pb and as a result blood Pb levels have been set lower (5 µg/L) (CDC, 2017) and should be regularly monitored where children are exposed. Pb is dangerous to young children because their bodies and brains are developing. Young bodies also absorb more Pb than adults. The small intestine of a developing child responds to nutritional needs by increasing the absorption of specific nutrients. Pb absorption affects the development of young children by causing speech delay, hyperactivity, attention deficit disorder, learning disabilities, behavioral disorders, neurological and renal damage, stunted growth, anemia, hearing loss, mental retardation and at high doses death just as was seen in the Pb poisoning epidemics in Zamfara state in June, 2010 and Rafi LGA of Niger state in June, 2016. Investigations of the Zamfara state Pb poisoning epidemic revealed that the lead poisoning was widespread. Thousands of children had dangerous levels of Pb in their blood, and hundreds of children and animals had died throughout the region. It was the largest known outbreak of lead poisoning in history according to Centre for Disease Control (CDC, 2010).

Conclusion

All samples except one had Pb levels above the WHO maximum permissible limit (10 µg/L), with MAIG/W/4 exceeding this limit over 590 times. The high levels of Pb in the water samples suggest high level of pollution caused byartisanal mining activities, leading to a discharge of the potentially toxic metals into the water bodies. The consumption or contact with the contaminated water bodies may have been responsible for the Pb poisoning epidemic which has claimed dozens of lives especially those of children in Rafi LGA of Niger State. Remediation procedures should be planned out and put in motion to quickly tackle the effect of this poisoning on human, livestock and the environment.

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https://doi.org/10.26626/978-85-5953-031-5.2018C003

‘Natal’ Orange (Citrus sinensis L. Osbeck) Growing Simulation Model Under Climate Change Conditions

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Abstract

The main objective of the research was to develop a model based on dynamic systems. The model was developed through a systematic analysis of the factors that interfere in the formation of crop biomass. It was determined as main variables: CO_2, air temperature, transpiration, precipitation, water deficit, irrigation water depth, canopy cover and their interrelations. The time step used for the simulations and applied was determined by the crop cycle, allowing a time frame from 2010 to 2100. The model has all the variables that are being able to be quantified, pursuing results closer to reality. In general, the results showed that the rising of CO_2 concentrations in the atmosphere combined with higher temperatures will promote greater efficiency of water use by this orange variety. Other factors were added such soil water deficit; it was verified that a reduction in the water productivity parameter for non-irrigated condition will be considerably higher than the irrigated condition by 2100. It was

concluded that the model, here presented, was able to determine the influence of climate, especially future CO_2 concentrations in air temperature changes in the water productivity parameter for Natal orange. Rising CO_2 concentrations in the atmosphere will influence positively the assimilation of CO_2 by the Natal orange and, therefore, a increase in gram per millimeter transpired by the orange tree. However this positive effect may be masked by the effects of other variables such as air temperature.

Keywords: system dynamics, water resources, agricultural production and climate variability.

Introduction

The current climate changes occur mainly due to the high concentrations of gases in the atmosphere. Data from the Intergovernmental Panel on Climate Change - IPCC (2014), show that carbon dioxide (CO_2) concentration in the atmosphere has increased by 40% between 1750 and 2011, and its concentration tends to increase in the future. (STICH *et al.*, 2008, IPCC, 2014).

There are several factors that influence the uptake of CO_2 by crops. Delgado *et al.* (2010) states that the water availability as the main factor. According to Ribeiro Machado (2007) and Ribeiro *et al.* (2009), if the hydric conditions are right, the most important factors that will influence, over the year, the photosynthesis of orange are: changes in air and soil temperature, day length and the plant's development stage.

With the concern of the influence of climate changes on agricultural productivity, there is a growing interest to understand the processes and factors of soil-plant-atmosphere system caused by increases in atmospheric CO_2 concentrations and changes in air temperature. In the literature there are models to evaluate the behavior of herbaceous crops in relation to climate change as, for example, the AquaCrop, which was developed from the reassessment and restructuring of the report 33 from the Food and Agriculture Organization of the United Nations - FAO (DOORENBOS e KASSAN, 1979; STEDUTO *et al.*, 2009; RAES *et al.*, 2009). However, when the desired responses are tree crops with long cycles, such as citrus, it is important to enhance the studies, and modeling is a possibility. It is necessary, therefore, a method that interconnects both the climatic factors and the crops yields behavior over the years. Thus, this study fits perfectly in the System Dynamics methodology. Considered by Capra (1996) as a new way of expressing the chains of existing cyclic events in nature, analyzing them always in an integrated manner.

Thus, the aim of the study was to develop a simulation model for the orange (Citrus sinensis L. Osbeck) growth in relation to climate changes, based on the principles of system dynamics to verify the effects of climate change and variability and its implication on the water use efficiency by the citriculture in the region of São José do Rio Preto, State of São Paulo, Brazil, mediated by changes in

CO_2 concentrations and air temperature variations.

Material and Methods

The dynamic simulation model of the water use efficiency for tree crops, especially citrus (MSE-Citrus), was developed with focus on system dynamics using STELLA 10.0.5 platform. A systematic analysis of the production process and formation of citrus yield was performed, considering the existence of models that simulate the biomass formation of herbaceous cultures in conditions of climate change, such as AquaCrop (STEDUTO *et al.*, 2009; RAES *et al.*, 2009). It was possible from then, to integrate previously developed researches and use these models for tree crops due to lack of models for citrus.

a) Structure of the simulation model of the water use efficiency by citrus (MSE-Citrus)

The conceptual diagram (Figure 1) shows the major variables involved in the yield formation, which was the source for the model development.

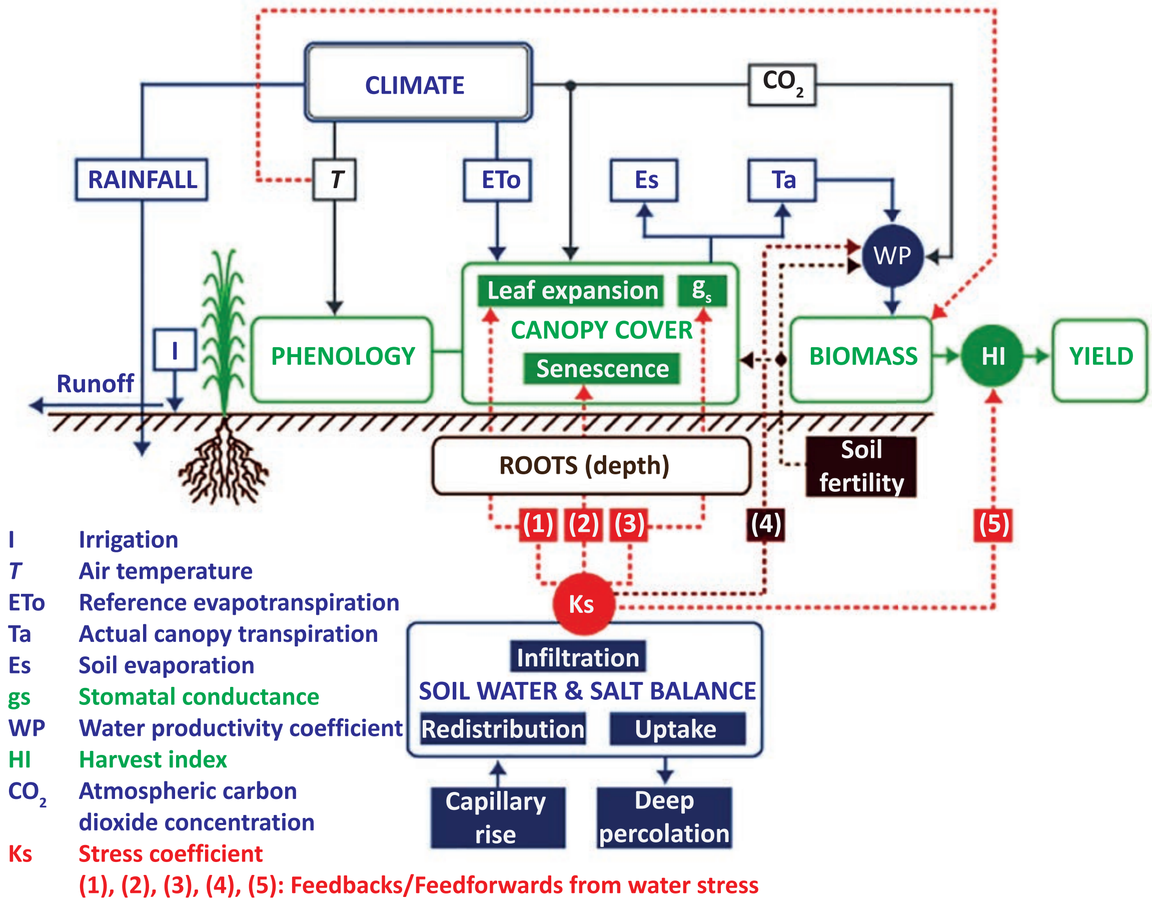

Figure 1 – Conceptual diagram of the yield formation process (adapted from RAES *et al.*, 2012).

The initial steps include the identification of the elements, their interrelationships and processes that constitute the biomass formation process, mainly the CO_2 concentrations in the atmosphere, the relationship of these concentrations with the air temperature and its influence on the water use efficiency by the citriculture. Then the model structure was represented in a causal diagram, also called diagram of influences (Figure 2).

In Figure 2 is shown the interrelations between the major variables involved, the water use efficiency and the CO_2 are the variables that cause main accumulations in the system. The reference evapotranspiration (ETo) and transpiration (Tr) are the variables that quantitatively influence the behavior of water use efficiency and Biomass is the main stock that accumulates in the system. The water use efficiency and biomass receive water during the biomass formation process; CO_2 also has a strong influence on the formation of biomass and water use efficiency, acting as a source in the carboxylation process. The ETo and Tr fill or empty the major stocks and, therefore, act as fluxes.

Existing feedback loops between the system components are characterized by the following points: the increase in CO_2 concentration will increase the water use efficiency (+), the same occurs with the increase in transpiration which will cause an increase in biomass and therefore will cause an increase in the water use efficiency (+), and an increase in ETo reduces the water use efficiency (-). The relation between biomass and transpiration shows the same response (+), note that it is a positive reinforcement.

From the causal circle (Figure 2) was developed the diagram of stocks and flows, shown in Figure 3, which allows us to describe the system operation in a more detailed way. Thus, it was possible to perform the mathematical simulation of the water use efficiency by orange crop.

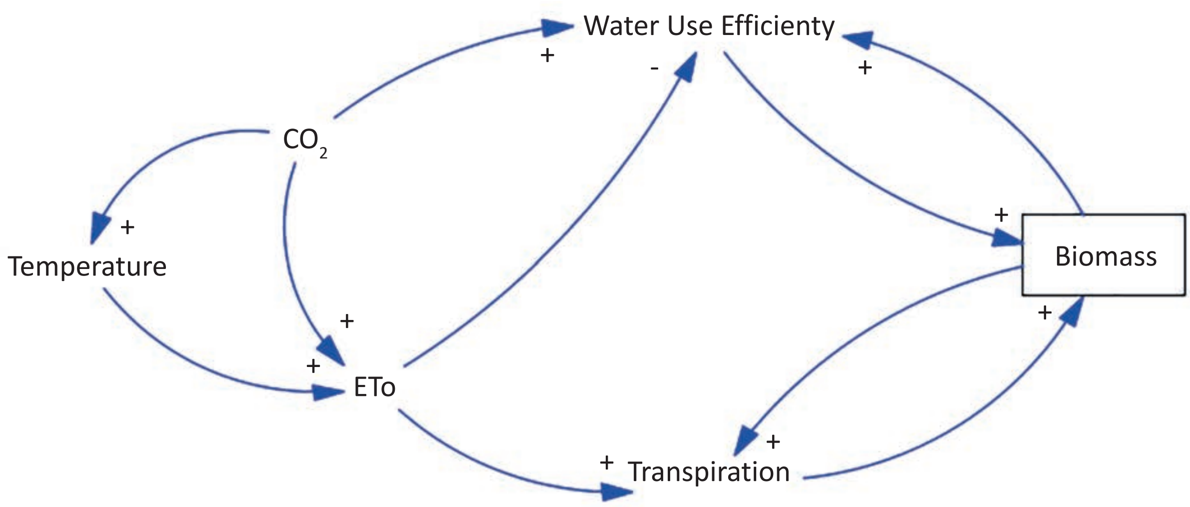

Figure 2 – Causal diagram of the developed model (adapted from PEREIRA; SÁNCHEZ-ROMÁN; ORELLANA GONZÁLEZ, 2017).

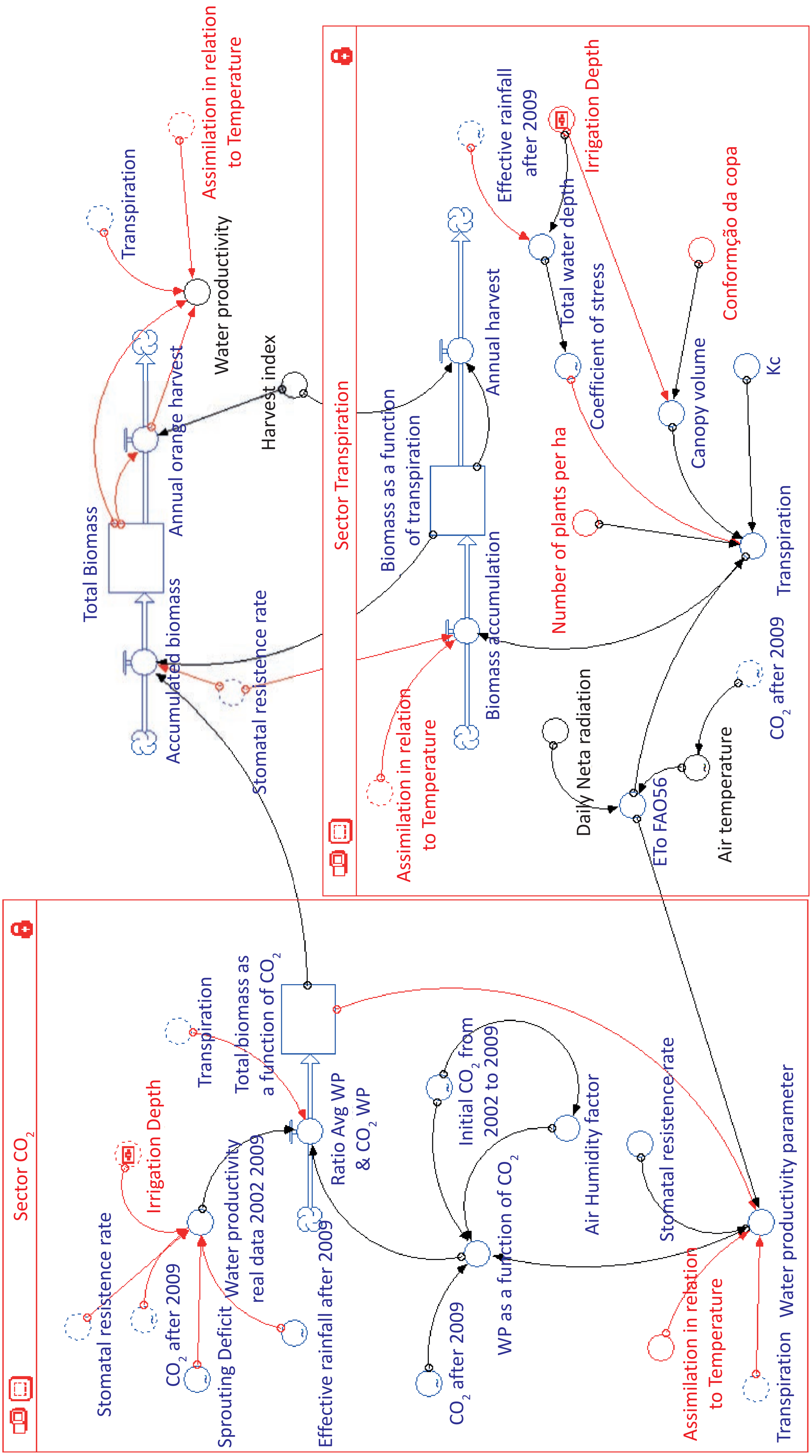

Figure 3 – Diagram of stocks and flows (adapted from PEREIRA; SÁNCHEZ-ROMÁN; ORELLANA GONZÁLEZ, 2017)

b) Mathematical basis for the development of MSE-Citrus

Was used to calculate the water use efficiency (WP) the methodology described in papers published by FAO (STEDUTO, HSIAO e FERERES 2007; RAES *et al.*, 2009; RAES *et al.*, 2012). Equations 1, 2 and 3 were fundamental to the WP calculation, and also for the normalization of CO_2 concentrations in the atmosphere.

$$WP = \left(\frac{B}{\sum \frac{Tr}{ETo}} \right) [CO_2] \qquad \text{Eq. 1}$$

Where:

B: Total Biomass, (Kg m^{-2});

WP: Water use efficiency (Kg m^{-2} mm) kilogram of biomass per square meter and per millimeter of water transpired, or kilogram of biomass per cubic meter of water transpired;

Tr: Crop transpiration (mm);

ETo: Reference evapotranspiration (mm);

CO_2: CO_2 concentration in the atmosphere (ppm).

Transpiration was calculated using Equation 2, proposed by Raes *et al.* (2009).

$$Tr = Ks * D * \%CC * Kc_{trx} * ETo \qquad \text{Eq. 2}$$

Where:

Ks: Drought stress coefficient (decimal);

%CC: Canopy volume (decimal);

Kc_{Trx}: Kc of the maximum transpiration (adimensional);

ETo: Reference evapotranspiration (mm).

All the complex metabolic processes of the CO_2 fixation are considered in the parameters of the equations 3 e 4, described in the work of Steduto, Hsiao e Fereres (2007).

$$WP = WP_b \frac{C_{a,o}}{C_a} * D \qquad \text{Eq. 3}$$

Where:

WP: Water use Efficiency as a function of CO_2 concentrations (g m^{-2} mm^{-1}),

WP_b: Biomass water use efficiency (data provided by Citrosuco company) (g m^{-2} mm^{-1});

$c_{a,o}$: Annual average concentration of CO_2 in the atmosphere measured by Mauna Loa Observatory (Havaii), for the reference year;

c_a: Annual average concentration of CO_2 in the atmosphere measured by Mauna Loa Observatory (Havaii), for the year in which the biomass is produced;

D: Empirical factor originated from an approximation of the sum of Δw, that is the sum of the difference in the concentration of water vapor between the intercellular air space and the atmosphere in a given situation (Δw) and in a reference situation (Δwo).

Steduto, Hsiao, Fereres (2007) recommend that D shall be obtained by Equation 4, where $C_{a,o}$, is taken as a reference value equal to 360 ppm.

$$D = a - b \times (C_a - C_{a,o}) \qquad \text{Eq. 4}$$

Where:

a: 1.

b: 0,000138

For the determination of the coefficients a and b of equation 4, Steduto, Hsiao e Fereres (2007) performed experiments in chambers under controlled conditions of CO_2 emissions, and other parameters related to the conditions of vapor saturation pressure, air temperature and humidity. Furthermore, the authors suggest that Equation 4 could be used for the standardization of different concentrations of CO_2 in the atmosphere.

c) Information source for the use of MSE-Citrus

After developing the model, were obtained data from consecutive years of biomass formation for the orange crop in non-irrigated condition, to check if the structured model can simulate water use efficiency values close to the values provided by FAO for C_3 plants (15 to 20 g m^{-2} mm^{-1}).

The planting of the crop was carried out in 1998 and the data of biomass formation were collected since 2002, when the crop was five years old.

The stress coefficient (Ks) was calculated for each year with the water amount resulting from rainfall. The climate database, the rainfall in the two farms, which formed the basis for the simulation model was obtained from the Department of Water and Power of the State of São Paulo (DAEE). Data for potential evapotranspiration were obtained from the Agronomic Institute of Campinas (IAC).

d) Calculation of water use efficiency parameter - WP

With orange biomass formation data provided by the Citrosuco company, the total biomass was calculated. The biomass data provided correspond to the useful orange biomass, i.e. the fruit. To convert these values in total biomass was used a conversion factor based on previous researches, that determined what percentage of orange trees correspond to useful biomass (MATTOS JUNIOR *et al.*, 2003).

The variable canopy volume (Vc) was obtained by values established in the literature (QUAGIO *et al.*, 2004; GRAÇA *et al.*, 2001; STUCHI e DONADIO 2000; LEDO *et al.*, 1999). According toLevy, Bielora, Shalhevet (1978) and Romero *et al.* (2006), in citrus orchards conducted in rainfed condition, it happens 41% reduction in canopy volume, from these growth reduction coefficients and values of canopy volume percentages, was applied the percentage reduction in the non-irrigated area. With the canopy volume, it is possible to determine the transpiration per plant. From the determination of the tranpiration and with the number of plants per hectare, it is determined the amount of water transpired annually per hectare in irrigated and unirrigated conditions.

To obtain the equations that guided the STELLA software, were evaluated the data provided by the Citrosuco company, and it was realized that the yields were influenced by some variables, for example, the water deficit that occurred in the sprouting period was influenced by weather conditions and the crop cycle. The water deficit was obtained by performing the calculation of the water balance in the period in which the biomass formation data was obtained (2002 to 2009).

The biggest water deficit occur annually in the period between the second half of May up to first half of August, moment that begins the replacement of evapotranspired water with the use of irrigation in the area conducted under irrigation. From the analysis of the biomass formation, it was created a multiple linear correlation.

The multiple linear correlation of non-irrigated area is shown in Equation 5; together these variables explain 96% of the WP's behavior in this growing condition (R^2= 0,96).

$$WP = -10,24 - 0,03 * DNB + 0,04 * PE \quad \text{Eq. 5}$$

Where:

- *WP*: Water use Efficiency (g m^{-2} mm^{-1});
- *DNB*: Deficit during sprouting (mm); (70 ≥ DNB ≤ 400);
- *PE*: Effective rainfall (mm); (600 ≥ PE ≤ 1000).

Equation 5 has been used in STELLA and added as input variables for the model, performing simulations in the software, with real values of water use efficiency.

To simulate the behavior of water use efficiency in relation to changes in air temperature, it was used the study conducted by Machado *et al.* (2005) (Table 1). These authors obtained responses curves of CO_2 assimilation due to changes in air temperature; the study was conducted in chambers with controlled conditions of air temperature and different concentrations of CO_2. Moreover, the authors reported that the limiting factor for photosynthesis exerted by the stomata is equivalent to 23%.

In its structure the model comprises adjacent parameters, which are fundamental. The water deficit included to the model was established from the information provided by Marengo (2006), this author has developed a model that simulates the behavior of rainfall until the year 2100, it was made an analogy of the future behavior of water deficit, using future scenarios of precipitation provided by the author cited above. In Table 2 are shown the input data for the simulation of the developed model.

In Table 3 are shown the characteristics of the 9 scenarios for the non-irrigated condition.

Table 1 – Annual CO_2 assimilation rate due to air temperature.

Temperature (°C)	25	30	40
Assimilation percentage (%)	81,37	93,01	59,96
Annual amount of CO_2 assimilation (g m^{-2} $year^{-1}$)	527,40	648,15	388,61

Source: adapted from Machado *et al.* (2005).

Table 2 – Description of the variables used in the execution of the model - input data.

Variables	Characteristics
Annual uptake of CO_2 in function of the air temperature (decimal)	Three temperatures 25°C, 30°C and 40°C, which corresponded, respectively, to 0,2; 0,1 and 0,4.
Rainfall (mm)	Total average, derived from the data of 2002 to 2009, an amount equal to 865,00 mm and was assumed behavioral trend established for Marengo (2006).
Hydric deficit (mm)	Total average deficit (57,76 mm), acquired by performing the calculation of the water balance in the period in which the income was obtained (2002 to 2009). To perform the simulations was adopted initial value in 2010 equal to 54 mm with a gradual increase to 74 mm of water deficit in 2100, this variable was determined from the study of Marengo (2006).
Stomatal resistance (decimal)	0,23 (MACHADO *et al.*, 2005).
Canopy volume (decimal)	1,0 in irrigated condition and 0,59 in non-irrigated condition (ROMERO *et al.*, 2006).
Kc_{Trx}	Following the recommendations of Doorenbos and Pruitt (1977, 1984), we used the amount equivalent to 0.85 to Kc of the maximum transpiration (Kc_{Trx}) during the phenological cycle of citrus.
CO_2 (ppm)	Three CO_2 concentrations in the atmosphere (SUST, MIN and MAX), determined by the IPCC.
Inflection point	600 ppm: reduction of 50% in carboxylation, parameter set from a review of studies (PINTO, ASSAD E ZULLO, 2004; STRECK and ALBERTO, 2006; STRECK, 2005; MACHADO *et al.*, 2005 and AMTHOR, 2001).

Table 3 - Proposed scenarios evaluated in the study

Scenarios	Description of the scenarios for the non-irrigated condition
A	Temperature 25ºC, CO_2 in sustainable atmosphere (387-544) ppm
B	Temperature 30ºC, CO_2 in sustainable atmosphere (387-544) ppm
C	Temperature 40ºC, CO_2 in sustainable atmosphere (387-544) ppm
D	Temperature 25ºC, CO_2 in maximum atmosphere (413-1142) ppm
E	Temperature 30ºC, CO_2 in maximum atmosphere (413-1142) ppm
F	Temperature 40ºC, CO_2 in maximum atmosphere (413-1142) ppm
G	Temperature 25ºC, CO_2 in minimum atmosphere (413-794) ppm
H	Temperature 30ºC, CO_2 in minimum atmosphere (413-794) ppm
I	Temperature 40ºC, CO_2 in minimum atmosphere (413-794) ppm

Results and Discussion

All quantities of CO_2 in the atmosphere projected by the IPCC and used in this study, Sustainable (SUST), Maximum (MAX) and Minimum (MIN), show an increase in the CO_2 concentration in the atmosphere from 2010 to 2100 (SUST, 387-544 ppm; MAX, 413-1142ppm e MÍN, 366-794ppm). The results obtained with the simulation of the developed model show an increase in the water use efficiency in the higher CO_2 concentrations. Taiz e Zeiger (1991), state that in plants the CO_2 is the primary substrate for photosynthesis, e o aumento da concentração desse gás na atmosfera ncreasing the concentration of this gas in the atmosphere provides increased growth rate, these authors add that plants with metabolism C_3 (citrus) are the most benefited by higher CO_2 concentrations (Table 4).

From the results it was observed that the air temperature corresponding to 30°C determined the highest values of grams of dry matter per mm of water transpired, having 27,69 g m^{-2} mm^{-1} at 2100 under the sustainable concentration of CO_2 in the atmosphere (scenario B in Table 4). Similar results were found by Machado *et al.* (2005) who found that the highest CO_2 assimilation rates in oranges occur between 25 and 30°C and at air temperatures above 30°C there is a reuction in the assimilation of CO_2. The results obtained by these authors was critical to the composition of the scenarios of the present research, because in their study they found that in extreme temperatures, 15 and 40°C, stomatal conductance is compromised, resulting in a reduction of photosynthetic rate.

Table 4 shows that water use efficiency is higher in scenario B, which provided water productivity of 27,69 g m^{-2} mm^{-1} in the year 2100.

Table 4 – Water use effiency achieved by the orange crop in each scenario.

			Water use effiency achieved by the orange crop (g m^{-2} mm^{-1})								
Scenario	**CO_2**	**Temperature°C**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2080**	**2090**	**2100**
A	SUST	25°C	10,92	13,71	15,87	17,66	19,2	20,57	21,82	22,97	23,95
B	SUST	30°C	12,7	15,91	18,4	20,46	22,23	23,8	25,23	26,56	27,69
C	SUST	40°C	10,1	12,74	14,77	16,46	17,91	19,2	20,38	21,47	22,39
D	MAX	25°C	10,57	13,19	15,14	8,34	8,95	9,46	9,88	10,23	10,51
E	MAX	30°C	12,3	15,32	17,55	9,65	10,36	10,94	11,42	11,83	12,15
F	MAX	40°C	9,77	12,25	14,08	7,76	8,34	8,81	9,21	9,54	9,8
G	MIN	25°C	10,39	13,1	15,18	16,88	18,28	19,46	10,23	10,66	10,99
H	MIN	30°C	13,05	16,36	18,9	20,97	22,7	24,14	12,68	13,21	13,62
I	MIN	40°C	10,06	12,86	14,98	16,7	18,12	19,32	10,17	10,6	10,94

CO_2 in the atmosphere projected by the IPCC: SUST - Sustainable (387-544) ppm, MAX - Maximum (413-1142) ppm, MIN - Minimum (413-794) ppm; WP Water use effiency (g m^{-2} mm^{-1}).

Martinez *et al.* (2014) performed an experiment with foragers plants subjected to a temperature increase of 2°C, also based on scenarios provided by the IPCC, and found that the increase in temperature by 2050 could benefit the physiology and the biochemical and biophysical processes involved in the growth of these plants. Furthermore, the authors found an increase of 32% in the leaf area index and 16% in the production of above-ground biomass compared to the plants cultivated in normal conditions. The model for the simulation of the orange growth, developed in the present study, predicts an increase in the water use efficiency primarily due to increased biomass production, until atmospheric temperature equal to 30°C and CO_2 concentration not exceeding 600 ppm.

According Taiz and Zeiger (2004), if the increase in CO_2 concentration is followed by an increase in air temperature, there can be no increase in growth and crop yields. The works of Allen e Vu (2009); Idso, Kimbal, (1991); Ribeiro e Machado, (2007); Ribeiro *et al.* (2009); Magalhães Filho *et al.* (2009) present justifications that the increase in CO_2 concentrations in the atmosphere may bring harmful responses in the productivity of citrus.

Other studies using modeling to predict the impact of climate change on agricultural income also demonstrate that for high levels of CO_2 in the atmosphere due to the simultaneous increase in temperature can cause a decrease on the agricultural production (KRISHNAN *et al.*, 2007). the authors found, according to their model simulations, a reduction of 56% in rice production, if the CO_2 concentration is equal to 700ppm and the air temperature increases 4°C.

The simulation results for future years (2020 to 2100) show an increase in the amount of biomass of orange per mm of water transpired with the increase of CO_2 in the atmosphere. In fact this is the main result achieved by the developed model, however, in previously published work by Medina, Machado e Pinto (1998), Medina, Machado e Gomes (1999), Medina *et al.* (2002) e Machado *et al.* (2005), the authors state that if the increase in CO_2 concentrations occur along with the increase in the vapor pressure deficit, both transpiration rate and CO_2 assimilation will be adversely affected, diminuindo o crescimento das plantas e, portanto, o parâmetro produtividade da água.

Conclusions

The model represented the processes involved in the water use efficiency by orange under climate changes. At CO_2 concentration equivalent to 600 ppm and atmospheric temperature of 30°C the biomass formation will be benefited, but the biomass formation will decrease in higher temperatures and carbon dioxide concentrations.

The increase in CO_2 concentrations in the atmosphere positively influences the assimilation and, therefore, increases the biomass production g per mm of water transpired, however, this beneficial effect may be masked by other effects of that elevation, related mainly to air temperature and vapor pressure deficit.

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https://doi.org/10.26626/978-85-5953-031-5.2018C004

Diversity of the Zooplankton (Alpha and Beta) in the Lentic Environment in the Miranda River Basin (MS, Brazil)

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Abstract

The zooplankton is one the main components of the freshwater environments, and play fundamental services in aquatic system. The diversity of the zooplankton is central to maintain these services and increase resilience of the system. The aim of this present work was to obtain the values of alpha-diversity, ecological diversity and beta-diversity for zooplankton (Rotifera, Cladocera and Copepoda) in lentic environments with different origins, uses, preservation stages in the Miranda River Basin (MRB), Mato Grosso do Sul State (Brazil). The zooplankton was sampled with a graduated trap and filtering water using a net with 20 µm of pore size. After counting, the organism it wasapplied the Whittaker beta diversity coefficient and Shannon-wiener diversity index. The total richness for each zooplankton group was 62 for Rotifera, 32 for Copepod and 26 for Cladocera. The MRB has two hotspot with different origin and use, one a urban

reservoir and another a water outcropping. Cladocera presents a more restricted distribution with highest diversity in the plateau and more homogenous population than Rotifera and Copepoda presented a similar pattern.

Keywords: zooplankton distribution, aquatic ecology, freshwater dispersion, Paraguay River Basin.

Introduction

The zooplankton is one the main components of the freshwater environments, and play fundamental services in aquatic system. These services include the nutrient cycling in water (VANNI, 2002) and the energy transfer by food chain web (TUNDISI, MATSUMURA-TUNDISI, 2003; DICKMAN et al. 2008). The diversity of the zooplankton is central to maintain these services and increase resilience of the system (DOWING, LEIBOLD, 2010; AWITI, 2011).

Among the many ways to measure the biological diversity, the richness (alpha-diversity) and ecological diversity (Shannon-Weiner index) are the most used (MATSUMURA-TUNDISI, 1997). Another diversity related to spatial area is the Beta-diversity that is the product of Gamma diversity (total species of some area) by alpha-diversity (the local number of species) (WITHAKER, 1972). Where, if the environment is composed by many sites with low beta-diversity means there is high similarity among them.

The environment changes promote by climate and by human activities impact the freshwater system (PERKINS et al., 2015; WALSH et al. 2016) and the diversity decreasing resulting in loss of biodiversity and diminishing the ecosystem services. In many freshwater systems surrounded by human activities, the biodiversity decrease changing the ecological diversity too in general became the environment less heterogenic. According McKnight et al. (2007) the environmental homogenization promoting by human activities implies in reduction of beta-diversity.

The aim of this present work was to obtain the values of alpha-diversity, ecological diversity and beta-diversity for zooplankton (Rotifera, Cladocera and Copepoda)

in lentic environments with different origins, uses, preservation stages in the Miranda River Basin (MRB), Mato Grosso do Sul State (Brazil).

Material and Methods

The figure 1 show the Miranda River Basin location and the sample point distributions. It were sampled 24 lentic water bodies, including natural and artificial ones. In each lake were sampled water for chemical and physical analysis. The zooplankton was sampled with a graduated trap and filtering water using a net with 20 µm of pore size. The filtered sample was preserved using formaldehyde with 4% in a polyethylene flask. The identification and quantification of zooplankton were done using optical microscope and stereoscope microscope and specialized bibliography. It were apply the Whittaker beta diversity coefficient (γ/α), where γ is the gamma diversity (all species in the river basin) and α is the alpha diversity (all local species) and Shannon-wiener diversity index ($-\sum pi \ln pi$) where pi is the relative density of each species at local. The median ($\tilde{x}$) was calculated for each group.

Results

The total richness for each zooplankton group was 62 for Rotifera, 32 for Copepod and 26 for Cladocera. The Rotifera has recorded in 23 sites, the Copepoda in 22 sites and the Cladocera in 15 sites.

The table 1 shows the values for richness, Shannon-Weiner Index and β-diversity for zooplankton groups in each sample point.

The results shows that Rotifera presented 12 sites above the median values for diversity index and 11 for Beta-diversity. Copepoda had the same values 12 sites for diversity index and 11 for Beta-diversity, but with one site less and Cladocera presented 8 and 7 respectively.

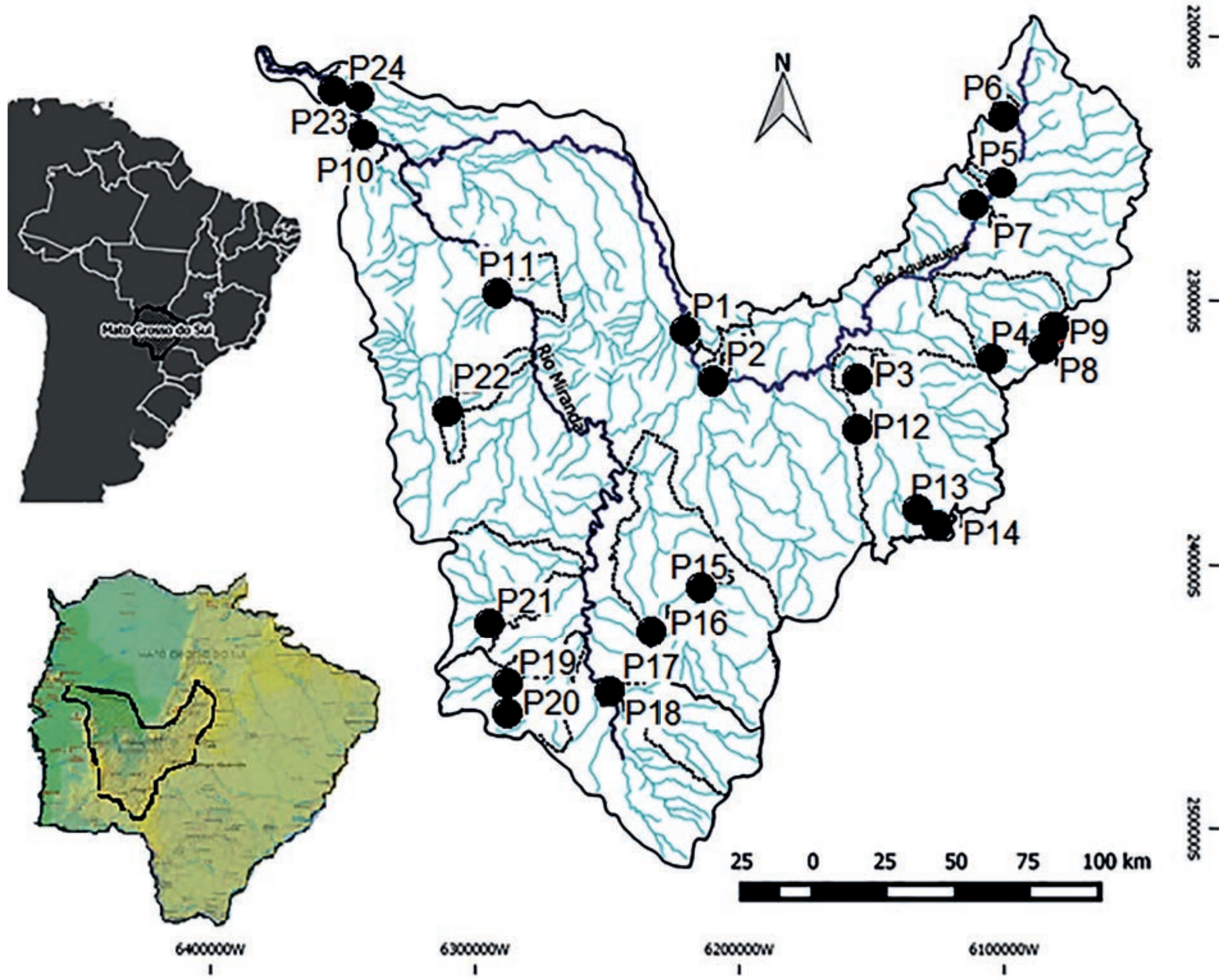

Figure 1 – Location of the Miranda River Basin in the Mato Grosso do Sul State and the samples points distribution.

Table 1 – The values for richness, Shannon-Weiner index (H) and Beta-diversity (β) for Rotifera, Copepoda and Cladocera in the MRB sites and median ($\tilde{x}$).

Rotifera				Copepoda				Cladocera			
Sites	Richness	H	β	Sites	Richness	H	β	Sites	Richness	H	β
P1	14	2,4	4,4	P1	3	0,9	10,7	P2	16	1,7	1,6
P2	17	2,4	3,6	P2	13	1,8	2,5	P4	6	1,6	4,3
P3	5	1,3	12,6	P3	4	0,6	8,0	P6	1	0,0	26,0
P4	12	1,5	5,2	P4	4	0,9	8,0	P11	1	0,0	26,0
P5	10	1,6	6,2	P5	3	0,2	10,7	P12	5	1,3	5,2
P5	8	1,7	7,8	P6	4	1,3	8,0	P13	3	0,4	8,7
P6	14	2,5	4,4	P7	1	0,0	32,0	P14	6	0,6	4,3
P8	4	1,3	15,5	P9	4	1,3	8,0	P15	3	0,5	8,7
P9	2	0,5	31,0	P10	1	0,0	32,0	P16	1	0,0	26,0
P11	3	0,6	20,7	P11	2	0,7	16,0	P17	3	1,1	8,7
P12	5	1,3	12,4	P13	4	1,4	8,0	P19	5	1,3	5,2
P13	8	0,7	7,8	P14	2	0,5	16,0	P20	5	0,9	5,2
P14	9	1,4	6,9	P15	11	1,7	2,9	P21	5	0,5	5,2
P15	13	0,8	4,8	P16	5	1,6	6,4	P22	4	0,9	6,5
P16	8	1,4	7,8	P17	3	1,1	10,7	P23	3	0,2	8,7
P17	10	1,6	6,2	P18	9	1,4	3,6				
P18	12	2,0	5,2	P19	3	1,1	10,7				
P19	15	2,6	4,1	P20	3	0,4	10,7				
P20	6	0,4	10,3	P21	6	0,9	5,3				
P21	2	0,7	31,0	P22	2	0,7	16,0				
P22	4	1,3	15,5	P23	8	1,0	4,0				
P23	10	2,0	6,2	P24	2	0,6	16,0				
P24	14	1,8	4,4								
$\tilde{x}$	9,0	1,4	6,9	$\tilde{x}$	3,5	0,9	9,3	$\tilde{x}$	4,0	0,6	6,5

The figure 2 A-C shows the location in the MRB of the samples points with high and lowest diversity for the zooplankton group. There were few coincident pointsfor both higher and lower diversity.

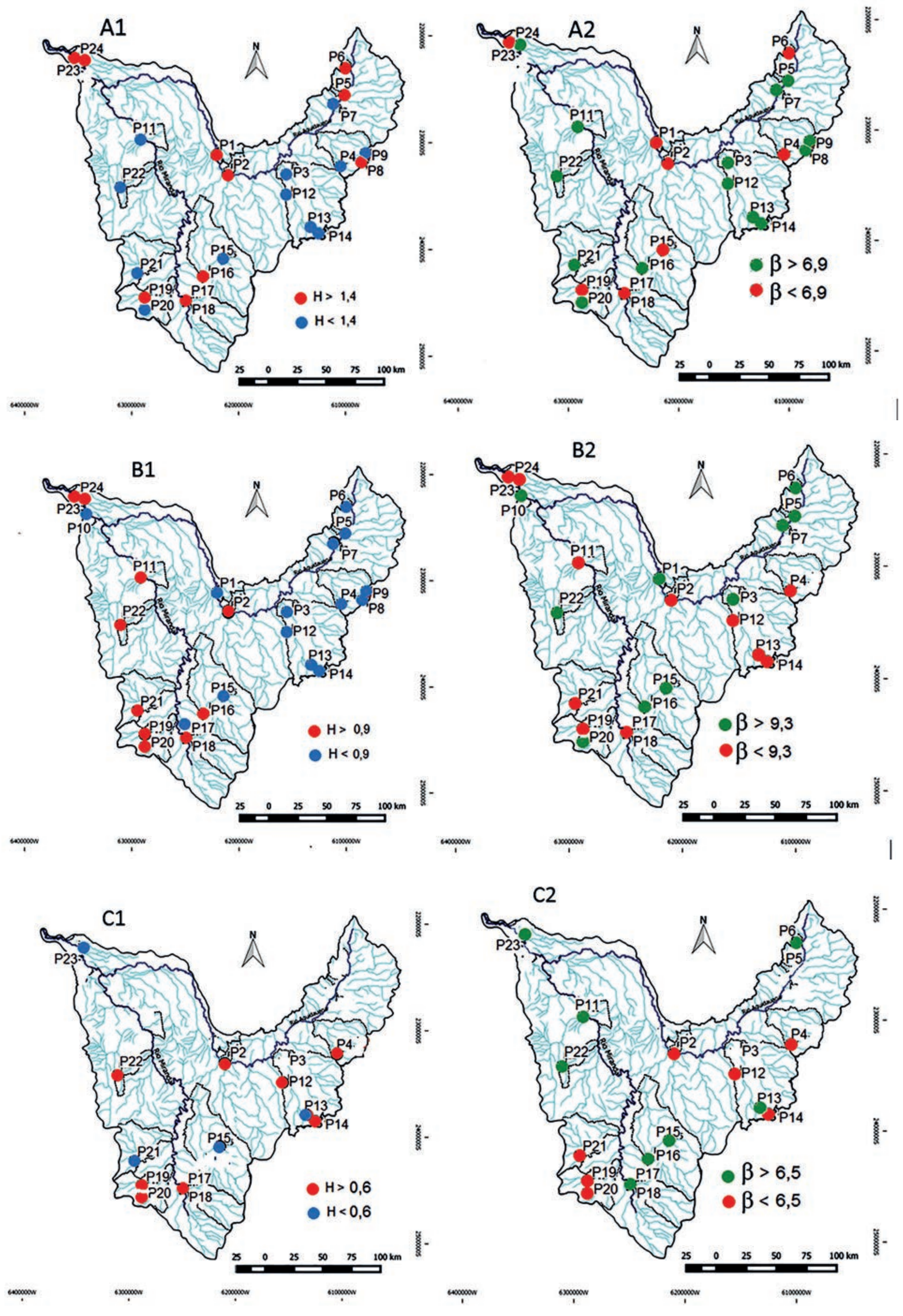

Figure 2 – Distribution of diversity index and beta-diversity for Rotifera A1 and A2; for Copepoda B1 and B2; for Cladocera C1 and C2.

Discussion

The distribution of zooplankton has two components by local such as water chemistry and regional factors such as climate variation (SHURIN et al. 2000). in the RMB the main regional factor is the altimetry degree with high in the east about 250 to 1200 m and low in the west, Pantanal floodplain about 80 to 150m (ALMEIDA et al. 2015).

Rotifera and Copepoda were the most frequent groups and the Cladocera the less one. The high absence of Cladocera show the narrow ecological when compared with the Rotifera and Copepoda as observed in other studies of distribution (PANARELLI et al. 2013; PINEL-ALLOUL, MIMOUNI, 2013). Cladoceran was not retricted to a region but has presented minor frequency in floodplain area, which is driven by high water fluctuation (ROSSA et al. 2001; PANARELLI et al. 2013; KARPOWICZ, 2016).

Diversity index highest values for Rotifera, Cladocera and Copepoda show some overlap, and point to the hotspot that support high diversity for all groups. Points 2 and 19 are the hotspot. The point 2 is an urban reservoir and 19 is a water outcropping in a cattle farm. These agree with the environmental heterogeneity promotes the diversity in zooplankton communities (COTTENIE, DE MEESTER, 2004; BARNETT, BEISNER, 2007). Both Rotifera and Copepoda has a hotspot too in the Pantanal area, points 23 and 24, and Cladocera not, with agreementof the hypothesis that this group are most susceptible to water level variation (ROSSA et al. 2001; PANARELLI et al. 2013; KARPOWICZ, 2016).

Beta-Diversity used be high when the diversity index is low, but some incongruence can be found. The Cladoceran presented a high congruence between both diversities and Rotifera and Cladocera less congruence. Cladocera population is more homogenous (shares more species) in the water bodies, and Rotifera and Copepoda more heterogeneous. The Cladocera presents more restricted environmets and probably is more sensitive to environmental changes (SHURIN et al. 2010), once that population is more homogenous. Most of lakes show a poor combination for diversity had high beta-diversity and low alpha-diversity (with low diversity index) that is expected (KOLEFF et al. 2003). The small lakes with low diversity index and high beta-diversity values are important repository cause has high density that facility the dispersion (DE BIE et al. 2008).

These results combining beta-diversity and diversity index drives for two main statements, which works as a tool for environmental managers. The first, Cladocera community shows more sensitive to regional changes, such as plateau and floodplain areas that is in agreement with other distribution studies (SHURIN et al. 2000; NEVALAINEN et al. 2010, SWEETMAN, RÜHLAND 2010). The second, Rotifera and Copepoda communities is determinate by local process, such as pollution and eutrophication, these communities historically is used for local water quality indicator (SLÁDEČEK, 1983, MATSUMURA-TUNDISI, 1999, SILVA, 2011, PERBICHE-NEVES et al., 2013).

Concluding, the MRB has two hotspot with different origin and use, one a urban reservoir and another a water outcropping. Cladocera presents a more restricted distribution with highest diversity in the plateau and more homogenous population than Rotifera and Copepoda presented a similar pattern.

Acknowledgement

We are thankful to FUNDECT/SUCITEC/SEMAC Nº 09/2012 - BIOTA-MS for their financial support and scholarship awarded.

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Impact Assessment of Water Translocation from the Tucutunemo River to Camatagua Reservoir (Aragua State, Venezuela)

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Abstract

In order to control the increase of water level of Lake of Valencia, during 2009 began the translocation of water from the Taiguaiguay reservoir, through the Tucutunemo and Guárico rivers, to Camatagua reservoir, which is used as the main source of drinking water for the city of Caracas; this water translocation stopped in January 2015. Considering that water of Taiguaiguay reservoir is fed with treated wastewater from Taiguaiguay treatment plant, which is rich in nutrients, mainly P and N, the objective of this study was to evaluate the impact of water transfer from Taiguaiguay reservoir on water quality and quantity of Camatagua reservoir. We analyzed the data from 37 samples made from 2012 to 2016, near the water intake, in which *in situ* measurements and samples were taken for physicochemical and biological analysis (Secchi disk transparency, turbidity, ammonia, phosphates, total dissolved phosphorus, total phosphorus and phytoplankton abundance). Decrease in translocation flow from 2013, until its final elimination in 2015, caused a marked decrease in the water level of Camatagua reservoir. Water transparency and turbidity were affected by the entry of water from the Taiguaiguay reservoir. Also, ammonia and total phosphorus

concentrations showed an increase from 2012 to 2016, as a consequence of the high content of nutrients reaching to Camatagua reservoir from Taiguaiguay reservoir, as well as the decomposition of the organic matter. Nutrient input stimulated the increase of phytoplankton density with dominance of the species *Cylindrospermopsis raciborskii*, *Oscillatoria planctonica*, *Leptolyngbya limnetica*, *Microcystis aeruginosa* and *Synechocystis aquatilis* for the whole study period.

Keywords: water translocation, camatagua reservoir, water quality, eutrophication.

Introduction

In order to control the water level increase in Lake Valencia, during 2009 the excess of water of Taiguaiguay reservoir was traslocated to the Tucutunemo River, which joins downstream to the Guárico River, the main affluent of the Camatagua reservoir (GONZÁLEZ et al., 2015). The water from Tucutunemo River is rich in nutrients (mostly N and P), which come from the Taiguaiguay treated wastewater treatment plant.

Camatagua is the main drinking water reservoir for the City of Caracas and other adjacent populations (ca. 6 million of inhabitants). The impact of this translocation affected the water quality supplied for human consume, increased the eutrophication process of reservoir and, by this reason, it finished in January 2015.

Camatagua reservoir was classified as eutrophic, according to the criteria of Salas and Martinó (1991) for warm tropical lakes, based on the concentration of total phosphorus (GONZÁLEZ, 2017).

Objective

Evaluate the impact of water translocation from Taiguaiguay reservoir on the water quality and quantity of Camatagua reservoir.

Study Area

Camatagua reservoir is located in the Central region of Venezuela (Figure 1).

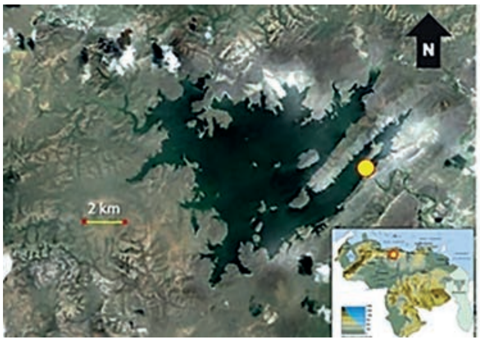

Figure 1 – Relative location of Camatagua reservoir and the sampling site ( ) near the uptake tower.

Main morphometric characteristics of the Camatagua reservoir

The main morphometric characteristics of Camatagua reservoir are (CASTILLO et al., 1973):

- Geographic location: 9°50' N – 67°00' W
- Surface: 59,000,000 m^2
- Volume: 1,250,000,000 m^3
- Altitude: 302 m.a.s.l.
- Mean depth: 21 m
- Discharge: 19 m^3/s

Methods

Data were analyzed from a total of 37 quarterly samples from 2012 to 2016, near the uptake tower in Camatagua reservoir. Samples were taken at the three levels: surface, intermediate and bottom, using a van Dorn bottle for physicochemical analysis and for phytoplankton in the euphotic layer. In the field, water transparency was measured (Secchi disk 20 cm in diameter).

Once in the laboratory, the following variables were analyzed:

- Turbidity: Nephelometer HACH.
- Ammonia, phosphates, total dissolved phosphorus and total phosphorus: Standard Methods (APHA, 1992).
- Biological variables: Phytoplankton

Samples were fixed with lugol solution. Phytoplankton species were identified after sedimentation in Uthermöhl chambers, observation under an inverted microscope and the help of taxonomical keys for the elaboration of the species inventory. Algal density was determined by counting of cells in Sedgewick-Rafter and Uthermöhl chambers, with the help of an optical microscope (APHA, 1992).

Results of all determined variables are shown based on the annual average values of the water column. Flow of water transferred from the Taiguaiguay reservoir to the Tucutunemo River corresponds to the annual average value.

Results and discussion

- **Translocation diagram from Taiguaiguay reservoir to Camatagua reservoir:** During 2009, water translocation from the Taiguaiguay reservoir to the Tucutunemo River and after to the Camatagua reservoir was made, with an initial flow of 3000 l/s. Figures 2 and 3 show the diagram of water translocation from Taiguaiguay reservoir to Camatagua reservoir. Figure 2 clearly shows clearly the high input of N and P to the Guárico River from the Tucutunemo River.

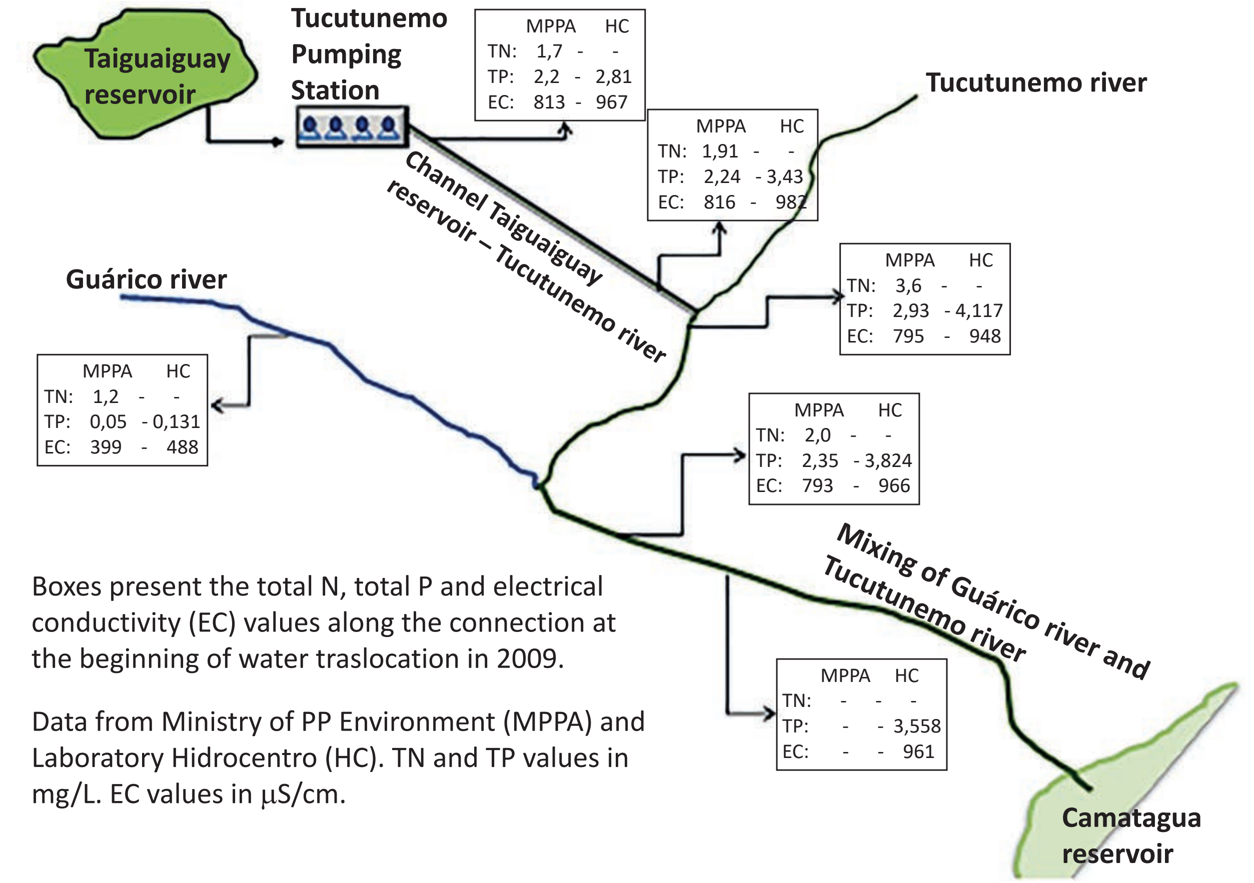

Figure 2 – Diagram of water translocation from Taiguaiguay reservoir to Camatagua reservoir and values of P, N and CE in 2009.

Figure 3 – Flow of translocation from the Taiguaiguay reservoir to the Tucutunemo River. It can be noted the development of a thick layer of phytoplankton in the pit of the pumping station.

- **Translocation and water level in Camatagua reservoir:** Water translocation made to control water level of Lake of Valencia, contributed to maintain the normal level of water in Camatagua reservoir. The decrease in translocation flow from 2013, until its final elimination in 2015, caused a marked decrease in the water level in Camatagua reservoir (Figure 4).
- **Transparency and turbidity**: Transparency and turbidity (Figure 5) were affected by the entry of water from the Taiguaiguay reservoir. The impact on water quality was still present, even after the stop of translocation. As in 2013, a decrease in water transparency was observed, probably due to the increase in turbidity and the high abundance of phytoplankton, which give the water a turbid greenish color, limiting penetration of light only to a few centimeters from the surface (euphotic layer with no more than 2 m of extension).
- **Ammonia concentration:** Ammonia concentration (Figure 6) also showed an increase from 2012 to 2016, as a consequence of the high content of nutrients reaching the Camatagua reservoir from the Taiguaiguay reservoir, as well as from the increased organic matter decomposition.

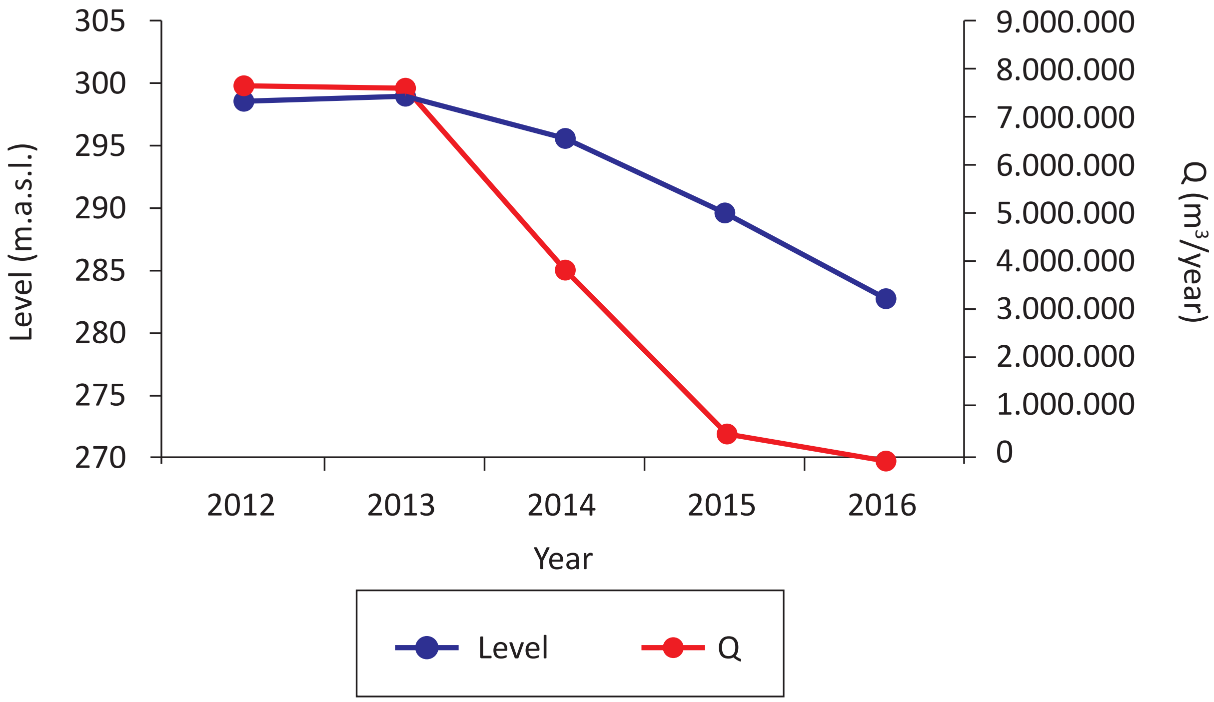

Figure 4 – Relationship between water translocation (Q) and water level in Camatagua reservoir.

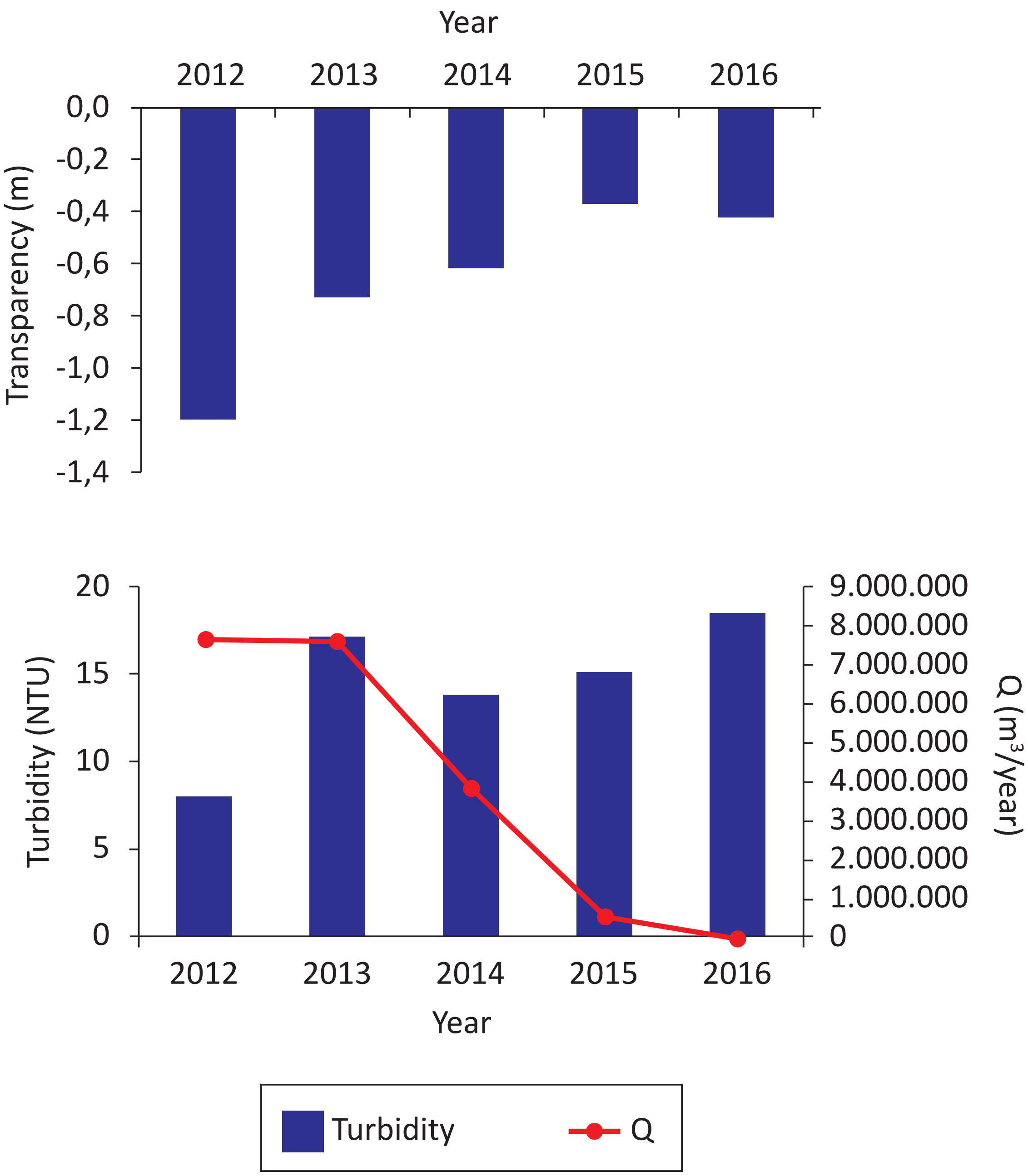

Figure 5 – Relationship between water translocation (Q), transparency and turbidity in Camatagua reservoir.

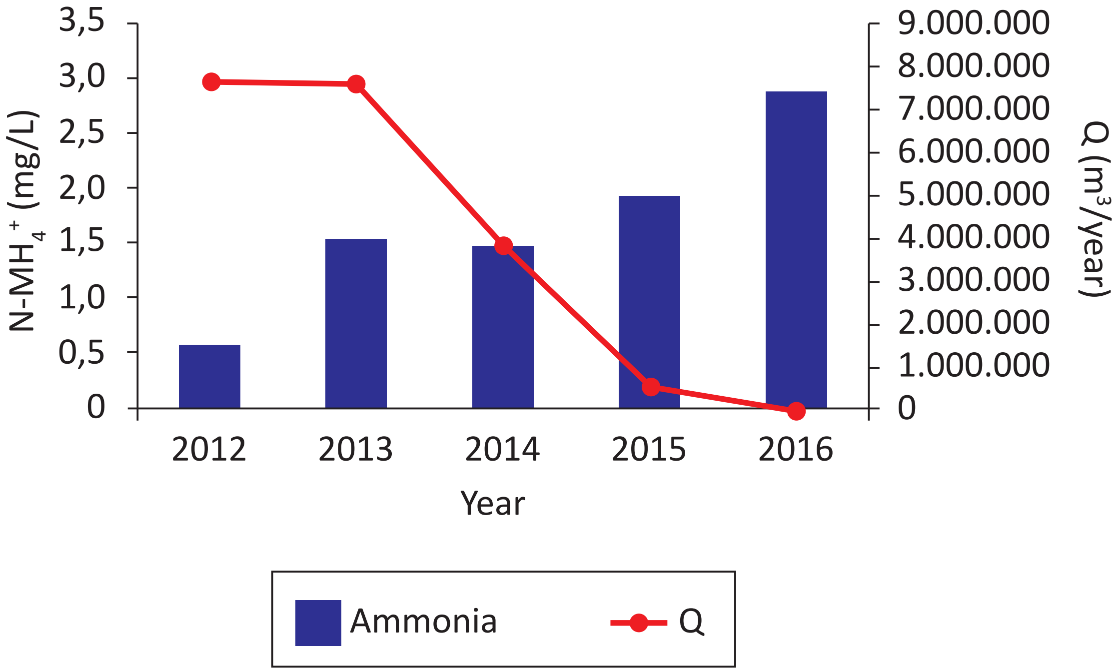

Figure 6 – Relationship between water translocation (Q) and ammonia in Camatagua reservoir.

- **Orthophosphate, total dissolved phosphorus and total phosphorus concentrations:** Orthophosphate, total dissolved phosphorus and total phosphorus concentration (Figure 7) also showed the same trend of ammonia. According to Salas, Martinó (1991) criteria, this water body was classified as eutrophic. The total-P increased from 40 µg/L in 1992, to more than 80 µg/L in the euphotic layer (GONZÁLEZ, 2017).

- **Phytoplankton**: Nutrient input stimulated the increase of phytoplankton density (Figure 8) and this community had a change in its composition. Cyanobacteria now accounted up to 90% of the relative proportion. *Cylindrospermopsis raciborskii*, *Oscillatoria planctonica*, *Leptolyngbya limnetica*, *Microcystis aeruginosa* and *Synechocystis aquatilis* were the dominant species during the whole study period.

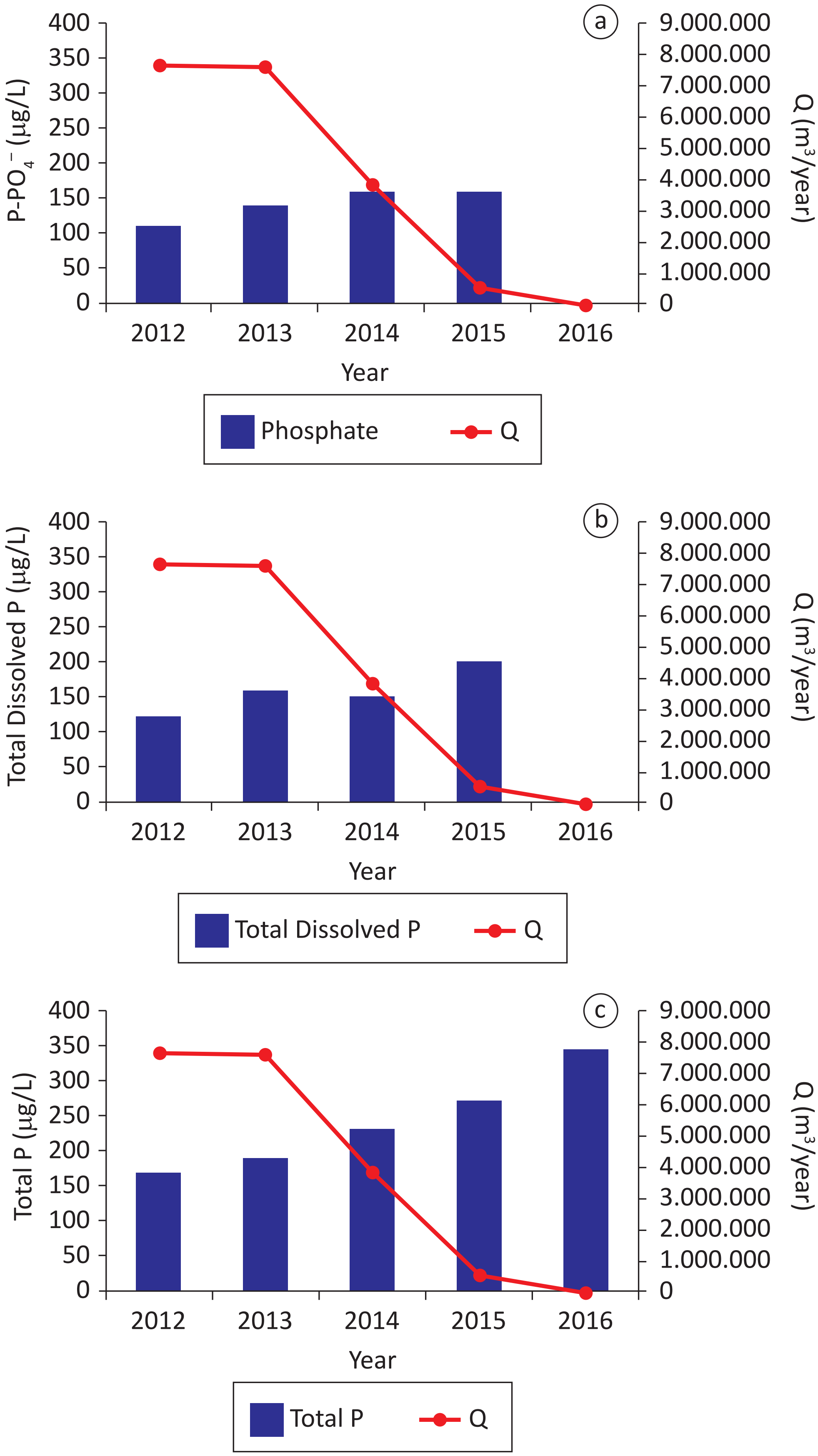

Figure 7 – Relationship between water translocation (Q) and orthophosphate (a), total dissolved phosphorus (b) and total phosphorus (c) in Camatagua reservoir.

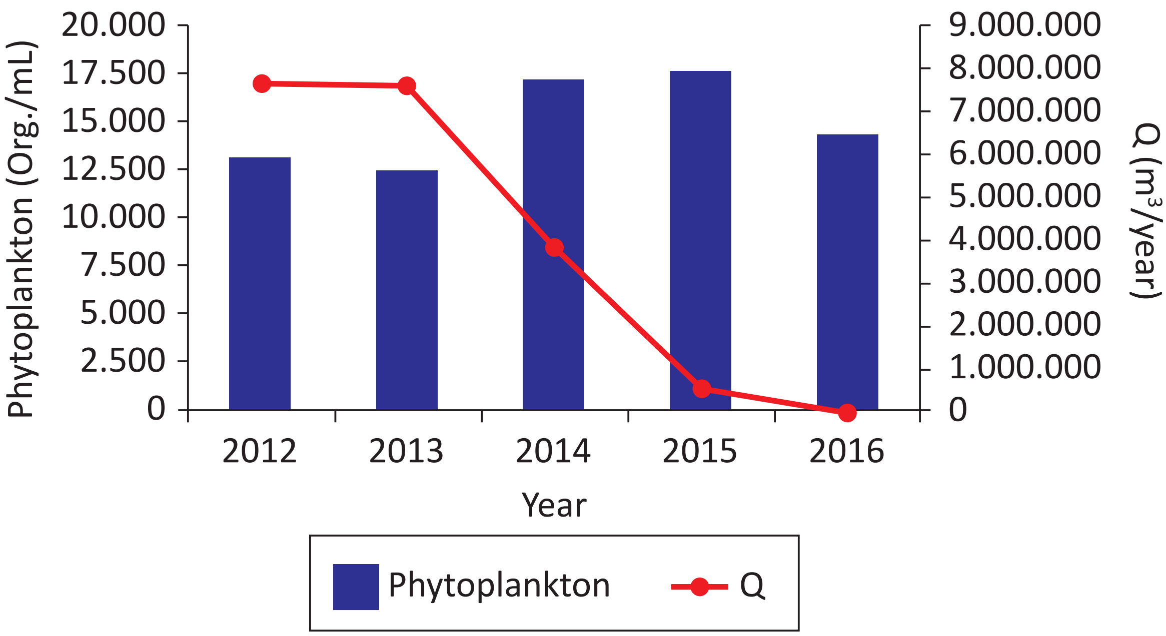

Figure 8 – Relationship between water translocation (Q) and phytoplankton abundance in Camatagua reservoir.

Conclusions

Water translocation from Taiguaiguay reservoir brought a relative benefit of maintaining the water volume in Camatagua reservoir at normal levels, but affecting its water quality.

Despite the reduction of the translocation since 2013 until its total elimination in January 2015, ammonia, orthophosphate, total dissolved phosphorus and total phosphorus concentrations, continue to increase in Camatagua reservoir, probably due to the decrease of water volume in Camatagua reservoir that also contributed to the increase of nutrient concentration.

An increase in phytoplankton abundance was also noted, mainly Cyanobacteria species, as a result of the nutrient input from the Taguaiguay reservoir.

Trophic state of Camatagua reservoir changed from oligo-mesotrophic in 1992, to eutrophic after the water translocation.

Acknowledgements

Authors wish to thank the hydrological companies HIDROCENTRO, HIDROCAPITAL and HIDROVEN, for financial and logistical support. We also thank E. González, who helped in the review of this article. M. L. Matos thanks the São Paulo Research Foundation (FAPESP) and International Institute of Ecology (IIE) for the travel grant to assist to the International Training Course of the São Paulo Advanced School on Integrated Water Resources Management, held in São Carlos, São Paulo State, Brazil, from November 2nd to 17th, 2017.

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Composition of the Characidae Family (Order: Characiformes, Pisces) in an Andean-Amazonian River, Case Study Hacha River Basin (Caquetá-Colombia)

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Abstract

An ichthyological inventory of the Characidae family (order: Characiformes) was carried out on an altitudinal gradient (2112 to 248 m.s.) of an Andean-Amazonian river basin of the Hacha river, located in the municipality of Florencia, department of Caquetá (Colombia). The collections were developed in 10 sampling stations through two fishing gears (electric fishing and traditional fishing); between the months of October to March, in two consecutive years (2009 and 2010), corresponding to the low water period. 459 individuals were collected, identified and grouped into 14 genera and 18 species; the highest abundances corresponded to the species *Hemibrycon sp.* (151 individuals), *Boehlkea cf. fredcochui* (88), *Creagrutusamoenus* (50) and *Creagrutuscochui* (35). In conclusion, it can be indicated that the greatest wealth (12sp.) occurs in the lower basin of the river, it is also noteworthy that the 18 species are new reports for the Hacha river basin, 12 species for Caquetá and one (1) species for the Colombian Amazon.

Keywords: Characidae, Hacha River, Andean-Amazonian.

Introduction

The order Characiformes is composed of approximately 1962 species, which correspond to about 34% of freshwater species in the world (ALBERT *et al.*, 2011), grouped into 274 genera and 18 families (GÉRY, 1977, REIS, KULLANDER 2003, MOYLE, CECH, 2004, NELSON, 2006). By regions, the Amazon basin exhibits the highest richness with about 1450 species of fish (GÉRY, 1984), of this number almost 50% are species of the order Characiformes (Nelson, 2006). However, despite the high wealth, there are regions of the basin where the knowledge of this order is meager, such as the Colombian Amazonian Andean region and in particular the case of the river basin of the Hacha River, located in the municipality of Florencia (Caquetá), which supplies drinking water to the municipality (the most populated city of the Colombian Amazon), the Hacha River is the main place of recreation and, a little noble use, as a receiver of the wastewater of the city (PELÁEZ *et al.*, 2006).

The first samplings for the Department of Caquetá were carried out by Brother Nicéforo María on the Ortegüaza River around 1900, the results of which were published by Fowler (1943, 1945). Mojica *et al.* (2005) and Galvis*et al.* (2007) reported 30 species for the order Characiformescollected in tributaries of the Caquetá river, among them the Ortegüaza river. At the local level, the Universidad of the Amazonia, has carried out some works, results of degree projectsand master thesis such as Celis, Ortiz (2003); Rueda, Almario (2004); Díaz, Escobar (2004); Celis (2010); Cháves (2011) and Perdomo *et al.* (2012). The following is an updated list of the Characidae family (order: Characiformes) of the Hacha River Basin, integrated from the literature review, the biological collection of the Institute of Natural Sciences (ICN) and what was reported in this work.

Materials and methods

The study was carried out in the main channel of a mountain river (Hacha) of the Andean-Amazonian region, department of Caquetá (Colombia) between the coordinates 01 ° 52’40,7 “N- 75 ° 40’44,1 “W and 1º33’19,2” N-75º31’55 “W. The hydrographic basin covers an area of 490.18 square kilometers and covers a distance of 66.7 km from its source at 2,400 m. a. s. l. in Cerro Gabinete until its convergence with the Ortegüaza River, at an altitude of 248 m. a. s. l. (POMCA, 2005) (Figure 1).

The collections were made during two consecutive years, between the months of October to March (low waters) of 2009 and 2010 respectively. These were carried out in 10 sampling stations representative of the uses given to the river Hacha (Annex A, the list of structural characteristics of the stations is presented), through two fishing techniques: traditional fishing (cast nets and hooks) and electric fishing (LOBÓN-CERVIÁ, 1991; ELOSEGI, SABATER 2009) in order to capture the largest number of specimens present in this ecosystem. The captured specimens were fixed in 10% formaldehyde, then in 70% alcohol (MOJICA *et al.*, 2005; MALDONADO-OCAMPO *et al.*, 2006) and were deposited in the ICN’s Ichthyological collection.

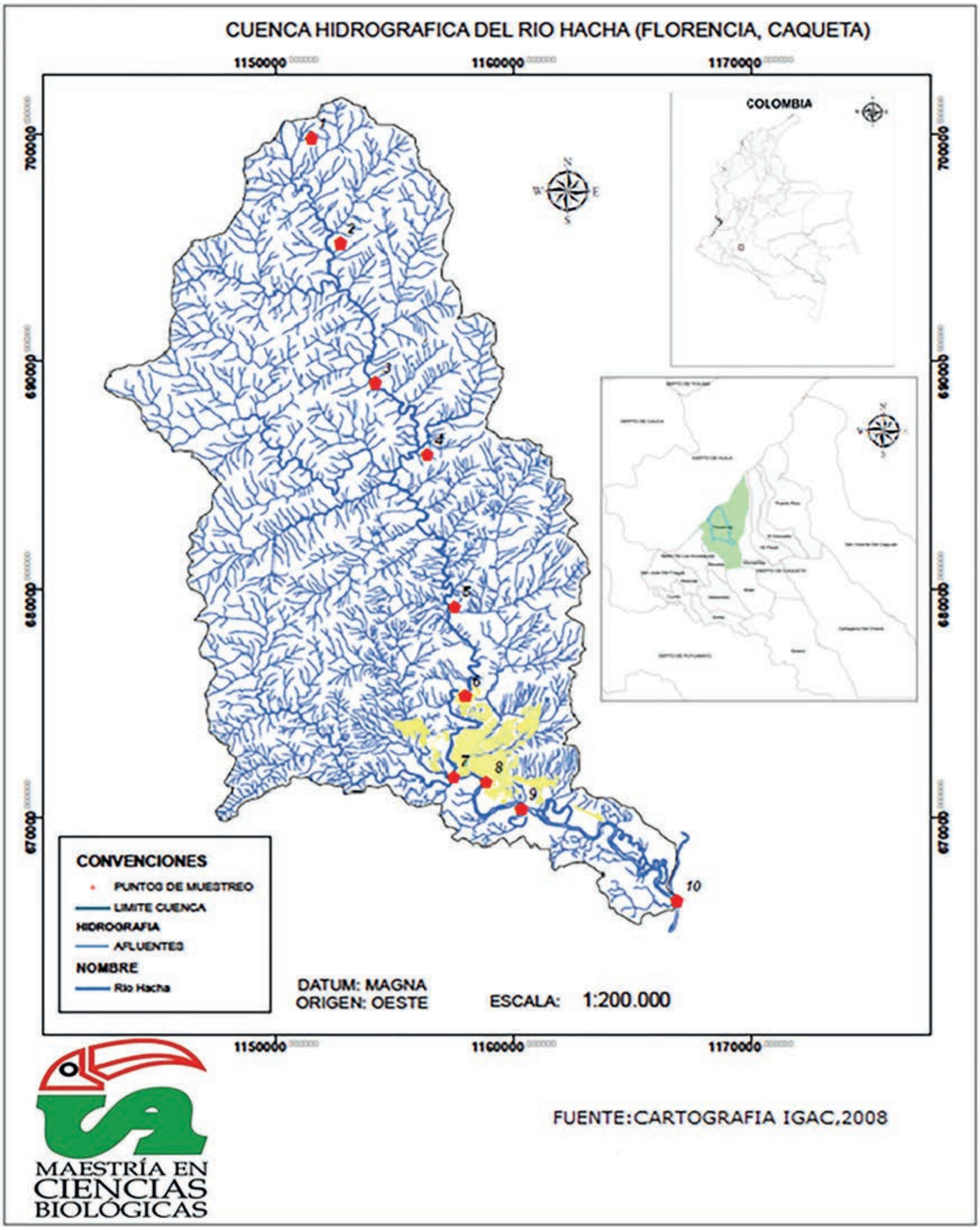

Figure 1 – Geographical location of the study area, municipality Florencia, Caquetá (Colombia).

For the taxonomic determination, we followed Fowler (1943); Fowler (1945); GÉRY (1977); Castro (1997); Mojica (1999); Maldonado *et al*. (2006); Gregory-Maldonado (2006); Ortega-Lara *et al*. (2006); Galvis *et al*. (2007); Rubio (2007) and Román-Valencia *et al*. (2013). Likewise, ichthyological material deposited in the reference collection of the ICN-MHN of the Universidad Nacional de Colombia and the advice of specialists was consulted.

Results

The results obtained are presented through a systematic list of the ichthyofauna found in the basin of the Hacha river. We collected 459 individuals grouped into 14 genera and 18 species (Appendix B) and Figure 2.

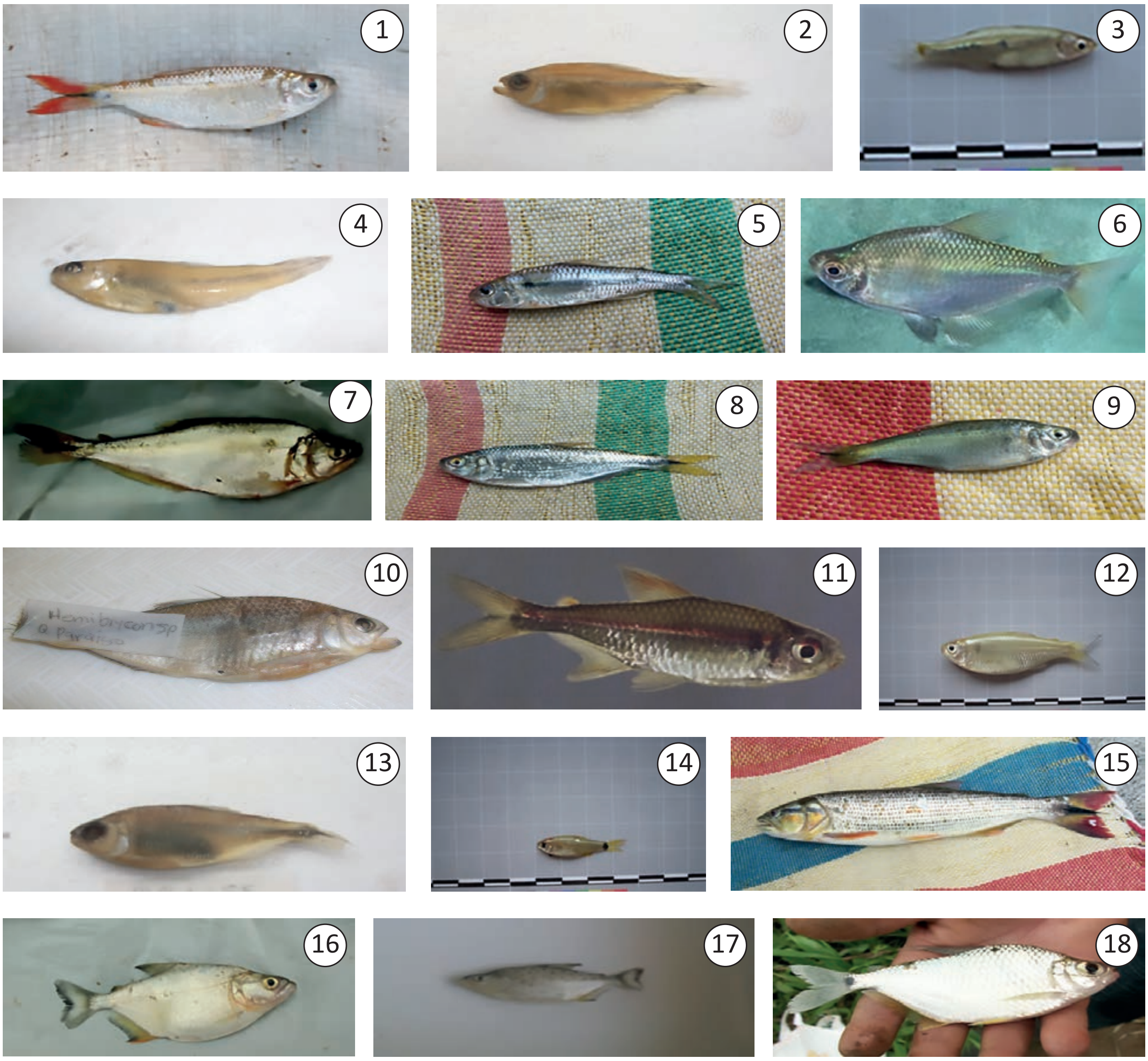

Figure 2 – Species Characidae family 1. *Astyanax fasciatus,* 2. *Astyanax symmetricus, 3. Boehlkea cf. fredcochui.* , 4. *Creagrutus cf. amoenus,* 5. *Creagrutuscochui,* 6. *Ctenobrycon cf. hauxwellianus,* 7. *Cynopotamusamazonum,* 8. *Hemybriconsp,* 9. *Hemibrycon sp2,* 10. *Hemibrycon sp3,* 11. *Hyphessobryconsp,* 12. *Knoduscarlosi,* 13. *Moenkhausiarobertsi,* 14. *Odontostilbe cf. caquetae,* 15. *Salminusaffinis,* 16. *Pristobryconcalmoni,* 17. *Serrasalmusrombeus,* 18. *Tetragonopterus argenteus.*

This list of species includes information on:

- **Scientific name:** Gender and specific epithet, followed by the author of the description and the year of publication.
- **Species in collection:** The number of the file of the deposited species is listed in the Institute of Natural Sciences (INS), Museum of Natural History (MNH), ichthyology area.
- **Synonymies:** Includes the scientific name, author and year.
- **Common name:** Reference the regional name of the species.
- **Description:** Information regarding the pigmentation, morphology, size and morphometry of the species.
- **Distribution:** It reviews the localities where there are reliable records of the species; they begin with the type locality (altitudinal range in the Hacha river); then, general data of the distribution for Colombia and the Neotropic are referenced, based on the literature review. Also, image of the species is attached.

ORDER CHARACIFORMES: CHARACIDAE FAMILY

1. *Astyanax fasciatus* (CUVIER, 1819).

Collection number ICN-MHN: 17918.

Synonyms: *A. fasciatusorteguasae* (FOWLER, 1943).

Common name: red tail sardine, yellow tail sardine, tolomba, greedy, old lady (Ven).

Description: Medium-sized fish that reach 17cm instandard length (SL), are silvery color dorsally, caudal with a well-marked black caudal spot. Some specimens show an intense reddish color in the caudal fin (GALVIS *et al*., 2007); middle rays of the dark caudal and the other orange with the hyaline ends (VARGAS-TISNES, 1989).

Distribution: Located in the stations of the urban area of the city of Florencia between 262-261m. a. s. l.; Fowler (1943, 1945) reported it for the Bodoquero river of Morelia Caquetá; However, in other regions it has a wide distribution as in the Magdalena, Cauca and the Amazon basins (FOWLER, 1943; MOJICA, 1999; ORTEGA-LARA *et al*., 2002; GREGORY-MALDONADO, 2006; Galvis *et al*., 2007; MALDONADO-OCAMPO *et al*., 2008; MALABARMA *et al*., 2003) report edit from Mexico to Argentina.

2. *Astyanax symmetricus* (EIGENMANN, 1908).

Collection number ICN-MHN: 17861.

Common name: Sardine.

Description: Small fish with SL from 3 to 6 cm, more or less uniform body, terminal mouth. In alcohol it turns brown with a light colored stripe on the ventral side.

Distribution: 262-261 m.a.s.l.; It was located in the stations known as La Floresta and Puente López in the municipality of Florencia (capture method: Electric fishing). Malabarma *et al*. (2003) reported for the Amazon River basin.

3. *Boehlkea cf. fredcochui* (GÉRY, 1966).

Synonymies: *Microbryconcochui* (NON LADIGES, 1950) www.fishbase.org.

Common name: Little sardine, blue tetra (Per).

Description: Small size fish of 4 to 5cm of SL, similar to the Hemibrycon (GÉRY, 1977), irregular lateral line. Its body is m*et al.*lic light blue.

Distribution: 635-262 m.a.s.l.; it was located between the station known as Carañoto the la Floresta station in the city of Florencia (method of capture: electric fishing). Gregory-Maldonado (2006) reported it for the Colombian Amazon.

4. *Creagrutusamoenus* (FOWLER, 1943).

Synonymies: *Creagrutusboehlkei* (GÉRY, 1977).

Common name: Little sardine.

Description: Fishes with SL of 8cm are recognized by presenting the maxilla more pronounced than the jaw. They have a gray spot on the dorsal fin and dark patches on the lateral line. The general coloration of the body is silver with reddish overtones and in alcohol presents a clear brown coloration.

Distribution: 635-296 m.a.s.l.; it was collected between the sites known as Paraíso-Carañoto the first bridge (north) of the city of Florencia (capture method: Electric fishing). Fowler (1943) and Galvis *et al*. (2007) reported it to the Ortegüaza River; Gregory-Maldonado (2006) for the Amazon River basin.

5. *Creagrutuscochui* (GÉRY, 1964).

Collection number ICN-MHN: 17871, 17874, 17887.

Common name: Squeaky (Florencia), little mojarra, little sardine.

Description: Small species that grows up to 7.9 cm of SL. With an elongated and cylindrical body, brown with a well-defined horizontal humeral spot and all its fins are hyaline except for the dorsal fin.

Distribution: 890-248 m.a.s.l.; between the sites known as the vereda Sucre to the confluence of the Hacha river with the Orteguaza (methods of capture: traditional fishing and electric fishing). Maldonado-Ocampo *et al*. (2008); Galvis *et al*. (2007); Gregory-Maldonado (2006), reported it in streams of intermediate waters near Leticia.

6. *Ctenobryconhauxwellianus* (COPE, 1870).

Synonymies: *C. spilurushauxwellianus, Tetragonopterushauxwellianus* (COPE, 1870).

Common name: Wide sardine (Florence), s. fat, pinky, little mojarra, lambari (Bra).

Description: Small species that reached 6.5 cm of SL. Wide body and small scales, light brown in the dorsal and silver on the ventral side, with a gray band on the lateral line.

Distribution: 253 - 248 m.a.s.l.; it was located between the Florencia Airport station to the confluence with the Ortegüaza river (capture method: Electric fishing). Galvis *et al*. (2007); Fowler (1943, 1945) reported it for tributaries of the Caquetá River in the municipality of Morelia. It is also distributed in the Amazon River basin (MOJICA *et al.* 2005; GREGORY-MALDONADO 2006; MALDONADO-OCAMPO *et al.* 2008; WWW. SINCHI.org.co/2011).

7. *Cynopotamusamazonum* (GÜNTHER, 1868).

Collection number ICN-MHN: 17901.

Subfamily: Characinae.

Synonymies: *Anacrytuslimaesquamis* (COPE, 1878).

Common name: Chango (Caquetá), clear, dog, dentex (Per), cacunda (Bra)

Description: Large species that reached 23 cm of SL of elongated body with a small hump between the dorsal fin and the head, the scales are rough. Its coloration is silver; the caudal and adipose fins have a yellow hue. Very similar to the Charax species (GÉRY, 1977).

Distribution: 248 m.a.s.l.; it was only captured at the confluence (Venecia sector) with the Ortegüaza river (method of capture: Traditional fishing). It is located in the Amazon River basin (GREGORY-MALDONADO 2006; MALDONADO-OCAMPO *et al*., 2008; WWW.SINCHI.org.co/2011).

8. *Hemibrycon sp*. (GÜNTHER, 1864).

Collection number ICN-MHN: 17857, 17858, 17918.

Common name: Yellow tail sardine, tolomba, mojara (Per).

Description: Medium-sized fish that reach 17cm in SL, are dorsally dark and laterally silvery in color; the rays of the anal fin are orange or yellow (ORTEGA-LARA *et al.,* 2002).

Distribution: 1100-248 m.a.s.l.; It has a wide distribution in the Hacha river basin (method of capture: traditional fishing gear and electric fishing). In Colombia, it is also found in the basin of the Meta, Magdalena and Amazonas rivers (GREGORY-MALDONADO *et al*. 2006, GALVIS *et al*. 2007).

9. *Hemibrycon sp2.* (GÜNTHER, 1864).

Collection number ICN-MHN: 17855.

Common name: Thunder sardine (Caquetá), boquilla (Ecu).

Description: Small species that reached 3.5 cm of SL of color silver and brown on the caudal region.

Distribution: 635-248 m.a.s.l; it was located between the Vereda Paraíso until the confluence with the Ortegüaza river (method of capture: Traditional fishing and electric fishing). It is distributed in the Amazon River basin (GREGORY-MALDONADO, 2006).

10. *Hemibrycon sp3.* (GÜNTHER, 1864).

Common name: Sardine, tolomba.

Description: Medium species that reached 7 cm of SL of silver color and prominent lower jaw.

Distribution: 262 m.a.s.l.;it was captured in the area called the forest (capture method: electric fishing). It is located in the Amazon basin, Orinoco and Magdalena (GÉRY, 1977; REIS, KULLANDER, 2003; GREGORY-MALDONADO, 2006; MALDONADO-OCAMPO *et al*., 2008).

Observation: First report for the Hacha and Caquetá basin.

11. *Hyphessobrycon sp.* (FOWLER, 1941).

Common name: Tetras, little sardines, Colombian tetra.

Description: Small species that reached 5 cm of SL. They are characterized by having the internal row of premaxillary teeth with five or more teeth on each side, incomplete lateral line, adipose fin and caudal non-scaly.

Distribution: 253-248 m.a.s.l.; It was collected in the airport sector until the confluence with the Ortegüaza River (capture method: Electric fishing). Maldonado *et al*. (2008), Gregory-Maldonado (2006) reported it for the Colombian Amazon.

12. *Knoduscarlosi* (ROMÁN-VALENCIA *et al*., 2013).

Common name: Little sardine.

Description: Small species that reached 6.5 cm of SL. Compressed body, robust and slender. Full lateral line, silver color and in the yellow outline, in alcohol it is observed of light brown color.

Distribution: 262-248 m.a.s.l.; It was collected in the Floresta sector until the confluence with the Ortegüaza River (capture method: Electric fishing). Román-Valencia *et al*., (2013) reported it for the Amazon River basin.

13. *Moenkhausiarobertsi* (GÉRY, 1964).

Common name: Sardine, tetra.

Description: Small species that reached the 7.6 cm of SL of silver color and with a broad humeral spot, its fins are hyaline. In alcohol it is observed in brown and some parts in black.

Distribution: 635-296 m.a.s.l.; It was located in the middle basin of the Hacha river (capture method: Electric fishing). Fowler (1943), reported for the Ortegüaza River the species *Moenkhausialepidura* and *Moenkhausiaorteguasae*. Also, it is located in the Amazon River basin (MOJICA *et al*., 2005; GREGORY-MALDONADO, 2006; MALDONADO-OCAMPO *et al*., 2008; WWW.SINCHI.org.co/2011).

14. *Odontostilbe cf. caquetae* (FOWLER, 1943).

Synonymies: *Fugitive Cheirodon, Fugitive Odontostilbe, O madeirae.*

Common name: Little sardine, mojarra.

Description: Small fish that reach 4 cm of SL. Body elongated and brown, with a silver strip that ends in a dark spot that may or may not cover the caudal peduncle (GÉRY, 1977).

Distribution: 261-248 m.a.s.l.; species captured in the area called the López bridge to the confluence with the Ortegüaza river (method of capture: traditional fishing and electric fishing). Galvis*et al*. (2007) and Fowler (1943, 1945) reported it in the same region. Gregory-Maldonado (2006) reported it for the Amazon River basin.

15. *Salminusaffinis* (STEINDACHNER, 1880).

Collection number ICN-MHN: 17910.

Subfamily: Salmininae.

Common name: Golden, beaked, blonde, lady (Ecu), male shad (Per).

Description: Medium sized fish that reached 32 cm of SL. Elongated body shape; caudal without elongation, the caudal lobes are pink-intense red towards the tips, at the base of the yellow fin and a black stripe towards the peduncle, red anal fin, the operculum is also pinkish-reddish, the fins present the color yellow, the dorsal part of the body is silver gray and the ventral part white-yellowish (MOJICA *et al*., 2012).

Distribution: 890-253 m.a.s.l.; It was located from the vereda Sucre to the airport sector of the municipality of Florencia (method of capture: Traditional fishing). It was reported for the Magdalena and Amazonas river basins (MOJICA *et al.* 2005; GREGORY-MALDONADO *et al.* 2006; MALDONADO-OCAMPO *et al*. 2008; WWW.SINCHI.org.co/2011).

Observation: In The Red Book of Freshwater Fishes of Colombia, it is classified as vulnerable in the IUCN category (A2 c, d) - National in Danger (B1bii, B1ciii) - Regional (MOJICA *et al*., 2012). It is also the first report for the basin of the Hacha and Caquetá river.

16. *Pristobryconcalmoni* (STEINDACHNER, 1908).

Collection number ICN-MHN: 17912.

Subfamily: Serrasalminae.

Synonymies: Serrasalmuscalmoni, S. bilineatus, Pygocentrusbilineatus.

Common name: Piranha, white piranha (Bra), Caribbean (Ven).

Description: Medium sized fish that reached 12 cm of SL of silver and orange coloration on the base of the anal, dorsal and adipose fin. Lower jaw prominent.

Distribution: 296-248 m.a.s.l.; It was collected from the sector called the first bridge to the confluence with the Ortegüaza river (method of capture: traditional fishing). It was reported for the Amazon and Orinoco river basins (MOJICA *et al.,* 2005; GREGORY-MALDONADO 2006; MALDONADO-OCAMPO *et al.,* 2008).

17. *Serrasalmusrhombeus* (LINEUS, 1766).

Collection number ICN-MHN: 17911.

Subfamily: Serrasalminae.

Synonymies: Pygocentrusnormani, Serrasalmohumeralisgracilior, S. immaculatus, S. normani, S. paraense.

Common name: Piranha, fist, Caribbean (Orinoco), black piranha (Bra).

Description: Medium fish that reached 13cm of SL of orange coloration with m*et al*.lic gray areas, caudal fin with black border. Border of the elongated lower jaw with well-developed teeth (CASTRO, 1997).

Distribution: 296-248 m.a.s.l.; It was collected in the area called the first bridge to the confluence with the Ortegüaza river (method of capture: traditional fishing). Also, it is located in the basin of the Amazon River, Putumayo, Caquetá and Guaviare (GÉRY, 1977; MOJICA, *et al*., 2005; GREGORY-MALDONADO, 2006; MALDONADO-OCAMPO *et al*., 2008; WWW.SINCHI.org.co/2011).

18. *Tetragonopterus argenteus* (CUVIER, 1816).

Collection number ICN-MHN: 17912.

Subfamily: Tetragonopterinae.

Common name: Palometa (Caquetá), Golden (Leticia), sabaleta, matupiri (Bra).

Description: Medium fish that reached 13cm of SL of silver coloration and on the ventral edge of yellow color. It has a high, discoidal, deep and compressed body that differentiates it from the *Moenkhausia* genus (GÉRY, 1977).

Distribution: 262-248 m.a.s.l.; It was located in the urban area of the municipality of Florencia to the confluence with the Ortegüaza River (method of capture: Traditional fishing). Celis (2010) reported it for the Quebrada la Venado tributary of the Bodoquero River (Morelia-Caquetá). In the same way, it is located in the Amazon basin (MOJICA *et al*., 2005; MALDONADO-OCAMPO *et al*., 2008; WWW.SINCHI.org.co/2011).

Discussion

Due to the few works developed on fish composition in the Colombian Amazonian Andean region, particularly in the Piedmont region of Caquetá, its wealth has been underestimated. In fact, the only investigations for the Hacha River Basin that address fish composition are that of Chaves (2011) for the order Siluriformes and Perdomo *et al*. (2012), this last author reported 13 species for the order Characiformes, of which he didn't report for the Characidae family. Fowler (1943, 1945) reported 5 species for Caquetá, referenced in the present work. Likewise, 5 species of the Characidae family coincide with the reports made by Galvis *et al*. (2007) for the department (Annex C). Therefore, the 18 species collected in this basin can predict that the richness for the order Characiformes can reach 30 species, since they would increase by more than 10 species.

This research is a good approximation to the total number of species of the Characidae family present in the basin, considering the size of the basin, the explored places, the scarce records of species and the uncertainties that arise over existing identifications (CHERNOFF *et al.,* 1999). In relation to the abundance and composition of the Characidae family (459 ind/18sp) it is the one with the greatest contribution to the Characiformes order, since from the global study it showed only 70 individuals belonging to 11 species (families: Anostomidae, Crenuchidae, Curimatadae, Erytrinidae, Hemiodontidae , Parodontidae, Prochilodontidae) coinciding with other authors in several systems of the Amazon basin (SILVANO *et al.,* 2000, LASSO *et al.,* 2004).

Fishing in the municipality of Florenciais directly related to economic (income) and social activities (population growth vs. food) (POMCA, 2005). However, according to the observation in the field and conversation with members of the community, it was identified that most of the species are used in subsistence fishing; young fish are usually caught, which leads to the interruption of the reproductive cycle of the species and the consequent decrease in their populations. Among the main methods used for fishing are hooks, trammel nets, fishing guns and cast nets.

Also, other factors that threaten the ichthyofauna are agricultural, domestic and industrial pollution; these actions, added to the limited distribution ranges, place the fish at extinction risk levels. Therefore, of the 18 species referenced the only one that is in danger (vulnerable national category: A2c, d) according to Trehe Red Book of Freshwater Fishes of Colombia is Salminus cf. affinis (MOJICA *et al.*, 2012). Consequently, even though Salminus cf. Affinis is in vulnerable danger, at the local level it is unknown that other species of fish may be in the same situation due to lack of studies.

Finally, it is urgent that research programs on the biology of species and the state of aquatic ecosystems be encouraged. Also, it is feasible to propose as conservation measures for the Hacha river basin the compliance with the regulation on the minimum sizes of capture and in general of the fishing and commercialization activity, through total or partial closures during the reproduction periods.

As a conclusion, it can be indicated that the richness of species is high, particularly in the lower basin of the HachaRiver. The most abundant and most widely distributed species was Hemibrycon sp. (151), Boehlkea cf. fredcochui (88), Creagrutusamoenus (50) and Creagrutuscochui (35). Also, of the 18 species collected, all are new reports for the basin, 12 in the department and one (1) in the Colombian Amazon.

Acknowledgements

The authorsthank the Universities of the Amazonia, Nacional and Navarra(Spain) for the loan of equipment and collections. Also to the CODECYT + I agreement N ° 098 of 2010 between Colciencias and Gobernación de Caquetá for the financial support through the young investigator scholarship. Also, we thank the different teachers (Rafael Miranda, DonalThaphorn, GermánGalvis, José Iván Mojica, Monica Shirley Celis, Jaime Velásquez, Alexander Velásquez and Jonathan Garaviz) for the comments and suggestions to this document and finally thank FAPESP (Fundacao de Amparo a la Pesquisa do Estado de Sao Paulo - Brazil) and Professors José Galicia Tundisi and Takako Matsumura-Tundisi for the opportunity offered to carry out the Integrated Water Resources Management course and to socialize the research.

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ANNEXES

Annexes A: Data on the composition of the habitat in the sampling stations of the Hacha river basin.

Station	Altitude	Location	Riparian Vegetation	Littoral Vegetation	Transparency (Water)	Bottom Type (Substrate)
1	2112	Hacha River (Ruidosa)	Intervened Natural Forest	Present (Shading 70%)	Total	Rocky, sandy, pebble
2	1341	Hacha River (Tarqui)	Intervened Natural Forest	Present (Shading 50%)	Total	Big rocks, pebble
3	890	Hacha River (Sucre)	Intervened Natural Forest	Present (Shading 50%)	Total	Big rocks, pebble
4	635	Hacha River (Paraíso)	Stubble	Present (Shading 30%)	Turbid	sandy, gravel, pebble
5	375	Hacha River (San Luis)	Stubble	Present (Shading 40%)	Total	Sandy, small rocks
6	296	Hacha River (Primer Puente)	Grasses	Partial (Shading 20%)	Total	Sandy, small rocks
7	262	Hacha River (Floresta)	Grasses, Stubbles, Colonized	Partial (Shading 20%)	Turbid	Gravel, sandy, small rocks
8	261	Hacha River (Puente López)	Grasses, Stubbles, Colonized	Partial (Shading 20%)	Turbia	Sandy, detritus, gravel
9	253	Hacha River (Aeropuerto)	Grasses, Stubbles, Colonized	Absent	Turbid	Sandy, detritus
10	248	Hacha River (Venecia)	Grasses, Stubbles	Absent	Turbid	Sandy, detritus

Annex B: Composition and abundance of species of the Characidae Family in the Hacha River Basin.

	Description of sampling stations	1	2	3	4	5	6	7	8	9	10	
		Ruidosa	Tarqui	Sucre	Paraíso	San Luis	1 Pte.	Floresta	Pte. López	Aeropuerto	Desembocadura	
	Altitude	**2112**	**1341**	**890**	**635**	**375**	**296**	**262**	**261**	**253**	**248**	
N°	**Species**											**Total**
1	*Astyanax fasciatus*							7	4			11
2	*Astyanax symmetricus*							4	2			6
3	*Boehlkea cf. fredcochui.*				10	39	35	4				88
4	*Creagrutus cf. amoenus*				7	25	4	11	1	1	1	50
5	*Creagrutuscocui*			18	4	3	1	6		1	2	35
6	*Ctenobrycon cf. hauxwellianus*									2	11	13
7	*Cynopotamusamazonum*										1	1
8	*Hemibryconsp.*			9	2	39	59	6	15	12	9	151
9	*Hemibryconsp2.*				1	4	3	4		6	7	25
10	*Hemibryconsp3.*							15				15
11	*Hyphessobrycon sp.*									1	2	3
12	*Knoduscarlosi*							15	1	3	3	22
13	*Moenkhausiarobertsi*				3		2					5
14	*Odontostilbe cf. caquetae*								1	4	9	14
15	*Salminus cf. affinis*			2	5		1			1		9
16	*Pristobryconcalmoni*						1		1	1	1	4
17	*Serrasalmusrhombeus*						1		1		3	5
18	*Tetragonopterus argenteus*							1			1	2
	Number of Individuals	0	0	29	32	110	107	73	26	32	50	459
	Number of speciesper station	0	0	4	7	5	9	10	8	10	12	

Annex C: Species of the Characidae Family (order: Characiformes) reported in the Colombian Amazon, Caquetá.

	Orteguaza (CAQ)	Orteguaza (CAQ)	Amazonia (COL)	Amazonia (COL)	Orteguaza (2007)	Amazonia (COL)	Amazonia (COL)	Amazonia (COL)	Florencia (CAQ)	1St. Report	
	Fowler, 1943	Fowler, 1945	Mojica, 2005	Maldonado, Ocampo, 2006	Galvis, 2007	Maldonado Ocampo, 2008	www. sinchi.org. co/, 2011	Roman-Valencia *et al.*, 2013	Remicio, 2014		
	N° SPECIES										
1	*Astyanaxfasciatus*	X		X	X	X	X			X	HACHA BASIN
2	*Astyanaxsymmetricus*									X	C. AM. COLOM, CAQ, HACHA
3	*Boehlkea cf. fredcochui.*				X		X			X	BASIN CAQUETA, HACHA
4	*Creagrutus cf. amoenus*	X			X	X	X			X	BASIN HACHA BASIN
5	*Creagrutuscochui*			X	X	X	X	X		X	HACHA BASIN
6	*Ctenobrycon cf. hauxwellianus*		X	X	X		X	X		X	HACHA BASIN
7	*Cynopotamusamazonum*						X	X		X	CAQUETA, BASIN
8	*Hemybricon*sp.				X	X	X			X	HACHA BASIN
9	*Hemibrycon*sp2.				X		X			X	HACHA BASIN CAQUETA, HACHA
10	*Hemibrycon*sp3.				X		X			X	BASIN CAQUETA, HACHA
11	*Hyphessobrycon*sp.				X		X			X	BASIN CAQUETA, HACHA
12	*Knoduscarlosi*								X	X	BASIN CAQUETA, HACHA
13	*Moenkhausiarobertsi*			X	X		X	X		X	BASIN CAQUETA, HACHA
14	*Odontostilbe cf. caquetae*	X	X			X				X	BASIN, HACHA
15	*Salminusaffinis*			X	X		X	X		X	BASIN CAQUETA, HACHA
16	*Pristobryconcalmoni*			X	X		X			X	BASIN CAQUETA,HACHA
17	*Serrasalmusrombeus*			X	X		X	X		X	BASIN CAQUETA,HACHA
18	*Tetragonopterusargenteus*			X			X	X		X	BASIN CAQUETA, HACHA BASIN

https://doi.org/10.26626/978-85-5953-031-5.2018C007

The Fluvial Forests as Indicators of the Flow and Permanence of Water

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Abstract

We evaluated the influence of the horizontal flows of the Paraná River on the composition and distribution of the floodplain landscape and we defined the ecohydrological signature of some species-index in the low Paraná River section, (27° 38' 04" S and 58° 50' 46" W). During the drought phase, the structure of the vegetation were characterizad using a Cottam & Curtis method. The trees were positioned in the topographic gradients during the flood phase, taking as reference the river water sheet in the nearest hydrometric gauge. To obtain the pulse attributes in different positions of the geomorphological gradient, PULSO software was used considering the daily water levels at Corrientes city between 1985 and 2015. Two main types of flooded forests were identified: pionner forest, dominated by one or two species (*Salix humboldtiana*, *Tessaria integrifolia*) in recent bars and islands, and pluri-specific flooded forests (*Albizia inundata*, *Cecropia pachystachya*, *Croton urucurana*, *Inga uruguensis*, *Ocotea diospyrifolia*, *Nectandra angustifolia* and *Peltophorum dubium*) occupying bars of the highest islands, with shorter flood phases, with trees are distributed in 2-3 strata in a closed canopy. Pulses were more frequent in pioneer forests than in multispecific forests. The ecohydrological signature allows the optimum condition and distribution limits of each species to be established. It is a tool to know the adjustment of biotic elements (populations) to the river variability regime. The procedure used can be used to anticipate the possible reorganization of the river plain landscape as a result of flow variations predicted by climate change models.

Keywords: hydrological regime, pulses, Paraná River, floodplains, ecohydrology, climatic change.

Introduction

Since the beginning of vegetation ecology, attention has been focused to know the number of species that inhabit a river and its basin. Few projects have been devoted to studying the causes of biodiversity in systems with a high fluctuation level. In this contribution we analyze an approach to link the vegetation composition as a consequence of the river regime on each site of the floodplain. Following the Pulse concepts (JUNK *et al.*, 1989, NEIFF, 1990, 1996) we attempt to know the relationship between the tree populations distribution and the pulse attributes. The vegetation, and especially the forests, are the most conspicuous structures and of greater permanence in the fluvial landscape. There is a clear asymmetry along the river between the floodplain vegetation and the adjacent phytogeographic territories to the Paraná River (CABRERA, 1976).

Objectives

To evaluate the influence of the horizontal flows of the Paraná River, on the composition and distribution of the fluvial forests.

To define the *ecohydrological* signature of some species of trees in the study area.

Materials and Methods

This study was carried out in the floodplain of the Paraná River, in Argentina, upstream of Paraná-Paraguay confluence (27°38’ 04’’ S and 58° 50’ 46” W, Figure 1). During the drought phase (limnophase), we study the vegetation structure by the centered quadrants method (COTTAM; CURTIS, 1956). The trees were positioned during the flood phase (potamofase) in the topographic gradient taking as reference the river water sheet in the nearest hydrometric gauge (Neiff, 1986). PULSO software (NEIFF; NEIFF, 2003) was used to obtain the pulse attributes in different positions of the geomorphic gradient. Between 1985 and 2015, daily records the water level in Corrientes city was analyzed. More than a thousand points were measured to cover all possible sites where each of the nine indicator species considered is growing.

Results

According to our results, it is possible to differentiate two types of forests: the pioneer forests, dominated by *Salix humboldtiana* and / or *Tessaria integrifolia*, in low bars, between 45.71 and 48.01 m.a.s.l.. These forests constitute a habitat of very wide variability (water level, runoff velocity, erosion/ sedimentation and nutrient dynamic). The populations that live there can respond to disturbances. The germination phase are short and the vegetative growth is very fast. Plants invest a lot of energy in maintaining a long period of fertility to synchronize the production and release of fruits and seeds in a favorable hydrological phase. As a typical *“r”* strategists.

The other type of fluvial forests (mixed gallery forest), growth in the higher position of the topographical gradient, with almost 20 spp., represented by *Albizia inundata*, between 46.21 and 48.01 m.a.s.l.; *Cecropia pachystachya* (between 46.11 and 48.01 m.a.s.l.); *Croton urucurana* (between 46.21 and 48.01 m.a.s.l.), *Inga uruguensis* (between 47.71 and 48.01 m.a.s.l.); *Ocotea diospyrifolia* (between 46.21 and 48.01 m.a.s.l.); *Nectandra angustifolia* (between 46.21 and 48.01 m.a.s.l.) and *Peltophorum dubium* (between 46.21 and 47.01 m.a.s.l.). These forest occupy bars or marginal levees, where the flood phase is shorter, the sediments have more fine materials and the soil has more organic matter in surface. The trees are distributed in 2-3 strata with a continuous canopy. They produce an important interference in the flow during extraordinary floods (NEIFF *et al.,* 2006).

In the last twenty years, Paraná River had a irregular regime, with two extraordinary floods which exceed 8 m in Corrientes gauge (Figure 2). The pulses were more frequent in pioneer forests than the multiespecific forests (Table 1), that is to say, they are functionally connected to the river flow more times in the same time series.

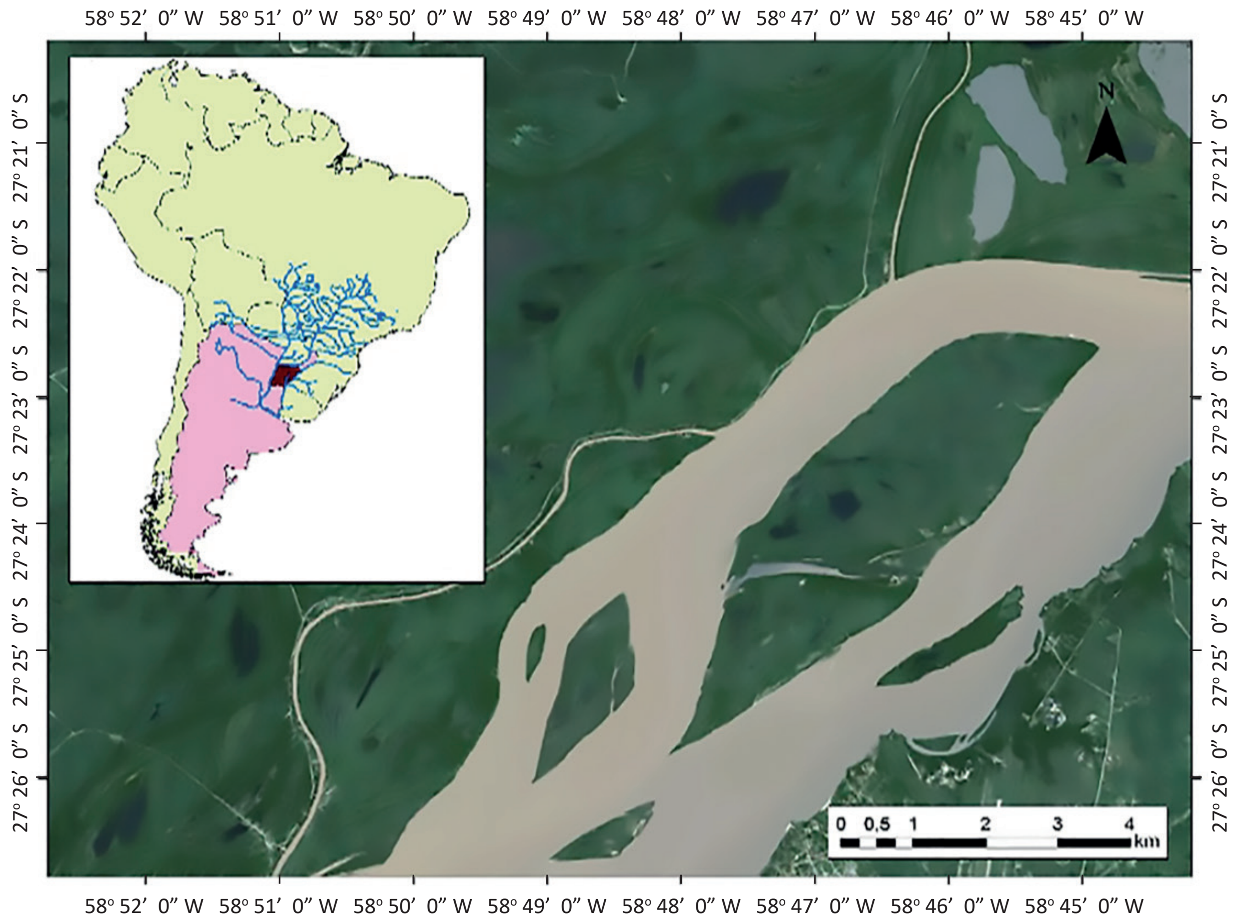

Figure 1 – Location of study area.

Table 1 – Pulse at tributes during 1985-2015.

Pulse attributes	Pioneer forests	Multiespecific forest
Overflow level (m.a.s.l.)	46.39 (4m)	48.39 (6 m)
Mean amplitude (days)	72.2	319.08
Mean intensity (m)	2.44	3.3
Pulse frequency	156	35
Mean water level (m)	3.95	3.95
Maximun mean (m)	6.41	1.18
Minimum mean (m)	2.14	0.71
Maximum tension	61.11	61.11
Minimum tension	65.44	65.44
Maximum (m)	8.64 (8 Jun. 1992)	
Minimum (m)	1.4 (30 Aug. 2001)	

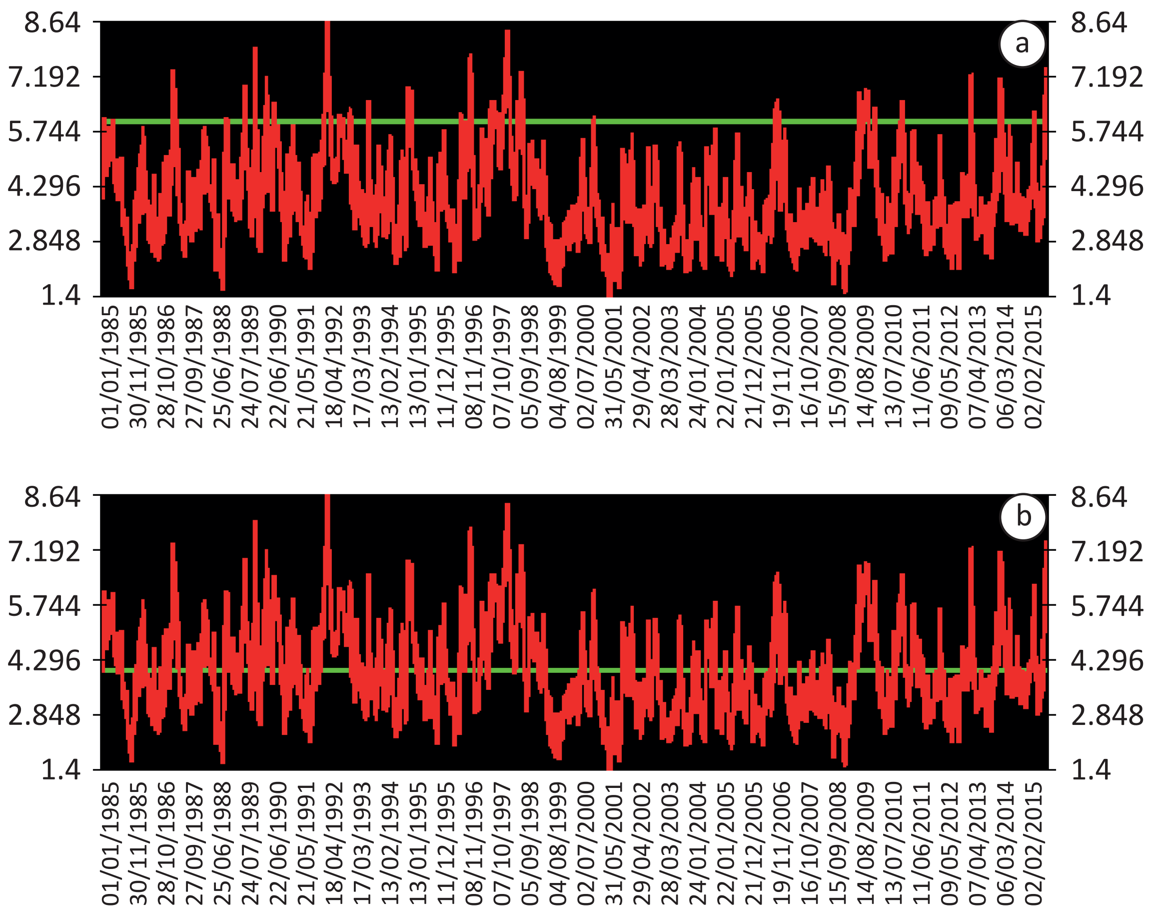

Figure 2 – Water level fluctuations of the Paraná River at Puerto Corrientes between 1985 and 2015. a. Overflow level of pioneer forests: 4 m; b. Overflow level of multiespecific forests: 6 m.

Conclusion

The multiespecific forests are located in the highest sites of the islands and the populations of the pioneer forests occupy the lowest sites of the topographic gradient. Knowledge of the distribution and abundance of organisms allows understanding the biotic complexity of the system, its temporal variability and the possibilities of organisms to colonize and maintain themselves in pulsatile environments of the rivers.

The species richness is conditioned by the frequency intensity, duration and timing of the hydrological phases. The current specific richness has a configuration that must be evaluated knowing the processes that regulate positively or negatively by the phases of the pulses. PULSE, can be seen as a tool to link the organization of biotic communities with the characteristics of the pulses (frequency, intensity, duration and seasonality). The analysis of periodic hydrological phenomena is a tool to understand why fluvial vegetation can be differentiated from the surrounding ecosystems, even from a satellite. Climatic changes that modify the hydrological dynamics influence the biodiversity of each site, by modifying the frequency, duration and seasonality of the flooded soil / dry soil phases of the site. These causes of biological settings on a site and in a basin require analysis at different scales: current evolutionary sucesionaly.

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https://doi.org/10.26626/978-85-5953-031-5.2018C008

Geographical Distribution of Calanoida Species (Copepoda-Crustacea), at 22 UGRHi of São Paulo State - Brazil

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Abstract

Geographical distribution of Calanoida species (Copepoda-Crustacea) from São Paulo State were studied considering the 22 UGRHi (Management Units of Hydric Resources). Samplings were carried out from 250 water ecosystems including small lakes, reservoirs and rivers during the period of 1999 to 2001. Some species showed a large geographical distribution occurring in almost all water ecosystems registered in 22 UGTHi. Other species occurred only in the waters of some UGRHi showing a narrow range of geographical distribution. This behavioral difference showed by the species can be attributed to several environmental factors: climatological conditions, biogeochemical factors, inter specific competition for food, habitat and hydrogeochemical factors.

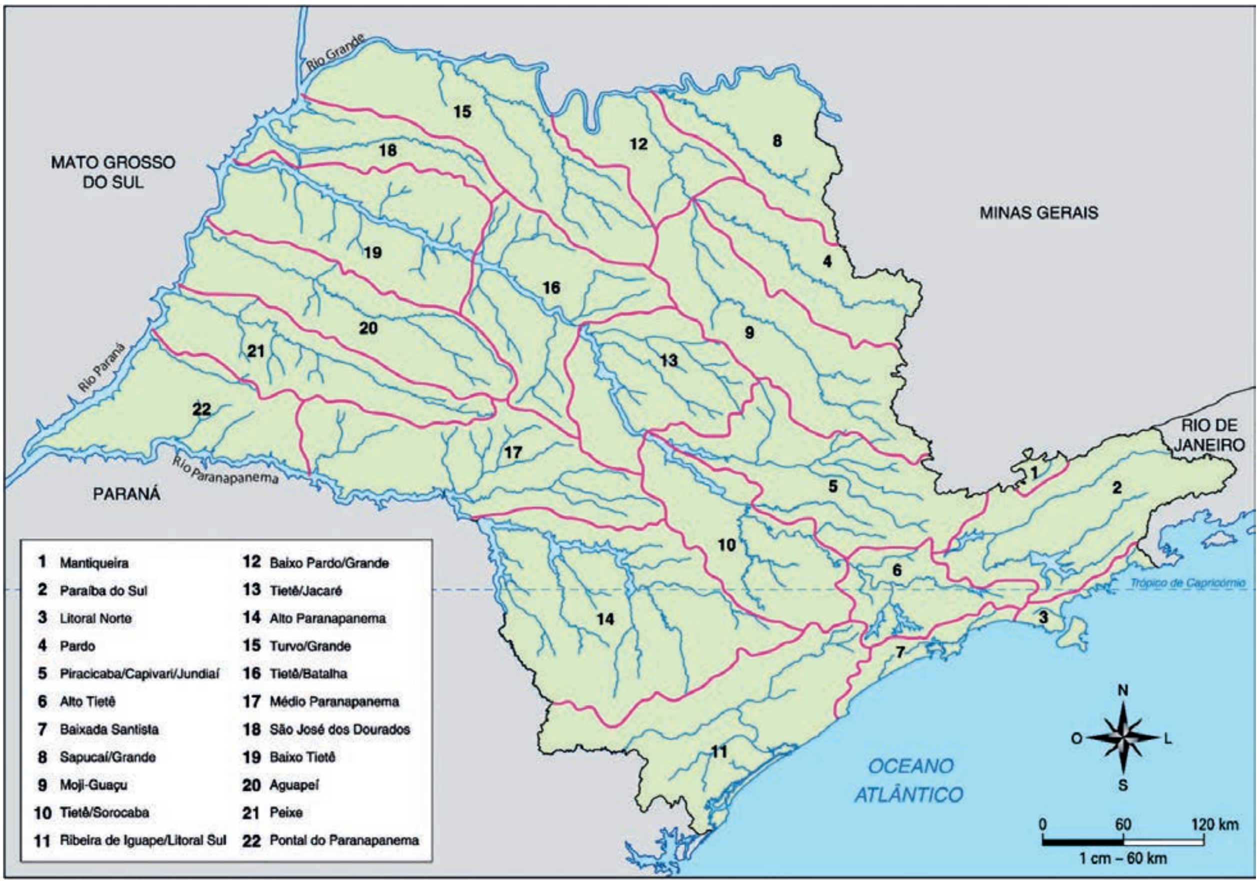
Keywords: eurioecious, stenoecious, climatological factors, biogeochemical factors, new species, interspecific competition.

Introduction

São Paulo State is separated by other States through three large rivers: Rio Grande at the north part making border with Minas Gerais State; Rio Paraná at the west part making border with Mato Grosso do Sul and Rio Paranapanema at the south part making border with Parana State. The fourth large river Tietê River across the center of São Paulo State from east to west direction to flow into Paraná River.

Based on watershed concept, São Paulo State was divided in 22 UGRHi (Management Units of Hydric Resources) where in each unit are include its hydric resources. Each unit has its number and the name of the main rivers contributors. The following Map shows the 22 UGRHi.

In each UGRHi there are some large dams constructed to the generation of hydroelectric power that will be shown in the Table 1.



Source: sanderlei.com.br/PT/Ensino-Fundamental/São-Paulo-Historia-Geografia-52

Table 1 – The main reservoirs belonging to each UGRHi of São Paulo State.

nº	UGRHi -Name	Dams construted
1	Mantiqueira	x
2	Paraiba do Sul	Paraibuna, Santa Branca,Jaguari, Funil
3	Litoral Norte	x
4	Pardo	Graminea (Caconde)
5	Piracicasba/Capivari/Jundiai	Atibaia,Atibainha, Salto Grande, Jacarei, Cachoeira
6	Alto Tietê	Guarapirang, Billings, Paiva Castro Aguas Claras, Pedro Beicht, Ponte Nova, Jundiai, Taiaçupeba, Biritiba, Paraitinga
7	Baixada Santista	x
8	Sapucaí/Grande	Estreito, Jaguara
9	Mogi Guaçu	Euclides da Cunha,Limoeiro
10	Tietê/Sorocaba	represa de Ituparararanga
11	Ribeira de Iguape e Litoral Sul	França, Fumaça, Barra,Porto Raso, Alecrim, Serraria
12	Baixo Pardo/Grande	Volta Grande, Porto Colombia
13	Tietê/Jacaré	Barra Bonita, Bariri, Ibitinga,Lobo/Broa
14	Alto Paranapanema	Pirajui, Jurumrim
15	Turvo/Grande	Marimbondo, Agua Vermelha,Turvo
16	Tietê/Batalha	Promissão
17	Médio Paranapanema	Capivara, Xavantes
18	São Jose´dos Dourados	Jupiá,Ilha Solteira
19	Baixo Tietê	Nova Avanhandava, Três Imãos
20	Aguapeí	Porto Primavera
21	Peixe	Boa Esperança
22	Baixo ou Pontal do Paranapanema	Taquaruçu, Rosana

In 1998 a large Project on Biodiversity in Sao Paulo State was carried out financed by FAPESP (BIOTA/FAPESP) Matsumura-Tundisi, 2003, covering both terrestrial and aquatic organisms, aimed to explore the maximum biodiversity and to know the geographical distribution of the organisms through the construction of the maps using GPS. In the case of aquatic organisms, specifically zooplankton community 330 water bodies were studied including, small lakes, reservoirs, rivers, in such a way that in each UGRHi we have explored among 10 to 15 water bodies.

Material and Methods

The Calanoida specimens were obtained through a standard net sampling with 70µm mesh size in horizontal hauls for a shallow water bodies and vertical hauls for deep water. In both cases the filtered water in the net was around 1 thousand liters. All the sampling sites were determined with GPS and after the analysis of the material at the laboratory identifying the Calanoida copepods at the level of species the metadata was sent to SinBiota (Instituto de Biodiversidade) to processing and producing the distribution map of Calanoida species at the 22 UGRHi of São Paulo State

Results

In the study of 250 water bodies (including small standing waters, rivers, large reservoirs), and 398 samplings carried out in São Paulo State, it was identified 12 species of Calanoida, one of them a new species described by Matsumura-Tundisi et al., 2010. They are: *Argyrodiaptomus furcatus* (SARS, 1901), *Argyrodiaptomus azevedoi* (WRIGHT, 1935), *Notodiaptomus iheringi* (WRIGHT, 1935), *Notodiaptomus cearensis* (WRIGHT, 1936) *Notodiaptomus henseni* (DAHL, 1894), *Notodiaptomus venezolanus deevoyorum* (BOWMAN, 1973), *Notodiaptomus spinuliferus* (DUSSART, MATSUMURA-TUNDISI, 1986; MATSUMURA-TUNDISI, 2008), *Notodiaptomus deitersi* (POPPE, 1891), *Notodiaptomus oliveirai* (MATSUMURA-TUNDISI, et al., 2015), *Odontodiaptomus paulistanus* (WRIGHT, 1936), *Pseudodiaptomus richardi* (DAHL, 1894), *Scolodiaptomus corderoi* (WRIGHT, 1936).

Geographical distribution of species

1. *Argyrodiaptomus furcatus*

This species (Figure 1a) was more frequent in the UGRHi of the northeast side of São Paulo State as can be seen in the Figure 1b.

The species were found mainly on the reservoirs of the following UGRHi: Sapucai/ Grande (8); Pardo (4); Mogi Guaçu (9); Tetê/Sorocaba (10); Piracicaba/Capivi/ Jundiai (5); Tietê/Jacaré (13); Alto Tietê (6); Paraiba do Sul (2) and in some reservoirs of River Paranapanema.

Argyrodiaptous furcatus was the only Calanoida species present in the Lobo/Broa reservoir (UGRHi-13).

Figure 1a – Characteristics of 5th leg of male of *Argyrodiaptomus furcatus.*

Figure 1b – Map of geographical distribution of *Argyrodiaptous furcatus* (SinBiota/FAPESP).

2. *Argyrodiaptomus azevedoi*

This species (Figure 2a) is restricted in the UGRHi that receive influence of River Paraná. They occurred in the following Unities located at the west part of the São Paulo State: São José dos Dourados (18); Baixo Tietê (19); Tietê/Batalha (16); Aguapei (20). Figure 2b shows the geographical distribution of this species in water boies os São Paulo State.

Figure 2a – Characteristics of 5th leg of male *Argyrodiaptomus azevedoi.*

Figure 2b – Map of geographical distribution of *Argyrodiaptous azevedoi* (SinBiota/ FAPESP).

3. *Notodiaptomus iheringi*

This species (Figure 3a) described by Wright, 1935 from the material coming from the northeast part of Brazil, probably dispersed to the South part at São Paulo State as has been stated Sendacz, Kubo, 1982 and Matsumura-Tundisi, Tundisi, 2003.

Currently as can be seen in the Figure 3b, the species are largely distributed occurring in the most UGRHi of São Paulo State, showing that the species has a strong plasticity supporting a great habitat variability.

Figure 3a – Characteristics of 5th leg of male of *Notodiaptomus iheringi*

Figure 3b – Map of geographical distribution of *Notodiaptomus iheringi* in São Paulo State (SinBiota/FAPESP).

4. *Notodiaptomus cearensis*

The species (Figure 4a) is very similar to *Notodiaptomus iheringi*, however is more larger than the last one, and also coming from the northeast part of Brazil.

Figure 4a – Characteristics of 5th leg of male of *Notodiaptomus cearensis.* Probably the species is coming from lower latitudes at northeast of Brazil.

Figure 4b – Map of geographical distribution of *Notodiaptomus iheringi* in São Paulo State (SinBiota/FAPESP).

5. *Notodiaptomus oliveirai*

Notodiaptomus oliveirai was observed at the first time in 1992-1993 in Barra Bonita reservoir by Espindola, 1994 as *Notodiaptomus* n sp. Furtheremore Matsumura-Tundisi et al., 2010 described as *Notodiaptomus oliveirai* (Figure 5a). Recently the species became the most abundant population of Barra Bonita reservoir dispersing also in the other water bodies belonging at 22 UGRH of São Paulo State as can be seen in the Figure 5b.

Figure 5a – Characteristics of 5th leg of male of *Notodiaptomus oliverai.*

Figure 5b – Map of geographical distribution of *Notodiaptomus oliveirai* in São Paulo State (SinBiota/FAPESP).

6. *Odontodiaptomus paulistanus*

This species (Figure 6a) described by Wright (1935) from the material collected in the water bodies of UGRH-Alto Tietê, never have been registered in other places of São Paulo State. At present study it has been registered only in UGRH Alto Tietê in the following reservoirs: Ribeirão do Campo,, Billings, Ponte Nova and Paiva Castro and in some lakes from UGRH 7 – Baixada Santista as can be seen in the Figure 6b.

Figure 6a – Characteristics of 5th leg of male of *Odontodiaptomus paulistanus.*

Figure 6b – Map of geographical distribution of *Odontodiaptomus paulistanus* in São Paulo State (SinBiota/FAPESP).

7. *Notodiaptomus henseni*

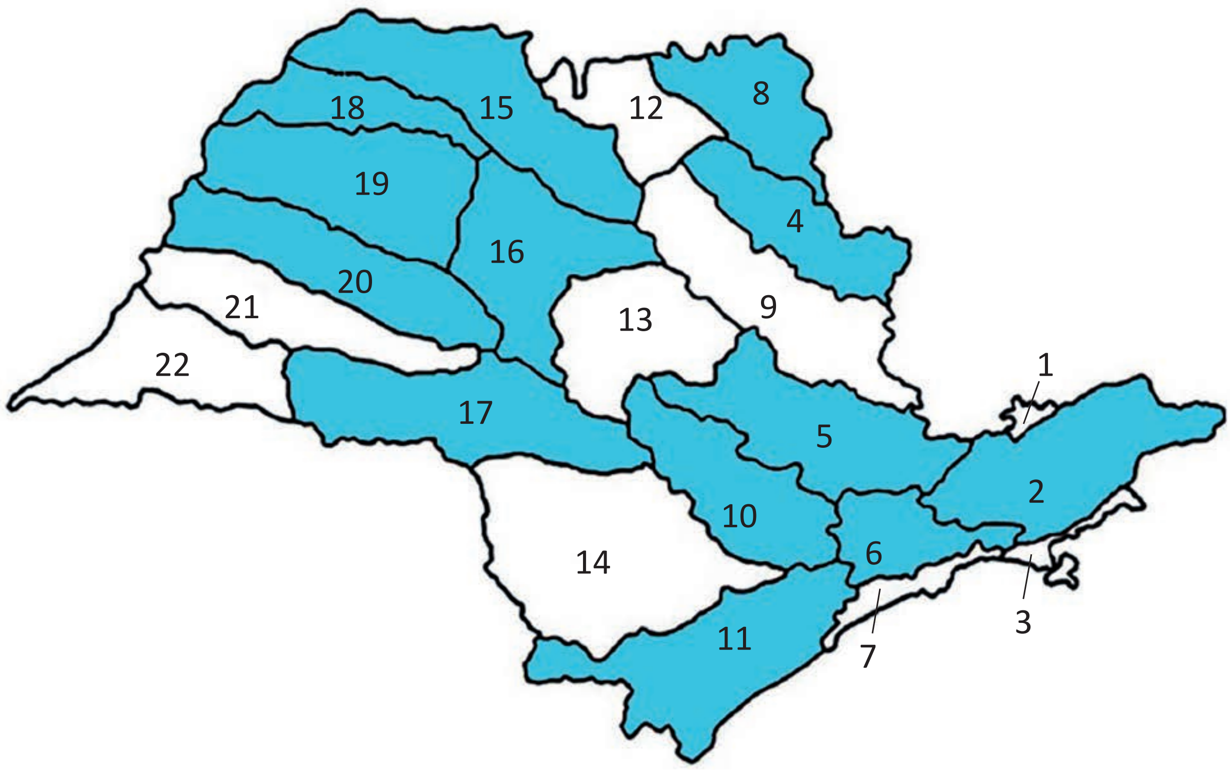
This species (Figure 7a) described by Dahl, 1891 from the material coming from Amazon it has been registered by the other authors such as Cipolli, Carvalho (1973) in the waters of Pará State, Matsumura-Tundisi in the lake José Maria (03°30'S lat. 40°W long).

The present study shows that the species there was restricted in the water of low latitudes it was introduced in some way to the water of more high latitudes (São Paulo State – 24°29'15''S) and has been adapted very well a new habitat enlarged their distribution in São Paulo State occurring in 13 UGRHi (Table 2).

Figure 7a – Characteristics of 5th leg of male of *Notodiaptomus henseni.*

Table 2 – Occurrence of *Notodiaptomus henseni* in the lakes and reservoirs of 13 UGRHi of São Paulo State.

Nº UGRHi	Name	Lakes & Reservoirs
2	Paraiba do Sul	Paraibuna
4	Pardo	Graminha
5	Piracicaba/Capivara/Jundiai	Paramirim,Atibainha
6	Alto Tietê	Aguas Claras, Taiaçupeba, Jundiai
8	Sapucaí/Grande	Jaguara, Sapucai, Igarapava, Volta Grande
10	Tietê/Sorocaba	Itupararanga
11	Ribeira do Iguape/Litoral Sul	Serraria,Alecrim, Cachoeira da França Fumaça, Barra
15	Turvo/Grande	Agua Vermelha, Turvo
16	Tietê/Batalha	Ibitinga, Bariri
17	Médio Paranapanema	Capivara
18	São José dos Dourados	Ilha Solteira,lagoa Estancia Semax
19	Baixo Tietê	Três Irmãos,Jupiá
20	Aguapeí	lago Country Clube(Rio Aguapeí), lago Pinopolis,lagoa Central (Rio Paraná)



Unidades de Gerenciamento de Recursos Hídricos – UGRHi

01 - Mantiqueira
02 - Paraíba do Sul
03 - Litoral Norte
04 - Pardo
05 - Piracicaba/Capivari/Jundiaí
06 - Alto Tietê
07 - Baixada Santista
08 - Sapucaí/Grande
09 - Mogi-Guaçu
10 - Tietê/Sorocaba
11 - Ribeira da Iguape/Litoral Sul
12 - Baixo Pardo/Grande
13 - Tietê/Jacaré
14 - Alto do Paranapanema
15 - Turvo/Grande
16 - Tietê/Batalha
17 - Médio Paranapanema
18 - São José dos Dourados
19 - Baixo Tietê
20 - Aguapeí
21 - Peixe
22 - Pontal do Paranapanema

Figure 7b – Map of geographical distribution of *Notodiaptomus henseni* in São Paulo State.

8. *Notodiaptomus deitersi*

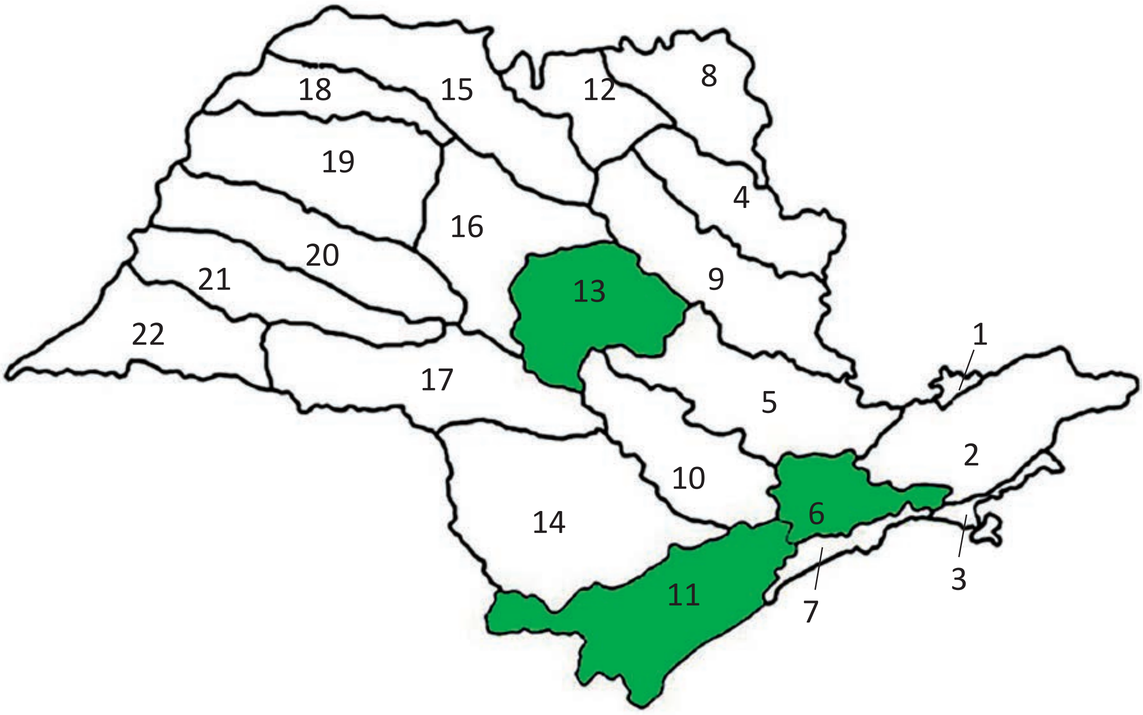
This species (Figure 8a) was recorded in the lakes of Pantanal Matogrossense (Recreio, Sá Mariana) located at 16°11'39''S lat. and 56°14'45''W long. (MATSUMURA-TUNDISI, 1986).

In the present work it was recorded only at three URGHi of São Paulo State (Alto Tietê, Tietê/Jacaré and Ribeira do Iguape/Litoral Sul) (Table 3).

Figure 8a – Characteristics of 5th leg of male of *Notodiaptomus deitersi.*

Table 3 – Occurrence of *Notodiaptomus deitersi* in the lakes and reservoirs of 3 UGRHi of São Paulo State.

Nº UGRHi	Name	Lakes & Reservoirs
6	Alto Tietê	Paiva Castro
13	Tietê /Jacaré	Ibitinga
11	Ribieira do Iguape/Litoral Sul	Porto Raso, Barra



Unidades de Gerenciamento de Recursos Hídricos – UGRHi

01 - Mantiqueira	12 - Baixo Pardo/Grande
02 - Paraíba do Sul	13 - Tietê/Jacaré
03 - Litoral Norte	14 - Alto Paranapanema
04 - Pardo	15 - Turvo/Grande
05 - Piracicaba/Capivari/Jundiaí	16 - Tietê/Batalha
06 - Alto Tietê	17 - Médio Paranapanema
07 - Baixada Santista	18 - São José dos Dourados
08 - Sapucaí/Grande	19 - Baixo Tietê
09 - Mogi-Guaçu	20 - Aguapeí
10 - Tietê/Sorocaba	21 - Peixe
11 - Ribeira da Iguape/Litoral Sul	22 - Pontal do Paranapanema

Figure 8b – Map of geographical distribution of *Notodiaptomus deitersi* in São Paulo State.

9. *Notodiaptomus spinuliferus*

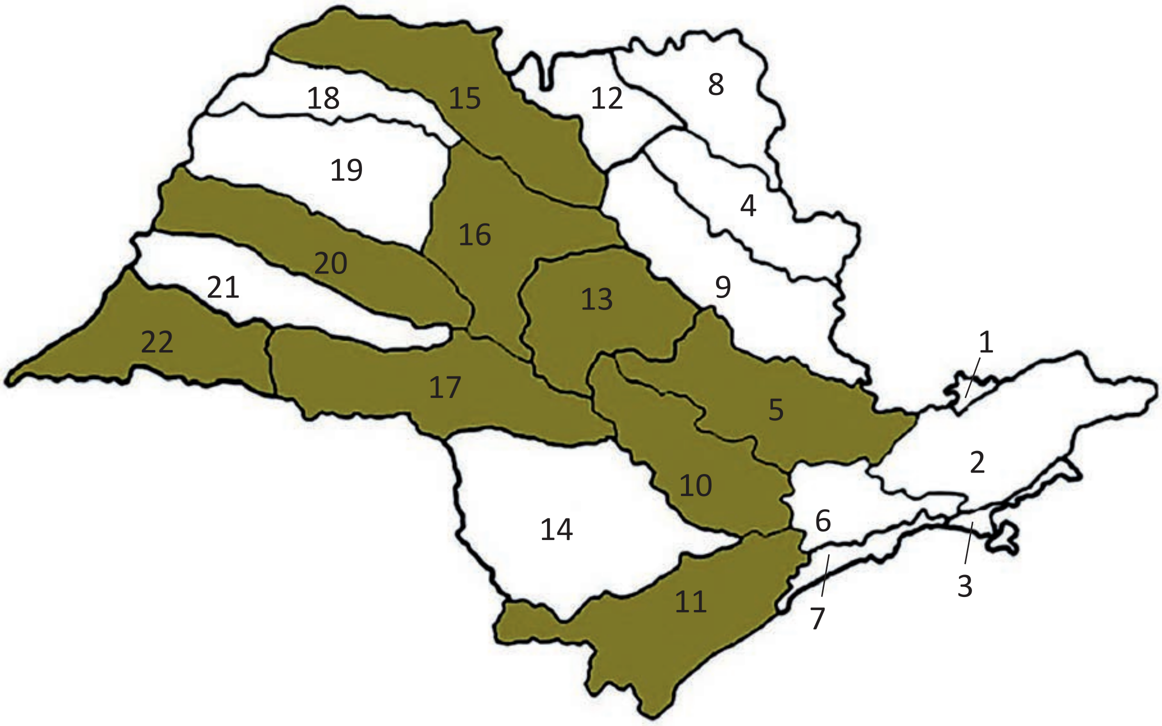
This Calanoida was found at the first time in the sampling carried out in Ilha Solteira reservoir (UGRHi-18, São José dos Dourados) during the process of the Project “Typology of reservoirs of São Paulo State” and described as a new species by Dussart, Matsumra-Tundisi,1986 and carried out for rectification by Matsumura-Tundisi, 2008. In the present study it was observed that the species enlarged its occurrence occupying lakes and reservoirs from 9 UGRHi of São Paulo State as ca be seen in the Table 4.

Figure 9b shows the map of geographical distribution of *Notodiaptomus spinuliferus* in the waters of São Paulo State.

Figure 9a – Characteristics of 5th leg of male of *Notodiaptomus spinuliferus.*

Table 4 – Occurrence of *Notodiaptomus spinuliferus* in the lakes and reservoirs from 9 UGRHi of São Paulo State.

Nº UGRHi	Name	Lakes & Reservoirs
5	Piracicaba/Capivara/Jundiai	Atibainha
10	Tietê/Sorocaba	Itupararanga, Prainha, Hedberg
11	Ribeira do Iguape/Litoral Sul	Jurupara
13	Tietê/Jacaré	Barra Bonita
15	Turvo/Grande	Cestari, Santa Ana
16	Tietê/Batalha	Lago Laranja Azeda (Ibitinga), Bariri, Promissão
17	Médio Paranapanema	Taquaruçu, Capivara
20	Aguapeí	Lagoas: Pau da Onça, Marreco
22	Baixo(Pontal) Paranapanema	Rosana



Unidades de Gerenciamento de Recursos Hídricos – UGRHi

01 - Mantiqueira
02 - Paraíba do Sul
03 - Litoral Norte
04 - Pardo
05 - Piracicaba/Capivari/Jundiaí
06 - Alto Tietê
07 - Baixada Santista
08 - Sapucaí/Grande
09 - Mogi-Guaçu
10 - Tietê/Sorocaba
11 - Ribeira da Iguape/Litoral Sul
12 - Baixo Pardo/Grande
13 - Tietê/Jacaré
14 - Alto Paranapanema
15 - Turvo/Grande
16 - Tietê/Batalha
17 - Médio Paranapanema
18 - São José dos Dourados
19 - Baixo Tietê
20 - Aguapeí
21 - Peixe
22 - Pontal do Paranapanema

Figure 9b – Map of geographical distribution of *Notodiaptomus spinuliferus* in São Paulo State.

10. *Notodiaptomus venezoelanus deevoyorum*

The species (Figure 10) described by Kiefer, 1956 from the material collected from the lakes of Venezuela, it was recorded at the first time in Brazil in the lakes of Pantanal Matogrossense (Sá Mariana, Chacororé, Buritizal) by Matsumura-Tundisi, 1986.

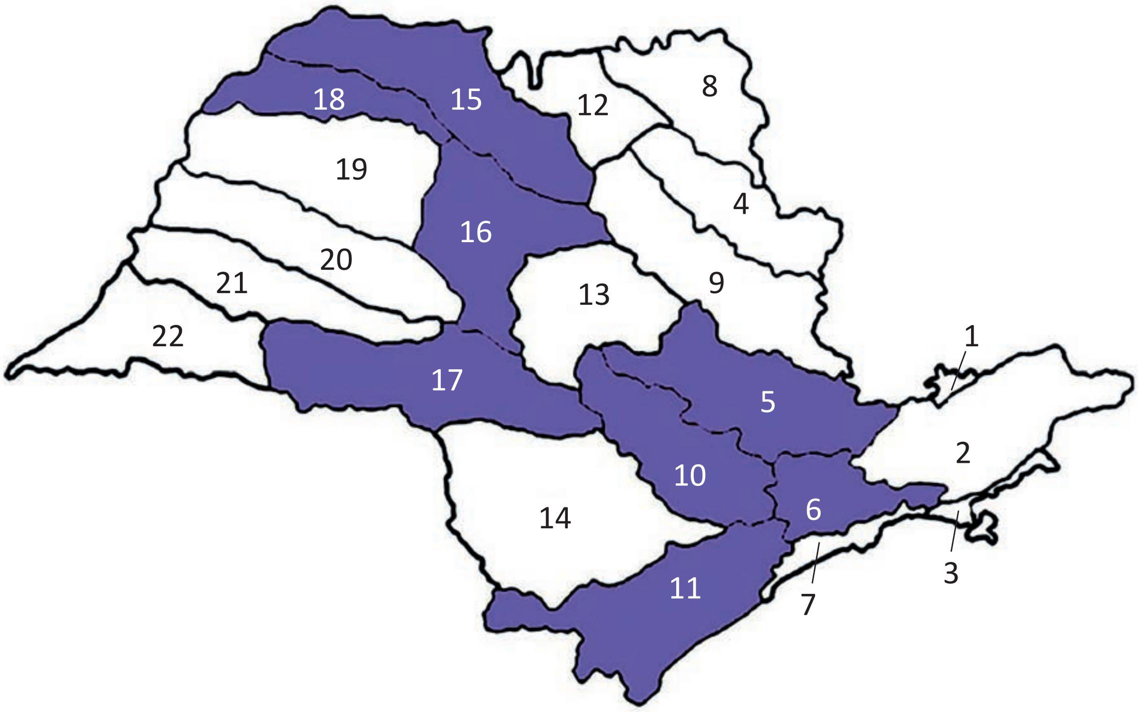
In the present investigation this species occurred I the lakes and reservoirs of São Paulo State at 24°29'15''S showing a large geographical distribution occupaying 8 UGRHi of São Paulo State (Table 4).

Figure 10b shows the map of geographical distribution of *Notodiaptomus venezoelanus deevoyorum* ocupaying 8 UGRHi of São Paulo State.

Figure 10a – Characteristics of 5th leg of male of *Notodiaptomus venezoelanus deevoyorum.*

Table 5 – Occurrence of *Notodiaptomus venezoelanus deevoyorum* in the lakes and reservoirs from 8 UGRHi of São Paulo State.

Nº UGRHi	Name	Lakes & Reservoirs
5	Piracicaba/Capivara/Jundiai	Igaratá
6	Alto Tietê	Taiaçupeba
10	Tietê/Sorocaba	Santa Branca, Paraibuna
11	Ribeira do Iguape/Litoral Sul	Porto Raso, Serraria, Barra
15	Turvo/Grande	Agua Vermelha
16	Tietê/Batalha	lago Laranja Azeda (Ibitinga), Bariri
17	Médio Paranapanema	Taquaruçu
18	São José dos Dourados	Ilha Solteira



Unidades de Gerenciamento de Recursos Hídricos – UGRHi

01 - Mantiqueira	12 - Baixo Pardo/Grande
02 - Paraíba do Sul	13 - Tietê/Jacaré
03 - Litoral Norte	14 - Alto Paranapanema
04 - Pardo	15 - Turvo/Grande
05 - Piracicaba/Capivari/Jundiaí	16 - Tietê/Batalha
06 - Alto Tietê	17 - Médio Paranapanema
07 - Baixada Santista	18 - São José dos Dourados
08 - Sapucaí/Grande	19 - Baixo Tietê
09 - Mogi-Guaçu	20 - Aguapeí
10 - Tietê/Sorocaba	21 - Peixe
11 - Ribeira da Iguape/Litoral Sul	22 - Pontal do Paranapanema

Figure 10b – Map of geographical distribution of *Notodiaptomus venezoelaus deevoyorum* in São Paulo State.

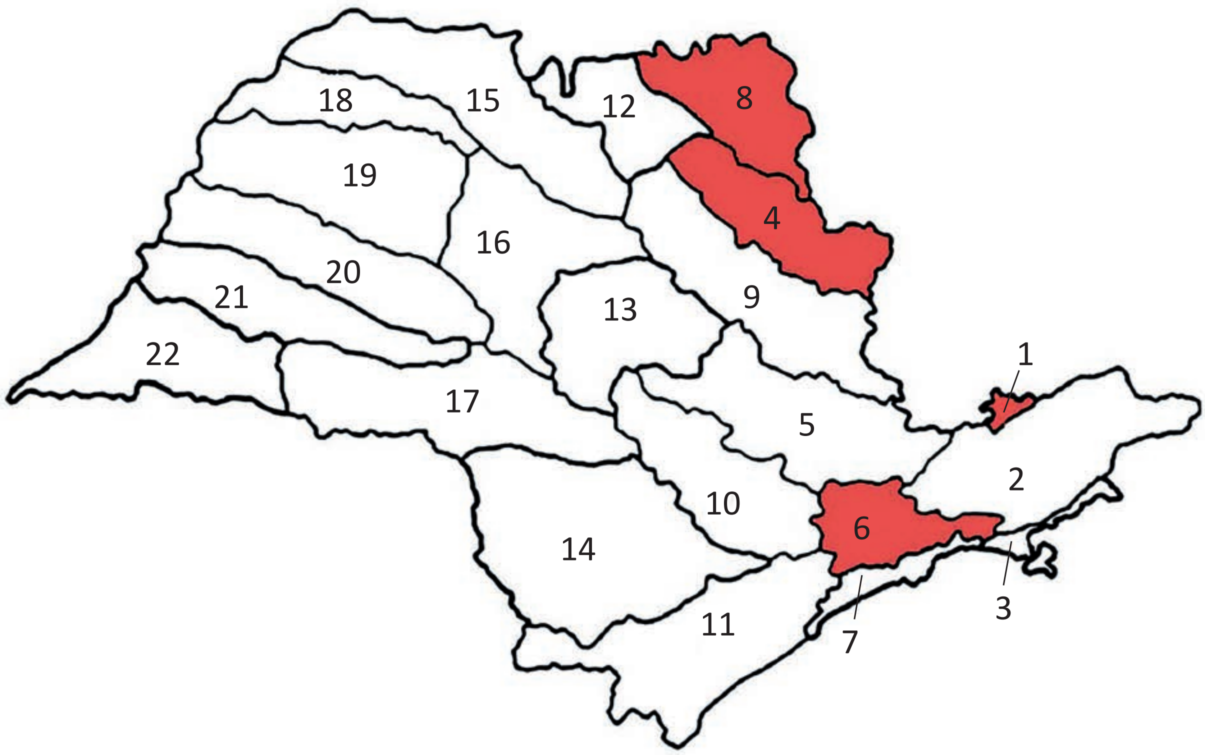
11. *Scolodiaptomus corderoi*

In the samplings made in 1979 (Typology of reservoirs of São Paulo State – TUNDISI, 1980) this species (Figure 11a) was present in the most of reservoirs belonging in the River Paraná basin, Rio Grande River basin and Rio Pardo basin, in large quantity (MATSUMURA-TUNDISI, TUNDISI, 2003). However recent studies showed the complete disappearance of this species from Barra Bonita reservoir that was present in abundance between 1983-1984 and from other reservoirs. The present data show the scarcity of ***Scolodiaptomus corderoi*** presence in the most water bodies of São Paulo State as can be seen in the table 6 occurring in some reservoirs from 4 (four) UGRHi: Mantiqueira, Pardo, Alto Tietê, Sapucai/Grande.

Figure 11a – Characteristics of 5th leg of male of *Solodiaptomus corderoi.*

Table 6 – Occurrence of *Scolodiaptomus corderoi* in the lakes and reservoirs from 4 UGRHi of São Paulo State.

Nº UGRHi	Name	Lakes & Reservoirs
1	Mantiqueira	Lago das Ninfeas, Horto
4	Pardo	Limoeiro
6	Alto Tietê	Aguas Claras, Guarapiranga
8	Sapuai/Grande	Jaguara, Volta Grande



Unidades de Gerenciamento de Recursos Hídricos – UGRHi

01 - Mantiqueira
02 - Paraíba do Sul
03 - Litoral Norte
04 - Pardo
05 - Piracicaba/Capivari/Jundiaí
06 - Alto Tietê
07 - Baixada Santista
08 - Sapucaí/Grande
09 - Mogi-Guaçu
10 - Tietê/Sorocaba
11 - Ribeira da Iguape/Litoral Sul
12 - Baixo Pardo/Grande
13 - Tietê/Jacaré
14 - Alto Paranapanema
15 - Turvo/Grande
16 - Tietê/Batalha
17 - Médio Paranapanema
18 - São José dos Dourados
19 - Baixo Tietê
20 - Aguapeí
21 - Peixe
22 - Pontal do Paranapanema

Figure 11b – Map of geographical distribution of *Scolodiaptomus corderoi* in São Paulo State.

12. *Pseudodiaptomus richardi*

This is a brackish water species (Figure 12a) found only in UGRHi 7 (Baixada Santista) where the Rio Aguapei that flows to the Atlantic Ocean suffers the influence of the seas. Table 7 and Figure 12b show the occurrence of *Pseudodiaptomus richard* only in the UGRHi Baixada Santista.

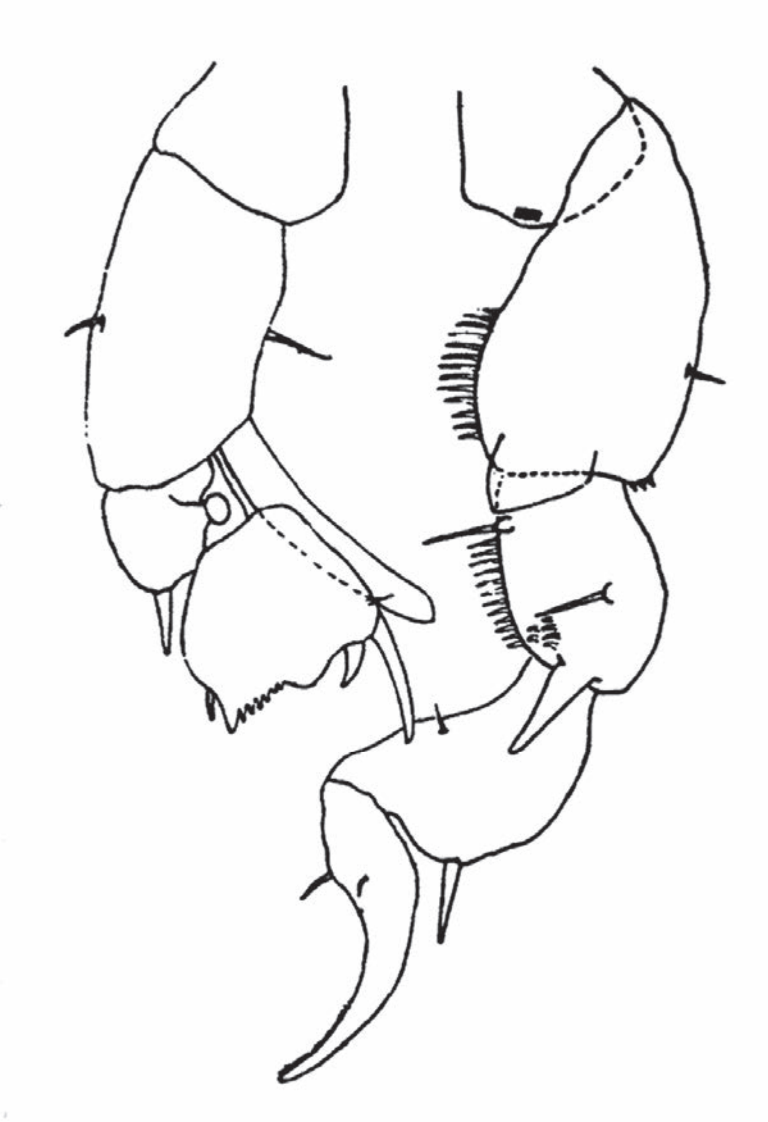
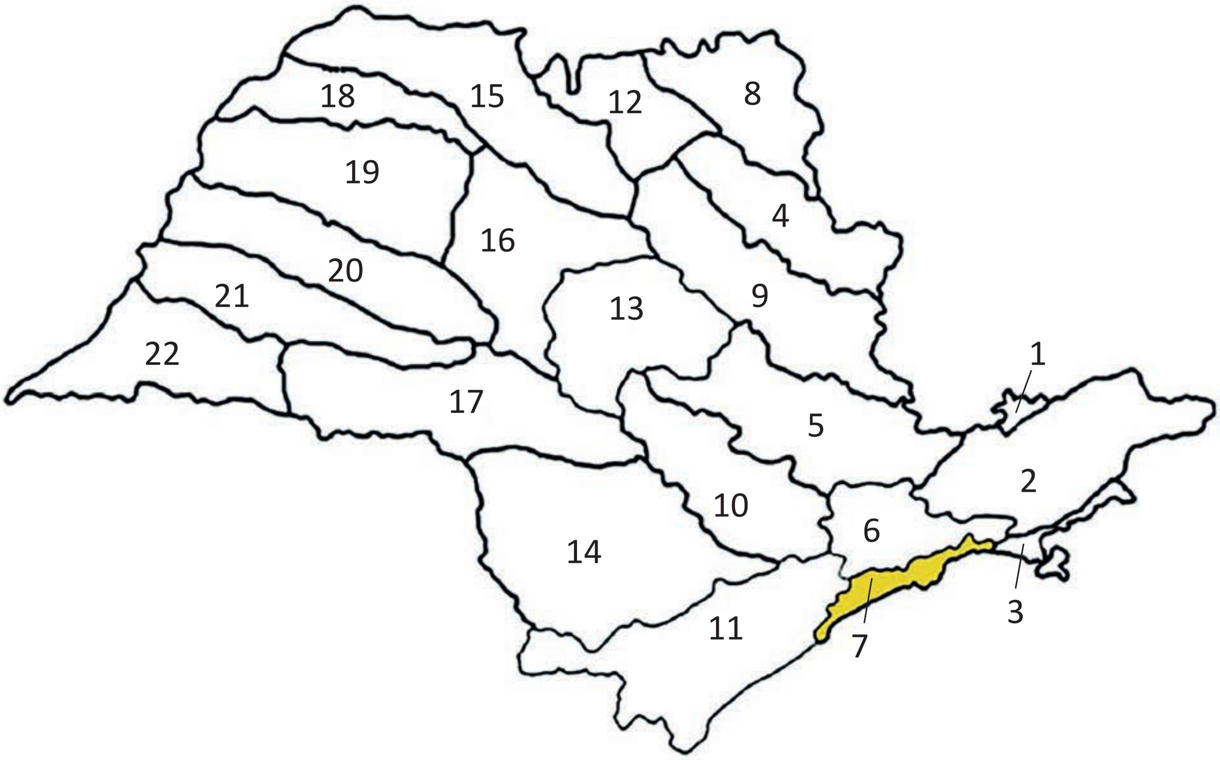


Figure 12a – Characteristics of 5th leg of male of *Pseudodiaptomus richardi.* Source: Sars, 1901.

Table 7 – Occurrence of *Pseudodiaptomus richardi* in the lakes and reservoirs in 1(one) UGRHi of São Paulo State.

Nº UGRHi	Name	Lakes & Reservoirs
7	Baixada Santista	Aguapei (Itanhaen)



Unidades de Gerenciamento de Recursos Hídricos – UGRHi

01 - Mantiqueira	12 - Baixo Pardo/Grande
02 - Paraíba do Sul	13 - Tietê/Jacaré
03 - Litoral Norte	14 - Alto Paranapanema
04 - Pardo	15 - Turvo/Grande
05 - Piracicaba/Capivari/Jundiaí	16 - Tietê/Batalha
06 - Alto Tietê	17 - Médio Paranapanema
07 - Baixada Santista	18 - São José dos Dourados
08 - Sapucaí/Grande	19 - Baixo Tietê
09 - Mogi-Guaçu	20 - Aguapeí
10 - Tietê/Sorocaba	21 - Peixe
11 - Ribeira da Iguape/Litoral Sul	22 - Pontal do Paranapanema

Figure 12b – Map of geographical distribution of *Pseudodiaptomus richardi* in São Paulo State.

Discussion

The twelve species of Calanoida identified in the freshwater continental ecosystems of São Paulo State (rivers, lakes and reservoirs) can be grouped as those that have large tolerance to environmental factors (climatological, habitats, chemical, physical, hydrogeological) as eurioecious species, and those that present a narrow tolerance to these factors as stenoecious species.

Of the identified Calanoida, five species, *Notodiaptomus iheringi, Notodiaptomus* *oliveirai, Notodiaptomus spinuliferus, Notodiaptomus henseni* and *Notodiaptomus venezoelanus deevoyorum* can be considered as eurioecious species. These tolerate an ample spectra of environmental factors with a presence in more than 50% of the UGRHi of São Paulo State, under the influence of the main rivers that limit the frontiers of the major UGRHi: Rio Grande, Rio Paraná, Rio Paranapanema, Rio Tietê and Rio Pardo.

The other species such as *Argyrodiaptomus azevedoi, Odontodiaptomus paulistanus,, Notodiaptomus deitersi, Scolodiaptomus corderoi* and *Psedodiaptomus richardi* are stenoecious species, once their occurrence was registered in a few UGRHi.

As discussed by Hutchinson (1967) most of the species of Calanoida, specially Diaptomidae have wide tolerance of soft and moderately hard waters. The response of the species of Diaptomidae to environmental factors specially what Hutchinson (op.cit.) describes as "chemical ecology of Calanoida" is from field evidences of distribution rather than to experimental work in the laboratory. The endemicity of Calanoida species is well known from these field samples, therefore. Baily (1969) hás shown a strong correlation between Calanoida distribution in Australian freshwaters ecosystems and the ionic composition of waters specially the $HCO_3^- + CO_3^-$/clorate. Thus there are many evidences that hydrogeochemical factors such as the ionic composition of the water, the eutrophication and acidification processes are key factors, together with temperature that affect the distribution and survival of Calanoida species. These facts could explain why the copepods Calanoida from Northern hemisphere do not occur in the Southern hemisphere or vice versa. Many authors that studied the Diaptomidae from South hemisphere, since 1891 (POPPE, 1891 described the Diaptomidae from Brasilian material as "*Diaptomus" deitersi*), described all the Calanoida found as "*Diaptomus"* until 1958, when Brehm, 1958, classified the different "*Diaptomus"* in several genera.

In response to eutrophication changes in the composition of phytoplankton are expected. Cyanobacteria blooms are more frequent or permanent components of the phytoplankton community and given the fact that many species of cyanobacteria can produce toxins, it is probably another factor that affects the distribution of the Copepoda.

Several reservoirs in São Paulo State changed trophic status in the last 20 years (MATSUMURA-TUNDISI, TUNDISI, 2003; TUNDISI, MATSUMNURA-TUNDISI, 2013) a fact that can explain the changes observed in the zooplankton composition as regards Calanoida.

As Margalef (1966) pointed out, there is a constant interaction between plants and animals and this regulates the speed of phytoplankton and zooplankton succession. Quality of food which is different at each stage of succession has a strong influence on zooplankton development and evolution. Food availability changes, therefore, from smaller particles at the early stages of succession to larger particles at latter stages of succession and this can affect the Copepoda Calanoida distribution. Rietzler et al. (2002) proposed that changes in particle size and availability was one of the factors that caused the change of *Argyrodiaptomus furcatus* to *Notodiaptomus iheringi* at Lobo/Broa reservoir.

The production of resting eggs by Copepoda Calanoida is another factor that can explain the wider geographical distribution of some species and the limited distribution of other species. As stated by Hutchinson (op. cit.) Diaptomidae can produce active and resting eggs The conditions under which the resting eggs hatch is relatively unknown but evidence from Lob/Broa reservoir a shallow ecosystem, with a high level of organic matter can explain the presence of *Argyrodiaptomus furcatus* the unique species of Calanoida present in this reservoir until 1986. On that time occurred the invasion of *Notodiaptomus iheringi* in competition with *A. furcatus*. The conditions of the reservoir also were undergoing becoming more eutrophic. Then it is possible to explain that the distribution of *Argyrodiaptomus furcatus* occurs only at the water ecosystems belonging at the UGRHi located in the northeast part of São Paulo State.

Other possible effect on the Copepoda Calanoida composition is the introduction of exoctic species of fishes in the reservoirs of São Paulo State. As shown by Matsumura-Tundisi & Tundisi (2003) major changes in zooplankton Copepoda Calanoida composition occurred mainly from 1980 to 1990. This was exactly the period during which at least 13 species of fishes from Amazon basin and other basins were introduced. The presence of *Notodiaptomus cearensis* in the present data and only in the UGRHi, influenced by River Tietê, could be explained by the transportation of this species native from lower latitudes by fishes to São Paulo State, where they found ideal conditions for their adaptation, reproduction and development.

The disappearance or the reduction of the geographic distribution of some species can be attributed to changes in the environmental conditions described above. Eutrophication, changes in the ionic composition or predation can be factors that limit the distribution or contribute for the changes in species composition. As Margalef (op. cit.) pointed out new empty spaces are continually produced in places where ecosystems are altered completely. Direct reactions of organisms to environmental change is most useful when the environment is altered in an unpredictable way. Reservoirs, lakes and rivers respond to environmental changes from the watershed inputs or the human activities in na unpredictable way depending on soil uses, the water uses, the load of nutrients and suspended material. Therefore a change in composition of Copepoda Calanoida should be expected under these dynamic and not so organized environmental conditions. These events may explain the retraction of the occurrence of *Scolodiaptomus corderoi* and *Notodiaptomus conifer* in the reservoirs os São Paulo State. Both species were present in 1979 in several reservoirs as related by Matsumura-Tundisi, Tundisi, 2003. At present *Scolodiaptomus corderoi* occurred in the reservoirs belonging at only three UGRHi, and *Notodiaptomus conifer* disappeared completely.

As stated by Matsumura-Tundisi, Tundisi (2003), during the decades of 1980 and 1990, eutrophication, acidification, the load of nutrients, suspended material and ionic composition changed drastically in several reservoirs of São Paulo State.For example in Barra Bonita reservoir amonium content (μgL^{-1}) had an increase of 200%; conductivity changed from $100\mu Scm^{-1}$ in 1979 to 370 μScm^{-1} in 2002 and the presence of sulphate íon (SO_4^{--}) was detected during 2002 sampling.

Several books and papers reported extensive changes in the limnological conditions of the reservoirs in São Paulo State in the last 20 years (TUNDISI, MATSUMURA-TUNDISI, 2013). This would favor the expansion in the distribution of some species and the reduction in the geographical distribution of other species.

As Margalef (1966) pointed out nature is a channel of information. The genetic channel is replicable individual structures. Then the genetic channel of information should probably be the response of the Copepoda Calanoida community to changes in the environment. The appearance of new species as *Notodiaptomus oliveirai,* would also be a consequence of this response. Due to the dynamic and rapid changes in the environmental conditions and the effect of man activities the genetic channel has been enlarged more rapidly than the ecological channel. The cultural channel of information was very much enlarged, too. This explain the changes and the appearance of new species in the zooplankton community of Copepoda Calanoida.

Reservoirs are complex systems. They are dynamic and variable ecosystems responding rapidly to the impacts of human activities ("the cultural channel", sensu Margalef, 1966). Effects of intraspecific competition, predation and changing environmental conditions would be responsible for the composition and succession of zooplankton community (PIANKA, 1999). The response of the Copepoda Calanoida populations dwelling in the reservoirs of São Paulo State can be a good example of the impact of man on the ecosystem structure and function.

Acknowledgements

This work is part of the BIOTA/FAPESP – The Biodiversity Virtual Institute Program (www.biotasp.org.br). The authors express their gratitude to FAPESP for financial support (Processes: 1290-7/78; 98/5092-2).

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https://doi.org/10.26626/978-85-5953-031-5.2018C009

Integrated Management Plan for the Itaquri Lobo Watershed and UHE Carlos Botelho (Lobo/Broa) Reservoir

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Abstract

This paper refers to the management plan for the watershed and reservoir of the UHE Carlos Botelho, also known as Lobo/Broa. The management is based on the ILBM Platform Process, that is Integrated Lake Basin Management. It includes three main basin regulations and management: *basin water quality regulations; basin infrastructure development plans; basin water quality plans*.

The management plan is based on the scientific and technical developments at the watershed and reservoir since 1971.

Keywords: watershed, reservoir, limnology, management, water resources.

Introduction

Lobo/Broa reservoir is situated in the Itaqueri/Lobo watershed. The watershed and the reservoir have the following characteristics: Latitude: 22°15'S, Longitude: 47°49'W; Area of watershed: 230 km^2; Area of reservoir: 7 km^2; Mean depth of reservoir: 3.0 meters; Volume of reservoir: 22.000.000 m^3.

The watershed is located in a region of Savanna vegetation ("cerrado") cover and areas of reforestation with *Pinus* sp and *Eucalyptus* sp.

Climatological fluctuations shows higher precipitation during summer, very little precipitation during winter and an average of 1.500mm of rainfall during the year concentrated in the summer months (November to March/April) (TUNDISI, MATSUMURA-TUNDISI, RODRIGUES, 2003).

Wind speed is around 10m/s during the winter. Due to the shallowness of the reservoir, a permanent mixing occurs in the open water. Retention time is around 20 days. The reservoir is used for hydropower generation (2 MW/h); recreation; sport fisheries; tourism; aquatic sports.

The reservoir has an important economical input for the region receiving around 10.000 tourists in the weekends specially during the summer. Periotto, Tundisi (2013) identified 20 services of watershed and the reservoir that are useful to the human well being and to the biological communities of terrestrial and aquatic organisms.

Therefore a management plan for the watershed and reservoir is essential in order to secure permanently a good soil use, pollution control, adequate water quality that will enhance touristic activities with economic impact. The management plan was based on the IBLM Platform Process (NAKAMURA, RAST, 2011).

The management plan

Figure 1 shows the integrated management plan for the reservoir and the watershed. The main purpose of this paper is to inform and guide the process of watershed and reservoir governance and the implementation of programs, policies and actions in an integrated and systemic view with ample participation of the basin communities, stakeholders, with high accountability and responsibility. This management plan is, to a large extent based on the research, planning and monitoring activity carried on in the watershed and reservoir since 1971, and in discussion with all municipalities, involved, stakeholders, research workers and The Public Ministry of S. Paulo State dedicated to this area (GAEMA) (TUNDISI, MATSUMURA-TUNDISI, RODRIGUES 2003; TUNDISI, MATSUMURA-TUNDISI, 2013, TUNDISI, 2017).

Discussion and Conclusion

As reported by Nakamura and Rast (2011) ILBM Platform activities develops a series of activities and steps in the following flows:

- Describe the state of lake/reservoir basin management. Develop a lake/reservoir brief.
- Prepare a database and knowledge bases of data and information from monitoring, reconnaissance, survey, inventory.
- Analyze the existing information to ensure a systemic approach and a integrated overview of ecosystems (watershed and reservoir).
- Integrate ways and means for implement future actions.
- Coordinate stakeholder consultations.
- Evaluate improvements in governance issues.

Figure 1 – The integrated management plan for the Itaqueri/Lobo basin and the Lobo/Broa reservoir. (original from TUNDISI, 2017 based on NAKAMURA, RAST, 2011).

This integrated management plan is complex due to several plans and regulations. Watershed and reservoirs are complex ecosystems with many interactions, of climatological, hydrological, hidrogeochemical, biological and geomorphological process in a dynamic, spatial and temporal succession and fluctuations. All these complexities were studied at Lobo/Broa reservoir and Itaqueri/Lobo watershed. Therefore the next step is to promote a sound management plan structured in the basic knowledge developed after many years of research (TUNDISI, MATSUMURA-TUNDISI, 2013; TUNDISI, 2017).

Acknowledgements

The authors acknowledge the financial support of FAPESP-PELD project (2012/51502-3) for the research at the Lobo/Broa reservoir and Itaqueri/Lobo watershed. The support of CNPq for PELD is also acknowledge (Process: 441564/2016).

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https://doi.org/10.26626/978-85-5953-031-5.2018C010

Enhancing Methane Yields by Anaerobic Co-digestion of Sludge with Food Residues*

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*This publication has been produced as a result of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH implemented project “Decentralized Integrated Sludge Management”- DISM activities on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ).

Abstract

Disposal of biodegradable waste (food residues and sewage sludge) has become a stringent waste management and environmental issue. As a result, anaerobic digestion has become one of the best alternative technologies to treat the food wastes and sewage sludge which can be an important source of bioenergy. This study focuses on the evaluation of biogas and methane yields from the co-digestion of different sewage sludge and food wastes mixture ratios. The biogas potential tests using both types of substrates were performed in lab scale and under mesophilic conditions (35°C). It was observed that the optimal mixing ratio of food waste to sewage sludge was 1:2, corresponding to biogas production of 0.184 Nm^3/kg VS. The study examines

the possibility of increasing biogas production up to 75% using food waste substrate addition to sewage sludge inanaerobic co-digestion.

Keywords: anaerobic, co-digestion, food residues, sewage sludge, methane, mesophilic conditions.

Introduction

About 50’000 tons of dried solid sludge are generated annually in Jordan as a by product of wastewater treatment in the 31 wastewater treatment plants (WWTP) distributed all over Jordan and treating more than 152MCM per year (MWI, 2015). Around 60% of the total municipal wastewater produced in Jordan is treated in As-Samra WWTP in Zarqa governorate, the plant serves the biggest two cities, Amman and Zarqa, where 71% of the population are living. To accommodate for the increasing demand, As-Samra WWTP is currently undergoing expansion to reach a daily capacity of 367,000 m^3. As-Samra WWTP utilizes anaerobic digesters to stabilize sludge, which is then dewatered using belt filter press system. While As-Samra’s sludge is utilized as energy sources, only one of the other 30 wastewater treatment facilities has proper utilization of sludge for energy production, which is in Al Shalalah WWTP in the north of Jordan. Thus the quantities of generated sludge in other treatment plants still create a serious environmental problem.

Nowadays, sludge management is an integral part of any modern municipal wastewater treatment plant in order to dispose sludge in a proper environmental way and also economically not to lose sludge valuable nutrients and to make efficient use of material and energy. Similarly, Jordan suffers from a solid waste crisis, which is looming in Jordan with more than 2 million tons of municipal waste and 18,000 tons of industrial wastes are being generated annually. Alarmingly, less than 5 % of total solid waste is currently recycled in Jordan.

Because of the growing demand on energy and limitation of resource in Jordan, wastewater sludge and solid wastes can be considered as alternative sources for energy production. Nowadays the possibilities for biogas production as an alternative energy source are becoming more important (MOUSDALE, 2008), and from a practical viewpoint determining the capabilities of different organic materials to produce biogas are vital. Anaerobic digestion (AD) and Co-digestion are promising environmental sustainable biotechnologies that can treat the organic fraction of the municipal solid waste and wastewater sludge to produce biogas as a source of energy. Using such biotechnologies would necessarily help in solving the problem of the huge accumulated sewage sludge and food wastes and reduce the greenhouse gases emissions from them. Digestion process will result in enhancing physical and chemical characteristics of sludge and make it more suitable for land applications.

The process of anaerobic digestion consists of three steps: Solubilization, Acidogenesis, and Methanogenesis (KIM, 2003). In the first hydrolysis step, the complex organic polymers (proteins, carbohydrates, and fats) are degraded into simple sugars, amino acids and fatty acids by the heterogeneous microorganism. As the second step, acidogenic bacteria produce fermentation intermediates, mainly volatile fatty acids (VFAs), and lastly, in the methane step, methane and carbon dioxide with a small amount of hydrogen (H_2) and traces of hydrogen sulphide (H_2S) and ammonia (NH_3) are produced from these intermediates by methanogenic bacterial metabolism (ABATZOGLOU, 2009). In each step, the gas production and decomposition rates of organic waste are influenced by environmental factors such as temperature, pH and hydraulic retention time (HRT) and substrate concentration (CRISTANCHO, 2006; GÜNGÖR-DEMIRCI, 2004; MATA-ALVAREZ, 2002).

Anaerobic digestion is conducted using simple reactor technologies such as Single Batch reactor, continuous stirred tank reactor (CSTR) and Plug flow reactor (PFR), (RITTMANN, 2012) ,The degradation process is complex and depends on a balanced action of several microbial groups (GUJER, 1983) in the absence of oxygen and renewable energy biogas is generated (CHEN, 2008).

Biogas from the anaerobic degradation of wastewater can be used in micro-turbines or internal combustion engines for generating electricity (CRAWFORD, 2010). The US EPA estimates that over 80% of municipalities that utilize anaerobic digestion flare excess biogas (EPA, 2007). Typical digester gas energy recovery systems can recover 20-40 % of the energy requirement for wastewater treatment plants that use the activated sludge process (CRAWFORD, 2010).

A substance or compound is biodegradable if it can be source of energy for the metabolism and for the growth of the biomass which performs its degradation; on the contrary, a substance is indicated as poorly or non-biodegradable, if structural (molecular) or external causes (concentration levels, availability of nutrients, etc.) hinder their degradation and thus remains partially or totally undegraded in the environment. It may happen that some intermediates are more recalcitrant or even toxic. The degradation process is complex and depends on a balanced action of several microbial groups (GUJER, 1983) in the absence of oxygen and renewable energy biogas is generated (CHEN, 2008).

Some factors may influence the activity of microorganisms, thus the biodegradation process. From a biochemical point of view, temperature and pH influence the reaction rate of an enzymatic process, in the sense that each enzyme is characterized by an optimal range of temperature and pH. Generally, when the temperature increases, the reactions are accelerated and the growth rate is higher; but if the temperature becomes too high, a process of irreversible denaturation of the cellular components may occur whereas if the temperature becomes too low, both the bacterial growth and substrate utilization eventually cease.

On behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ), GIZ is supporting the Water Authority of Jordan in its efforts to find suitable solutions for the treatment and reuse of sewage sludge. The project aims to reduce the carbon footprint of the sludge handling process. To this end, it considers the use of sludge primarily as a source of energy, but also as a soil conditioner and a fertilizer. The project also seeks to demonstrate an integrated approach to the treatment and reuse of sludge in combination with other biomass sources (co-digestion). After the energy potential of the sludge has been tapped, any residual sludge undergoes further processing, together with other sources of biomass, to produce a treated organic mix that can be used to improve soil quality. The integrated approach ensures the involvement of all significant stakeholders, from the relevant ministries and municipalities, to the water utilities and farmers. The project also includes close scientific cooperation with Mu'ta University in Karak by building and operating anaerobic co-digestion experiments using a (100 L) STR system and using the same biomass, the University is located close (2.5 km) to the Mu'ta-Mazar demonstration plant in the Governorate of Karak.

Objective

The objective of the current study was to find the maximum mixing ratio of food waste and sludge, and methane production using Laboratory Equipment Modular compact basis plant BTP-2 which is the standard system for substrate testing and gas yield tests.

Material & Methods

The biogas yield experiment in Mu'ta Almazar WWTP was performed to simulate the real digester. For this purpose,the (Modular compact basis plant BTP-2) device is ideal as shown in Figure 2. The device has one testing unit with reactor volume capacity up to 17 L of degradable material (liquid or pulps). The units can be thermostatically managed from 0 to 60°C, with temperatures of 35-55°C are ideal for the anaerobic tests. The device is equipped with a mixer, stirring the solution at programmed mixing intervals. With continuous monitoring of pH-values, temperature and biogas production. Data collection using data logger technology.

The producing of biogas is analyzed with **OPTIMA 7** biogas analyzer as shown in Figure 3 simultaneous measurements of up to 7 gas components. The biogas measurements include O_2, H_2S, CH_4 and CO_2 (infrared for CO_2/CH_4).

Figure 1 – Biogas Test Plant BTP2.

Figure 2 – OPTIMA Biogas Analyzer.

Seeding Sludge (Inocula)

Seeding sludge (Inocula) was taken from Mu'ta university biogas reactor. Once collected, the seeding sludge was added to biogas BTP-2. Analyses of its volatile and total solids content (VS, TS) were performed at the lab of the WWTP.

Substrate

Sludge and a mixture of food residues and sludge were used as substrate in this study. Food residues were taken from Mu'ta University military wing restaurant, after grinding by an electric blender, the material was stored in a refrigerator at 4°C. The sludge was taken from Mu'ta Almazar WWTP,the physicochemical parameters (pH, TS, VS, T-N)were determined according to standard methods (Standard methods for the examination 2010) in the Royal Scientific Society (RSS) and Eurofins Umwelt Ost GmbH Hauptniederlassung Jena, berlin – Germany. The physicochemical characteristics of substrate are presented in Table 1.

Table 1 – Physicochemical Characteristics of substrate used in this study.

Parameters	Sludge	Foodwaste
pH	6.75	4.6
Total Solid %	0.61	32.1
Volatile Solid %	59.2	29.8
Electrical Conductivity µs/cm	2400	
Total Nitrogen %	34.1	2.8
NH_4-N %	22.4	0.003
NO_3-N mg/Kg	281	<10

Productivity, yield, and degree of degradation

Productivity ($P_{(CH4)}$), yield ($A_{(CH4)}$) and degree of degradation (η_{VS}) are appropriate parameters for describing the performance of a biogas experiment. If gas production is given in relation to digester volume, this is referred to as the productivity. This is defined as the quotient of daily gas production and reactor volume and is consequently an indication of the efficiency. Productivity can be related to both biogas production ($P_{(biogas)}$) and methane production $P_{(CH4)}$ and is given in $Nm^3/(m^3 \cdot d)$.

$$P_{(CH_4)} = \frac{V_{(CH_4)}}{V_R}\left[Nm^3 m^{-3} d^{-1}\right] \qquad \text{Eq. (1)}$$

Where:

Methane productivity

$V_{(CH_4)}$: methane production [Nm³/d];

V_R: reactor volume [m³].

Gas production expressed in relation to the input materials is the yield (Lebuhn 2014). The yield can likewise be related to biogas production ($A_{(biogas)}$) or methane production ($A_{(CH4)}$). This is defined as the quotient of the volume of gas produced and the amount of organic matter added and is given in Nm³/t VS.

$$A_{CH_4} = \frac{V_{CH_4}}{m_{VS}} \quad \left[Nm^3 t^{-1} VS\right] \qquad \text{Eq. (2)}$$

Where:

Methane yield

V_{CH_4}: methane production [Nm³/d];

m_{VS}: added volatile solids [t/d]).

The yields denote the efficiency of biogas production or methane production from the loaded substrates. They are of little informative value as individual parameters, however, because they do not include the effective loading of the digester. For this reason, the yields should always be looked at in connection with the organic loading rate. The degree of degradation (η_{VS}) provides information about the efficiency with which the substrates are converted. The degree of degradation can be determined on the basis of volatile solids (VS) or chemical oxygen demand (COD). Given the analytical methods most commonly used in practice, it is advisable to determine the degree of degradation of the volatile solids (LEBUHN, 2014).

$$\eta_{VS} = \frac{VS_{sub} \times m_{FM} - (VS_{vsc} \times m_{vsc})}{VS_{sub} \times m_{FM}} \times 100\% \qquad \text{Eq. (3)}$$

Where:

Degree of degradation (η_{VS}) of biomass,

VS_{Sub}: volatile solids of added fresh mass [kg/t fm];

m_{FM}: mass of added fresh mass [t];

VS_{vsc}: volatile solid content of digester discharge [kg/t FM];

m_{vsc}: mass of digestate [t])

Experimental Design

The experiment was conducted using 17L reactor of modular compact basis plant BTP-2 as shown in Figure 1. The various mixtures of food residual and sewage sludge were added to each batch experiment. Their initial concentrations were all set, as shown in table 3. Each experiment contained organic waste co-digested with different ratio of sludge, food residual and Inocula. The experiment was started with Inocula 100%, other treatments were made by mixing food residual/sludge by a ratio of (30%, 50%) food residue addition as volatile solid (VS), and the final experiment have been 100% sludge. Everythirty minutes temperature, gas flow rate, total gas volume and pH value and stirringat 100 rpm are carried out by the device, while maintaining temperature at 35 ± 5°C.

Table 2 – Batch experiment operating conditions.

Temperature	Batch Experiment No.	Preparation of Substrate			
		Sewage Sludge (% of VS)	Sewage Sludge (g VS add)	Food waste (% of VS)	Food waste (g VS add)
Mesophilic (35°C)	1	100	29.4	0	0
	2	75	29.4	25	10.6
	3	65	29.4	35	15.6

Result and Discussion

Effect of food waste addition on co-digestion performance based on mixing ratio food waste with sludge used in BMP, three batch experiments were operated at 35ºC with different mixtures of foodwaste and sewage sludge using mesophilic seed sludge. As shown in Figure 3, accelerated hydrolysis was observed by the addition of the proper amount of food waste within the same temperature conditions. Mesophilic digestion showed a higher conversion rate in hydrolysis as well as acidogenesis. In mesophilic conditions, the major portion of biogas was sharply increased within the first six days by fast acidogenesis and methanogenesis. In anaerobic digestion of organic materials including large molecules or sterically incompatible molecules or crystalline molecules, which cannot be easily transported into the bacterial cells, a further step of hydrolysis by exoenzymes should be considered (Borghi 1999).

Figure 4 shows that as the mixing ratios of food waste increased up to 35%, cumulative biogas production also increased. Similar observation was reported by (HEO, 2004) for the digestion of separately collected (SC) food residuesand sewage sludge. Therefore, it indicated that the application of co-substrate significantly improved feed characteristics, resulting in higher biogas and methane potential.

Higher ultimate methane yield of food waste can be found in Table 3, which shows reported data from various OFMSW. Also, it was confirmed that co-substrate, food waste, gave higher methane yields thanpreviously reported BMP values (Table 3).

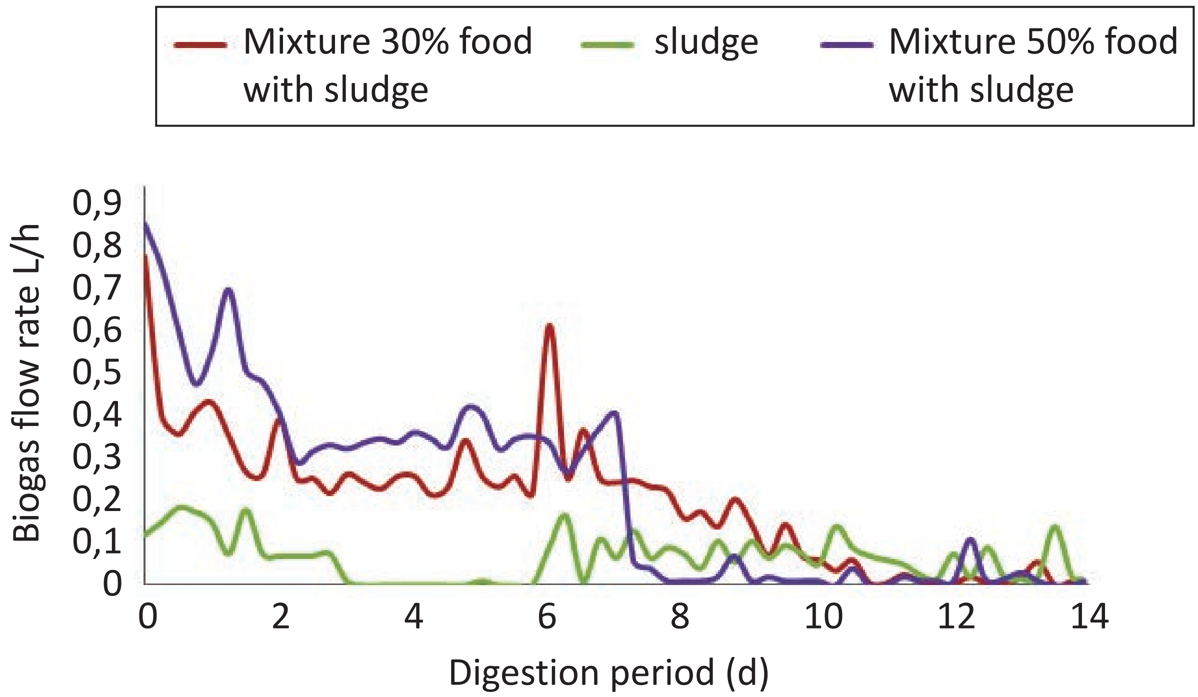

Figure 3 – Daily Biogas Production.

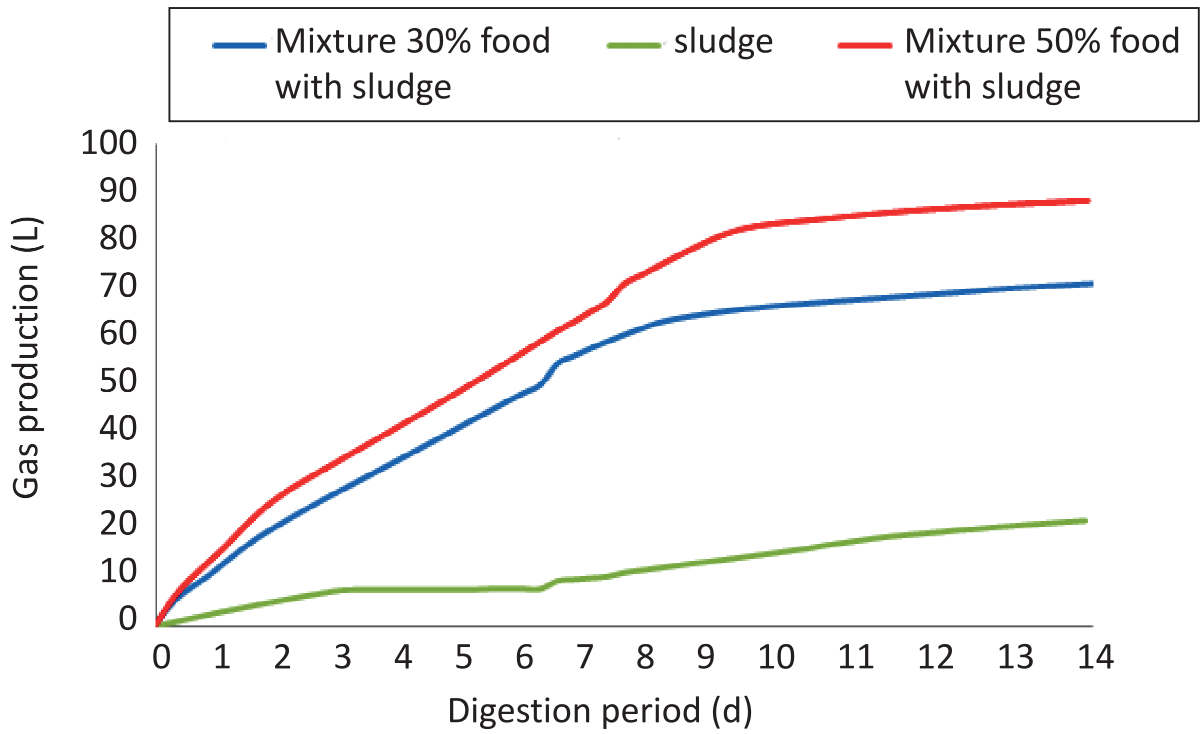

Figure 4 – Cumulative Biogas Production.

Table 3 – Comparisons of biogas production from co-digestion of various food waste and sewage sludge in mesophilic conditions.

Reference	Food Residues	SPG (l/g VS)	Methane CH_4 %
This study	SS only	0.09	n.r
Food waste Source	26.5 % Food waste, 73.5 % SS	0.112	48
(University Canteen)	34 % Food waste, 66 % SS	0.184	55
(CABBAI et al., 2013)	100 % WAS	0.39	64
Food waste Source	58.5 % Food waste, 41.5 % WAS	0.62	n.r
(Canteen, Supermarket, Household)	25 % Food waste, 75 % WAS	0.45	53.8
(CAVINATO et al., 2013) Food waste Source (Canteen, Supermarket, Household)	100 % WAS	0.15	61.8
	50 % Food waste, 50 % WAS	0.34	60
(NIELFA; CANO; FDZ–POLANCO, 2015) Synthetic OFMSW	100% biological sludge	0.27	60
(ZUPANˇCIˇCA; URANJEK-ŽEVARTB; ROŠA, 2008) Domestic refuse (swill)	80% Food waste, 20% biological sludge	0.22	n.r

SS : sewage sludge ; **WAS** : Waste of Activated Sludge, OFMSW: Organic fraction municipal solid waste

The Biogas yields of all experiments are shown in Table 3. Within the mesophilic digestion conditionthe biogas yield increased by 19% with the addition of 26.5 % food residues to the total VS. (Cabbai, et al. 2013)reported that within food residues addition by 25% biogas yield increased by 13%, intrinsically. These trends of biogas yields could be explained by higher degrading capability and methanogenic activity as shown in Figure 3. (KIM, 2003) has reported that the important factors for the enhanced performance of co-digestion are the additional organic carbon, nutrient balance and adequate mixing ratio. Additional carbon source supplied by food residues create preferable environment for the growth and activity of anaerobic microorganism.

Conclusion

The experiment has shown that the codigestion of sewage sludge mixed with food waste had a distinct positive effect on biogas and methane yields by keeping the adequate fraction of food waste. As expected using food waste substrates positively affects biogas and methane production, with a significant increases biogas yield in the range of 20% to 30%, and an increase in the range of 50 to 60% in removable VS by increase the food waste substrate in the range of 26% to 35%. Biogas cumulative production during co-digestion of food waste with sludge increases notably when increasing the food waste to sewage sludge ratio.

Acknowledgements

The authorswould like to thank GIZ Water Portfolio for allowing using DISM project findings for this publication. Thanks to DISM project colleaguesfor their technical support andto Mu'ta Almazar WWTP staff and University of Muta for their cooperation.

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https://doi.org/10.26626/978-85-5953-031-5.2018C011

Improving Global Wash Sustainability

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Abstract

This paper provides a review of the health and economic effects of water, health, and sanitation (WASH) infrastructure. Global strategies to increase WASH infrastructure and the current coverage levels are discussed revealing mixed progress and disparities particularly in rural areas. Many rural WASH infrastructure interventions have failed or operate significantly below intended capacity demonstrating the need for a greater focus on sustainability. This paper defines sustainability in the context of WASH infrastructure and describes the tools used to assess sustainability of water projects. Finally, this paper concludes with specific recommendations for governments, non-governmental organizations, and donors to improve the sustainability of water projects and ultimately the development of communities.

Keywords: sustainable development goals, water, sanitation, hygiene, global health, development.

Introduction

Depending on one's point of view and situation, water, sanitation, and hygiene (WASH) services contain the ability to sustain healthy life and positive development (NAUGES; STRAND, 2013; WHO, 2012) or, on the other hand, developmental determent and cause of one's suffering and untimely death (FERDOUS *et al.*, 2013; GUERRANT; DEBOER; MOORE; SCHARF; LIMA, 2013; HASANAIN; JAMSIAH; ZALEHA; AZMI; MOHAMMED, 2012; PRÜSS-USTÜN *et al.*, 2014). Sustainable WASH services is crucial to ensure its effectiveness and long-term benefits (BOULENOUAR; SCHWEITZER;

LOCKWOOD, 2013; KWANGWARE; MAYO; HOKO, 2014; MCCONVILLE; MIHELCIC, 2007; RONDI; SORLINI; COLLIVIGNARELLI, 2015; SCHWEITZER; MIHELCIC, 2012).

Health and Economic Consequences

The lack of adequate WASH services poses the paramount threat to the health and development of the global community. Improper WASH causes a variety of diseases including diarrheal diseases, dracunculiasis, and lymphatic filariasis through the ingestion of pathogenic organisms in drinking water and unsanitary soil with pathogens such as *Entamoeba histolytica, Giardia duodenalis*, and *Ascaris lumbricoides*(GEERS CHILDERS; PALMIERI; SAMPSON; BRUNET, 2014). In terms of effect on health, inadequate WASH was estimated to be the cause of 842,000 diarrhea deaths globally representing 58% of diarrheal diseases in 2012 (PRÜSS-USTÜN *et al.,* 2014), which is approximately 2,300 deaths per day. An estimated 361,000 deaths among children under five years of age, representing 5.5% of deaths in that age group, could have been prevented with proper WASH. Persistent diarrhea among children is associated with malnutrition, cognitive impairment (FERDOUS *et al.,* 2013; HASANAIN *et al.,* 2012), and an increased risk of developing obesity later in life (GUERRANT *et al.,* 2013). Proper WASH is crucial to a healthy life and development.

Concerning effect on development, the water crisis ranks number one in terms of global societal impact and number eight in terms of likelihood to occur within the next ten years (WEF, 2015). Lack of a clean drinking water source poses such a great economic threat due to the resulting mortality, morbidity, and disability by rendering a person unable to work and due to the enormous quantity of time demanded to haul water. Women and children bear the majority of the water hauling responsibilities with the largest group spending more than 30 minutes on a single trip totaling an estimated 140 million hours every day hauling water (UNICEF; WHO, 2015). This daily time demand causes obvious conflict with development by reducing time invested in an income-generating job, caring for family members, or attending school. However, through improved water sources and, thus, reduced hauling times, children's school attendance has significantly increased in multiple developing countries (NAUGES; STRAND, 2013). Investing in WASH infrastructure also has a high rate of return with an estimated US$ 4 economic return on every US$ 1 spent by keeping people healthy and productive (WHO, 2012). Investing in adequate WASH infrastructure would greatly reduce this burden of disease and provide enormous economic benefits.

Global Framework for Solutions

Clean water and sanitation is a building block to global public health and development as evidenced by its inclusion in the Millennium Development Goals (MDGs) and now the Sustainable Development Goals (SDGs). On September 25, 2015, the member states of the United Nations celebrated the beginning of a new era of cooperation in development with the adoption of the SDGs for 2030 (UNITED NATIONS, 2015). The SDGs are the post-2015 goals that follow the MDGs, which was the framework of development between 2000 to 2015 (UNITED NATIONS, 2000). The MDGs contained eight broad goals of which MDG 7c was to halve the proportion of people without sustainable access to safe drinking water and basic sanitation between 1990 and 2015. Well ahead of the 2015 deadline, the goal for improved drinking water was announced as being met and surpassed in 2010 (UNICEF; WHO, 2012). However, this announcement was criticized as being overly optimistic when the microbial water quality was considered revealing improved water supplies with unsafe levels of coliforms in several countries raising serious concerns about the safety of the improved water sources (BAUM; KAYSER; STAUBER; SOBSEY, 2014; SHAHEED; ORGILL; MONTGOMERY; JEULAND; BROWN, 2014). This suggests new efforts are needed to ensure both quantity and quality of improved water sources.

When the final MDGs assessment report was published in 2015, it boasted numerous significant improvements but also revealed areas of needed improvement (UNICEF; WHO, 2015). Concerning drinking water, key positive highlights were that 91% of the global population was measured as using an improved water source and 2.6 billion people gained access to an improved water source since 1990. On the other hand, an unachieved goal was that the Caucasus and Central Asia, Northern Africa, Oceania, and Sub-Saharan Africa regions did not achieve their regional coverage goals. Specific disparities were noticed as 96% of the global urban population uses improved drinking water sources compared to only 84% of the global rural population. Stated another way, 8 out of 10 people without an improved drinking water source live in rural areas. As of the report's publishing, 663 million people still lack an improved drinking water source. Despite the global increase of improved rural water systems, evidence shows that 30-40% of these systems fail or operate significantly below intended capacity demonstrating the need for a greater focus on sustainability (LOCKWOOD; SMITS; SCHOUTEN; MORIARTY, 2010).

Concerning sanitation, the target of 77% improved sanitation coverage was missed by almost 700 million people (UNICEF; WHO, 2015). Geographic disparities also exist in improved sanitation coverage as 82% of urban population was reported to have access to an improved sanitation facility compared to only 51% of rural population. Of those who lack access to an improved sanitation facility, 7 out of 10 live in rural areas, and 9 out of 10 people who practice open defecation live in rural areas. Although this target was not achieved, a highlight is that 2.1 billion people gained access to improved sanitation since 1990. However, 2.4 billion people still lack access to an improved sanitation facility. Based on this report, the SDGs were created to continue this progress.

There are 17 SDGs set to be achieved by 2030. SDG six is “Clean Water and Sanitation.” Addressing drinking water and sanitation, target 6.1 is to “achieve universal and equitable access to safe and affordable drinking water for all” and target 6.2 is to “achieve access to adequate and equitable sanitation and hygiene for all and end open defecation…” (UNITED NATIONS, 2015). There are several other targets under this goal but these targets are relevant for the scope of this paper.

Interventions: Focus on Sustainability

The goal in providing WASH services is to ensure the entire array of benefits while minimizing its costs over time. Sustainable development has been defined as “development that meets the needs of current generations without compromising the ability of future generations to meet their own needs” (WCED, 1987, p. 43). Thus, sustainable WASH infrastructure is the continued delivery of clean drinking water and sanitation without resource depletion. How to best ensure sustainability is highly debated but one recurring theme is demand-driven approach (DAYAL; VAN WIJK; MUKHERJEE, 2000; KWANGWARE *et al.*, 2014; MADRIGAL; ALPÍZAR; SCHLÜTER, 2011; MONTGOMERY; BARTRAM; ELIMELECH, 2009).

Demand-driven approach

Demand-driven approach is the principle that local communities are active in the decisions that affect their communities and the consideration that different user groups may desire different interventions (DAYAL *et al.*, 2000; MADRIGAL *et al.*, 2011). Evidence has revealed that community participation in the design, financing, and administration significantly increases project sustainability (BARNES; ASHBOLT; ROSER; BROWN, 2014; MADRIGAL *et al.*, 2011; MARKS; KOMIVES; DAVIS, 2014). Depth, not breadth, of resident’s involvement in the planning process is associated with water point sustainability. Project outcomes are better when the community participates more in management decisions and less favorably with technical decisions (MARKS *et al.*, 2014).The opposite of demand-driven approach is the supply-driven approach in which communities are not included in the decision-making process but are simply observers. Supply-driven approach, a paternalistic behavior, perpetuates cyclical poverty and ineffective interventions (CORBETT; FIKKERT, 2014). To improve sustainability outcomes, sustainability frameworks and assessment tools have been developed to guide and measure sustainable development.

Sustainability assessment tools

Dozens of sustainability assessment tools have been made to improve the sustainability of development projects addressingall stages of the planning and life cycle utilizing various sustainability models. The sustainability assessment tools contain a litany of questions based on its specific model of sustainability framework rating the likelihood of success and sustainability. Schweitzer, Grayson, and Lockwood (2014) performed a review of 191 sustainability assessment tools evaluating the context of their use and their strengths and weaknesses. Their review should be used as a resource in choosing the proper tool for the anticipated project. Besides these sustainability assessment tools, other specific recommendations exist for various groups that provide WASH infrastructure.

Recommendations for governments

According to Boulenouar and Schweitzer(2015), governments should develop an infrastructure asset management (IAM) strategy particularly for rural water supply where parastatal corporations and community management organizations manage the majority of WASH infrastructure. IAM in the WASH sector refers to the physical components of water systems as well as the decisions and processes to assure services. The government should also provide template contracts between service authorities and service providers and ensure the financing of WASH infrastructure. Lastly, government should provide the technical support and training to both service authorities and service providers. Evidence suggests that access to post-construction support services greatly affects sustainability outcomes (FERDOUS *et al.*, 2013; MARKS *et al.*, 2014). Although government financing is suggested, strong government subsidies have many drawbacks and may not appropriate for every project (GOMES; HELLER; CAIRNCROSS; DOMENÈCH; PENA, 2014). A more effective financing method to the financial recovery and functionality of installed water systems is the collection of a user fee (FOSTER, 2013; MONTGOMERY *et al.*, 2009).

Recommendations for non-governmental organizations and donors

Boulenouar and Schweitzer (2015) suggest that non-governmental organizations (NGOs) can improve the sustainability of WASH infrastructure by supporting local governments to inventory the water assets in their jurisdiction and to implement the national IAM guidelines. Donors should also support the government by providing technical and financial support, ensuring all the water assets are registered, and sharing pertinent information. Many studies have demonstrated that the use of financial tools are beneficial to project sustainability (BOULENOUAR *et al.*, 2013; JONES, 2013; KWANGWARE *et al.*, 2014; MADRIGAL *et al.*, 2011; RONDI *et al.*, 2015; SCHWEITZER; MIHELCIC, 2012). These three levels of organizations working together can provide greater accountability and local support, which increases project sustainability (JONES, 2013; SMITS; ROJAS; TAMAYO, 2013; WINTERS, 2010).

Conclusion

In order to achieve SGD six and to reduce the rates of death and disease as well as its associated economic consequences, WASH services and infrastructure must be built especially in the areas where it is lacked most and disease is most prevalent, namely rural areas. Simply providing WASH infrastructure (i.e. supply-driven demand) to communities in need has resulted in inoperable systems and the perpetuation of poverty foiling development efforts(Lockwood *et al.*, 2010). Therefore, through the recommendations of demand-driven approach and usage of sustainability assessment tools, new WASH infrastructure can provide lasting health benefits and support the economic development of the recipient communities in both rural and urban areas.

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System of Sustainability Indicators Applied in River Basin Management

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Abstract

The historical context of the indicators clearly shows their complementary role in the decision-making processes, seeking to make perceptible a current condition resulting from a historical process of past practices and actions, reflecting the reflexes of previous planning. This tool can be used for river basin planning and management, including monitoring, assessment and reporting. The general aim of this research is to suggest a model of sustainability indicators for the PCJ basin committees management, as an auxiliary tool for assessing the region's sustainability level. The research to be developed has quantitative and qualitative characteristics, characterized as a mixed method. The Preliminary findings of this research point to the need for institutional innovations and their formalization and emancipation before public management, with the creation and performance of participatory procedures prescribed in specific laws, such as in the area of water resources, where the participation of multi-stakeholders through the Watershed Committees represents a significant breakthrough for good governance. It is necessary to consolidate the articulation between institutions at the municipal level so that the dimensions of sustainability are treated in a fair and proactive way, so that progress towards regional sustainable development is possible.

Keywords: sustainability indicators, river basin management, PCJ basin committees.

Introduction

Sustainability supports a universally shared common vision of progress towards a just, secure and sustainable society for humanity. This concept recognizes not only the need for environmental protection but also the urgency to improve the quality of life through strategies that create socio-economic growth and address a wide range of cross-cutting issues. While there is a growing consensus that a more sustainable society embraces all individuals, opinions about what sustainability means and how that can be achieved are diverse (ALSHUWAIKHAT *et al.*, 2017).

In the monitoring of regional environmental and sustainability issues one of the main goals is to support decision-making processes, thus improving regional sustainability management and achieving better development results. In the face of heterogeneity of methods and tools for measuring sustainability, indicators almost always play a fundamental role. Sustainable Indicators are one possible way of ensuring that sustainability issues are being consistently and transparently integrated into sector activities on a local, regional and national scale. Indicators provide substantial sustainability performance measurement, reporting and transparency to stakeholders (RAMOS, 2009). According to Santos (2004), regardless of the objectives or the planned site, this strategy requires the specialization of a broad set of data that needed to be compared, overlapped and evaluated in a holistic way.

The historical context of the indicators clearly shows their complementary role in the decision-making processes, seeking to make perceptible a current condition resulting from a historical process of past practices and actions, reflecting the reflexes of previous planning. When an indicator is analyzed, its current portrait is viewed from the historical perspective, sustaining the ability to project future trends and conditions to develop ways to monitor and measure its temporal behavior (BATALHÃO; TEIXEIRA, 2017).

Sustainability indicators are essential tools to ensure the identification of a comprehensive strategies and realistic way of assessing and improving sustainability. This tool can be used for river basin planning and management, including monitoring, assessment and reporting. Also, indicators are important assessment tools to identify social needs and contribute to public planning and management. However, the proper use of indicators in the public management is still a methodological and political challenge with rather vague guidelines in many scales. Few studies explored the different potential uses and impacts of indicators as complementary tool to decision-making in water management and planning processes (WU; LEONG, 2016).

The development of strategies related to the monitoring of sustainable development requires data and information of various natures. Indicators fulfill this role, with quantitative and qualitative attributions, as they quantify and simplify complex phenomena and realities to a manageable amount of significant information to foment the decision-making process (HARMANCIOGLU; BARBAROS; CETINKAYA, 2013).

At regional scale, planning for the proposal of sustainable development is more comprehensive and robust, by the size of the territory and by the number of key actors, which facilitates the identification of problems, community demands and local knowledge, with greater possibilities for participation. Mickwitz *et al*. (2006) emphasizes that on a regional scale any attempt at methodological generalization can be questioned because the problems are different and need customized tools.

Meet the sustainability development demands are critical to a renewal and maintenance of practices that enable an effective and secure flow of information to strengthen the most important decision-making processes. From the management of water and the environment we can perceive multiple relationships and interactions and their regional interests. Therefore, it is necessary to promote assessments and work with findings to project trends. This is justified by the increasing demand for evaluation systems using indicators that capture the subjectivities of the research object and make them objective.

In this perspective, this study can also assist river basin committees and public management, serving as a reference for the development and maintenance of public policies aimed at basin sustainability, considering the use of water, its economic importance, environmental degradation, and the level of productivity, among its multiple dimensions. This contributes to broadening the vision of all the actors involved in the management of the basins and the municipalities that constitute these spaces, generating new discussions about the factors that may enable a way to promote development, not forgetting the social and environmental demands, leaving behind the concept that development is only chained to economic growth. Scientifically, its relevance is in the development and reproducibility of the methodology, considering possible adaptations to the regions of analysis, and can serve as a starting point for future work.

For this, the research´s main issue should answer the question:

- Is it possible to find ways to evaluate the sustainability level of Piracicaba, Capivari and Jundiaí (PCJ) basin region in Brazil using the Basin Plan as a reference and involving key stakeholders (decision makers, basin committees, organized civil society, municipal/state/federal agencies, consultancies and other users) based on a set of indicators which considers the characteristics of sustainability and meets the wishes and demands of the stakeholders, to improve the management of the subjects related to sustainable development?

In addition, confirm or falsify a main hypothesis which is:

- It is possible to develop a model (structure) of indicators based on the participation of the key stakeholders, which can serve as an evaluation tool for the elaboration of a situational picture of the object, and also as a complementary tool for the management of sustainable development within the framework of PCJ basin.

The general aim of this research is to suggest a model of sustainability indicators for the PCJ basin committees the management, as an auxiliary tool for assessing the region's sustainability level. In order to achieve the major goal, the research plan will be developed in five tasks that are shortly described:

To provide an overview of the challenges and demands present in the literature and associate them with the main stages of elaboration and implementation of sustainability indicators.

- To analyze the main models of systems of indicators applied in river basins region based on initiatives of indicators in the world;
- To evaluate practices and environmental and sustainability management) related to municipal water resources based on self-assessment;
- To identify and involve the decision makers of the basin committees and other stakeholders in order to ensure their participation in the process of selection and development of the set of indicators based on Agenda 2030 (building the archetype);
- To apply the new methodological proposal of indicators systems developed in the previous stage, in order to evaluate the level of sustainability of the region and to visualize future scenarios.

Methods

Study area

The study area of this research is delimited by the region of PCJ river basins, and has an approximate area of 15,320 km^2. Approximately 92% of this area about 14,040 km^2 are in the State of São Paulo and the remaining 1,280 km^2 belong to the State of Minas Gerais, Brazil, where the headwaters of the Jaguari, Camanducaia and Atibaia rivers are located. This area is located between the meridians 46º and 49º west and the latitudes 22º and 23.5º south, presenting an approximate extension of 300 km, in the east-west direction, and of 100 km, in the north-south direction (AGENCIA DAS BACIAS PCJ, 2016).

The region of PCJ river basins covers areas of 76 municipalities, and 62 are headquartered in the region's drainage areas. Of these, 58 are in the State of São Paulo and four in Minas Gerais. With approximately five million inhabitants, this region is considered one of the most important in Brazil due to its economic development, which represents about 7% of the National Gross Domestic Product (GDP). The municipalities of the State of São Paulo with headquarters in the region belong to Campinas, which also includes municipalities located in the Alto Mogi-Guaçu basin. In the PCJ basins there are five Government regions of São Paulo´s State: Campinas region, Jundiaí region, Piracicaba region, Limeira region and Bragança Paulista region, which are intermediate levels of political-administrative management between the Administrative Region and municipalities. (PCJ, 2016).

The main justification for choosing the hydrographic basins of the Piracicaba, Capivari and Jundiaí rivers for research is the emerging need to communicate (information system) the society and the main stakeholders about the levels of development and sustainability of these basins, which has great economic and strategic importance for the State of São Paulo, Brazil, in order to evaluate the environmental, economic, social and institutional spheres seeking the understanding of the sustainable society- environment relationship.

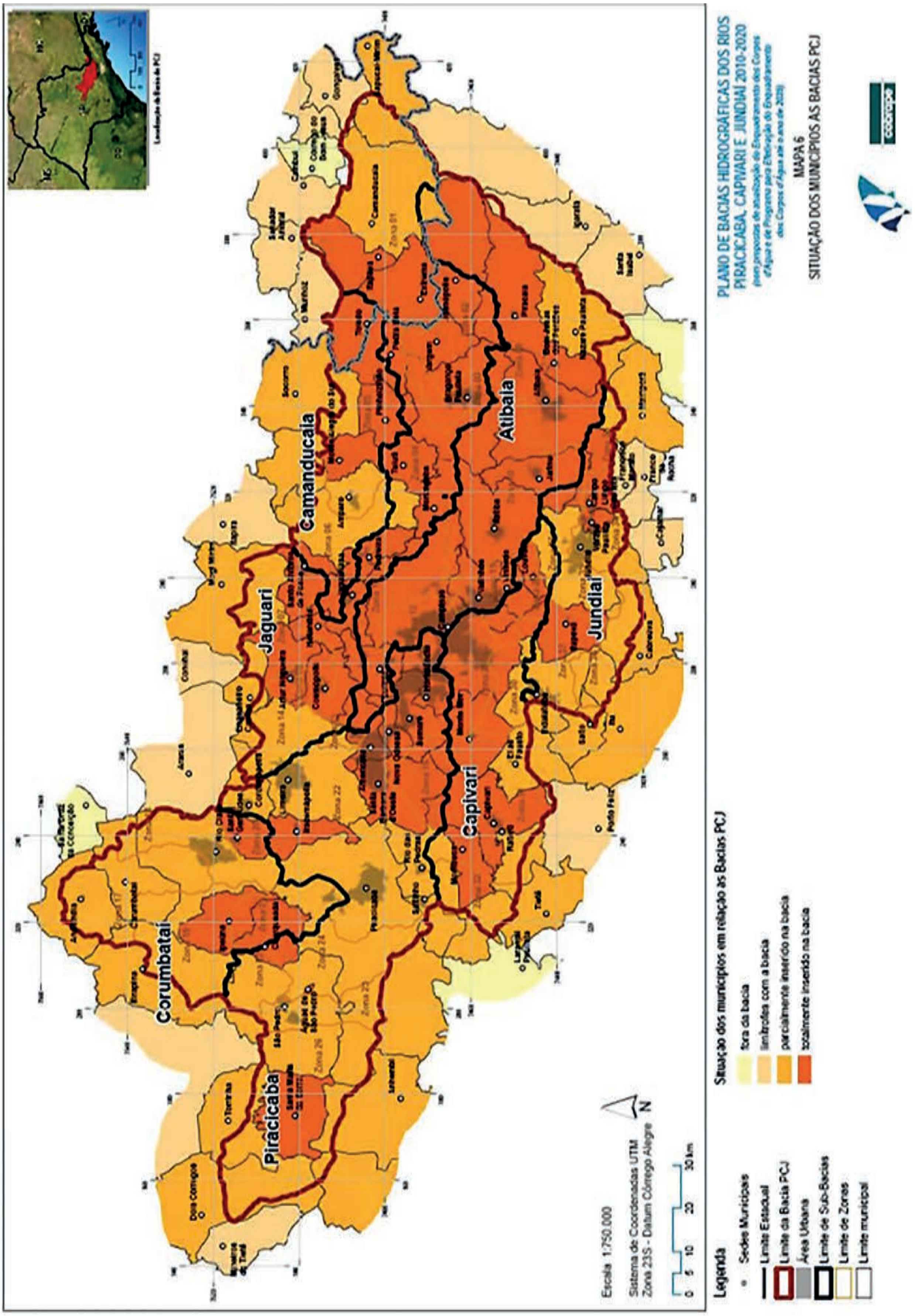

Figure 1 – Spatial location of the object of study. Source: Agência das Bacias PCJ, 2016.

Methodological resources

The research to be developed has quantitative and qualitative characteristics, characterized as a mixed method. The quantitative part will be based on a structured procedure for the collection of secondary data, sought in reference sources already used in the Basin Plan, and other sources that are in line with the research objectives. Already, in the qualitative part will be used the semi-structured questionnaire instruments and individual and collective interviews, personally and electronically, with the participants chosen for the research, representing a focus group. In this case, the scope of potentially relevant information provided by the interviewee is restricted, where the interview guide has a directive function. Mixed methods allow better exploration and explanation of data and information, and are an opportunity to develop new methodological skills for research.

The triangulation method will be used to combine the results of quantitative and qualitative methods. In this case, the different methodological perspectives are complemented for the analysis of a theme, this process being understood as the complementary compensation of the deficiencies and the obscure points of each isolated method. The basis of this view is that "qualitative and quantitative methods must be seen as complementary rather than rival fields" (JICK, 1983, p. 135). However, the various methods remain autonomous, continue to operate side by side, having as a meeting point the subject under study.

Figure 2 contains the methodological summary in a simplified way.

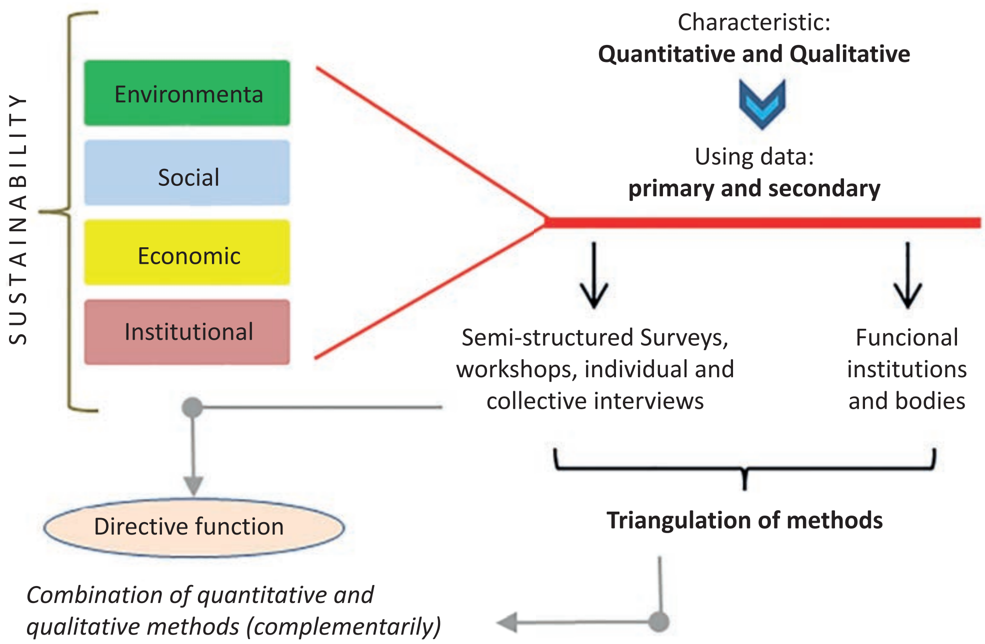

Figure 2 – Methodological summary of study. Source: Prepared by the authors.

Preliminary results

So far we can offer some preliminary results of this research. We generate the profile of river basin initiatives in the world that use indicators in their experiences. These findings generate the general profile:

- Regional area;
- Using pure indicators approach;
- Based on environmental scope; (it limits the evaluation of sustainability, and does not reflect the interactions between environment and society).

These findings may be better perceived in Figure 3.

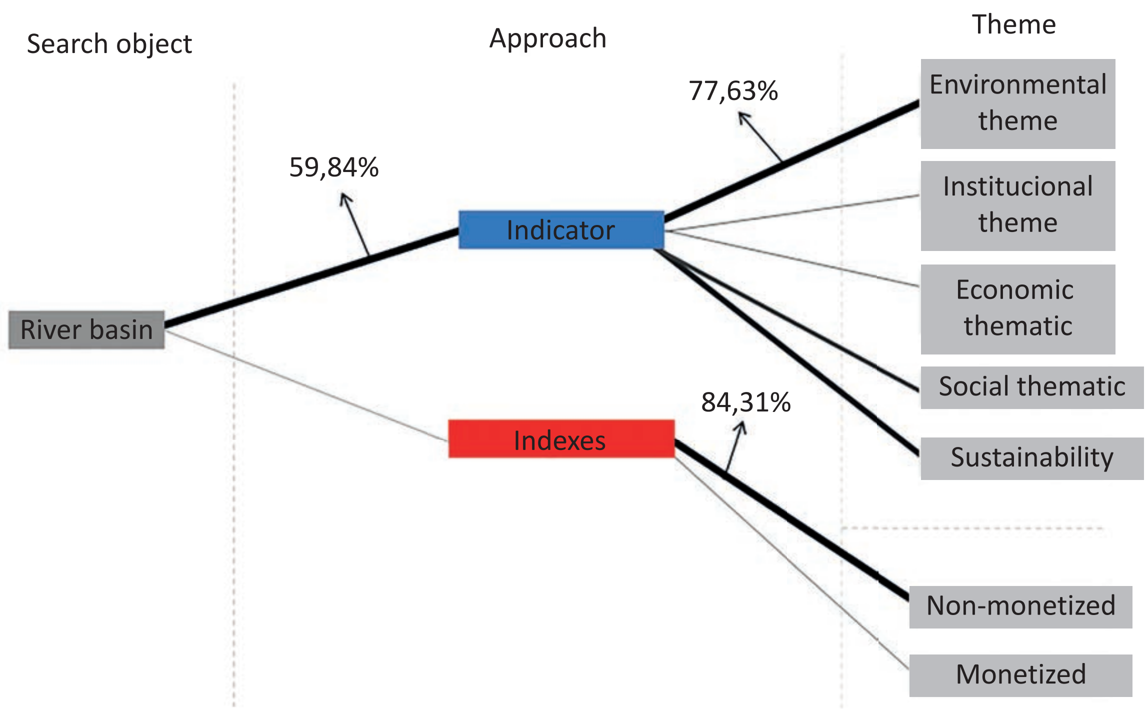

Figure 3 – Profile of river basin initiatives in the world using indicators. Source: Prepared by the authors.

In indexes the scope does not have a centrality in the environmental dimension, using different dimensions (ecological, social, economic, and institutional). Here the non-monetized was greater than the monetary valuation.So far we have the following findings regarding field research:

- 76 municipalities are involved in this research;
- 42% were concluded so far being 70% face-to-face visits;
- 58% of them had a high level of response (75% - 100%).

Figure 4 presents these preliminary fieldwork findings.

Municipalities covered so far → **42%** → 70% face-to-face visits

Distribution by size of municipality in study area	Proportion
up to 100 thousand inhabitants	74%
100 thousand - 500 thousand inhabitants	25%
above 500 thousand inhabitants	1%

Responses by municipality size so far	Proportion
up to 100 thousand inhabitants	47%
100 thousand - 500 thousand inhabitants	35%
above 500 thousand inhabitants	100%

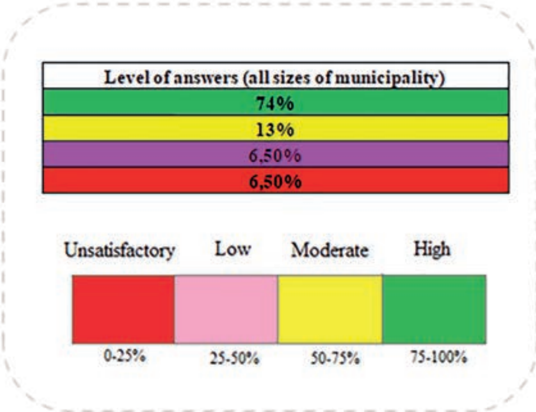

Figure 4 – Preliminary results of fieldwork.

According to the literature of the topic studied, the level of response is considered acceptable for analysis of the results. However, we are still looking to improve these numbers to provide a more robust result.

There is increasing recognition of one's own institutional limitations in dealing with complex problems at all spatial scales. The findings of this research point to the need for institutional innovations and their formalization and emancipation before public management, with the creation and performance of participatory procedures prescribed in specific laws, such as in the area of water resources, where the participation of multi-stakeholders through the Watershed Committees represents a significant breakthrough for good governance. It is necessary to consolidate the articulation between institutions at the municipal level so that the dimensions of sustainability are treated in a fair and proactive way, so that progress towards regional sustainable development is possible. The difficulty in this research so far is to access and streamline a link with the various stakeholders and to build interfaces with inter-sectoral relationships to stimulate the flow of information in these networks.

Many challenges have been found for the construction of evaluation systems with indicators like: geographical or spatial delimitation; temporal discontinuity; validation; type of aggregation; lack of information; subjectivity of the concept of sustainability; access to data; decision support/policy advisor; methodological consensus; integration of information; measurability; complexity; quality of data; potential use; medium and long-term approach - targets; legal congruence; participatory approach; relevance; credibility; legitimacy; transparency; technical knowledge; effective communication; comparative analysis; operationalization; selection; monitoring; self-evaluation; scope definition.

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https://doi.org/10.26626/978-85-5953-031-5.2018C013

The Management of Water Resources as a Factor of Urban Resilience

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Abstract

The urban centers represent a dense and complex system of interconnected services and as such face a growing number of aspects leading to disaster risk. In this way, urban resilience emerges as a city's ability to resist, absorb, adapt and recover from exposure to threats, producing effects in a timely and efficient manner, which includes preserving and restoring its structures and functions. For the development of the project it is intended to work the city in the context of urban waters, through a case study of three municipalities in which criteria such as size (small, medium or large), water availability (high, medium or low) and vocation of the municipality (tourism, agribusiness, industry, among others) will be carried out a methodological adaptation that will present an evaluation tool for the application of resilience thinking, aiming at increasing the understanding of water resources and their vulnerability in cities. Water safety is a key determinant of city growth, so the development of methodologies that assess urban systems will help planners to address water issues and develop a legal framework to regulate, guide, and promote the practice of resilience water resources. Therefore, as a result, the research aims to provide technical inputs for decision-making on resilient development through integrated water resources management to generate water security at the local level and river basin committees.

Keywords: resilient cities, waters in resilient cities, urban waters, water resources, management of water resources, sustainability.

Introduction

Resilience is a concept often used in many fields, specifically ecology, economics, and engineering. According to Djordjevic *et al.* (2011) there are several definitions for the same concept. Resilience is determined by the degree to which the social system is able to organize itself to increase its learning capacity with past disasters, protection of a better future and for the improvement of risk reduction measures.

In 2013 the Rockefeller Foundation launched a network called 100 Resilient Cities. This is an initiative that is dedicated, through funds to share experiences and peer-to-peer knowledge to help cities to adapt to the shocks and pressures of today's world and turn them into opportunities for growth (THE ROCKEFELLER FOUNDATION, 2016). Nowadays among the participants of the network there are cities like Barcelona, Milan, Paris, London, Boston Lisbon, Chicago, Singapore and Buenos Aires. In Brazil, there are Porto Alegre, Rio de Janeiro and Salvador as participants as well.

Objective

The general aim of the research is to evaluate the role of integrated water resources management in the urban environment as a resilience factor. After understanding the problem, we want to identify and evaluate methodological options. We hope to present results such as the discussion about the application of methodology studied to support the selection of a methodology with better applicability for the study object. We also hope to identify stakeholders and their roles in the development stages of the methodology; to discuss the need to invest in water security for the resilient development of the cities; to develop and discuss strategies for water resilience of those cities; to discuss the results with members of river basin committees and potential users, and to discuss the potential applicability of the study to other river basins.

Method

The method and the work plan that will be used in the research are presented, and can be visualized in the flow chart of Figure 1.

Construction of the Conceptual Base

Cities and urban areas represent a dense and complex system of interconnected services. As such, they face a growing number of aspects that lead to the risk of disaster. Strategies and public policies can be developed to meet each aspect as part of a global vision to build cities of all sizes and more resilient and livable profiles. (UNITED NATIONS OFFICE FOR DISASTER RISK REDUCTION, 2012).

Resilience at the municipal level recognizes the urban area as a dynamic and complex system that must continuously adapt to various challenges in an integrated and holistic way (UNITED NATIONS 2015), so through the integrated and predictive planning of water resources it is possible to build a resilience to better manage water resources and, consequently, benefit various sectors of society.

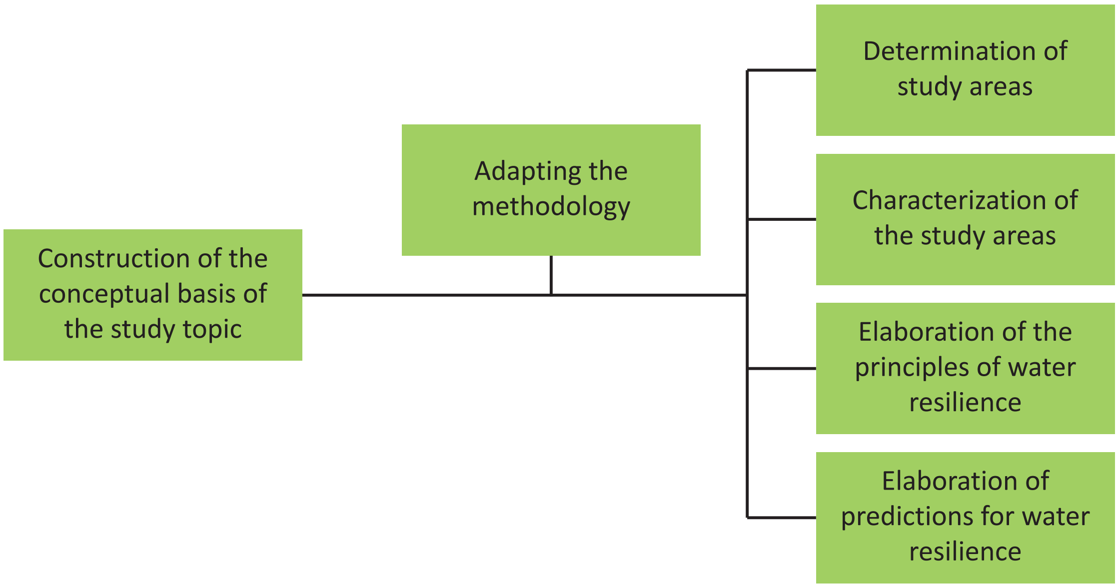

Figure 1 – Schematic representation of the work plan.

In order to evaluate the hypotheses, a descriptive research of an exploratory nature will be carried out, in order to deepen the bibliographical review with articles published in international and national journals, books, theses, dissertations and also in the legislation regarding urban planning, resilience and water resources. Experiences will also be raised in other cities that are applying the concept of resilience.

The methodological line to be followed contemplates the aspect of exploratory and descriptive character, aiming to understand the context of the topic addressed.

Determination of study areas

For the development of the project, it is intended to work the city in the urban context by carrying out a case study in three municipalities in which criteria such as size (small, medium or large), availability of water (high, medium or low) and vocation of the municipality (tourism, agribusiness, industry, among others). For the study, the cities of São Carlos and Brotas in the State of São Paulo and Porto Alegre in Rio Grande do Sul will be used. Two municipalities, São Carlos-SP and Brotas-SP, are included in the Tietê-Jacaré Basin and the municipality of Porto Alegre-RS is inserted in the Lagoa da Guaíba Hydrographic Basin. The cities mentioned have the following characteristics:

São Carlos-SP: medium size, with high water availability with vocation for industry;

Brotas-SP: small and with high water availability and vocation for tourism;

Porto Alegre-RS: large size, high water availability and with vocation for industry and agriculture.

In the case of Porto Alegre, there is more interest in study because the city is a partner of the Rockefeller Foundation and has joined the campaign of Resilient Cities of the United Nations (UN), The city already has a resilient strategy developed.

It is worth mentioning that the municipalities and the criteria to determine the cities can be modified, since they will depend on the application of the methodology.

Adaptation of urban resilience construction methodology

A city can be understood as the place that concentrates the offer of cultural, religious, infrastructure or consumption services bringing together the most diverse streams of human activities. According to Benevolo (2006), this overlapping of functions is due to the different achievements of its inhabitants over time, which are juxtaposed in the urban environment to adapt the structure to diverse needs and interests. Therefore, a city has elements that differ from one another, making it necessary for the methodology to be used to be applied according to its specificities.

For the adaptation of the methodology will be made an evaluation of the characteristics of the methods used in the conceptual basis and their applicability in the Brazilian municipalities that will be studied in the project.

The aim is to adapt the methodology of the Resilience Alliance for the construction of urban resilience through water resources. The Resilience Alliance is a research network of scientists and practitioners from different disciplines working to develop and apply the concepts of resilience. Researchers develop a "Resilience Assessment" methodology as "an alternative way of thinking and practicing natural resource management" (RESILIENCE ALLIANCE, 2007a). There are several formats for conducting a resilience assessment, as presented in two versions of a manual for professionals (RESILIENCE ALLIANCE, 2007a; RESILIENCE ALLIANCE, 2007a), a manual for scientists (RESILIENCE ALLIANCE, 2007b) and publications such as Walker et al . (2009) and Strickland-Munro et al. (2010). This literature is quite consistent in a general approach: a group with specialized knowledge will define the boundaries of the system, its components and key issues; will characterize real and potential system dynamics (thresholds and alternative states), and uses this understanding to decide "where and how to intervene in the system in order to increase resilience" (RESILIENCE ALLIANCE, 2007a).

The idea is that the methodological adaptation presents an evaluation tool for the application of resilience thinking, aiming to increase understanding of water resources and their vulnerability in cities.

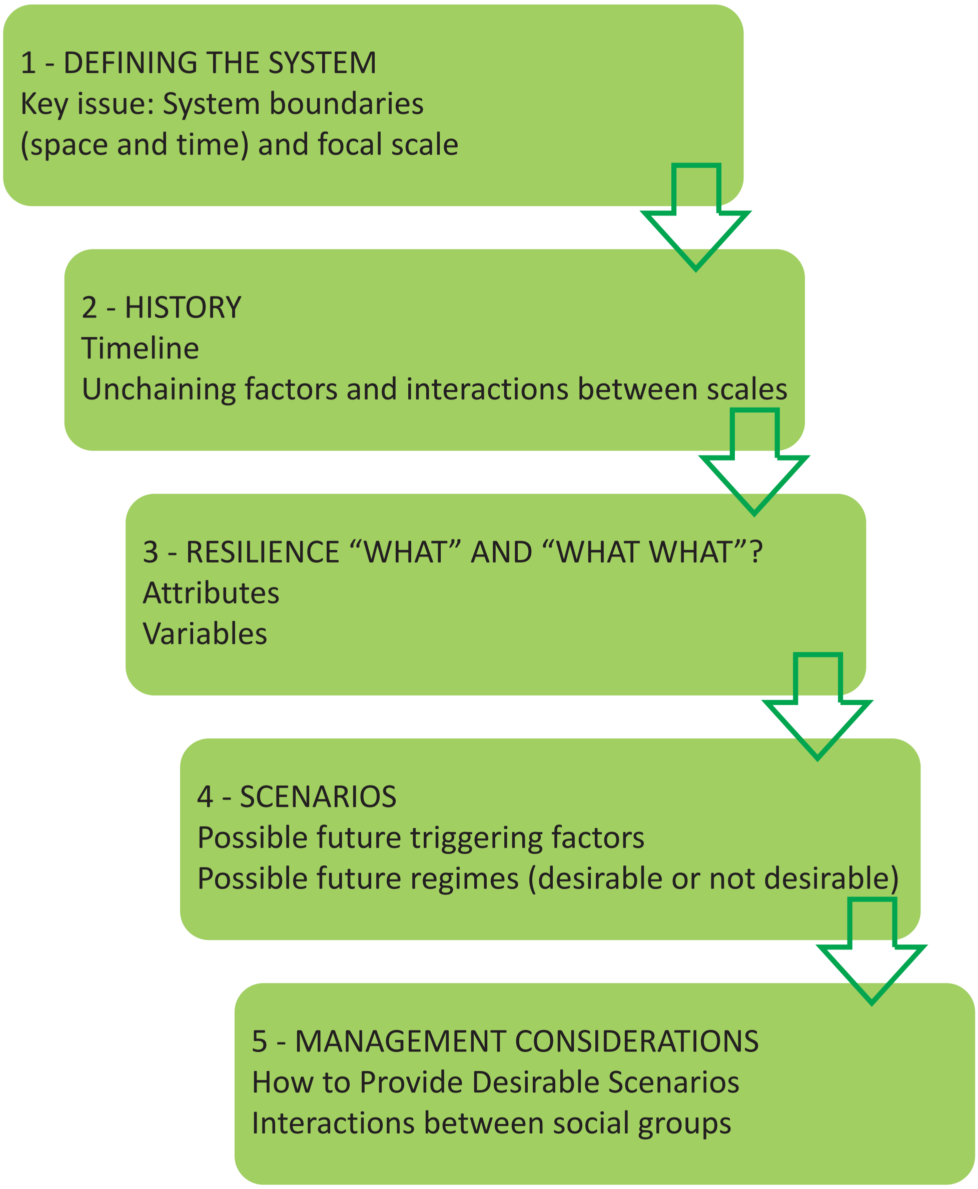

Figure 2 – Resilience evaluation methodology developed by Buschbacher *et al.* (2016). Adapted from Buschbacher *et al*. (2016).

Characterization of study areas.

In order to better understand the functioning of the hydrological system of the municipalities and to define the fields and strategies of action of the water resilience, the following investigations will be made:

- Classification of the vocation of the municipality (tourism, industry, agribusiness, among others);
- Diagnose the areas of greatest water vulnerability of the municipality;

- Evaluate the water connection, analyzing how the rivers and streams are flowing and their environmental quality (level of vitality);
- Historical survey of the transformations that occurred in water bodies, such as rivers, streams, lakes and ponds, flooded and floodable areas, including in areas where there was occupation process;
- To compare the occupancy times and the transformations that occurred to verify the interventions that may have altered the flows and the natural processes of the waters over time, with changes in the land uses and the consequent waterproofing;
- Map existing bodies and water flows, visible or subterranean drainage channels and the sanitation system, rainfall and prevailing precipitation flows, waterways and places where they accumulate and the history of wetlands and their vulnerability to precipitation volumes;
- To quantify the infiltrated, detained and retained waters and their contribution to avoid floods and to supply the aquifers and underground sheets;
- Evaluate the percentage of impermeable soil in the urban area, measuring the amount of water that flows superficially.

Application of the modified methodology

After the completion of the previous processes, the methodology will be applied adapted in the municipalities under study, in order to test the hypothesis through concrete situations. To do so, the data collected in the study areas will be inserted in the methodology and future scenarios will be proposed to be considered in the evaluation of the instrument elaborated.

Expected Results

Water is a key factor for the sectors of economic growth and contributes to employment, job creation and gross domestic product (GDP), it is at the heart of the development goals of most sectors, including health, energy, agriculture, environment and social protection. However, most countries are far from achieving water security and the triggering of climate change will further jeopardize their prospects.

Water safety is a key determinant of city growth, so the development of methodologies that assess urban systems will help planners to address water issues and develop a legal framework to regulate, guide, and promote the practice of resilience water resources.

Therefore, after understanding the problem, identifying and evaluating methodological options, the following results are expected:

- Discussion on the applied methodology of application, to substantiate the selection of a methodology with better applicability for the object of study in question;

Identify stakeholders and their roles in the development of the methodology;

- Discuss the need to invest in water security for the resilient development of municipalities;
- Develop and discuss strategies for action of water resilience in municipalities;

- Discuss results with members of river basin committees and potential users;
- Discussion on the potential applicability of the study to other river basins.

Discussion

Problems and limitations in urban water management are among the main causes of economic losses in cities. Water safety is a determinant by city growth, so the development of methodologies that evaluate urban systems will help planners to address water issues and develop a legal framework to regulate, guide and promote the practices of water resilience.

In this way, it is possible from the study of water resources to establish new methodologies and processes for cities to become more resilient and, consequently, to develop new strategies and tools.

They could be used to analyze the internal dynamics of urban ecosystems as well and thus reassess the planning of the city to make the best decision of making the use of the water resources when it faces the challenges imposed by the rapid urbanization.

Acknowledgement

The Federal University of São Carlos-UFSCar. The Coordination of Improvement of Higher Level Personnel - CAPES.

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https://doi.org/10.26626/978-85-5953-031-5.2018C014

Assessment of an *in situ* Real Time UV/VIS Based Spectrometry System for Chemical Oxygen Demand Measurement in a Wastewater Anaerobic Treatment Reactor

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Abstract

Analysis of physical and chemical parameters is more and more important for operation checking and performance control in wastewater treatment plants (WWTP). Recently developed UV/VIS spectrometry based sensors are being used for measurement of parameters like chemical oxygen demand (COD). The aim of this work is to report results ofreal time *in situ* COD measurementusing a spectrophotometric system in a wastewater treatment plant with upflowanaerobicsludgeblanket (UASB).The studies focused a medium size WWTP (wastewater average flow around 319 L/s) located in Paraná State (Brazil), and used several statistical tools, like as relative error, boxplot charts, statistical dispersion, Student's t-test (significance level α = 0.05) and bilateral test, to compare measurement system results with laboratorial analyses.The results indicate that sensor monitoring can be effective for the UASB affluent, as the probe measurement results and laboratorial analyses of COD showed no statistical significant difference for three different calibration scenarios. Linear local calibration showed the best performance in the assessed WWTP, with mean error being 4.32%, standard deviation σ = 2.76% and determination coefficient R^2 = 0.7667. For the UASB reactor effluent the behavior has not shown the expected adherence: only the offset calibration, among four assessed methods, showed no significant difference, with mean error being 27.53%, standard deviation σ = 24.11% and determination coefficient R^2 = 0.1246. COD removal efficiency in the WTP was between 56% and 60%.

Keywords: UV/VIS Spectrophotometry, COD, UASB, Probe, Sanitation System.

Introduction

In the wastewater treatment plants of Brazil, and of Paraná State in particular, the upflow anaerobic sludge blanket (UASB) treatment method is prevailing, due to its low energy consumption, reduced area requirement and higher operational simplicity. Besides, UASB reactors have low sludge production and reduced implantation cost (CHERNICHARO *et al.*, 1999).

Sampling and analysis are more and more important for treatment plants operation assessment, since the high-quality data of present systems allow plant monitoring. Traditional approach is based on punctual short runs for sampling and later laboratory analyses, which use to be lengthy, demand expensive and/or toxic reagents and produce residues needing later treatment (VANROLLEGHEM, LEE, 2003; BRITO *et al.*,2014).

Usually assessed parameters, like as temperature, pH and conductivity among others, can be continuously monitored. In the last few years some papers reported the monitoring of total organic carbon (TOC), total suspended solids (TSS) and chemical oxygen demand (COD) using spectrometric techniques (BRITO *et al.*, 2014).

The chemical oxygen demand is a global parameter very used as indicator of oxygen content in design and control of UASB anaerobic treatment systems (CHERNICHARO *et al.*, 2015). Aisse *et al.* (2002) obtained COD = 151 ± 64 mg/L as a typical value for the effluent of domestic wastewater treated in UASB reactor. Considering a value of 453 ± 147 mg/L for COD in the affluent the authors determined a removal efficiency of 69%. The volumetric organic load (VOL) can be assumed to be 1.80 kg(COD).m^{-3}.day^{-1}, for a hydraulic retention time of 8 hours.

The full UV spectrum has been used for the TOC, COD and biochemical oxygen demand (BOD_5) estimation in wastewater (THOMAS *et al.*, 1997).The spectrometry in the ultraviolet and visible ranges (UV/VIS) allows to obtain relevant information (VAN DEL BROEKE *et al*., 2006; BRITO *et al*., 2014). It is a fast and easy to implement technique, used for wastewater quality assessment (THOMAS *et al*., 2005). The used wavelength varies from 200 to 800 nm, and it is possible to relate the radiation absorbance features (absorption wavelength ranges) with the compounds that account for COD values.

In the measurement process it is very important to consider the sample peculiarities (matrix effect) and assessment of the error, which can be reduced with previous calibration and with control of local sampling variables, such as flow fluctuation, coarse solids and equipment cleansing. A good monitoring depends on true results. Van der Broke *et al*. (2006) affirm that online spectra acquisition has been implemented in most WWTP. One can admit that measurement instruments must deal with additional challenges, due to water quality matrix variability and to facility related operation and safety issues (BRITO *et al*., 2014). There are few works in Brazil that support the installation of *in situ* COD real time probes in UASB reactors based WWTP.

In this respect, the objective of this work is to report the results of using a spectrophotometric measurement system for real time *in situ* COD determination in a wastewater treatment plant with up flow anaerobic sludge blanket reactor.

Metodology

Location of Study

This study took place in a medium size WWTP with average flow of 319 L/s, located in Curitiba, PR. The wastewater pretreatment occurs in a system composed of 20 mm manual screen, 3 mm mechanical screen, grit removal system, Parshall flume and the biological treatment is done in six UASB reactors, each one with rated capacity of 70 L/s.Post treatment of anaerobic effluent post-treatment could take place in aerated facultative ponds.

Wastewater COD Concentration Meter (Probe)

The COD measurement system, Carbolyser model supplied by S::can (shown in Figure 1) is composed of a probe and a control unit. The system can determine concentrations between 100 and 3,250 mg(COD)/L using UV/VIS spectrophotometry. The probe measures the difference between optical intensity emitted by a lamp inside the measuring window and the optical intensity that reaches the detector, after crossing the waste water flow. The probe is 0.6 m in length and 44 mm in diameter, operates in a wavelength range between 200 and 750 nm and uses a xenon lamp.

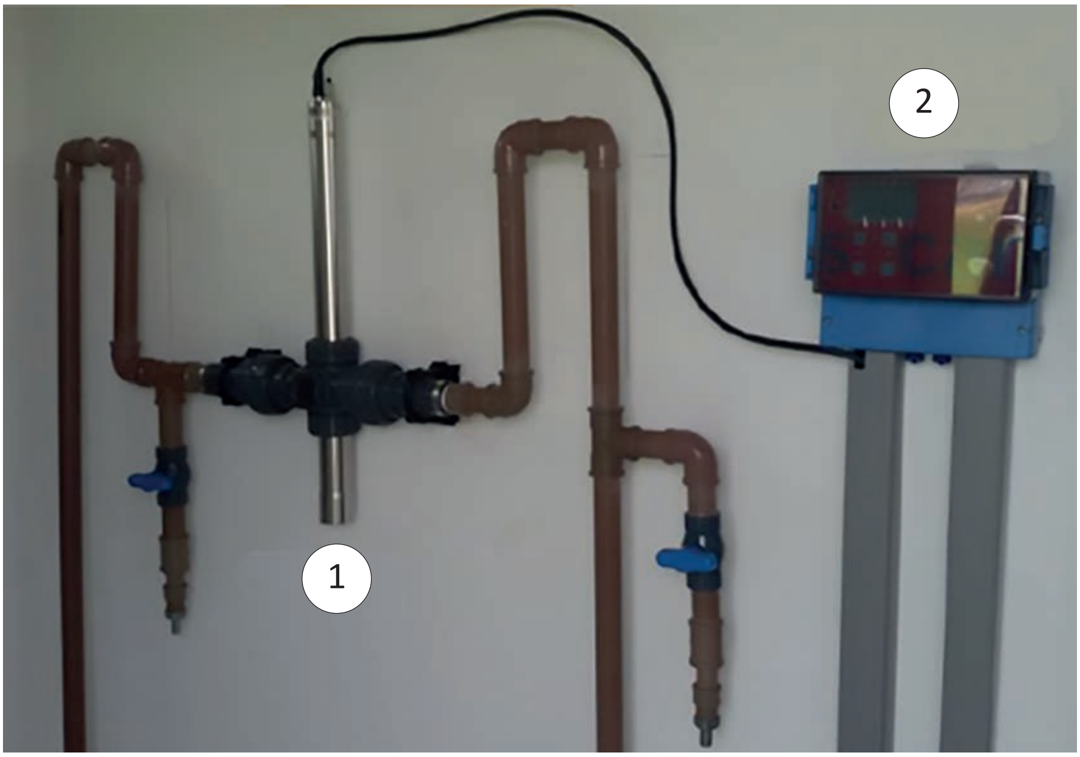


Figure 1 – COD probe installation layout. Notes: (1) Carbolyser probe (spectrophotometer); (2) Equipment control display.

The installation of the instrument in the WTP allowed the assessment of affluent to and effluent from the UASB reactor, using an automated pumping system for alternate sampling of affluent and effluent flows.

The COD measurement system has a compressed air self-cleaning system with maximum pressure of 5 bar; manual cleaning is also allowed. The cleaning procedure, developed for the removal of solid deposits from the measurement hollow, includes the use of lukewarm water, pure ethanol and brushes provided by the manufacturer. The frequency of the manual cleaning was increased from biweekly to two times a week after day 14 reading.

Calibration Methods and Comparison with Laboratory Analyses

Besides the real-time measurements, collected wastewater samples were analyzed in laboratory, through procedures preconized in the APHA Standard Methods (APHA, 2012).At laboratory the samples were transferred to a digestion flask at 150ºC for 2 hours. COD was determined by colorimetric method based on absorbance measurement at 620 nm in a workbench spectrophotometer DR6000 (Hach Industries) and previous calibration curve. Total 25 affluent and 29 effluent samples were collected in different days, between 9:00 and 11:00 am and during summer and autumn of 2016.

The calibration of the COD measurement system installed in the WTP was done so that the samples covered the historic variation of wastewater concentration values. Three scenarios were outlined for affluent COD readings: 1) global calibration (from factory), 2) local offset calibration (for both field and laboratory measurements, used to fit the global calibration to present situation, shifting the position but not the inclination of global calibration curve), and 3) local linear calibration (from two field samples and two laboratory results, global calibration inclination and alignment change). For the effluent COD recording 4 scenarios were proposed: 1) global calibration (from factory), 2) local offset calibration, 3) local linear calibration, and 4) new calibration curve supplied by the manufacturer.

Results were analyzed with statistical tools such as percentage mean error, boxplot charts, scatter plots, Student's t-test, for two samples with presumed equivalent variances and significance level α = 0.05, and bilateral test, to compare results obtained from measurement system at WTP with laboratory analyses.

Results and Discussion

Figure 2 shows the relative error between values registered by measurement system installed in WTP and values obtained in the laboratory analyses, for wastewater affluent samples. Mean relative error values is 64.7% ± 64.0% for global calibration (reading days #1 to #11), 38.3 ± 40.5% for offset calibration (#11 to #20) and 4.3 ± 2.8% for local linear calibration (#21 to #25). The improved probe performance from day #16 can be attributed to the increased cleaning frequency (from biweekly to two times a week) from day #14.

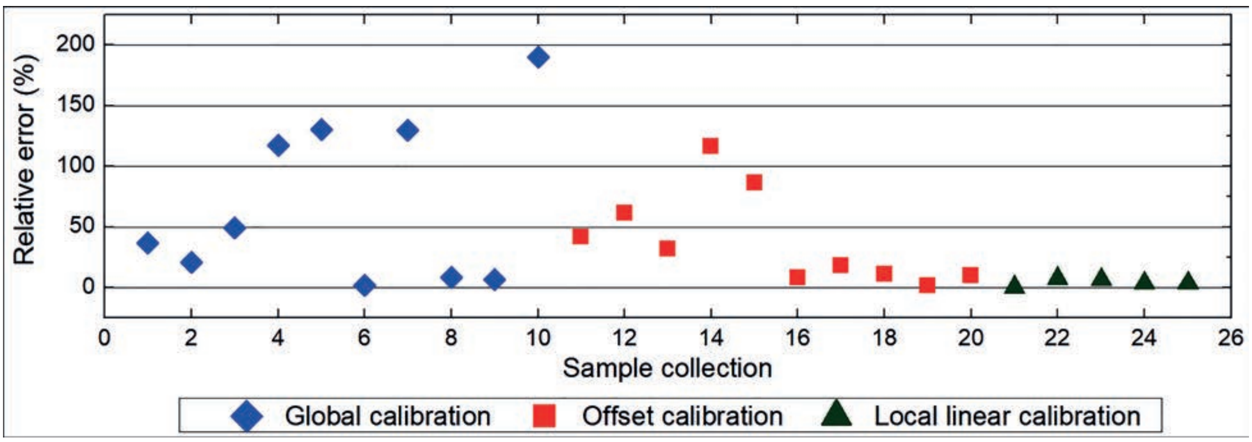
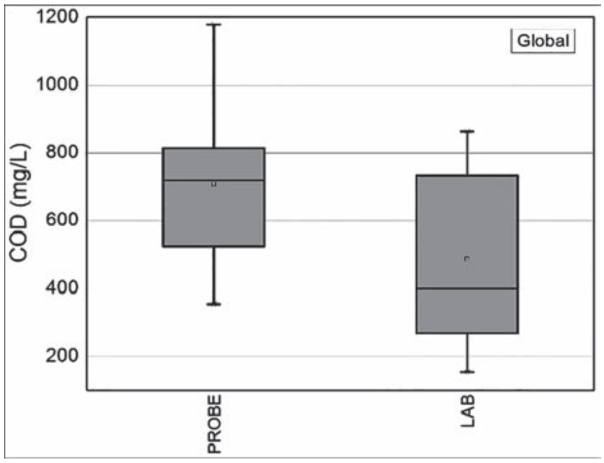


Figure 2 – Relative error scatter plot for the affluent in the calibration modes: global, offset and local linear.

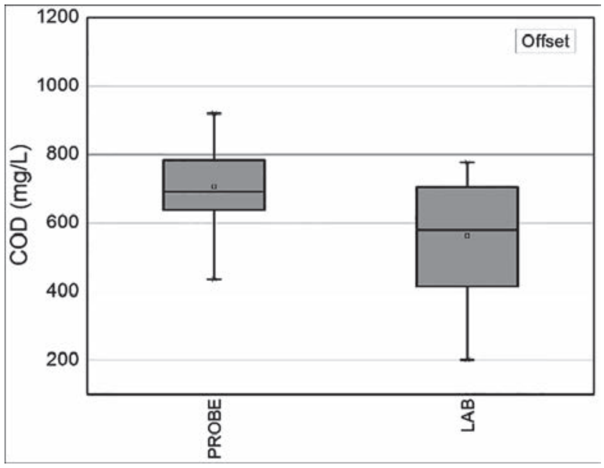
Figure 3 shows the COD boxplot charts for the wastewater affluent, measured by the probe and in the laboratory. For global calibration (Figure 3a) the average probe measured COD is 708 ± 252 mg/L and 486± 250 mg/L at the laboratory; in the case of offset calibration (Figure 3b) probe average COD is 705 ± 152 mg/L and laboratory average, 562 ± 190 mg/L; for the local linear calibration (Figure 3c), probe average COD is much closer to laboratory average: 650 ± 52 mg/L (probe) and 651 ± 73mg/L (laboratory). The linear calibration has shown the best results among the three scenarios.

The application of Student's t-test in all the three calibration scenarios has not shown significant differences. Nevertheless, it is clear from Figures 2 and 3c that linear calibration is the best one in comparison with global (manufacturer) and offset calibrations, based on its lowest relative error, equal to 4.3%, and on the lowest difference between probe and laboratory averages.

Figure 4 shows the scatter plots of affluent COD results obtained with laboratory analyses *versus* measurements obtained with the probe at WTP, assessed with the three different calibration scenarios. The following determination coefficient (R^2) values were found: 0,6178 for global calibration (Figure 4a), 0,4612 for local offset calibration (Figure 4b) and 0,7667 for local linear calibration. Again, the local linear calibration scenario is the more adequate to the studied situation.



(a)



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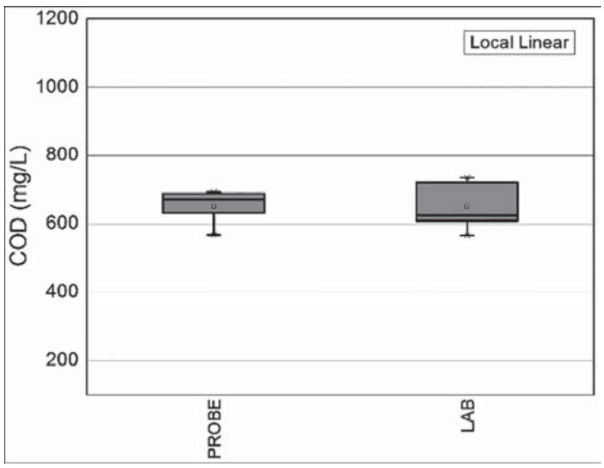
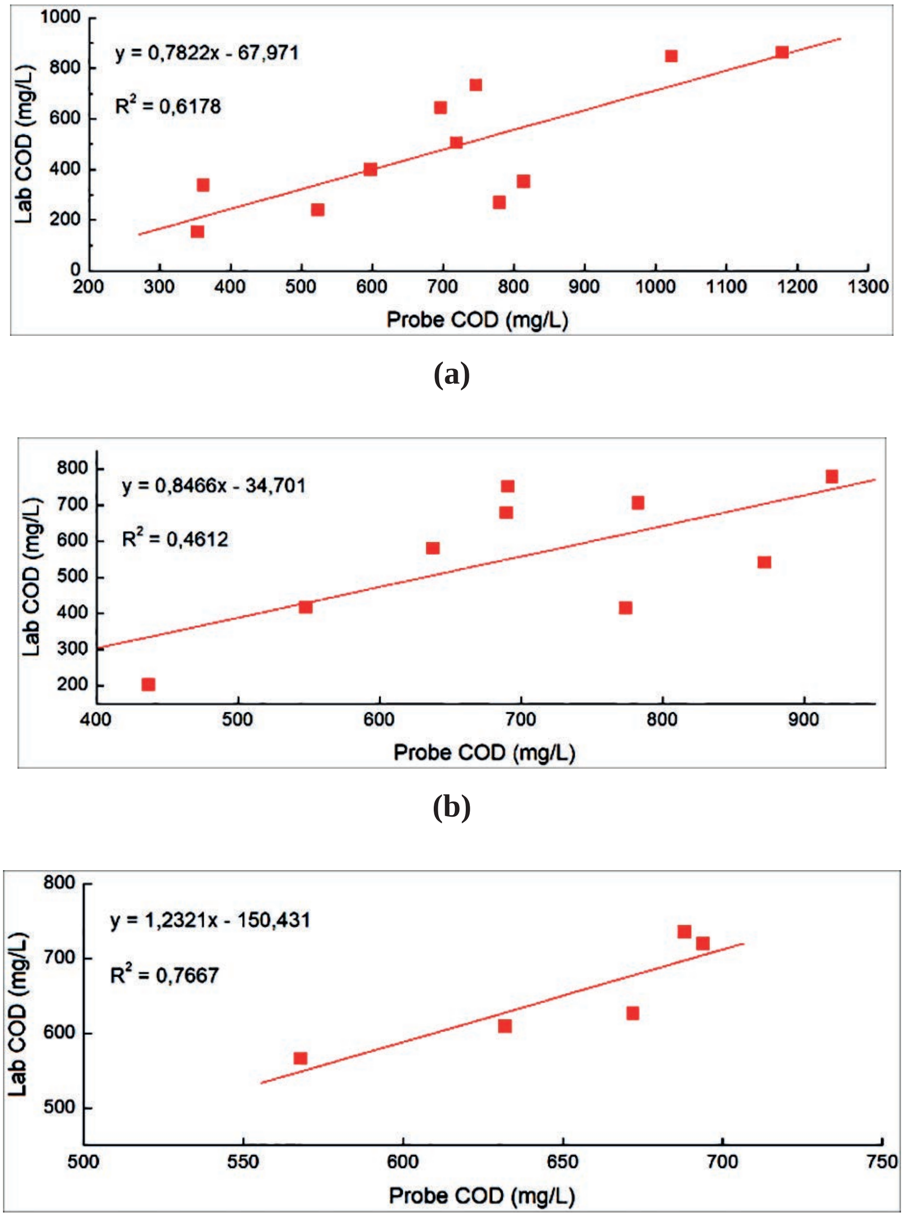


(c)

Figure 3 – Boxplot charts for the affluent: (a) global calibration; (b) local offset calibration; (c) linear local calibration.



(a)

(b)

(c)

Figure 4 – Affluent CODlaboratory *vs*. probe dispersion scatter plots: (a) global calibration; (b) local offset calibration; (c) local linear calibration.

The relative error between the probe and the laboratory values for the effluent are shown in Figure 5.

Between readings #1 and #9 (manufacturer global calibration) the observed average error is 51.66% ± 35.60; for the measurement days from #10 to #19 (local offset calibration) the found error is 27.53 ± 24,11%; for the samples #20 to #24 the recalibrated probe (local linear calibration) has shown an average error of 10.09 ± 1.95%.

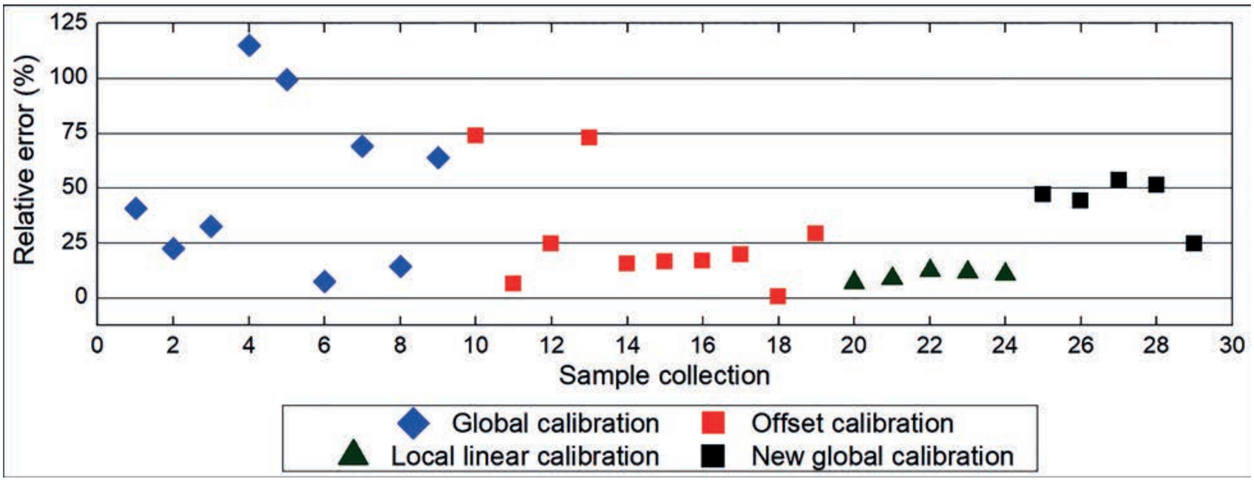


Figure 5 – Effluent COD relative error dispersion scatter plot for: (a) global calibration; (b) local offset calibration; (c) local linear calibration; (d) new global calibration.

As for the affluent samples, the increased cleaning frequency improved the probe performance for effluent samples from collection day #14. Besides the previous three calibration scenarios, a new global calibration was supplied by the probe manufacturer, with average relative error of 44.14 ± 10.25%. The effluent COD values can be seen in Figure 6, for the four different calibration conditions.

The probe has not shown the expected adherent behavior for the wastewater effluent. For global calibration (Figure 6a) measurements with the probe showed average COD of 319 ± 73 mg/L and laboratory results of 225 ± 68 mg/L. For local offset calibration (Figure 6b) the results were 277 ± 60 mg/L with the probe and 241 ± 53 mg/Lat the laboratory. Local linear calibration results (Figure 6c) were 242 ± 4 mg/L with the probe and 270 ± 9 mg/L at the laboratory. Finally, average COD results were 114 ± 43 mg/L with the probe and 204 ± 74 mg/L at the laboratory for the new global calibration.

The application of Student's t-test indicated that only offset calibration has not showed significant difference between probe and laboratory measurements, rejecting the other three conditions.

Figure 7 shows the determination coefficient R^2 for the effluent in the four studied calibration scenarios. The R^2 equals 0,3845 for global calibration (Figure 7a), 0,1246 for local offset calibration (Figure 7b), 0,5566 for local linear calibration (Figure 7c) and 0,7927 for the new global calibration (Figure 7d).

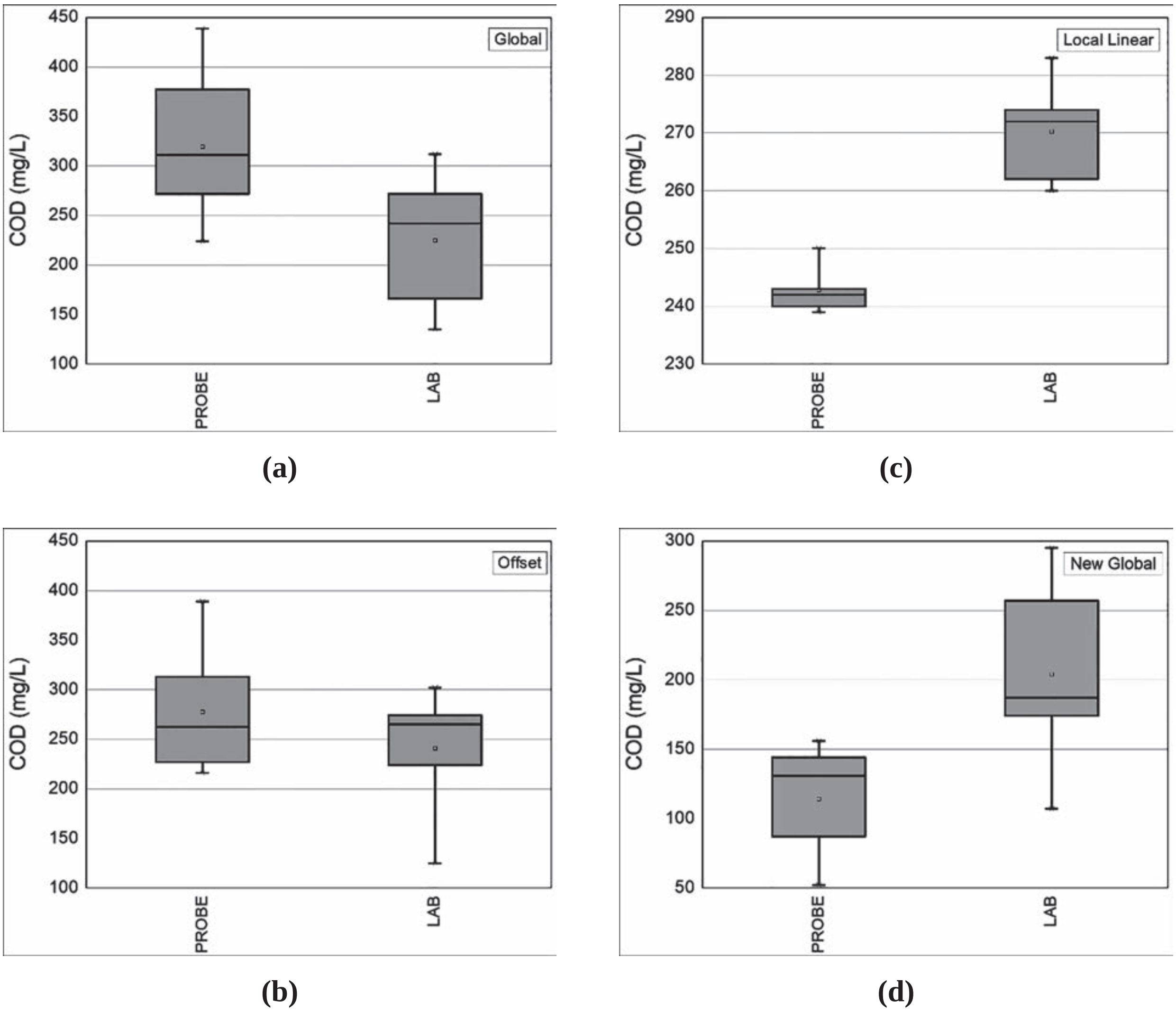
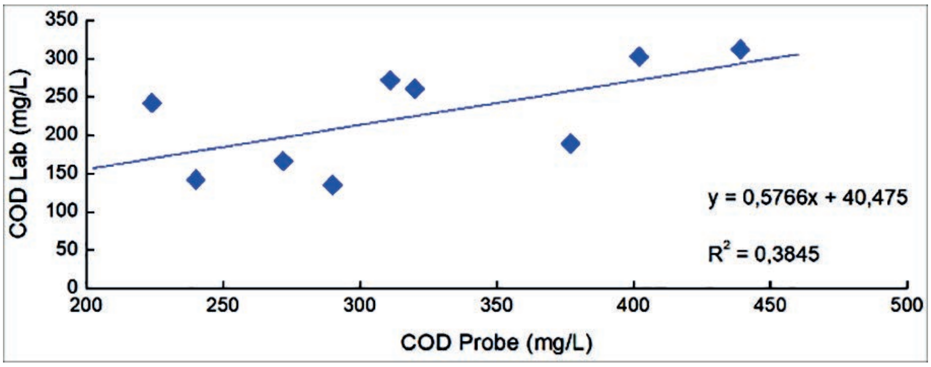


Figure 6 – Effluent boxplot charts for the different calibration scenarios: (a) global calibration; (b) local offset calibration; (c) local linear calibration; (d) new global calibration.

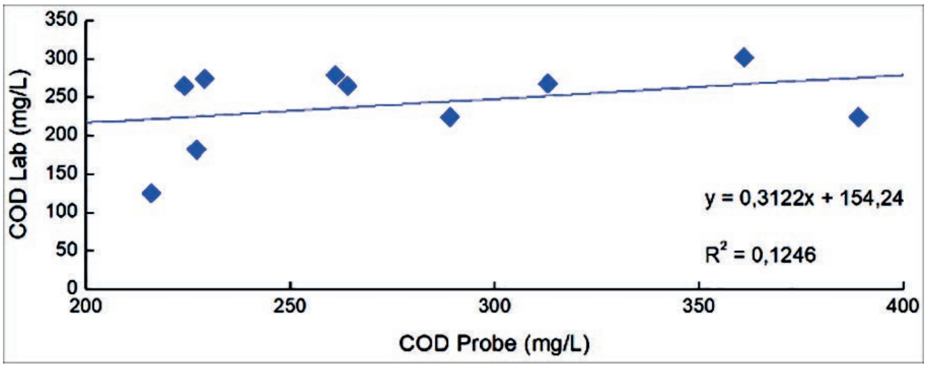
Other Comments

One possible explanation for the difference between probe and laboratory measurements is that the spectrophotometer detects only the organic matter fraction absorbing in the UV/VIS range, e.g. organic acids and carbon hydrates. The laboratory analysis detects sulfide, chloride and Fe(II) ions by dichromate oxidation. If the probe spectrophotometer has not the ability to detect ion species, field measurements should give lower COD values. According Figures 4 and 7, this is the case only for the wastewater effluent and only for local linear and new global calibrations.

The probe has the important ability to measure, besides COD, total suspended solids. Joint calibration can allow fitting the parameters of the initially built intrinsic software model (Gruber *et al.*, 2006). This can improve the supplier's global calibration, which has not shown reliable values for the effluent.



(a)



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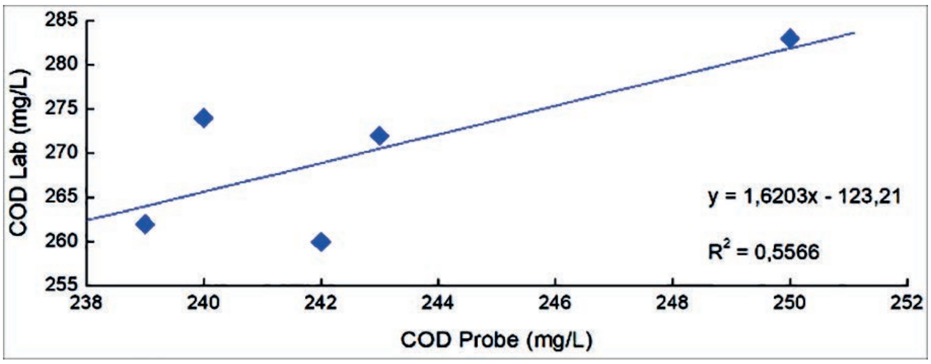

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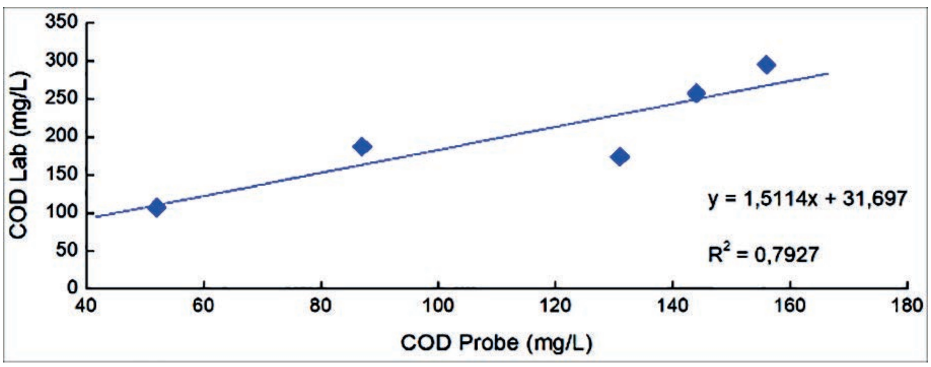

(d)

Figure 7 – Dispersion scatter plots for calibration modes: (a) global calibration, (b) local offset calibration, (c) local linear calibration, (d) new global calibration.

It is worth mentioning that this study is the first attempt to use spectrophotometry for assessment of COD in wastewater treatment UASB reactors, a successful technology for urban drainage. The local linear calibration is the best adapted configuration for affluent wastewater monitoring and it also has shown the smaller relative errors for effluent samples.

Operational Aspects

It is mandatory to avoid air bubbles, optical window hindrance and other measurement interfering phenomena (VANROLLEGHEM *et al.*, 2003). These phenomena were recurrent in this study, including obstruction and clogging of the pipeline connecting the effluent/affluent boxes to the probe site. The frequency of retention valves cleaning and pumps maintenance was increased to mitigate these problems. Feeding pump flow speeds lower than 3 m/s ensured the measurement quality. Weekly maintenance and cleaning of submersible pumps kept the optical window free of impurities, which could encumber the measurement. Additionally, distilled water and detergent together with manual brushing completed the cleaning process.

Air cleaning systems are an important requirement spectrophotometer reliability. If cleaning air systems are not able to remove the grime deposited on the measurement window COD values tend to be increased (drift) (GRUBER *et al.*, 2005). According to Langengraber *et al.* (2004), Gruber *et al.* (2005). Air cleaning systems should prevent film formation and growth, but in this study case it was not enough to eliminate the film formed at the window, even using the maximum allowed pressure (5 mbar). The UASB wastewater characteristics could be the reason for this phenomenon, and additional studies are needed.

Cleaning issues were a specific variable in this study and can be related to calibration modes. Manufacturer global calibration is based on standard algorithms developed for typical applications, but wastewater quality matrix can vary with location and wastewater origin. Local calibration can reflect this variability and produce better estimation results (LANGERGRABER *et al.*, 2004; BRITO *et al.*, 2014). The present study indicates the importance of local calibration adapted to the brazilian wastewater matrix.

Assessment of Removal Efficiency for UASB reactor

Table 1 summarizes the UASB reactors performance, with lowest relative error being the choice criterion of collection days. For the chosen collection days, the relative error between probe and laboratory measurements were 10% for the affluent and 13% for the effluent.

Table 1 – UASB reactor performance assessment[1].

Parameter	Unit	COD affluent[2]	COD effluent[3]	TSS affluent	TSS effluent	COD efficiency	TSS efficiency
Probe	mg/L	682	271	–	–	60%	–
Laboratory	mg/L	613	267	196	82	56%	58%

Notes: (1) observation period from January to May 2016, collection schedule from 9 to 11 am; (2) values for collection day #16 on; (3) values for collection days #14 and #24.

One can notice that both measurement techniques provided similar COD removal efficiency values (56% and 60%). For the entire assessment period (January to May 2016) COD removal measured at the laboratory was 56.76%, with average of 541 mg/L at reactor entry and 234 at the exit. These efficiency values are similar to the lower limit COD reported by Aisse *et al*. (2002) and Chernicharo *et al*. (2015), authors who compilated the performance of anaerobic treatment plants in large scale, with focus on brazilian plants. The assessed WTP operates with hydraulic retention times close by the rated value.

Conclusions

The scope of this study was to assess the real time *in situ* utilization of a spectrophotometric measurement system with COD probein UASB reactor entry and exit of a wastewater treatment plant located in the Paraná State.

Results allow to conclude that monitoring can be effective for the UASB affluent. COD values obtained with spectrophotometric probe and laboratory colorimetric analysis have shown no statistically significant difference for three different calibration scenarios. Linear local calibration is the most adequate to the WTP wastewater conditions, with average relative error equal to 4.32%, standard deviation of 2.76% and 0.7667 for the determination coefficient.

The probe has not shown the expected adherence for the UASB reactor effluent. Global calibration has not shown any reliable value for the effleuent and only the local offset calibration, among four calibration scenarios, has shown no significant difference (average relative error of 27.53%, standard deviation of 24.11% and determination coefficient of 0.1246). COD removal efficiency values were between 56% and 60%, close by the lower limit reported in the literature for brazilian wastewater treatment plants.

Therefore, the application of spectrophotometer techniques consists of an advancement to the real time *in situ* monitoring of brazilian wastewater treatment plants. Even then the spectrophotometric probes could not be considered as wastewater quality indicators, they allow real time monitoring wastewater treatment plants. However, it is necessary to first define the best practices to obtain more reliable results. The development of cleaning procedures is an example of a better practice adequate for the UASB reactor WTP.

Recommendations

The following recommendations will base future works on the use of spectrophotometer techniques in wastewater treatment plants:

- Improvement of the COD measurement for the effluent with probe operation changes, since the results were not conclusive in this case.
- Building of global calibration curves adequate for the Brazilian wastewater condition, for example, UASB reactors effluent.
- Assessment of behavior and correlations for other variables, also measured with the probe, such as filtered COD and total suspended solids (for UASB affluent and effluent), and the different post-treatment configurations used for the anaereobic affluent.

Acknowledgements

The authors are grateful to the Brazil-Germany Project on Biogas (PROBIOGÁS) for the research funding, and to SANEPAR, UFPR and UFMG for the manifested support. To OEA for the granted studentship during the doctorate course.

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https://doi.org/10.26626/978-85-5953-031-5.2018C015

Real Time Monitoring of Water Quality in Supply Pipelines and Industrial Facilities

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Abstract

The main goal of this project is to findalow costIoT solution for real-time monitoring of water quality. With the support of a sensors network, we should be able to collect inorganic parameters in water for both domestic and industrial applications.For the first time, this tool can allow to monitoring and control the water chemical and physical data along the mains water supply and distribution.The projectrelies on support of development companies such as FAPESP and with collaboration of the International Institute of Ecology in partnership with Matsu-Aquatech and the Innovation Agency of UFSCar.

Keywords: internet of things, sensors network, real-time monitoring, water quality.

Introduction

All living things depend of water to survive and we, human beings, are not an exception. However, water goes beyond our biological needs. We require water in our everyday activities, from washing our dishes, to the cleaning of industrial equipment or dissolution of chemical drugs. All those processes depend on the water quality.

In this context, the applicable local regulations aim to define standards for the water quality combining several physical and chemical parameters.

But nevertheless, there is evidence that Humanity's inadequate actions on the environment impacts the dynamic equilibrium in the Nature. It is an example the degradation of river waters, which, by the time, have considerably deteriorated due to the precariousness of basic sanitation and the increasing of industrial pollution. Therefore, monitoring of water quality is now a mandatory step for the preservation, the analysis and where possible the possible recovery on the basis of safety standards from the Health Ministry (MINISTÉRIO DA SAÚDE, 2011).

Justification

The amount of chlorine, well-known bactericide, in the drinking water is one of the parameter available on the water bills in São Carlos. Since December 2015 we have monitored this value and we observed in the region next to the Federal University of São Carlos an average value of 1.2 mg/L, six times 0.2 mg/L, the minimum amount fixed by SABESP (Basic Sanitation Company of the State of Sao Paulo) (SABESP, 2017).

In the scientific literature, it is documented a correlation between an excess of chlorine and the breast cancer (SCIENTIFC AMERICAN, 2017). There is also evidence of that this chemical element be detrimental to kidneys and liver (DEN BESTEN, CATHALINE et al., 1991). In addition, the chemical reactions of chlorine with the environment can impact in producing carcinogenic toxins exposed in nature (DRECHSLER, P.A., WILDMAN, E.E. and PANKEY, W., 1990).

Made aware of the consequences for our health and for the environment, we have started to develop a compact, reconfigurable, hot-pluggable and low-cost stations for monitoring in real time the water chemical and physical parameters along the mains water supply in the city (FAPESP - PIPE: 2017/15930-4 and UFSCar ProEx 23112.003836/2015-99). For this purpose, we work on integrating sensors in an equipment able to measure, record and send data in real time for modeling, monitoring and, if necessary, taking action. We are looking for a standardization of water quality verification in our city. The project is interdisciplinary and takes advantages from the collaboration with the International Institute of Ecology (IIE – São Carlos) and from the support of the company Matsu-Aquatech.

Methods and Materials

The prototype benefits from sensors both available on the market and self-fabricated.

A microcontroller manages the sensors, extracts and records the data. Firstly, the equipment will be tested and calibrated in the Óptica, LAser Fotônica laboratory - ÓLAF/DF-UFSCar (see Figure 1) with ‘ad-hoc’ samples prepared by the International Institute of Ecology. In this way, we expect to reach a high sensitivity, making our architectural solution competitive with others, more expensive, available on the market.

In a second stage of the project, the stations will be installed in different place along the water supply network. Adopting different solutions depending on the available network facilities, the equipment will transmit processed information (e.g. pH, flux, temperature, etc.) to the data processing workstation.

The collected data are going to be analyzed and modelled by expert in the area. This monitoring facilities will be a precious tool for all the enterprises working with water and water distribution.

The authors in collaboration with the Innovation Agency (UFSCar) work on the documentation to submit the patent to the INPI agency.

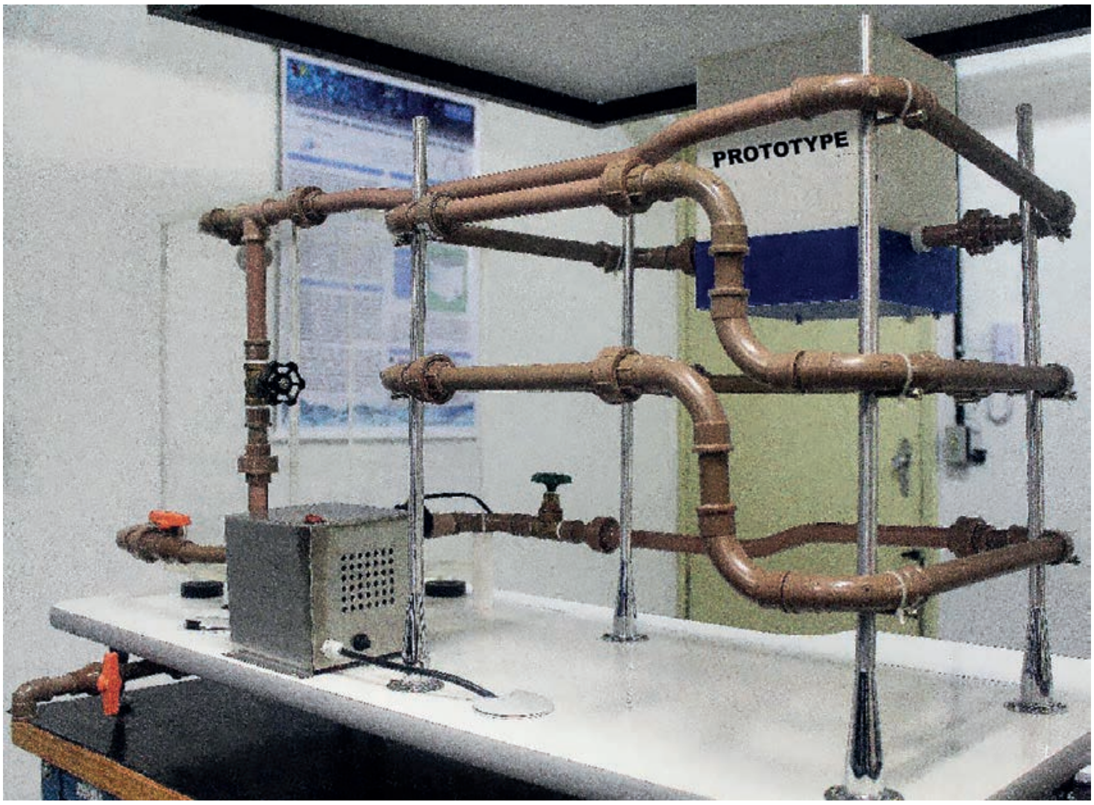

Figure 1 – Testing apparatus for the prototype (courtesy of Laboratório de Óptica, Laser e Fotônica – ÓLAF/DF-UFSCar).

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https://doi.org/10.26626/978-85-5953-031-5.2018C016

Preliminary Study of a Low-Cost, Easily-Implementable Alternative for Waterbody Restoration

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Abstract

As the population increasingly grows, the impacts of climate change rise and the lack of clean water start to surround us, the need for the restoration of waterbodies increase. Thus, new technologies have to be developed aiming to improve the water quality of rivers and boost its natural recovery. The objective of this preliminary study was to develop a cheap and accessible alternativeto improve the water quality of rivers and lakes by using low-cost waste materials. Experiments were conducted to observe the decrease of organic matter of biofilms supported in coconut fibers and in P.U spongesthrough time. Both biofilms presented high degradation efficiencies and at low contact times.The biofilm in coconut fiber showed a higher average organic matter degradation rate, but the biofilm in P.U sponges showed a higher decrease of coloration and odor. A structure was created to simulate the condition of a river and both materials were placed into it in order to analyze their efficiency. The results showed considerable decrease in nutrients, organic matter, suspended solids, turbidity and coloration. Considering the system had a relatively high flow rate, thus not allowing the water to have contact with the structure for a long time, these results establish that the structure could be applied in a real effluent to improve the water quality. However, further research is needed to analyze the effects of more variables and establish some strategies of how this should be applied in a real waterbody.

Keywords: waterbody, restoration, low-cost, biofilm, coconut, polyurethane.

Introduction

Considering the increasing impacts of climate change, the population growth and the quantity of rivers and lakes that currently are eutrophic, the efforts concerning river restoration have to be one of the main focuses of environmental engineers.

Government agencies and stakeholders recognize the importance of river restoration for the conservation of the environment. However, even with legal mandates, massive expenses, and the emerging industry of riparian restoration, aquatic ecosystems continue to deteriorate due to human influences (KARR, CHU, 1999).

According to the latest survey of Fundação SOS Mata Atlântica, of the water analyzed in 184 rivers, streams and lakes of 11 Brazilian States and the Federal District,27.5% showed poor quality, 70% showed regular quality and only 2.5% showed good quality (FUNDAÇÃO SOS MATA ATLÂNTICA, 2017).

When a river or stream is degraded, we lose many of the ecosystem services that are essential to society (BARON et al. 2002). River restoration aims to recoup some of these losses and to do it in more public acceptable ways and at lower costs than through technological fixes such as waste treatment plants (PALMER et al. 2004).

During the last decades, the use of aquatic macrophytes to improve the quality of water bodies has been very successful. These aquatic plants and the microorganisms associated to its roots can effectively decrease the quantity of nutrients, organic matter, heavy metals and turbidity of the water (SRIVASTAVA, CHANDRA, 2008). By improving the water quality, the aquatic environment can effectively start to recover itself. Thus, the use of macrophytes can offer a good alternative for effluent restoration, however the implantation and the accessibility of this technology is not flashy in some regions. Additionally, the macrophytes when saturated need to be replaced by new ones and they can become hazardous boosters for eutrophication if not controlled properly.

In order to conserve the environment and ensure the availability of water resources to any being in the future, new technologies have to be developed to improve the water quality of the aquatic ecosystems. These technologies can either be an alternative for the use of macrophytes or be used along with these plants. Any proper effort in the restoration of water bodies is valuable to augment the already strained water resource portfolios and preserve the diversity of not only the rivers, streams and lakes, but also the wetlands, forests and swamps interconnected to them.

Objective

Aiming to restore the water quality of rivers, prevent eutrophication and thus help ensure the availability of water resources to any living being in the future, this preliminary work has the object of developing a low-cost alternative method to reduce the concentration of organic matter, turbidity, coloration, suspended solids and nutrients of river waters using waste materials that are in abundance in Brazil.

Methodology

Sampling

Samples were collected from three main sources. The first source was the Gregorio River in which the sampling point was near a settlement called SESC, in the center of São Carlos, SP, Brazil. The second source was the Mojolinho River in which the sampling point was in a course near a lake located inside the Federal University of São Carlos. The third source was the sewage from São Carlos's neighborhood Santa Felicia which was provided by the Department of Environmental Engineering of the University of São Paulo. The samples were collected with buckets and stored in sterilized flasks.

Effect of time on organic matter degradation of biofilms supported in coconut fibers and polyurethane sponges

A study in laboratory scale was made to evaluate the degradation of organic matter of biofilms supported in coconut fibers and polyurethane (P.U) spongesthroughtime.

Twenty liters of water from the Gregorio River collected as described in this methodology before were flowed in an inert water tank, and then 200 grams of coconut fiber were added to the tank. Analysis of Biochemical Oxygen Demand (BOD) was made in the raw sample of the river water and then the same analysis was made in the water sample after 30 minutes, 1, 2, 3 and 5 hours of contact with the coconut fiber. The figure below portrays the water tank with the coconut fibers inside.

Figure 1 – Water tank with coconut fibers.

To compare the efficiency of organic matter degradation of the biofilms, twenty liters of the same water from the Gregorio River were flowed in a second inert water tank, and then 150 grams of P.U sponges were added to the tank. The sponges were cut into small pieces to allow water flow and the pieces were wrapped with a nylon cloth to prevent the water from floating the sponges up. BOD analysis was made in the raw sample of the river water and then the same analysis was made in the water sample after 30 minutes, 1, 2, 3 and 5 hours of contact with the P.U sponges. The figure below portrays the water tank with the sponges inside.

Figure 2 – Water tank with P.U sponges.

Development of a biofilm cell

In order to create a "biofilm cell" which would be applied directly in the effluent to enhance its quality, the following materials were used: coconut fibers, polyurethane sponges, nylon cloth and PVC tubes. The coconut fibers and the P.U sponges were previously left for 7 days in contact with organic matter and microorganism from a São Carlos water river sample (Monjolinho River); afterward, both materials were wrapped in a nylon cloth in order for them not to disperse in the water. In each biofilm cell, 100 grams of coconut fiber and 50 grams of P.U sponges were used. The sponges were disposed more at the top and the bottom of the cell; the coconut fibers were disposed at the center. It was made because biofilms created in coconut fibers are more efficient in the degradation of organic matter and the biofilms in the P.U sponges are more efficient in the reduction of coloration and turbidity as detected before in this study. This arrangement allows the water to have a greater contact with the coconut fiber while its suspended solids are retained by the P.U sponges. The PVC tube would be the support for the cell, and would be attached to the nylon cloth. The figure below outlines the biofilm cell.

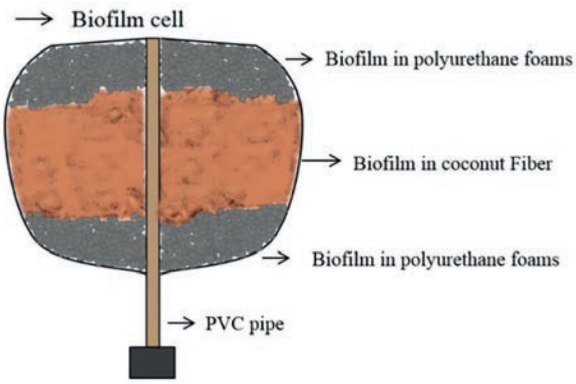

Figure 3 – Biofilm cell.

River condition simulation for efficiency analysis of the biofilm cells

Aiming to evaluate and establish the efficiency of the biofilm cells in the improvement of river's water, a structure was developed to simulate the condition of an effluent. The following materials were used: three wooden planks (Dimensions of 30 × 70 cm), impermeable plastic canvas, 50-liter water tank and wooden supports. The planks were nailed together to form a rectangle without its top face and the plastic canvas was used to clothe the wood and prevent water absorption by it. The water tank was attached to one side of the structure and an opening was made on the other side. The biofilm cells would be placed in the middle of the system, the contaminated water would be dispensed from the tank and the treated water collected at the other side as illustrated in the figure below.

For an initial efficiency test, 5 biofilm cells were placed in the center of the simulator structure. Sewage collected in the University of São Paulo as described before was taken to analysis in triplicate of biological oxygen demand (BOD), electrical conductivity, total suspended solids, turbidity, coloration, phosphorus, and nitrate. Afterwards, the sewage was poured with constant flow in the simulation system and the treated water was taken to the same analyses of the raw sample. The inlet flow rate was approximately 20 ml/s and the samples analyzed were only collected when 5 liters of water had already left the system in order to ensure that the system was already stabilized. A total of 3 treated water samples were collected.

Laboratory analysis

The laboratory analyses were all conducted in the International Institute of Ecology. Analysis for biochemical oxygen demand (BOD) began within 24 h of sample collection using the 5-day BOD test (APHA, 1998). Electrical Conductivity was measured using a Digimed EC meter. Turbidity was measured with a Hach 2100P Turbidimeter using nephelometric methods. Coloration was measured with a calibrated Hach DR3900 spectrophotometer. The Total Suspended Solids (TSS) was analyzed using the Standard method 2540D. Finally, for analysis of nutrients, 30 ml aliquots were used and analyzed by the method of digestion with Potassium Persulfate (VALDERRAMA, 1994), followed by colorimetric reading in the form of nitrate or phosphate as described in Strickland and Parsons (1972).

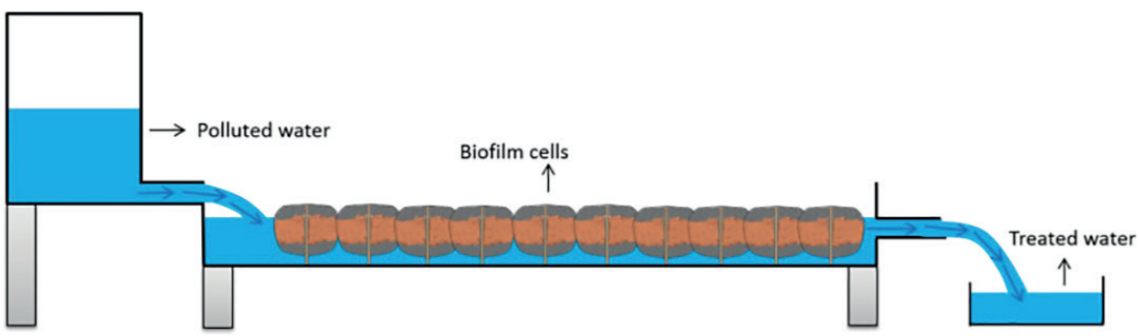

Figure 4 – Structure to simulate a river condition.

Results and Discussion

Effect of time on organic matter degradation of biofilms supported in coconut fibers and polyurethane sponges

The following graph deploys the results of the BOD analysis made to evaluate the effect of time in the organic matter degradation of the biofilms as described in the methodology and a line of best fit.

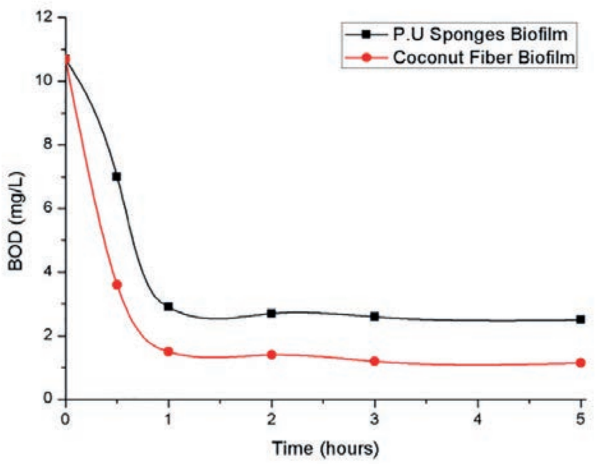

Figure 5 – Graph of BOD throughtime ofwater samples in contact with coconut fiber and P.U sponges biofilms.

As shown in the graph, the organic matter concentration decays exponentially in the first hour and then remains almost static in the next hours.An explanation for this may be that the remaining organic matter after the first hour werePersistent organic pollutants (POPs), therefore the biofilms were not able to degrade it rapidly. The biofilm supported in coconut fiber had an average organic matter degradation rate greater than the biofilm supported in the P.U Sponges. The pores of the coconut fibers are smaller than the ones of the P.U sponges, this makes the fibers more suitable for microorganisms and explains why the coconut fibers had a greater total efficiency for BOD reduction. However, the coloration and the odor of the water were observed todecrease faster in the biofilm supported in P.U sponges, establishing that it contains microorganisms of different functions compared to the ones in the coconut fiber.

These results demonstrate that the biofilms can have potential uses in river restoration once the degradation time was relatively slow for high efficiencies, what is an essential feature for their appliance in water bodies.

Efficiency analysis

The following table displays the results of the laboratory analyses of biochemical oxygen demand (BOD), electrical conductivity (EC), turbidity, coloration, total suspended solids (TSS), total phosphorus and nitrate in the samples collected to evaluate the efficiency of the biofilms cells as described in the methodology. The results shown are the arithmetic mean of the results of all analyzed samples.

Table 1 – Laboratory analysis results of samples in the efficiency analysis.

	Raw Sample	After treatment
BOD (mg/L)	34,82 ±1.21	23.42 ± 2.40
EC (µS/cm)	260.2 ±0.74	218.1 ±7.24
Turbidity (NTU)	50.2 ±0.08	28.6 ±2.08
Coloration (Pt/Co)	80.2 ±0.14	54.9 ± 0.78
TSS (mg/L)	30.00 ±1.75	10.67 ±1.24
Total Phosphorus (µg/L)	840.2 ±32.60	730.1 ± 37.10
Nitrate (mg/L)	5.04 ± 0.29	4.12 ± 0.23

As shown in the table, the biofilm cells are efficient at improving the water quality, having an efficiency of 32.73% in the reduction of BOD, 16% in the reduction of electrical conductivity, 43% in the reduction of turbidity, 31.5% in the reduction of coloration, 64.4% in the reduction of suspended solids, 13.1% in the reduction of phosphorus and 23.6% in the reduction of nitrate.

The decrease in BOD reveals that the microorganism established in the biofilm cells can effectively and rapidly degrade organic matter. The reduction of nutrients in the water is reflected in the fact thatthe coconut fiber can act as a natural biosorbent of nutrients due to its physical and chemical properties (LO MONACO, MATOS, SARMENTO, LOPES JÚNIOR, LIMA, 2009). Considering the simulation system was with a relatively high flow rate, hence not allowing the water to have contact with the coconut fibers and the P.U sponges for a long time, the reduction of organic matter, nutrients, and suspended solids show the potential of the biofilm cells of reducing these parameters in a real river condition, where the contact time will be even lower. The more biofilms cells in the system, the more it is expected to have higher efficiencies once there will be more microorganisms and more absorbent materials available. Therefore, these results show that the biofilm cells can be applied to improve the water quality of effluents.

Conclusion

Biofilms supported in coconut fibers and polyurethane sponges are efficient in the degradation of organic matter and the contact time needed to achieve great decrease percentages is relatively low. The biofilm supported in coconut fibers is more efficient at the decrease of BOD, but the biofilm supported in the P.U sponges is more efficient in the decrease of coloration and odor. By gathering both materials and applying them in a river simulating condition, it was possible to detect their efficiency in the reduction of organic matter, suspended solids, turbidity, coloration, and nutrients. The results gathered showed relatively great efficiencies to all parameters studiedand the contact time of the water with the materials was very low, what reveals the potential use of these materials to improve the water quality of waterbodies and thus boost its restoration.

The structures developed and studied in this preliminary work could either be applied directly in a river or applied along with floating macrophytes in order to achieve greater efficiencies. Thestructures are easy to implement, have a low-cost, and should be placed in several parts of a river or lake, tothereby gradually improve their water quality. However, further research is needed to establish the relationship between the number of biofilm cells and the system efficiency, the influence of the water flow rate, the influence of pH and temperature, the potential decrease of heavy metals and the maximum usage time of the biofilm cells.

Acknowledgement

This research was partially supported by the International Institute of Ecology (IIE). I thank my colleagues from IIE who helped me in the experiments execution and laboratory analysis, especially Leandro Campanelli, who accompanied me in all laboratory analysis and provided full support. I would also like to show gratitude to Prof. José Galizia Tundisi, who provided me the use of the laboratory, supported the funding and gave me the opportunity of publishing this paper.

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The Use of Geotechnologies In the Environmental Vulnerability Diagnosed in Sustainable Use Conservation Unit

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Abstract

The misuse of agricultural activities has been a cause for concern as to the risks of contamination of soil and water, with possible health and environmental impacts. The objective of this study was to verify the environmental vulnerability of water resources in the Environmental Protection Area of the Uberaba (APA). The condition of risk and fragility that the environment is found was determined using the multicriteria modeling

of morphometric parameters and soil occupation, and data analysis was performed in a geographic information system (GIS) platform. The intervening factors selected for analysis were: drainage density, slope, soil classes, distance of water lines and land use and occupation. It was possible to jointly evaluate the different information plans and to generate from the multicriteria the vulnerability of the water resources in the APA.

Keywords: information system, morphometry, conservation planning, multiple criteria.

Introduction

Environmental vulnerability refers to the risk of degradation of the natural environment, related to soil erosion, loss of biodiversity, soil and water resources contamination and loss of vegetation cover exacerbated by anthropogenic factors, which may result in the loss of biodiversity and compromise the quality and quantity of natural resources (COSTA *et al.*, 2007).

Multicriteria decision modelling (MCE) based on the geographic information System is the basis of decision-making, and the weighted Linear combination (WLC) is one of the basic methods, which makes Exchange of factors “with each other”. Modeling is an important tool for the study of environmental analysis (VELDKAMP, LAMBIN, 2001). This methodology provides alternative techniques to incorporate decisions preferences in the environmental assessment process. Thus, the objective of the use of MCE model is to find solutions to the problems of decision making characterized by multiple alternatives, which can be evaluated by using decision criteria (PINTO, 2010, BOTTERO *et al.*, 2013).

Fuzzy logic, drawn by Zadeh (1965) became an important topic of research during the Decade of 1980 for use in GIS and environmental adequacy analysis. Consists in algebraic logic analyses of maps, sustained by the similarity Bayesian probability and Boolean, generating maps by map cumulative algebra through the standardization of the variables used, converting the data values unique in fitness values to the desired purpose.

Several researches in different areas were developed using MCE. Such studies in agriculture (AKINCI *et al.*; 2013, DRAGINCIC *et al.*; 2015;), soil conservation and fitness (VALLE JUNIOR *et al.*; 2014;), irrigation (CHEN, PAYDAR 2012), conservation of water resources (VALLE JUNIOR *et al.*; 2015; CALIZAYA *et al.*; 2010), conservation of natural resources and forestry (Bottero *et al.*; 2013; KAYA and KAHRAMAN 2011), transport and industrial projects (MACHARIS *et al.* 2012), Economics (MARTIN-ORTEGA, BERBEL 2010; ZUBARYEVA *et al.*; 2012) among others, showed the functionality of the multi-criteria analysis in decision making in different application areas.

The APA of Uberaba River just had a recognition and concern in 2003, in which in the Alegria, this basin in the APA, there was a derailment of a freight train, and this accident is considered the largest environmental disaster of the TriânguloMineiro until the present day. The charges were made up by the octanol ($C_8H_{18}O$), methanol (CH_4O), ISO-butanol ($C_4H_{10}O$) and potassium chloride (KCl) in which, with the accident, an explosion occurred and which devastated more than 1000.0 m of native vegetation, as well as deposit and disperse more than 670 kg of contaminants in soil and water. Public water supply was interrupted for more than 5 days and it was decreed a State of public calamity. In this period the lack of water was supplied by water trucks, however, insufficient. More than 250,000 inhabitants were impacted by the lack of water due to this accident and the contamination of water resources.

The aim of this paper is to draw up the diagnosis of environmental vulnerability of water resources from the multi-criteria modeling of physical parameters and microbasin in the APA morphometric of Uberaba River, through the use of GIS.

Area of study

Their diagnosis of vulnerability of water intercepted by highways in Environmental Protection Area APA of Uberaba River (Figure 1) which is part of the Uberaba River basin, located between the geographical coordinates 19.51° and 19.74° South and 47.64 and 47.98° West of Greenwich in the city of Uberaba-MG.

With a total area of 525.27 km², the APA of Uberaba River has 62 microbasins, bounded from the main course, which contribute significantly to the quantity and quality of water resources which supplies the city of Uberaba.

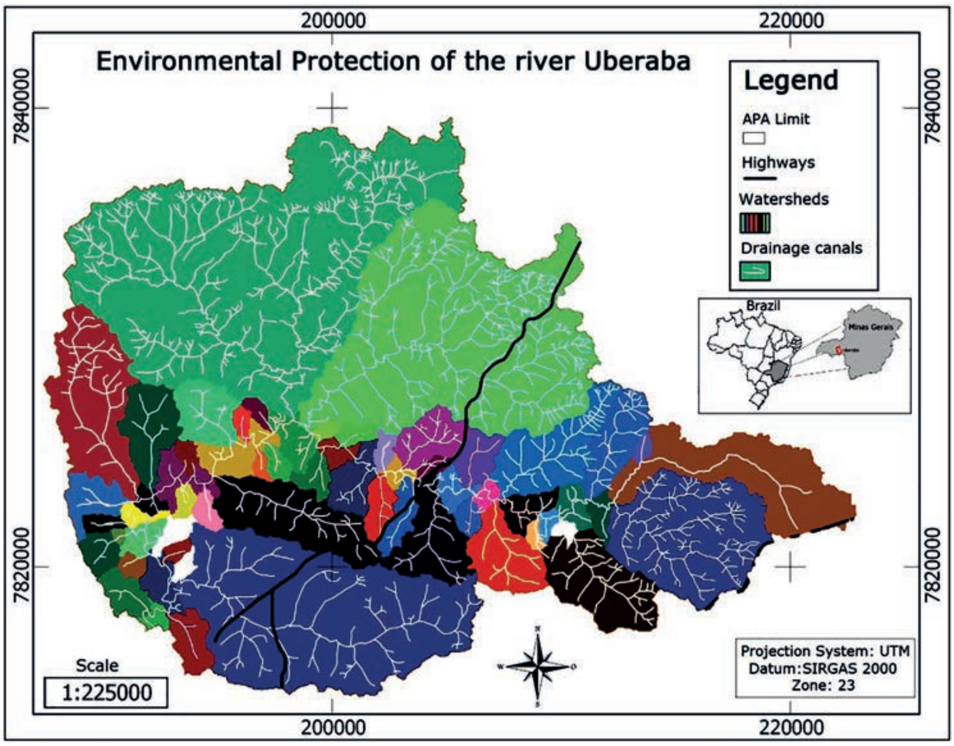

Figure 1 – APA of Uberaba River. Source: Siqueira.

The climate of the region is classified according to the Köppen type Aw-hot humid tropical, with cold winter and dry, being the domain ranking the humid climate with 4 to 5 dry months (ABDALA, 2012). The average annual precipitation varies between 1300 and 1700 mm in the rainy period corresponds to the warmest period of the year. Therefore, there is a characteristic rainy scheme from October to March and a dry season from April to September. The months of December and January are the rainiest.

The municipality of Uberaba is located in Sandstone Plateau Basalt relief of the Paraná basin with soil showing varied characteristics. Most have average texture, ranging from sandy to clay and are classified, in general, as the presence of microaggregates showing varying degrees of fertility, with a predominance of Red Latosol Distroférrico medium-textured, Red Latosol typical and Acrisol Red-Yellow Latosol (NISHIYAMA, 1998).

Cruz (2003) points out that the topography is characterized by flat or slightly wavy surfaces, geologically formed by sedimentary rocks, basically the sandstone, the Cretaceous Bauru formation.

Materials and Methods

Multi-Criteria Analysis

The Idrisi GIS features integrated image processing feature for analysis and visualization of spatial data, developed by researchers at CLARK LABS, Department of geography, Clark University, Worcester, MA. In addition to the GIS analysis modules, image processing, surface analysis, change and time series analysis and modeling, the Idrisi provides a set of useful tools to support the decision-making process. In particular, it provides functions to implement the objective evaluation weighting procedure multi-criteria, standardization and diffuse set of criteria for aggregation. The Weighted Linear combination (WLC) present in the module, multiple criteria evaluation (MCE) of Idrisi Jungle, made it possible for this type of work (EASTMAN, 2012).

Second Malczewski (1999) and Garfi *et al.*, (2011), multicriteria methodology, the developed model follows three phases: (1) selection of the criteria (factors and constraints) for the analysis and creation of raster maps; (2) assignment of weight to each criterion; (3) combination of criteria and creating the final suitability map. In general the methodological process of multi-criteria analysis can be observed as shown in Figure 2.

Data acquisition and choice of factors and constraints

It was determined for this study of environmental vulnerability of water resources in APA of Uberaba River the acquisition and preparation of thematic mapping of physical factors and watershed morphometric totaling 5 (five) factors (drainage density, distance from watercourses, slope of the land, use and occupation of the soil and soil classes) and 1 (one) constraint (drainage networks). The restriction was used to the water courses were not classified in classes of vulnerability.

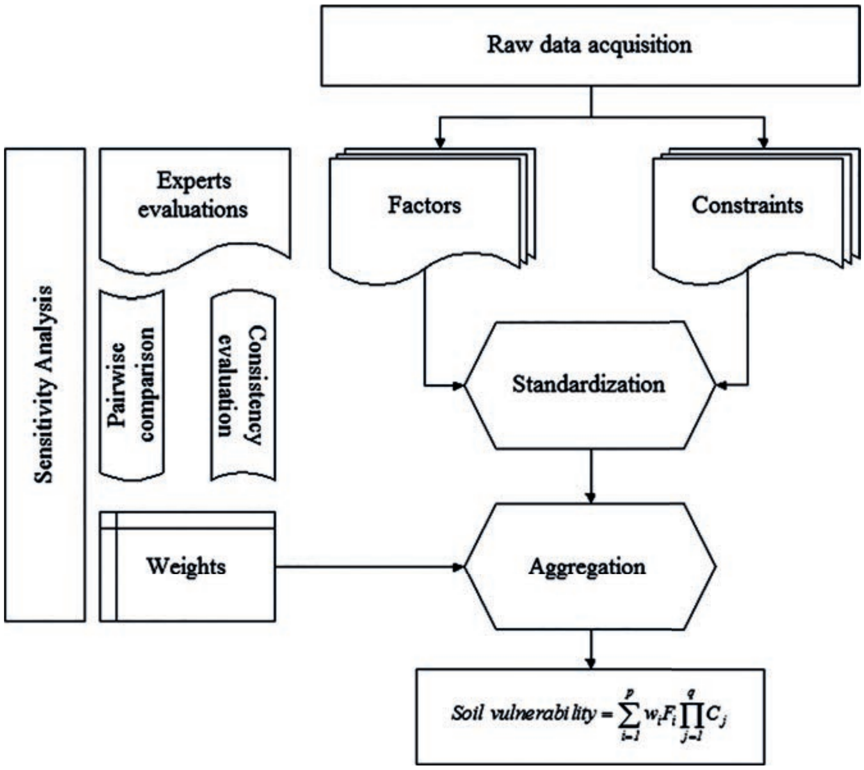

Figure 2 – Methodological process of multi-criteria analysis. Source: Adapted from Siqueira *et al*. (2017).

The map of the drainage network (Figure 3) in the area under study was drawn from the Digital Elevation Model-DEM, rendered image of the Aster GDEM Sensor (Digital Global Elevation Model), at the geographic information System – GIS. The vector file of drainage was exported to the "Google Earth", which has made checking and modification, when necessary, of the respective watercourses. Subsequently, exported the vector file (drainage network) for the GIS Idrisi Jungle, being this the Cartographic base for the development of the database.

The demarcation of the microbasin of the study area were performed from the DEM, in GIS Idrisi Jungle, through the "Watershed". Once generated the information flow was traced the point closest to the exhilarating (mouth) of each watershed with the main course of the Uberaba River and using "Watershed" was bounded each hydrographic watershed.

Drainage density corresponding to relative to the total length of the channels ($\sum L$) in (km) and the area of the watershed (ABH) in (km²) (CHRISTOFOLETTI, 1980), was calculated on the following formula:

$$Dd = \sum L / ABH \qquad \text{Eq. 1}$$

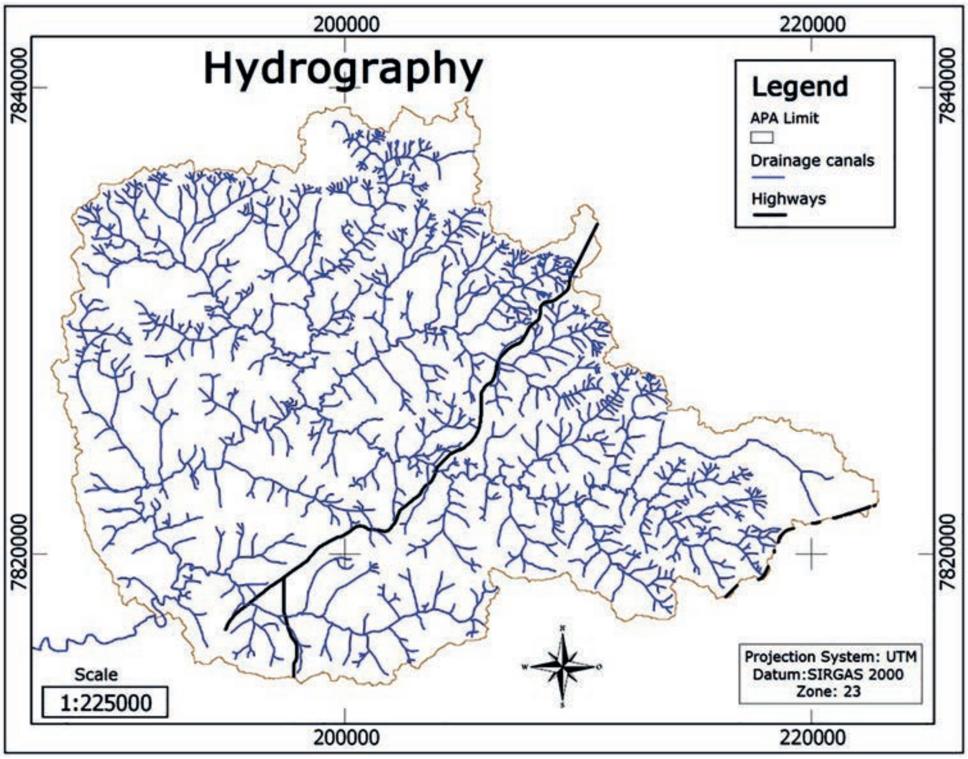

Figure 3 – Map of the APA of Uberaba River drainage.

The data were obtained from the morphometric study of the APA of Uberaba River microbasin. Using vector files of drainage networks and proceeded to read of the lengths of each strand of microbasins in AutoCad software by the command "Modify-Lengthen." The area of the basin was automatically calculated in the GIS with the tool "area".

The values of the density of each drainage basin of the APA were classified according to the criteria described by Vilela and Mattos (1975), such that the index of Dd varies from 0.5 $km.km^{-2}$, for with poor drainage basins, the 3.5 or more, for exceptionally well drained basins. Was held on Standardization of information plans where the drainage density values were reclassified as shown in Figure 4.

The map of the distance from the waterline (Figure 5), drawn from the drainage networks, originated from GIS Idrisi Jungle by distance operation menu "Buffer". Generated from the "Buffer" command the matrix file from distances of 30, 50, 100, 150 and 200 meters.

The map of slope land was drawn from the DEM where was applied in the GIS image clipping of the study area. With the use of the "Slope" tool in the GIS were generated in percentages the land slope classes. After raised the percentages of declivity was conducted the reclassification of slope classes using the reference ranges of EMBRAPA (1999) described in Table 1 and illustrated in Figure 6.

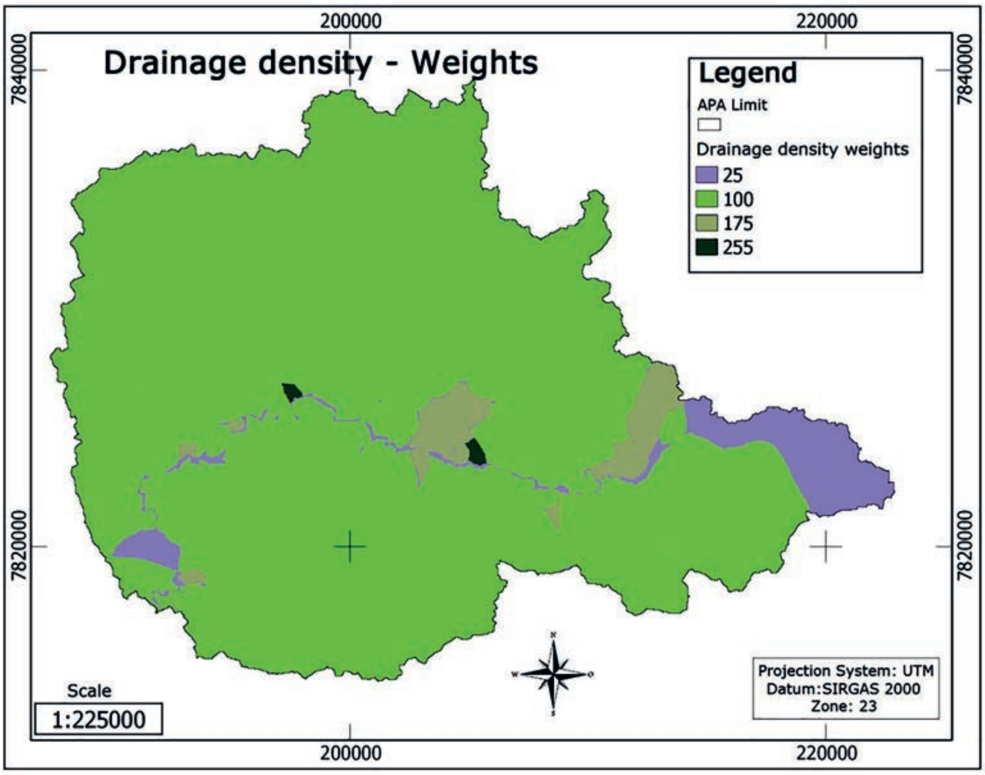

Figure 4 – Map of drainage density of the APA of Uberaba River.

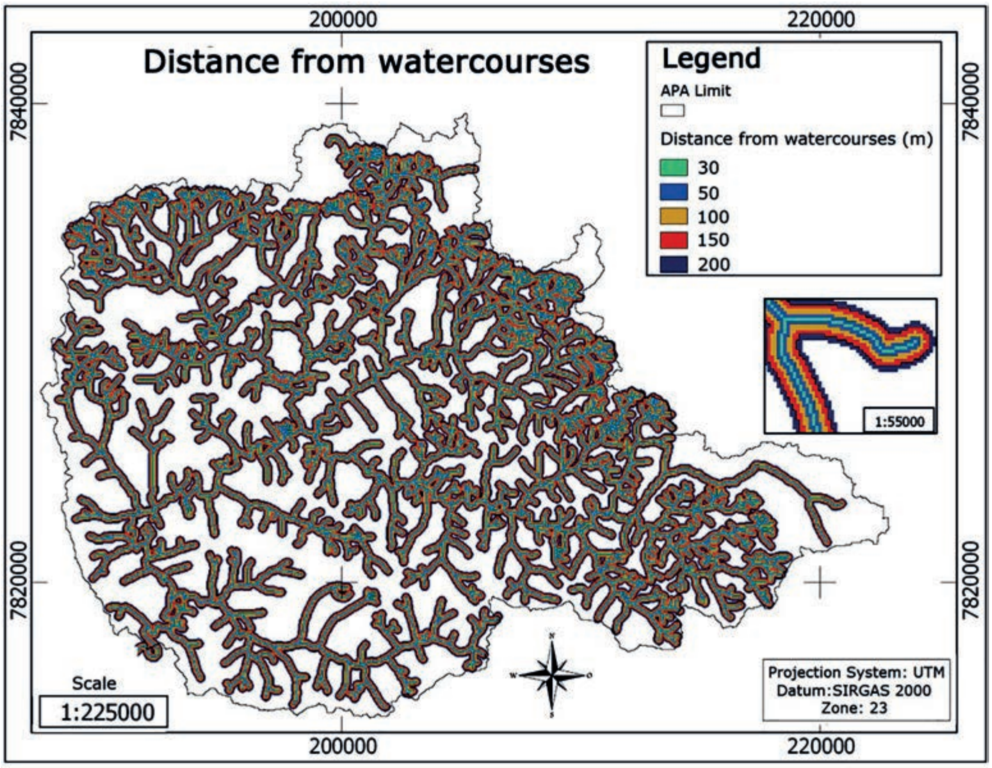

Figure 5 – Map of the distance from the waterline.

Table 1 – Class intervals of slope and its corresponding reliefs.

Slope	Discrimination
0-5	Relief plan the gentle wavy
5-10	Gently rolling relief the wavy
10-20	Wavy to moderately undulating relief
20-47	The rugged mountainous relief
> 47	Mountainous relief

Source: EMPRAPA (1999).

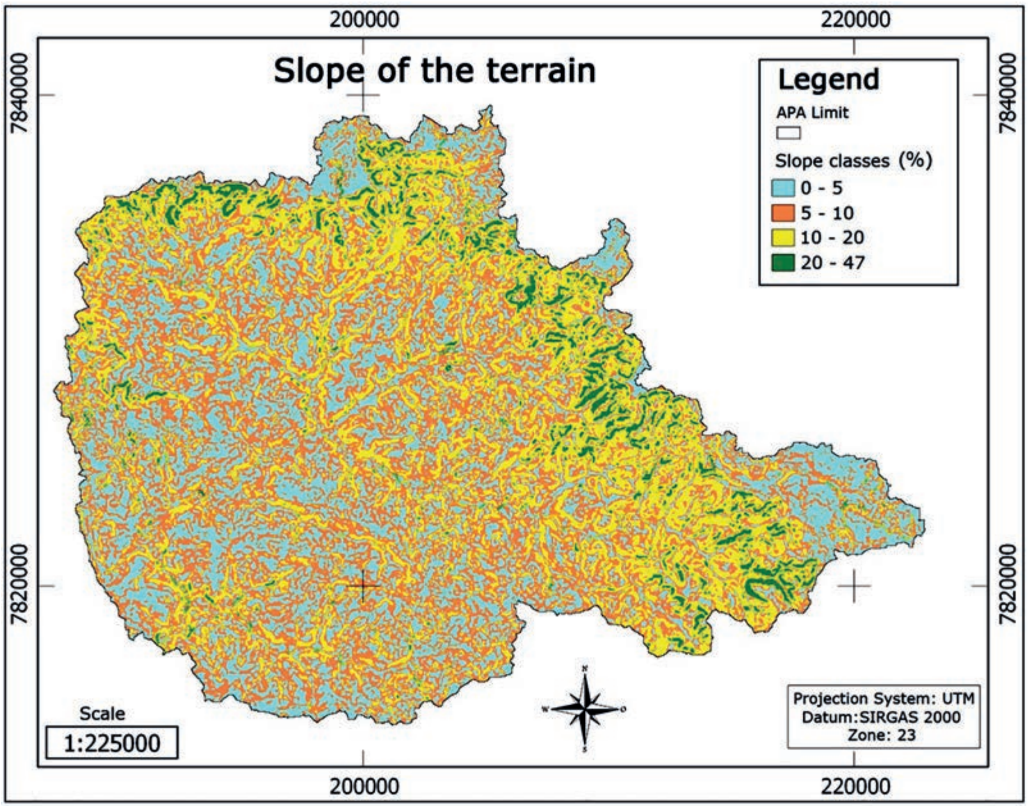

Figure 6 – Map of declivity of the APA of Uberaba River.

The map of soil use and occupation (Figure 7) has been developed using the supervised classification with use of the tool "Maxlike" of the GIS were used images from the Landsat 8 satellite Sensor "OLI-TIR" collected by the geological survey of the United States dated 06 February 2014, with spectral resolution of 30 metres. Were used for the colour composition bands 4 (R), 3 (G) and 2 (B) in which these scenes were cut individually in GIS. Following devised the Landsat 8 RGB composition with the use of "Composite" tool. Were classified as to the use of the soil the following vegetable toppings: pasture, forests and annual crops.

The map of soil classes was generated from the cut in the soil of the State of Minas Gerais provided by UFV *et al.* (2010), illustrated in Figure 8.

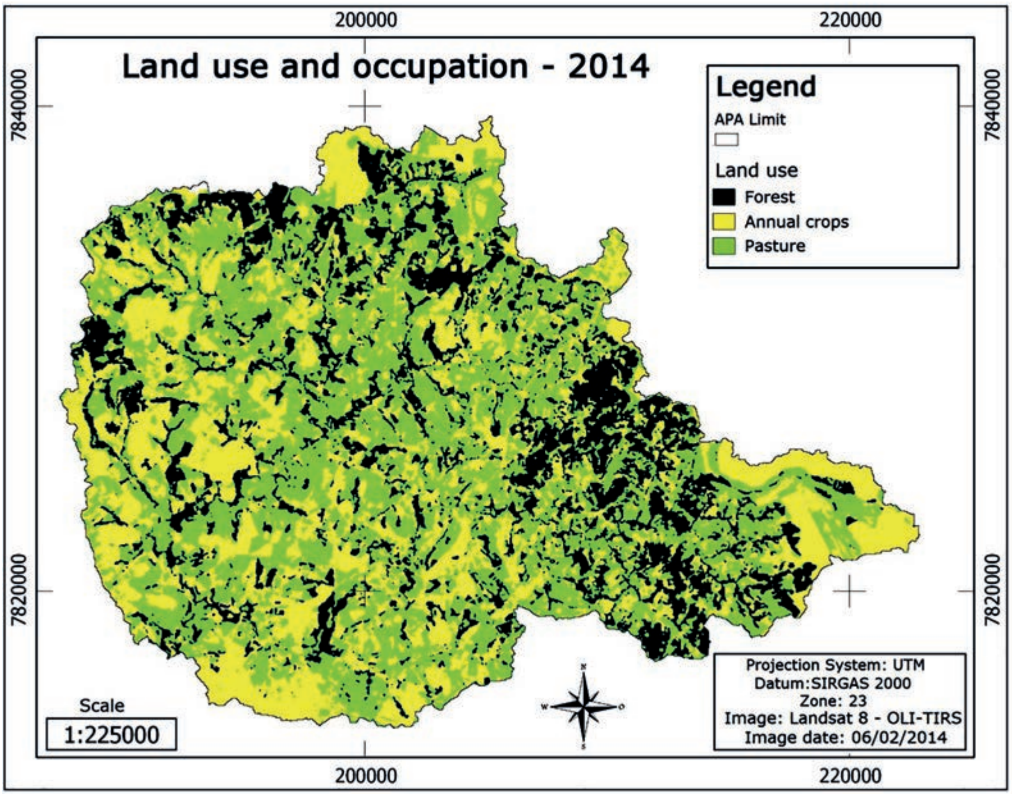

Figure 7 – Map of soil use and occupation of the APA of Uberaba River (2014).

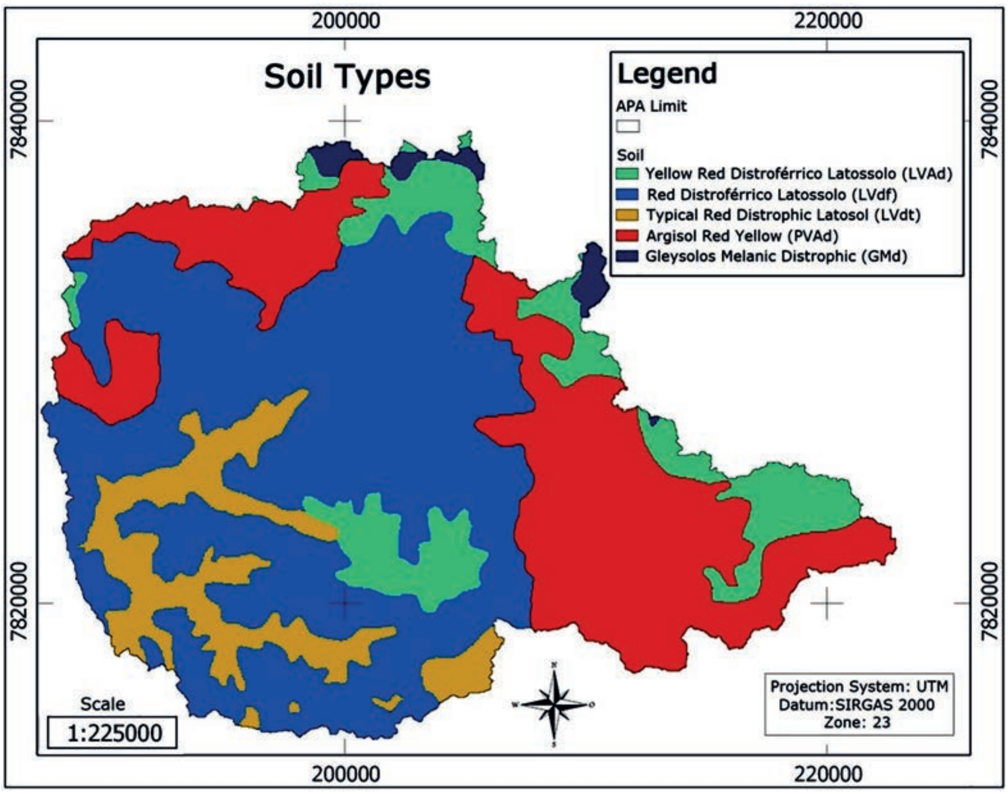

Figure 8 – Map of soil classes of APA of Uberaba River.

The maps generated in this study adopts the system of Universal Transverse Mercator projection (UTM); 23 zone; Datum horizontal alignment 2000 SIRGAS (Geocentric Reference System for the Americas).

Standardization

The standardization of the criteria analyzed followed a byte-level range (0 to 255), assigning the level 0 less importance and 255 greater importance. The construction of decision rule was executed by means of the functions of relevance to the whole “fuzzy”. The slope, drainage density, distance of water courses, classes of soil and the use and occupation of the soil were analyzed as continuous maps in “raster” format.

Sensory analysis and assignment of weights

Possession of the structured criteria in database in GIS, sensory analysis of these criteria, which consisted of bibliographic surveys and discussions with multidisciplinary team about the importance of each factor in the process of vulnerability of water resources. Sought in the discussions with the various forms of interpretation and of values assignments and importance in the different criteria used in these studies (Table 2).

Importance values used in this study was also observed in research developed by Abbaspour *et al.* (2011), Pinto (2010) and Valle Junior (2014) related to environmental vulnerability.

Depending on the use of several factors for surface analysis of water resources vulnerability and whereas these have different weights in the decision-making process was established the routine WEIGHT (“Weighted Linear Combination”-WLC) from IrisDRISI, a weighting of variables, according to your degree of relative importance on the decision. Through a paired comparison technique, developed by Saaty (1980), in the context of a decision-making process known as analytic hierarchy process (AHP), which consists of the categorization problem in linear hierarchical levels of importance in relation to each environmental factor (Table 3).

Based on the scale of comparators in Idrisi were adopted 3 (three) different weighting factors scenarios by assigning greater importance to the criterion value of slope of the land (scenario 1), drainage density (scenario 2) and soil class 3 scenario (Table 4). This procedure was used to compare and identify, after the assignment of weights in different scenarios, which criteria indicates the areas of vulnerability of water resources.

The routine of the MCE of Idrisi, once assigned importance values, determined the statistical weights for each factor (Table 4) and calculated the consistency index.Indicates the probability of the consistency of the points array to be generated at random and shall be less than 0.1 for model be considered accepTable (EASTMAN, 2012).

Table 2 – Criteria identified for the study of environmental vulnerability.

Criteria (factors)	Assigned	Values
Drainage density (Km/Km^2)	Too Low	5
	Low	25
	Media	75
	High	125
	Too high	255
Away from the water lines (m)	Distance (30 m)	255
	Distance (50 m)	175
	Distance (100 m)	115
	Distance (150 m)	75
	Distance (200 m)	50
Slope of the land (%)	Slope (0 to 5%)	25
	Slope (5 to 10%)	75
	Slope (10 to 20%)	125
	Slope (20 to 47%)	175
	Slope (47%) >	255
Soil class	The presence of microaggregates	100
	Argissolos	200
	Gleyssolos	255
Soil use and occupation	Forest Fragments	255
	Pasture	125
	Annual Crops	75

Table 3 – Scale of comparators with the respective weights of importance – fundamental Scale Saaty (1980).

Values	Mutual importance
1/9	Extremely less important than
1/7	Very strongly less important than
1/5	Strongly less important than
1/3	Moderately less important than
1	Equally important to
3	Moderately less important than
5	Strongly more important than
7	Very strongly more important than
9	Extremely important that

Source: Saaty (1980).

Table 4 – Paired comparison matrix which is part of the analytic hierarchy process-AHP (SAATY, 1980).

	Distance from watercourses	Use of soil	Soil class	Slope of the land	Drainage density	Weight
Distance from watercourses	1	1/3	1/5	1	1	0.0863
Use of soil	3	1	1/3	1/5	1	0.2702
Soil class	5	3	1	1/3	1/5	0.4658
Slope of the land	1	1/3	1/5	1	1/3	0.0863
Drainage density	1	1/5	1/3	1	1	0.0913

The AHP was implemented by the module of weight of the IDRISI Junglesoftware. To this set of factors, the consistency index calculated was 0.07 in scenario 1, 0.07 in scenario 2 and 0.04 in scenario 3 considered acceptable for all scenarios adopted.

Aggregation

The data were aggregated on weighted linear combination (WLC) (“Weighted Linear Combination”) of the Idrisi, considering their respective weights resulting in a map from 0 to 255. It was necessary to combine the data, in order to achieve the General map of vulnerability. In this case, a weighted linear combination was used, which combined the criteria and restriction maps according to the following formula:

$$Sj = \left(\Sigma Wi\, Xi\right)\ \Pi\left(Ck\right) \qquad \text{Eq. 2}$$

Where:

- Sj: represents the risk to pixel j;
- Wi: represents the weight of the factor i;
- Xi: represents the criterion score of factor i;
- Ck: represents the constraint criteria score k and;
- Π: is the symbol of the product.

The factors were combined in applying weights following adequacy calculated from the product factors to the restrictions. The map was reclassified (Table 5) in five classes of vulnerability of water resources: Invulnerable, Moderately Vulnerable, Vulnerable, Heavily Vulnerable and extremely vulnerable and their respective areas were spatialized and calculated.

Table 5 – Range defined for classifying degree of vulnerability.

Risk classes	Range of Classes
Invulnerable	0-50
Moderately Vulnerable	50-100
Vulnerable	100-150
Heavily Vulnerable	150-200
Extremely Vulnerable	200-255

Results and Discussion

Sensitivities of the factors and assignment of weights

The importance of soil class, fator weights were the 0.0863 (distance of watercourses), 0.2702 (soil use and occupation), 0.4658 (soil class), 0.0863 (slope of the land) and 0.0913 for drainage density; being the relationship of consistency of 4%. However, for similar weights for the same scenario 3 noted that the consistency index was the sameobtained by (VALLE JUNIOR *et al.* 2014). In this manner, appending the drainage density factor the consistency index remained the same.

The vulnerability in the APA

The map of vulnerability of water resources based on weighted linear combination (Eq. 2) of the factors referred to above is illustrated in Figure 9, with the values of the vulnerability described in the Table 6. The results of the vulnerability represent am the high potential risk of contamination of water resources therefore strongly classes and extremely vulnerable occupy a portion of (16.39%, 7.12%) of the APA and the vulnerable class (49.89%) total 73.4%. The most plausible cause for this fact is the occupation of the areas Gleysolos, Argissolos and the presence of Microaggregates coupled with land use factor thatwereclassifiedwith a very high note until 255 byte.

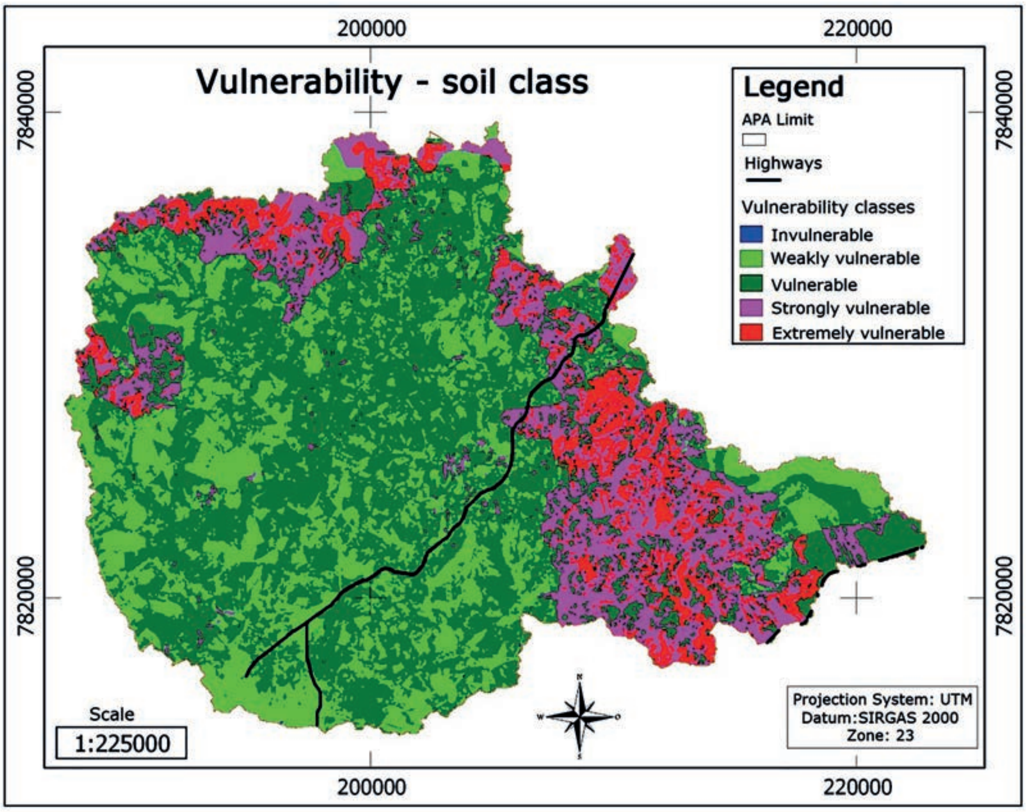

Figure 9 – Map of vulnerability of water resources in APA of Uberaba River.

Table 6 – Areas of vulnerability in the APA of Uberaba River.

Risk classes	Area (km^2)	Percentage of area (%)
Invulnerable	0.00	0
Moderately Vulnerable	138.438	26.6
Vulnerable	259.690	49.9
Heavily Vulnerable	85.340	16.4
Extremely Vulnerable	37.061	7.1
Total	**520, 529**	**100**

With this study it was possible to determine in the APA of Uberaba River the vulnerability environmental. According to morphometric and physical parameters of the catchment area and with the use of the Geographical information system it was possible to evaluate jointly the different levels of information.

Because it is a conservation are a the area of Environmental protection, whose activities must be sustainable and use their water resources (main course of the Uberaba River) bein the supplying the population of Uberaba, thereis a need for studies that seek to assess the environmental quality of the existing natural resources as well as propose measures of preservation and conservation.

Environmental vulnerability occurs in the area studied, which indicates the risk of degradation of the natural environment, related to soil erosion, loss of biodiversity, contamination of soil and water resources and vegetation cover loss aggravated by roads and misuse of the soil.

The dominant factor in the transport of contaminants to the water courses is the runoff, being the same powered by declivities, uses presented soil and physical characteristics of the same. In this way the classes of soils prone to shallow streams generation given its characteristics, the topography, the distance of the courses of the rivers interfluvial (drainage density and uses data to soils) should be strongly considered as elements of decision making for the management of water resources of this area, in order to promote the maintenance of them quantitatively and qualitatively.

Conclusion

The use of multi-criteria analysis applied to the study of vulnerability of water resources can be employed in several studies since thereis a correlation to the factors involved.

Morphometric and physical aspects of influence in basin environmental vulnerability.

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https://doi.org/10.26626/978-85-5953-031-5.2018C018

World Bank Model Calibration Project with SWAT Methodology in Ochomogo River, Nicaragua (1st Stage)

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Abstract

The World Bank's Model Calibration Project with the SWAT Methodology in the Ochomogo River (1st stage) is an investigation that begins as a necessity for generating field data to calibrate the data already presented in the study conducted by the World Bank (2013).Considering the Ochomogo River as an important tributary for the Cocibolca Lake, the World Bank by using SWAT modeling calculated an estimation of the incoming volume of sediments that enter to the lake, in order to identify the principal pressure exerted on the river by the diverse human activities taking place in the sub-basins than discharge into the lake. This investigation consisted generating the data for tracing calibration curves used for the analysis of the watershed behavior. Besides obtaining data from the sensors, installed by the investigation team in alliance with Seattle University, used for monitoring the levels of the river in real time and the flow measurements made weekly, currently there are also installed two rain gauges which recordings match the historical data of precipitation for that area. In order to improve the credibility of the data, it's recommended to continue the monitoring, especially the data obtained about the correlation between the led sensor recordings

and the quantity of total suspended solids. The principal goal expected to achieve in the following stages is to apply the SWAT modeling with the information that'll be generated to the basin and being able to calibrate it and improve it with time.

Keywords: hydrographic basin, hydrological monitoring, flow, lake, sedimentation, modeling validation.

Introduction

The Lake Cocibolca Watershed located in Nicaragua is an important freshwater resource for the country, and its value transcends all of Central America. Currently, this resource is being used as water supply for some cities and its use may increase in the future. Being second largest lake in Latin America and the watershed's location within the Mesoamerican Biological Corridor has made it a meeting ground for fish, bird and mammal species from North and South America.

The Lake Cocibolca and its watershed are under pressure from multiple sources that threaten its ecological balance, as the sediment and nutrient load coming from the sub-basins that compound it; given the few information available and lack of monitoring over time, the degree of environmental degradation is unclear. In this context, the International Bank for Reconstruction and Development (The World Bank) carried out a study in 2013 where they evaluated the sources and the magnitude of these pressures that threaten the Lake, through the application of a hydrological and land use model SWAT (Soil and Water Assessment Tool). The study was developed to obtain an approximation about the volume of sediments and nutrients that arrive annually to the lake.

In this study the Ochomogo River was identified as one of the main sediment contributors, however, this evaluation should be interpreted cautiously because the model has not been calibrated; this is due to the little availability of data, which limits the assessment of the severity of environmental problems and their likely of social and economic impacts. Therefore, these measures should be taken as indicative measures of magnitude instead of precise estimates.

The present investigation begins as a need to analyze the estimates presented in the study conducted by the World Bank. And it covers from the analysis of available information, such as maps of current land use, topographic sheets and meteorological information, to the analysis of information generated in the field. To obtain field data it was necessary the installation of equipment in the Ochomogo river, in the lower part of the basin. This equipment has sensors that allow monitoring in real time, atmospheric pressure, hydrostatic pressure, temperature, suspended solids (measured by turbidity) and precipitation.

This investigation offers the possibility of generating information that is extremely useful for the beginning of future research. The data obtained have the purpose of contributing to the development of the communities; in this case, the intention is make flood maps, identification of risk areas through the analysis of the hydrological characteristics of the basin and the hydraulics of the main channel.

The analysis of the data obtained leads to the calibration of the model in one of the basins that contributes the largest volumes of sediment to the lake according to the World Bank report, such as the Ochomogo River. The information obtained to date has allowed generating calibration curves for the analysis of the behavior of the basin. Likewise, in order to verify the veracity of the data comparisons were made of the rainfall data from the meteorological stations of the Nicaraguan Institute of Territorial Studies (INETER) and the one obtained by the sensors installed by the research team, compound by Universidad Centroamericana and Seattle University professors and Students.

The main aim of the present study was to analyze the results of meteorological and hydraulic data obtained in the first stage of the World Bank Model Calibration Project with the SWAT methodology in the Ochomogo River located in the department of Granada, Nicaragua.

Methodology

Placement of instruments

The study was performed in the Ochomogo river basin, delimited with the SWAT tool and validated through the Nicaragua Basins Guide under the Pfafstetter methodology developed by the Nicaraguan Institute of Territorial Studies (2014). The installation of equipment for data collection, based on the methodology of the study of Wagner, Boulger, Oblinger, & Smith (2006). This consisted of the placement of two rain gauges with information storage systems at distant points within the watershed and the location of topographic sights and an electronic circuit in the lower part of the watershed on the riverside. The circuit was constituted by a pressure transducer, a turbidity sensor, a temperature and atmospheric pressure meter, programmed through an arduino and coupled with a mini GSM module, this allows the transmission of the values obtained in 15 minutes intervals, by satellite signal to a web page corresponding to a public data collection site called ThinkSpeak.

A series of area reconnaissance visits were carried out, in order to select the most appropriate place to obtain real data, considering the lowest anthropogenic incidence, the security of the installed equipment and the guarantee of the transmission in real time. As well the disposition by the owner of the farm was contemplated due to the need to take note of the river level in the topographic sights twice a day.

The installation of the electronic circuit was made according to the method described by Kelley *et al.* (2014), it was installed on September 13th, 2016 in the lower part of the basin, near the river, ensuring the submersion of the pressure transducer and the turbidity sensor up to the reference level considered after the placement of topographic sights.

The Rainwise pluviometers were calibrated to know exactly the number of millimeters of water represented by each registered unit. These were placed on October 17, 2016, one was placed on the farm adjacent to the site of installation of equipment in the river, and the second one was located in the middle of the basin, in the urban area of the city of Nandaime.

For the establishment of the correlation between the readings made by the turbidity sensor and the concentration of solids in the water, the dilution of 6 samples with various amounts of sediments was carried out prior to the installation.

Field measurements

The compilation of information in situ was carried out through nine visits, after the installation of the equipment, in these we proceeded to make battery changes, maintenance of the equipment and download of the stored information.

For the determination of the river flow, a current meter was used, through which velocity measurements were obtained in manner of revolutions per minute in a cross section of the river as described by the World Meteorological Organization (2011). This was determined through the vertical measurements from the starting point, to over the total width, dividing it in sections of 1,5 meters each; considering the relationship of the velocity with the water column of the section, measurements were made at 20 and 60 percent of the total depth to obtain a more truthful average. In view of the flooding of the river, due to safety measures, the method of surface determination by flotation was used.

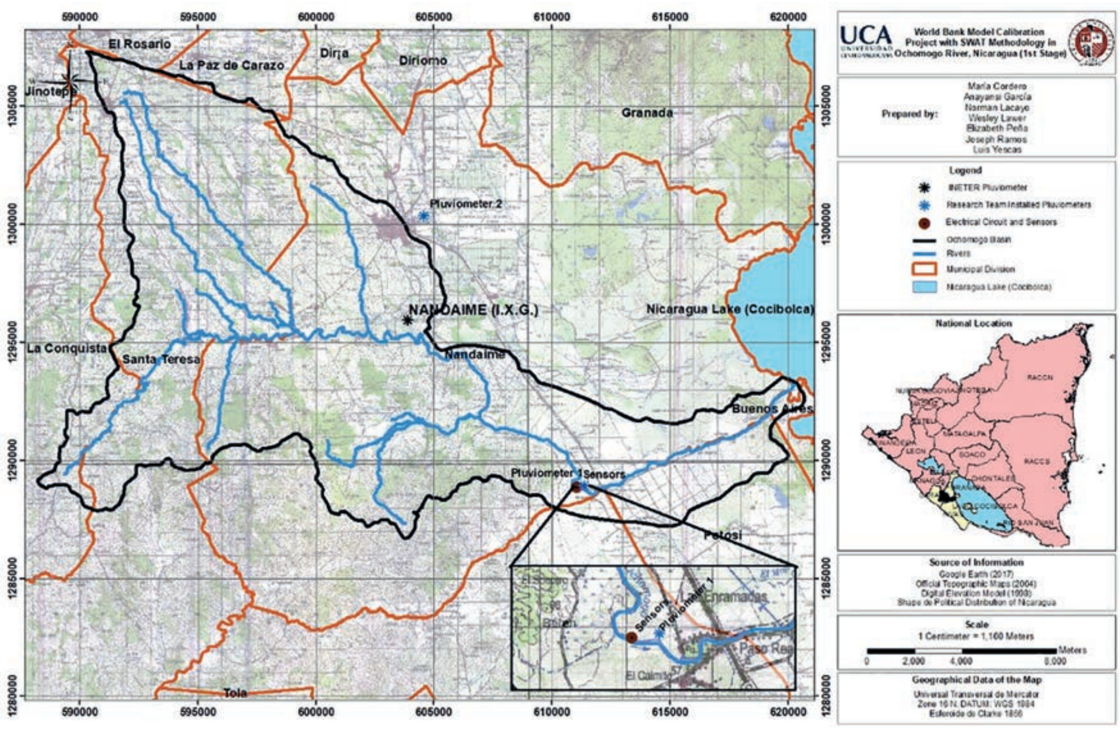

Figure 1 – Map of the Ochomogo sub-basing showing the location of monitoring points.

The sampling of water was made during the months of September-December 2016, at the same point of the flow measurement, using the collector vessel to perform the immersion to an appropriate depth in an ascending and descending manner, guaranteeing its total filling.

The discharge of the two rain gauge information was differentiated, obtaining values from its installation until the middle of November for the first one and the second until the first 16 days of the month of December.

Determination of solids concentrations

The water samples were analyzed through the methodologies established by the Standard Methods for the Examination of Water and Wastewater prepared by American Public Health Association (1998), this was carried out for the parameters of total suspended solids, total solids and their fixed and volatile components. All the prepared dilutions were made considering the total volume of the sample, it was only used 10 milliliters for each of the nine samplings made in the field visits.

Information Processing

The information obtained was compiled and arranged, the existing bibliographic information was considered for structuring the results.

The precipitation values of the two sampled sites were correlated for the analogy of events within the basin. It was compared with the historical data of the Nicaraguan Institute of Territorial Studies (INETER) in the Nandaime station of the last 16 years for the only month of complete measurements, corresponding to the month of November.

Consecutively, the transformation of the speed readings to flow was carried out using the current meter equation, followed by the use of the AutoCAD program for the estimate of the cross section's area.

The analysis of the turbidity readings was realized in relation to the total solids concentrations obtained from the dilutions for the calibration, as well as the analysis of the values and readings of the nine samples.

Considering the flow measurements versus the measured water level, a correspondence equation was determined, at the same time a relationship with the determined hydrostatic pressure values was developed.

First Results

Correlation of hydrological monitoring parameters

The flows determined during the nine measurements made in the Ochomogo River are shown in Table 1, as well as the water level that was reported at the precise moment of the gauging.

Table 1 – Resume of the flows with river levels.

Date	Method	Effective area (m^2)	Average speed (m/s)	Flow (m^3/s)	Measurement time	Riverlevel (x10 cm)
16/09/26	Current meter	2,67	0,364	0,97	13:30	2,1
16/01/03	Current meter	2,9	0,306	0,89	10:11	1,6
16/10/10	Current meter	3,8	0,374	1,09	10:50	2,5
16/10/17	Current meter	2,36	0,377	0,86	8:55	1,7
16/10/19	Floatmethod	15,95	0,680	10,85	9:07	7,2
16/10/31	Current meter	2,67	0,481	1,29	9:09	1,7
16/11/02	Current meter	21,8	0,735	16,01	16:49	8,8
16/11/11	Current meter	2,75	0,500	1,38	8:58	1,7
16/11/14	Current meter	2,97	0,342	1,19	10:28	1,7

From the previous table, the following image was extracted showing the relationship between the river level, the area and the hydrostatic pressure in the river.

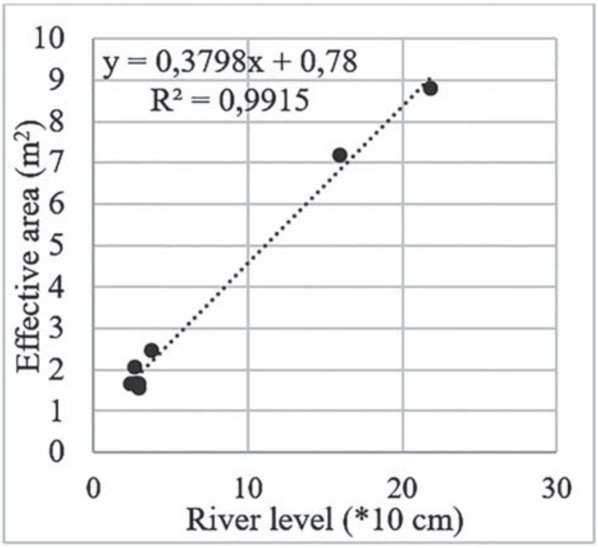

Figure 2 – Relation between area and river level.

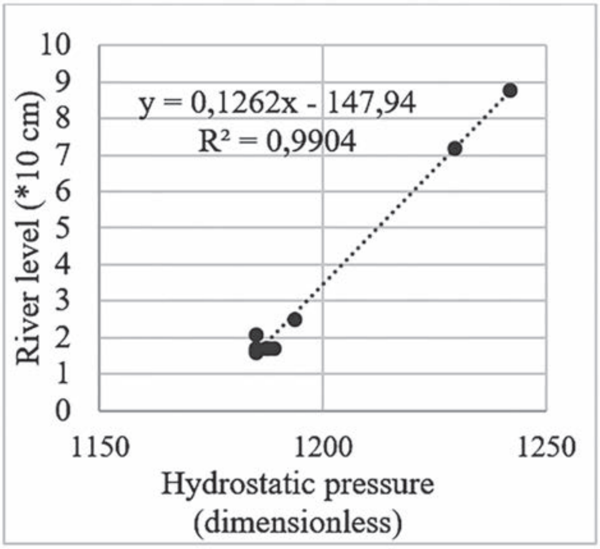

Figure 3 – Relation between hydrostatic pressure and river level.

Considering that flows determined by the flotation method and the ones made with the current meter, the following correlations were obtained:

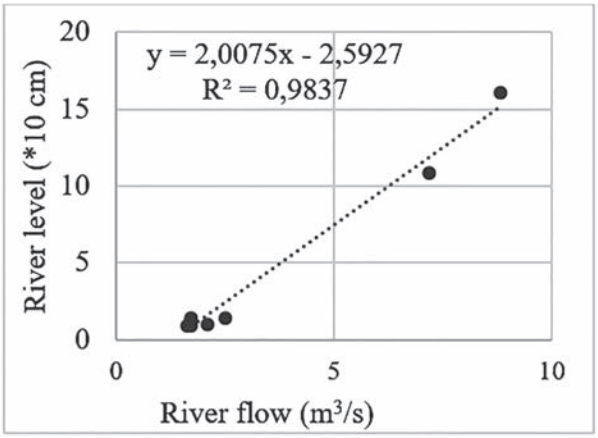

Figure 4 – Flow vs river level.

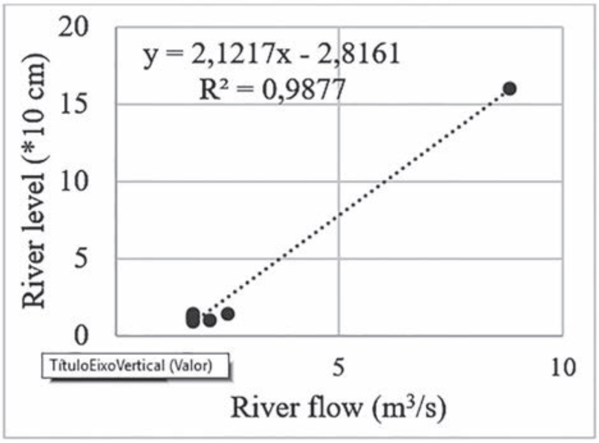

Figure 5 – Flow determined with current meter *vs.* river level.

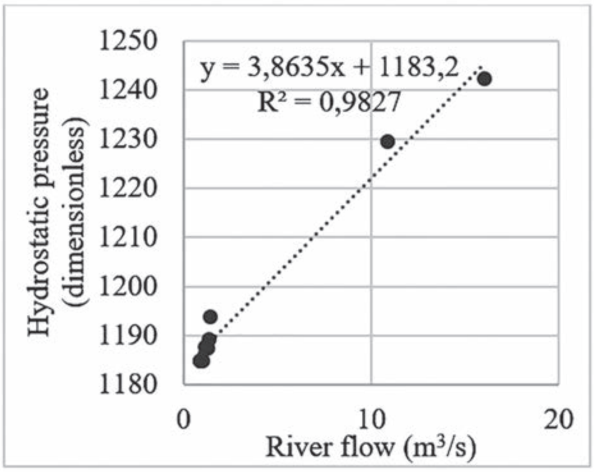

Figure 6 – Flow vs hydrostatic pressure.

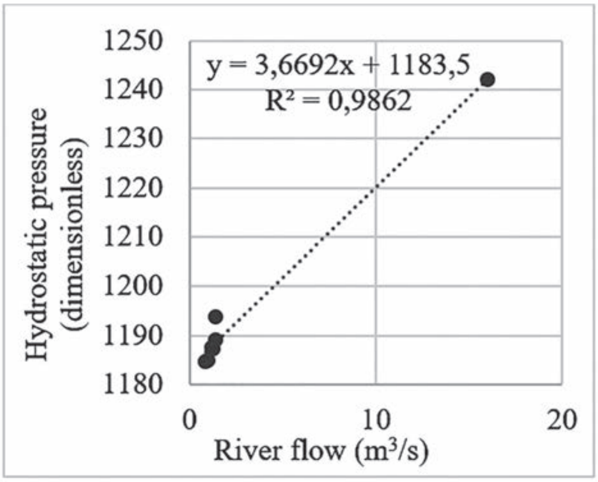

Figure 7 – Flow determined with current meter *vs.* hydrostatic pressure.

Precipitation inside the basin

To make the correlations of rainfall in the area, the rain gauge installed near the Ochomogo River was used in the farm within which the monitoring equipment is located, because it has the most complete records. The precipitation data in the study area and the data from official meteorological stations (monitored by INETER) were compared in order to validate the values obtained from the installed rain gauges. Theinformationis presented in Table 2 and Table3, respectively.

Table 2 – Precipitation data of rain gauge No. 1 for November.

November	mm of rain
Total	104,00
Average	3,355
Average by event	8,00
Maximum	37,00

Table 3 – Official data for November reported by INETER.

November	mm of rain
Total number of years evaluated	41
Average	174
Maximun	461.3
Minimum	38,9

The data obtained from rain gauge No. 1, located in the study area, were obtained graphs that represent the relationship between the flows and the rainfall on the day the measurement was made.

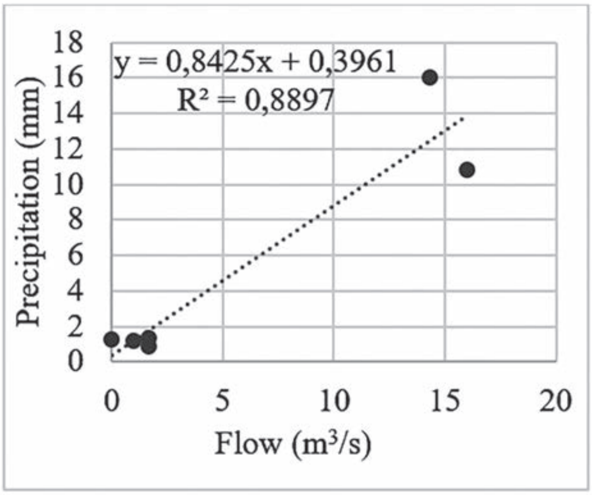

Figure 8 – Relation between flow and precipitation reported the day of measurement.

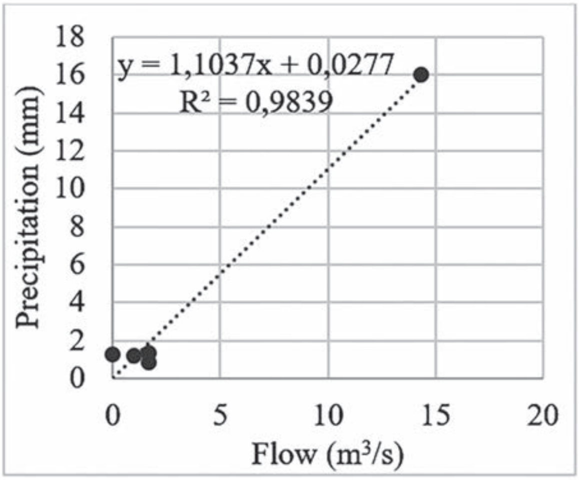

Figure 9 – Relation between flow with current meter and precipitation the day before measurement.

Determination of solids in water

Table 4 shows the concentrations of total, volatile and fixed solids, as well as the total suspended solids and the LED sensor readings.

From the data presented in Table 1 and Table 4 correlations were made between the LED readings and the variation of the flow, with the alterations of the solids in the river.

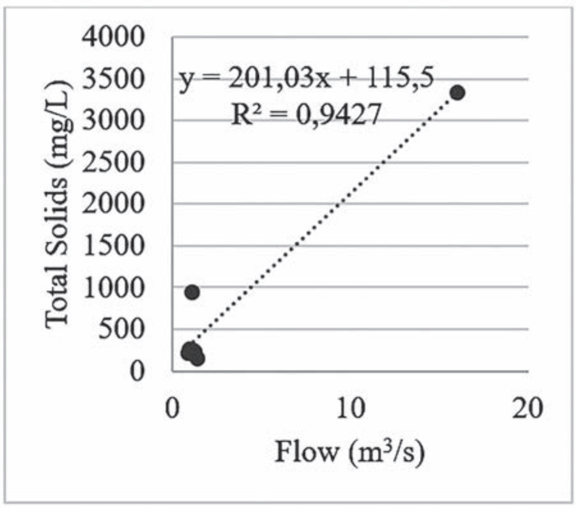

Figure 10 – Relation between flow and total solids concentration.

Table 4 – Values of total solids, volatile and fixed components.

Nº	Sampling day	Totales Solids (mg/L)	Total Volatile Solids (mg/L)	Total Fixed Solids (mg/L)	Total Suspended Solids (mg/L)	LED Frequency
1	16/09/26	270	100	170	40	1826
2	16/10/10	940	500	440	340	1634
3	16/10/17	215	105	110	15	0
4	16/10/31	235	155	80	40	106
5	16/11/02	3340	1390	1950	3890	10
6	16/11/11	145	95	50	26	8
7	16/11/14	245	95	150	30	92

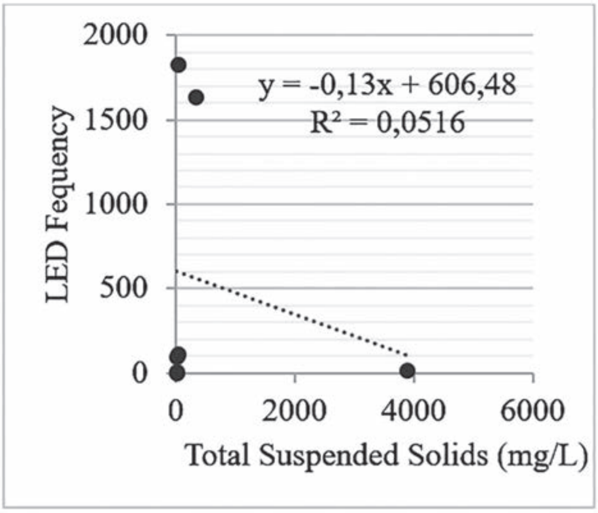

Figure 11 – Relation between total suspended solids and LED sensor reading.

Discussion

Flow

The channel of the river where the flow measurements were made consists of a width of 30,10 meters. When measuring the cross section it had a maximum height of 1,68 meters, an area of 42,74 square meters and perimeter of 62,70 meters. Under normal conditions, the riverbed in this section would only be 15 meters to 16,50 meters wide, but during heavy precipitation events, it covers the total visible width of the channel.

When doing the topographic survey of the cross section, it can be predicted, by means of the equation on Figure 2, the effective area or area used by the water that crosses the channel.

The flow measurements were made using the area/velocity method with two different techniques: the determination of the water velocity with the velocity meter and the floater method. For each case, two correlations are presented, which show that the measurements made with the velocity meter has a slight increase in the correlation of the data, which ranges from 0,0035 to 0,0040, with the exception of Figure 9, in which the relation between precipitation and flow rate increases by almost 10%, that is to say that the flow obtained by the flotation method is relatively close to a real value.

For the aforementioned, it was possible to develop a set of equations that allowed monitoring the river in real time, from anywhere on the world that has access to the internet. The determination of the flow was made possible by developing the equation presented in the Figure 7. On the monitoring web page, hydrostatic pressure is obtained, which, when substituted, yields a flow rate with a precision percentage of 98,62%.

To obtain the values of width and height of the channel that's occupied by the volume of water, the equations on Figures 2 and Figure 3 are used, which, having the hydrostatic pressure of the river, obtain the level and by means of the cross section measures the volume can be calculated, so width and length that the water occupies at that moment, under a correlation greater than 99%.

Precipitation

The rain gauges installed have a diameter of 11,5 cm and therefore a surface of 330 cm^2. In these, 33 cm^3 equals one millimeter of rain, therefore, it was adapted to be recorded every 11 cm^3, so it has an accuracy of 0, 33 mm of rain. Both pluviometers show similar behavior, but for the validation of the data, only the one closest to the river was used, since it has more record.

The comparison was made with the Nandaime rainfall station, which according to table 3. Presents historical values for the month of November between 38,9 and 461,3 mm of rain, and an average of 174 mm. The data obtained by the rain gauge No 1. Present a total of 104 mm of rain during the month, being within the historical range, thus allowing the use of this data for the run of the hydrological model.

Figure 9 shows the proportionality that exists between the precipitation within the basin and the flow of the studied channel. Theoretically, it is known that the greater the precipitation in the basin, the greater the flow within the channel, this being different in each basin due to its hydrological characteristics. Obtaining a 98% reliability equation with a single rain gauge installed near the control site is not considered significant to determine the flow rate at the study site, as it does not provide sufficient information on the amount of rain that may fall on the entire basin.

Sediments

Table 4 shows the concentrations of solids that the Ochomogo River discharges to Lake Cocibolca. When correlating the total solids vs the flow at the time of taking the sample (Figure 10), it corroborates that the higher the flow, the more turbulent the flow, which favors the lifting and mixing of the solids, considerably increasing the concentrations for these.

The flow increases as precipitation increases, a part of the water that falls, infiltrates and another is transported to the main channel by means of runoff that drag part of the organic matter present in the soil, for this reason approximately 50% of the total solids are volatile, which means that they are calcinated at 550°C, which is characteristic of all the organic matter that is transformed into CO_2 and H_2O.

The main point to improve in the research is the relationship and calibration of the LED sensor with the amount of total suspended solids, a parameter that gives turbidity to water, since at first sight there is no logical relation and the fluctuations in the values are very large, when performing a data correlation a value of 5% is obtained considering it null.

This null correlation can be given by the placement of the sensor, which has a led located in a 90° position, which could mean that at low concentrations the light is scattered and the sensor can detect it, but at high concentrations, the light is blocked and the sensor does not detect brightness at all.

The more data or measurements are made, the equations will be developed to achieve a better correlation. The investigation was stopped on November 15th because the companies that grow cane and rice in the surrounding areas close the dam located next to the Pan-American highway, and it is well known that the flow cannot be measured before a dam because it obtains stagnant water readings.

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https://doi.org/10.26626/978-85-5953-031-5.2018C019

Using MQual 1.5 Modelling to Assess the Water Quality of a Subtropical Catchment

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Abstract

The aim of this research was to study the point and non-points sources of the catchment of Agua Branca stream located, in Itirapina municipality, São Paulo State. Various scenarios were proposed in order to analyze the behaviors of BOD5 days at 20°C and dissolved oxygen along with physical and chemical parameters measured in situ with the data on total nitrogen, total phosphorus, total and fecal coliforms obtained in the laboratory, from samples of six station in the stream, if was possible to distribute spatially the components and represent this graphically. The data showed that the situation of the water quality of the stream Agua Branca is critical and a new sewage treatment plant is urgent required. Of the various scenarios studied if was demonstrated that if the diffuse load was reduced by 20% in the agricultural area better water quality was achieved in the stream. With an increase in the agricultural activity, a 50% decrease in water quality could occur. For point sources, the best scenario was the construction of a new wastewater treatment plant. The worst scenario for point source was the non-implementation of this new wastewater treatment plant of Itirapina town.

Keywords: non point sources; point sources; mathematical modeling (MQual 1.5); land use; water quality, scenarios.

Introduction

The quality and quantity of water is dependent of the soil use, the hydrological cycle and water availability. The multiple uses of water affect both water quality and water quantity. Water quality results from natural phenomenon such as surface runoff, infiltration of soil impurities, soil cover and anthropic activities such as domestic and industrial waters, agricultural pesticides, land use and occupation and untreated waste water from urban areas.

In watersheds loads from human activities are key factors to degrade water quality of streams, lakes rivers and reservoirs. Softwares with advanced technologies are used in order to determine the impacts of loads from point and non-point sources in the surface aquatic ecosystems. By classifying land use in the area of influence, it is possible to locate point and non-point sources of pollution. Export coefficients are used to complete the load scenarios, from the different areas.

The present research work was carried out in order to evaluate the water quality of the Agua Branca stream as well to study the effects of loads from point and non-point sources. The land use, land occupation population growth, were used in different scenarios. This can provide the necessary tools from planning, management and restoration of the stream Agua Branca.

Material and Methods

Study site

The Água Branca stream is part of the Itaqueri river basin, one of its tributaries that most generate all nutrients (BOD, total and fecal coliforms, phosphorus and nitrogen, among others). These are from the discharge of sewage from the municipality of Itirapina, located near the source of the stream. As a receiver of Itirapina sewage, it is the most degraded of water bodies evaluated in this study, besides being the main contributor of nutrients and fecal coliforms to the Lobo reservoir, through the Itaqueri river.

The Water and Sewage Division (DAE) of the municipality of Itirapina, responsible for the distribution and control of water consumption, and to carry out the collection and treatment of sewage, states that the municipality has seven deep wells to collect water to attend all population, and a sewage treatment plant that treats 72% of the sewage produced.

The old station has been operating for more than twenty years, that is, above its limit, which has already caused legal problems for the municipality of Itirapina. To address this problem, the new treatment plant will have a 20-year service life and the ability to treat 80 liters of sewage per second.

Another relevant aspect to be evaluated is the use of the soil in the watershed of the Água Branca stream. This area presents urban uses (Itirapina), reforestation (*Pinus* and *Eucalyptus*), agricultural activities (orange and sugar cane), natural forest, cerrado, field, pasture, exposed soil.

In the watershed area of the Água Branca stream, sandy soils dominate, with more fertile soils due to the presence of basalt. The vegetation of cerrado if dominant is related to the type of soil, and replaced by the mesophyllous forest or forest of plateau in places with more fertile soils, where there is presence of basalt, and by riparian forests or swamps, near the courses rivers, in more wetland regions.

However, much of this natural vegetation has undergone anthropic changes that have modified the landscape. One of them is the substitution of part of this vegetation for the agriculture, implantation of sand mining in the banks of the river Itaqueri and construction of the Lobo dam (Broa), with the impoundment of the river Itaqueri, and river Lobo.

Using MQUAL 1.5 for simulating river and stream water quality based on point and non point sources and loads

To obtain non-point source loads, the land uses were classified in the following aspects:

1 - urban area;

2 - agricultural uses;

3 - natural forest;

4 - artificial reforest;

5 - pasture;

6 - Exposed soil;

7 - Field.

The following equation was used to estimate the diffuse load:

Diffuse Load = Area (km²) ×
Export coefficient (kg/km².day)

The coefficients were extracted from the MQUAL 1.5 model developed by the Environment Department of the State of São Paulo (SMA, 2003).

The estimate of loads of total phosphorus, total nitrogen, suspended solids, total coliforms and $BOD_{5,20}$ the mean values of domestic sewage concentration were used (METCALF; EDDY, 1991).

The area for each use of soil was obtained using following data base and *software*:

- Digital database made available by ANA, composed of Hydrographic Basins, of drainage, in 1: 1,000,000 scale (ANA, 2005);
- Digital database made available by the IBGE, consisting of Carta files International to millionths (1: 1,000,000) (IBGE, 1999);
- *Arcview/Arcgis 9.3* software with *Spatial Analyst* extensions and *ArcHydro*Tools 9.0.

Figure 1 – Map showing Itirapina city, Agua Branca stream and the location of six stations for water samplings.

The point sources load was calculated by the equation:

Point sources load = 150 L × 0.80 × Population x Average Concentration (mg/L)

The following parameters were adopted:

- *Average water consumption In habitant/day: 150 Liters* (SNIS, 2007);
- *Percentage of water returning to the sewage network: 80%* (VON SPERLING, 1996);
- *Current Population: 14,829 inhabitants* (IBGE, 2009).

To obtain point sources loud was carried out samplings in the Agua Branca stream at six Stations (Figure 1) for physical-chemical and microbiological analyzes, during the period of intensive rainfall: St1 located in the Agua Branca Stream; St2 on the tributarie 1 and downstream of the Sewage Treatment Plant, in operation; St3 and St4 at the downstream of the municipality; St5 at the tributarie Limoeiro and St6 at outfall of the river Itaqueri.

The following parameters such as: temperature, conductivity, dissolved oxygen, turbidity, total suspended solids, pH, local depth, were measured were measured in the local using multi-parameter probe Horiba. Also it was been measured the velocity of the stream at the sampling points of the Água Branca stream and the tributaries. GPS was essential for locating station by providing accurate latitude and longitude data.

Other analysis such as BOD for 5 days at 20°C ($BOD_{5,20}$), total Nitrogen and total and fecal coliforms were carried out according Alpha (1988). Total phosphorus followed the method described by Valderrama (1981).

Proposed scenarios for simulation

For Non Point Sources load

- Scenario 01: Reduction of 50% of the forest area with increase relative to the urban area;
- Scenario 02: Reduction of 50% of the forest area with increase relative to the agricultural area;
- Scenario 03: Reduction of 10% of the agricultural area with increase relative to the forest area;
- Scenario 04: Reduction of 20% of the agricultural area with increase relative to the area of reforestation.

Scenarios 1 and 2 present the more critical situations, with deforestation of 50% of the forest area and growth of urban and agricultural area, while scenarios 3 and 4 present situations of improvement in the use of the soil in relation to the production of non-point loads. The improvement scenarios were useful to encourage the implementation of legal reserves on the properties or incentive to reforestation activity that may be economically viable for agricultural producers.

For Point Sources load

The point load sources in the municipality of Itirapina were estimated for the current scenario without sewage treatment (14.829 inhabitants according to IBGE, 2009); with treatment of 73% of the sewage produced, according to information from Itirapina's Water Department (DAE); and with an increase of 50% of the population considering that the Sewage Treatment Station would be deactivated due to the end of its useful life, also considering that another Sewage Treatment Station is not activated in operation.

For the point sources loads, the following scenarios were:

- Scenario 01: Current situation without treatment of the municipal sewage;
- Scenario 02: Wastewater treatment plant operating with efficiency of 73%;
- Scenario 03: Growth of 50% of the population in the river basin, with treatment station inactive.

Results

Non point loads

Table 1 and the Figure 2 show the total area of the Agua Branca stream watershed and the calculated area for different land uses.

Table 1 – Calculated área for different land uses of Agua Branca stream catchment.

Land uses	Area (km^2)	%
Water	0.315	0.79
Artificial reforest	9.286	23.30
Exposeds oil	6.462	16.21
Pasture	4.761	11.95
Urban area	2.078	5.20
Natural forest	6.865	17.23
Agriculture	7.076	17.75
Field	3.076	7.56
Total area	39.854	99.99

As can be seen the reforestation represents the class with the largest area within the basin: 23.3%, followed by agriculture, 17.75%. The relationship between the agricultural area and the forest area, presents almost the same size. The urban use represents the smallest area within the basin, together with areas of open field.

After obtaining the values of the land use and occupation, it was possible to estimate the non-point loads in the watershed of the Água Branca stream.

The tables 2, 3, 4, 5, 6 and 7 shows respectively the diffuse loads of total phosphorus, total nitrogen, BODc (Biochemical Demand for Carbon), BODn (Biochemical Demand for nitrogen), Suspended Solids, Coliforms for each type of land use.

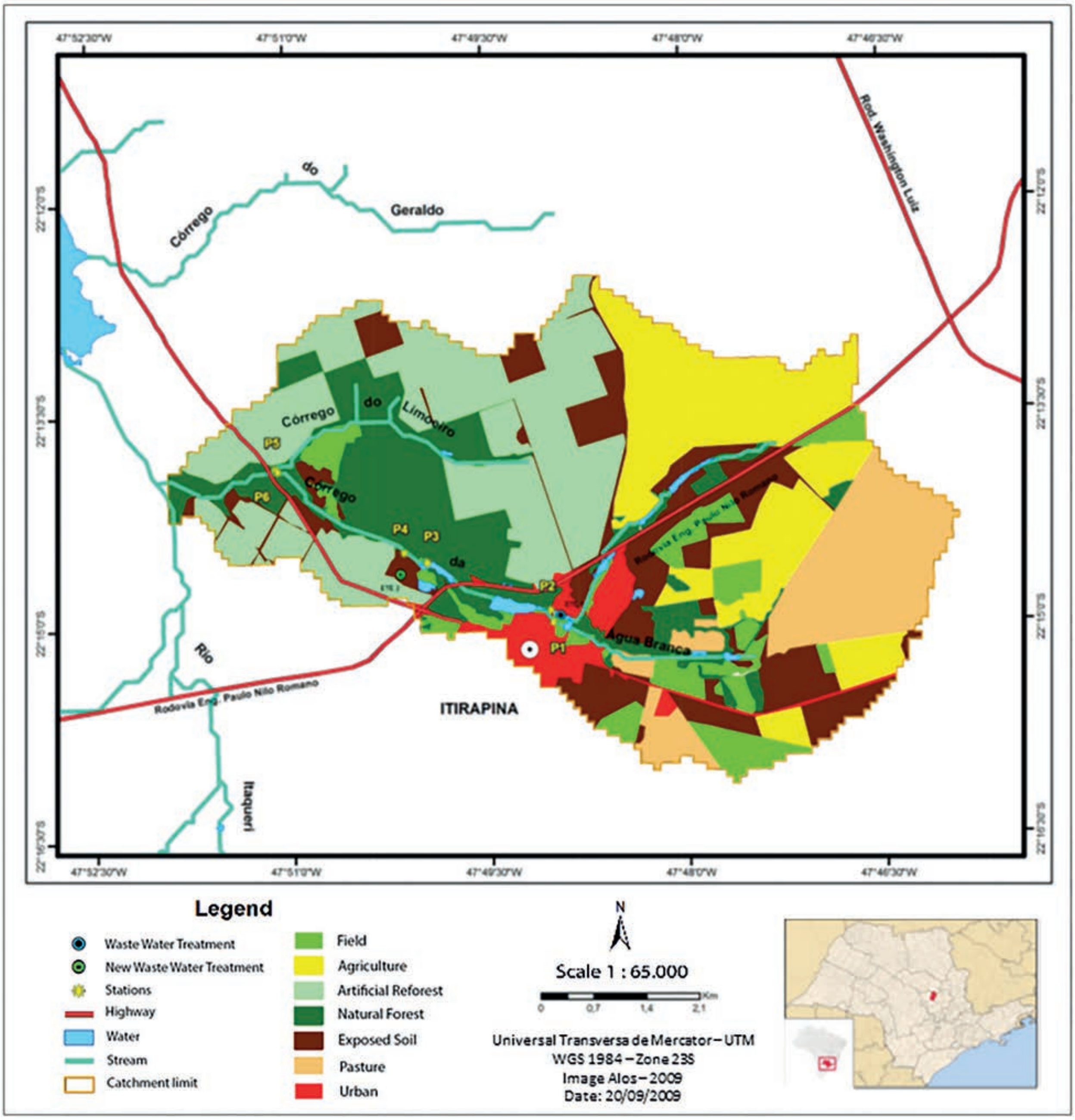

Figure 2 – Land use and occupation of the water catchment area of the Água Branca stream, Itirapina – SP.

Table 2 – Coefficient (kg/km²/day) and load (kg /day) of total phosphorus for each type of land uses.

Land use	Area (km²)	Coefficient – P total (kg/km²/day)	Load P (kg/day)
Artificial Reforest	9,286	0,039	0,363
Exposed Soil	6,461	0,034	0,220
Pasture	4,761	0,050	0,239
Urban area	2,077	0,034	0,070
Natural Forest	6,865	0,039	0,268
Agriculture	7,075	0,346	2,448
Field	3,011	0,028	0,084
Total	39,539		3,692

Table 3 – Coefficient (kg/km²/day) and load (kg/day) of total nitrogen for each type of land uses.

Land use	Area (km²)	Coefficient N (kg/km²/day)	Load N (kg /day)
Artificial Reforest	9,286	0,600	5,572
Exposed Soil	6,461	1,274	8,232
Pasture	4,761	0,900	4,285
Urban area	2,077	1,274	2,647
Natural Forest	6,865	0,600	4,119
Agriculture	7,075	2,950	20,874
Field	3,011	0,500	1,506
Total	39,539		47,235

Table 4 – Coefficient (kg/km³/day) and load (kg/day) of BODc for each type of land uses.

Land use	Area (km²)	Coefficient BODc (kg/km²/day)	Load BODc (kg/day)
Artificial Reforest	9,286	1,302	12,091
Exposed Soil	6,461	4,000	25,848
Pasture	4,761	2,000	9,523
Urban area	2,077	4,000	8,311
Natural Forest	6,865	1,302	8,938
Agriculture	7,075	7,564	53,522
Field	3,011	1,079	3,248
Total	39,539		121,480

Table 5 – Coefficient (kg/km³/day) and load (kg/day) of BODn for each type of land uses.

Land use	Area (km²)	Coefficient BODn (kg/km²/day)	Load (kg BODn/day)
Artificial Reforest	9,286	1,197	11,116
Exposed Soil	6,461	5,535	35,767
Pasture	4,761	2,250	10,713
Urban area	2,077	5,535	11,501
Natural Forest	6,865	1,197	8,217
Agriculture	7,075	7,315	51,760
Field	3,011	1,064	3,204
Total	39,539		132,277

Table 6 – Coefficient (kg/km³/day) and load (kg/day) of suspended solids for each type of land uses.

Land use	Area (km²)	Coefficient S.S (kg/km²/day)	Load Susp. Sol. (kg/day)
Artificial Reforest	9,286	20	185,725
Exposed Soil	6,461	50	323,095
Pasture	4,761	40	190,453
Urban area	2,077	50	103,891
Natural Forest	6,865	20	137,301
Agriculture	7,075	230	1627,443
Field	3,011	30	90,332
Total	39,539		2.658,239

Table 7 – Coefficient (kg/km³/day) and load (kg/day) of coliforms for each type of land uses.

Use	Area (km²)	Coefficient Coliforms (kg/km²/day)	Load Coliforms (kg/day)
Artificial Reforest	9,286	1,00E+08	9,29E+08
Exposed Soil	6,461	1,00E+09	6,46E+09
Pasture	4,761	1,00E+09	7,76E+09
Urban area	2,077	1,00E+09	2,08E+09
Natural Forest	6,865	1,00E+08	6,87E+08
Agriculture	7,075	1,00E+11	7,08E+11
Field	3,011	1,00E+08	3,01E+08
Total	39,539		7,23E+11

After obtaining the diffuse load estimates, they were evaluated for the proposed scenarios. Table 8 shows the scenarios of diffuse loads in the watershed of the Agua Branca stream, using loads for total phosphorus, total nitrogen, biochemical demand of carbon, biochemical demand of nitrogen suspended solids and total coliforms.

The following results are presented:

- **For scenario 1** (reduction of 50% of the natural forest area, and increase of the urban area) it was observed a reduction of 0.47% of the load of P, increases of 13.4% of the load of N, 7.62% of the BODc load, 11.25% of the BODn load. It does not occurred high difference among the suspended solids load and the total coliform load;

- **For scenario 2** (reduction of 50% of the natural forest area, and increase of the area of agricultural use) there were increases of 27.74% of the load of P, 16.17% of the load of N, of 17.7% of the BODc load, 15.87% of the BOD load, 17.12% of the suspended solids load and 47.44% of the total coliform load;

- **For scenario 3** (a reduction of 10% of the agricultural area with an increase relative to the natural forest area) there was a reduction of 5.72% of the load of P, but did't show any significant change in the loads of total N, BODc, BODn, suspended solids and total coliforms;

- **For scenario 4** (a reduction of 20% of the agricultural area with an increase relative to the reforestation area), there was a reduction of 11.44% of the load of P, 6.67% of the N load, 7.3% of the BODc load, 6.55% of the BOD load, 11.18% of the suspended solids load and 19.56% of the total coliform load;

- With this it can be observed that the most critical case was scenario 2, presenting significant increases in the loads; it is the most common situation currently. The best scenario for diffuse loads was the 4, due to the significant reduction of the loads of P, N, BODc, BODn, suspended solids and coliforms.

This alternative could contribute to the improvement of the water quality of the Água Branca stream and encourage reforestation activities that are of great ecological and economic importance in Itirapina and the region.

Table 8 – Scenarios of diffuse loads in the watershed of the Água Branca stream.

Diffuse loads in different scenarios						
	P (kg/day)	**N (kg/day)**	**BODc (kg/day)**	**BODn (kg/day)**	**SS (kg/day)**	**Total Coliforms (kg/day)**
Current Scenario	3,69	47,23	121,48	132,28	2.658,24	7,23E+11
Scenario 1	3,78	56,57	130,74	147,17	2.761,21	7,26E+11
Scenario 2	4,85	57,95	142,97	153,28	3.379,07	1,07E+12
Scenario 3	3,58	49,88	121,48	132,28	2.658,24	7,23E+11
Scenario 4	3,36	46,56	112,62	123,62	2.361,05	5,81E+11

Point sources loads

The chemical and physical parameters (temperature, conductivity, dissolved oxygen, biochemical oxygen demand ($BOD_{5,20}$) and pH measured at six stations in the Agua Branca stream and its tributaries are presented in the Table 9.

Also the hydraulic data such as width, section area, chain speed, declivity, altitude and flow rate for each station were performed and presented in the Table 10.

The results obtained through the analysis of water samples collected at the six stations of the stream, showed the following situation for the water quality of the Agua Branca stream. Acording CONAMA Resolution 357/05 (2005), the quality of the water from Stations 1, 2, 3 could be considered as belonging to Class II and the water quality from 4,5,6 as Class III or some times IV.

The total coliform concentration was higher than 2,419.6 NMP/100 mL at all stations. The E. coli concentration was higher downstream of Point 2 and near Point 4, respectively. The presence of total and fecal coliforms makes water from the Água Branca stream unfit for human consumption and for fishing and leisure activities.

Table 9 – Physical and chemical data obtained in the 6 stations located in the Agua Branca stream and in its tributaries.

Parameter	Unity	St 1	St 2	St 3	St 4	St 5	St 6 (downstream)
Temperature	°C	22,8	23,40	26,68	26,30	24,70	23,62
Conductivity	uS/cm	50	48	34	39	57	60
DO	mg/L	6,60	5,81	5,79	4,85	3,52	2,83
BOD	mg/L	3,561	7,00	7,00	6,29	6,30	5,21
pH		8,47	8,05	8,11	7,02	6,78	6,60

Table 10 – Hydraulic data measured in the Água Branca stream.

Parameter	Unity	St 1	St 2	St 3	St 4	St 5	St 6
Width	**m**	3,00	1,60	Lagoon	1,00	0,52	2,80
Section area	**m²**	0,81000	0,042	xx	0,00446	0,00122	1,04
Chain speed	**cm/s**	5,84	40,2	xx	32,84	8,34	15,9
Declivity	**m/m**	0,0077	tributary	0,2857	0,009	tributary	downstream
Altitude	**m**	768	760	748	748	724	724
Flow rate	**m³/s**	0,0473	0,017	xx	0,1465	0,0102	0,1653

Considering the following simulation scenarios:

- Scenario 01: Current situation without treatment of the municipal sewage;
- Scenario 02: Wastewater treatment plant operating with efficiency of 73%;
- Scenario 03: Growth of 50% of the population in the river basin, with treatment station inactive, Table 11 presents the variation of the point source loads for various factors

The simulating scenarios show that the population growth is more important than the treatment of domestic sewage improving with 73% efficiency.

Discussion

The bad water quality of Água Branca stream of Itirapina city is determined mainly by the poor efficiency of domestic sewage treatment based in the current number of population (point sources loads) associated by the inappropriate land uses. As it was demonstrated by simulation, the increase in efficiency of sewage treatment in 73%, reduce considerably the phosphorus, nitrogen, BOD_c, BOD_n and coliforms loads However when the population increases in 50% there is duplication of loads.

As it was demonstrated in the present analysis it was possible to distinguish between pollution from point sources and non point sources. Impacts on rivers, reservoirs and lakes from point sources are originated mainly from discharge of wastewater. This is the case of the Agua Branca river that receives wastewater from Itirapina town. Acceptable solution therefore would be to construct the new wastewater treatment plant that reduce the impact.

The water pollution problems associated with municipal wastewater include their content of:

- Nutrients causing eutrophication;
- Biodegradable organic matter causing oxygen depletion;
- Bacteria and virus affecting the sanitary quality of water which impairs multiple uses (JORGENSEN et al., 2013).

Table 11 – Variation of point source loads of variable factors for proposed scenarios.

	Variable factors				
Scenarios	**P total (kg/day)**	**N total (kg/day)**	**BODc (kg/day)**	**BODn (kg/day)**	**Coliforms (kg/day)**
Current Situation (without treatment)	0,16	0,82	4,53	4,53	2.059.583,33
Treatment with 73% efficiency	0,04	0,22	1,22	1,22	556.087,50
50% increase in population	0,25	1,24	6,80	6,80	3.089.375,00

If the identification of point sources is well determined as it is in the case of Agua Branca river, the load from non point sources is more difficult to measure. This is due to the highly dynamic character of the non point sources, to diverse soil uses, difficult to quantify loads with traditional hydrologic techniques and variability of values that range across several orders of magnitude.

Non structural control measures can offer a viable option for controlling non point sources in many drainage basins. Changes in agricultural practices could reduce significantly phosphorus inputs from agricultural runoff. Reducing fertilizers or pesticides applied in agricultural fields reduces input to the river. Reforestation of watersheds is another possible activity that concerns reducing sediment or suspended matter loads, nutrients, heavy metals and organic substances (JORGENSEN et al, 2005).

Since sources typically arise from extensive land areas the use of models to simulate the loads is indicated. Effective pollution control programs involves farmers, urban inhabitants; changes in human practices have the potential to reduce pollutants loads to rivers.

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The Ecological Dynamics of UHE Carlos Botelho (Lobo/Broa) Reservoir: Temporal Changes

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Abstract

The temporal and spatial variability of the aquatic ecosystems are fundamental processes in the ecological dynamics of these ecosystems. Particularly in reservoirs these characteristics are very important. Determining the hierarchical relationships of these key mechanisms is an important step in the knowledge of the functioning of these artificial ecosystems. In order to develop a more comprehensive theory of reservoir dynamics in necessary to adapt a broader perspective encompassing physical, chemical and biological responses coupled with the hierarchy of forcing functions. The objective of this paper is to present and discuss the "tipping point concept" applied to UHE Carlos Botelho (Lobo/Broa) reservoir based on recent changes in the climatological forcing functions that produced several alterations in this reservoir ecological dynamics.

Keywords: reservoirs, ecological dynamics, climate, changes, tipping point concept, hierarchy.

Introduction

Ecological research at small aquatic ecosystems is undoubtedly an advanced development for the scientific understand of the limnology of these water systems. Reservoirs, particularly, can be very useful once they are controlled by man, have a known origin and age and provide water for a variety of applications. Small, shallow reservoirs, with a volume of around 20.000.000 m^3 are very much relevant since they can be used as a "quasi-experimental site" (MARGALEF, 1966; EDMONDSON, 1994).

Such was the approach taken at the establishment of ecological and limnological research, in 1971 (TUNDISI; MATSUMURA-TUNDISI, 2013) at Lobo/Broa reservoir, a shallow, well mixed, subtropical artificial aquatic ecosystem constructed in 1936 to supply hydroelectricity to the small town of Itirapina at that time.

The reservoir has been monitored since then. It has a watershed area of 230 km^2; an average depth of 3 meters; a maximum depth of 12 meters; the watershed is dominated by a savanna type of vegetation ("cerrado"); areas of reforestation with *Pinus* sp and *Eucalyptus* sp; The soil of the watershed has a high concentration of aluminum and areas with high iron concentration; the reservoir has an area of 7 km^2, a width of 1 km, and two spatial compartments.

The research and monitoring projects developed at Lobo/Broa reservoir included all climatological, biological, physical, hydrological and chemical processes. During 47 years of this research and monitoring a clear understanding of the main climatological forcing functions and the responses of the reservoir in terms of vertical and horizontal circulation and the biological communities was promoted.

Forcing functions as wind speed and direction, precipitation, and circulation and nutrient cycles were well known. Therefore the fluctuations during the climatological year, the response of the reservoir and the communities to these fluctuations and the succession processes are known and described in several publications and books (TUNDISI; MATSUMURA-TUNDISI, 2013). Different stages of succession and stability were extremely repetitive showed by the many years of research, sampling and monitoring. (TUNDISI, 2017).

As Margalef (1966) pointed out, the strong fluctuations in the environment stop and change succession. Climatic changes are among those fluctuation that interfere with succession, especially it they are forcing functions that drive the ecosystem.

In this paper the authors discuss the effects of climate changes in the Lobo/Broa reservoir ecological dynamics. Succession of species, eutrophication and water quality were affected by a combination of climatic alterations, water uses and nutrient input due to human exploitation. Figures 1 and 2 show the location and general characteristics of the watershed and reservoir.

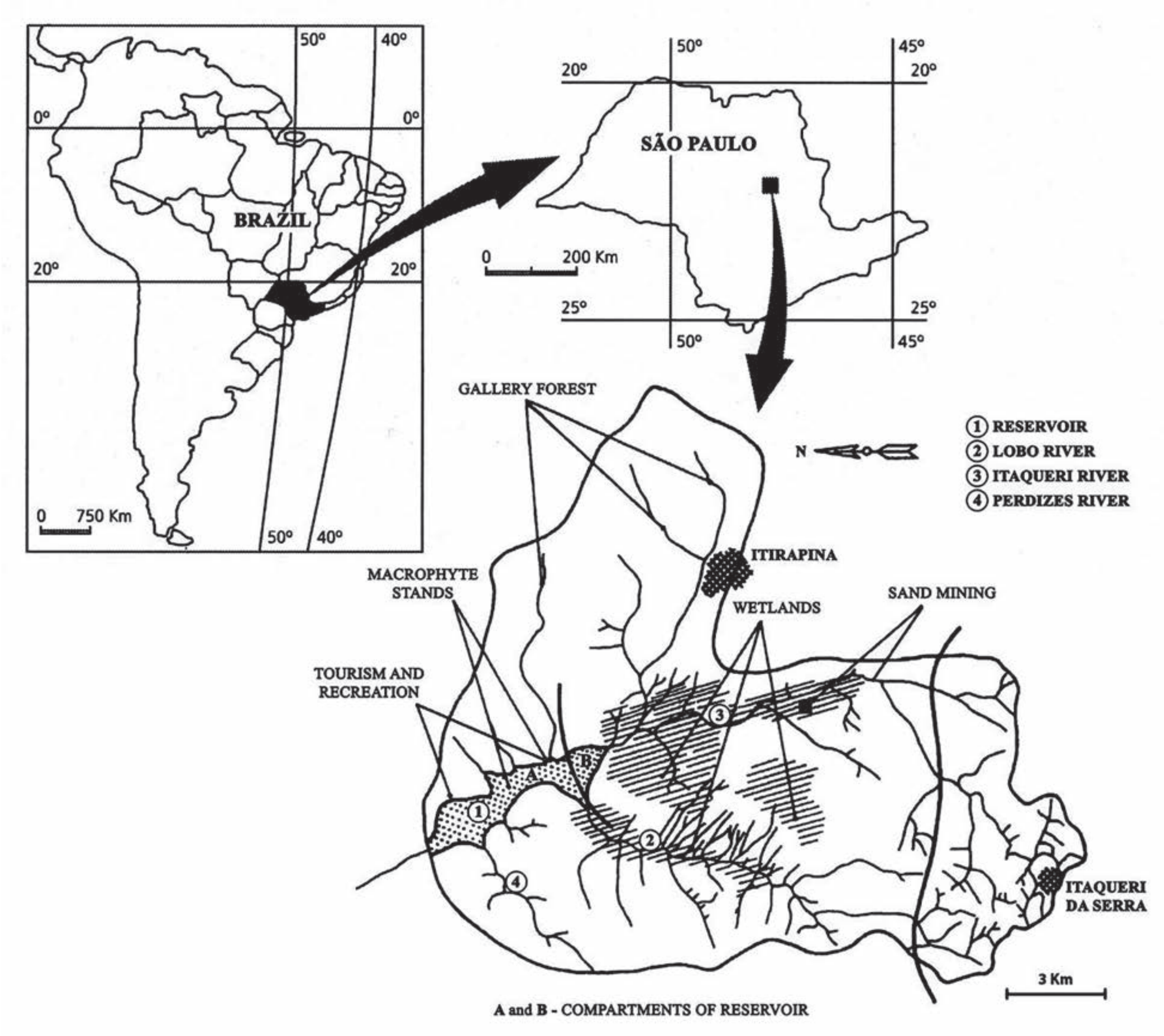

Figure 1 – Location of Itaqueri/Lobo watershed and UHE Carlos Botelho reservoir (Lobo/Broa) in São Paulo State, Brazil.

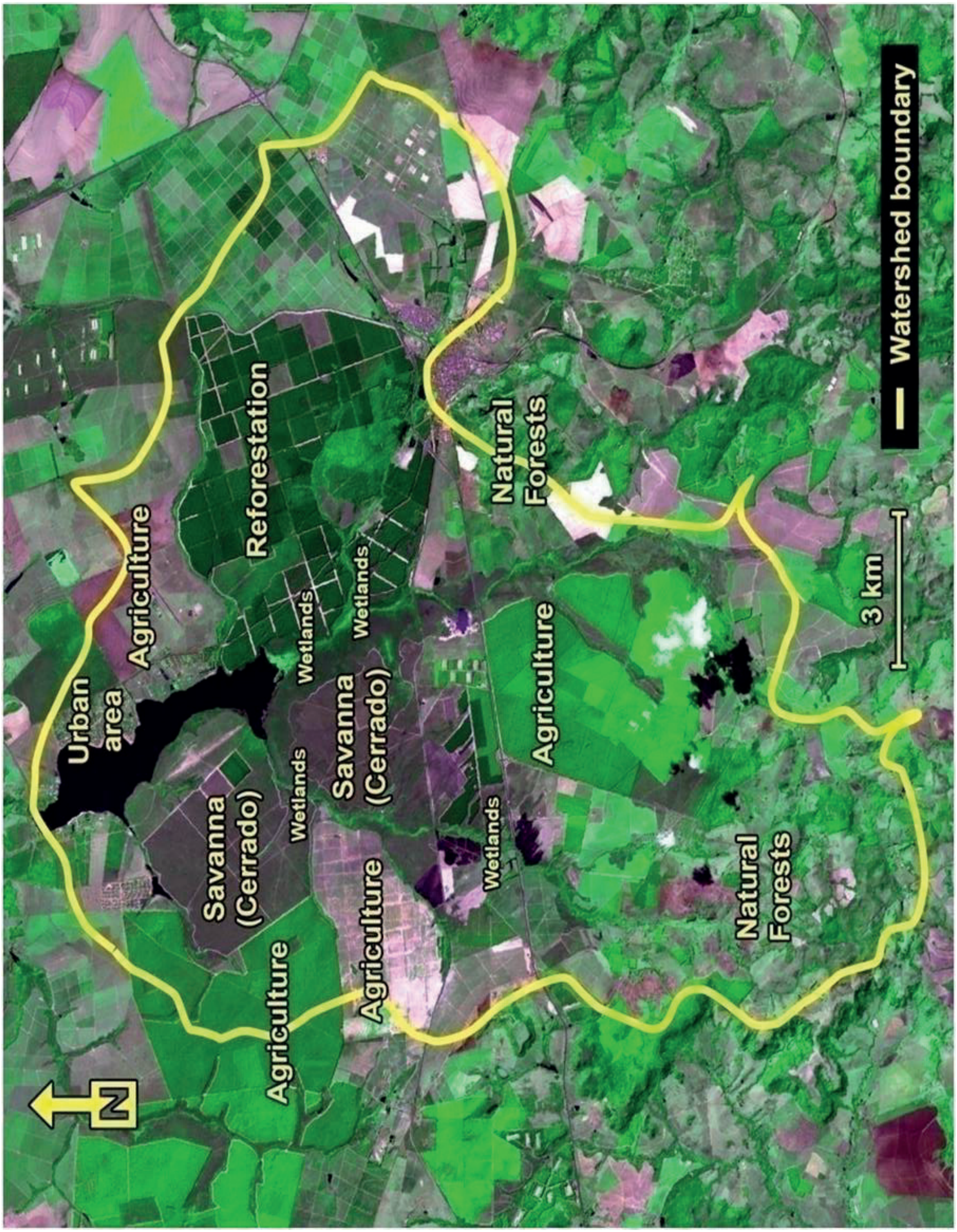

Figure 2 – The Itaqueri/Lobo watershed and its components (Source: TUNDISI et al., 2016).

Description of main events

Throughout the many years of study a clear picture of the ecological dynamics of the reservoir emerged. Fluctuations of the climatological forcing functions such as precipitation and wind, air and water temperature showed a regular fluctuation process that promoted responses of the reservoir: hidrogeochemical, hidrological, limnological and biological. This was predictable year after year (Figure 3).

The use of reservoir for hydroelectricity generation maintained a low retention time, , therefore low nutrient content in the water was detected. Due to permanent mixing promoted by wind (GRANADEIROS RIOS, 2003) phosphorus was forced to the sediment reducing also its concentration (dissolved inorganic phosphate) in the water column, therefore maintain a low phytoplankton biomass (TUNDISI, 2017).

This sequence of events lasted from 1971, first year of sampling and monitoring to 2015, therefore 44 years.

In 2014 and 2015, changes in the precipitation, surface water temperature, and retention time occurred. The reduction of precipitation and the increase of 2ºC in surface water temperature (2ºC above the average surface temperature for 43 years), were attributed to climatological changes that affected the south east of Brazil in 2014 and 2015. (MARENGO et al., 2015). Lower values of precipitation with values of less 250mm in relation of the average during this period occurred. At Itaqueri/Lobo watershed and reservoir the reduction in precipitation is shown in Figure 4.

Since the reservoir hydroelectric power plant was in continuous usage in order to maintain hydropower production of 2 MW/h retention time was increased to 60 days instead of the normal 20 days period (Figures 5 and 6).

The overall consequence of these climatological/ hydrological events combined with the human activities such as hydropower generation was an increase in the nutrient in the water, deterioration of water quality and the growth of *Cylindrospermopsis raciborskii* in the reservoir; concentrations of chlorophyll a from 99 mgxl^{-1} to 108,0 mgxl^{-1} were determined. (TUNDISI, 2017). When compared with the data of Passerini (2010) that measured chlorophyll a values from 23 mgxl^{-1} to 26 mgxl^{-1} this shows the impact of the Cyanobacteria growth. Lower diversity of phytoplankton and zooplankton were measured also during the period of the bloom (OGASHAWARA et al., 2017).

Therefore the changes in climatological events, and the human uses of the water had as a consequence the presence of heavy blooms of Cyanobacteria and loss of diversity and feedback control systems in the reservoir.

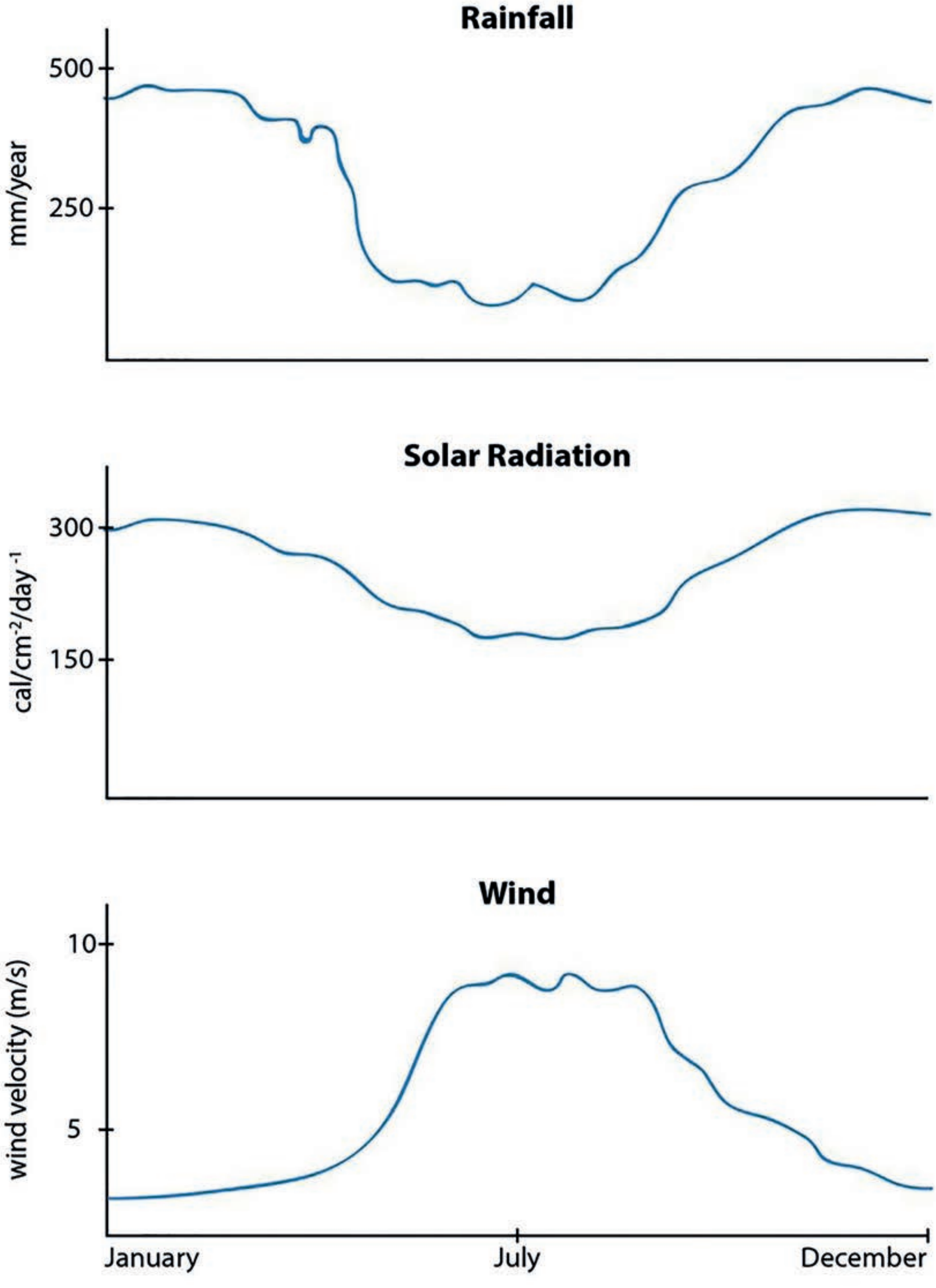

Figure 3 – The climatological onditions at Itaueri/Lobo watershed. Average values for 44 years (Source: TUNDISI et al., 2013).

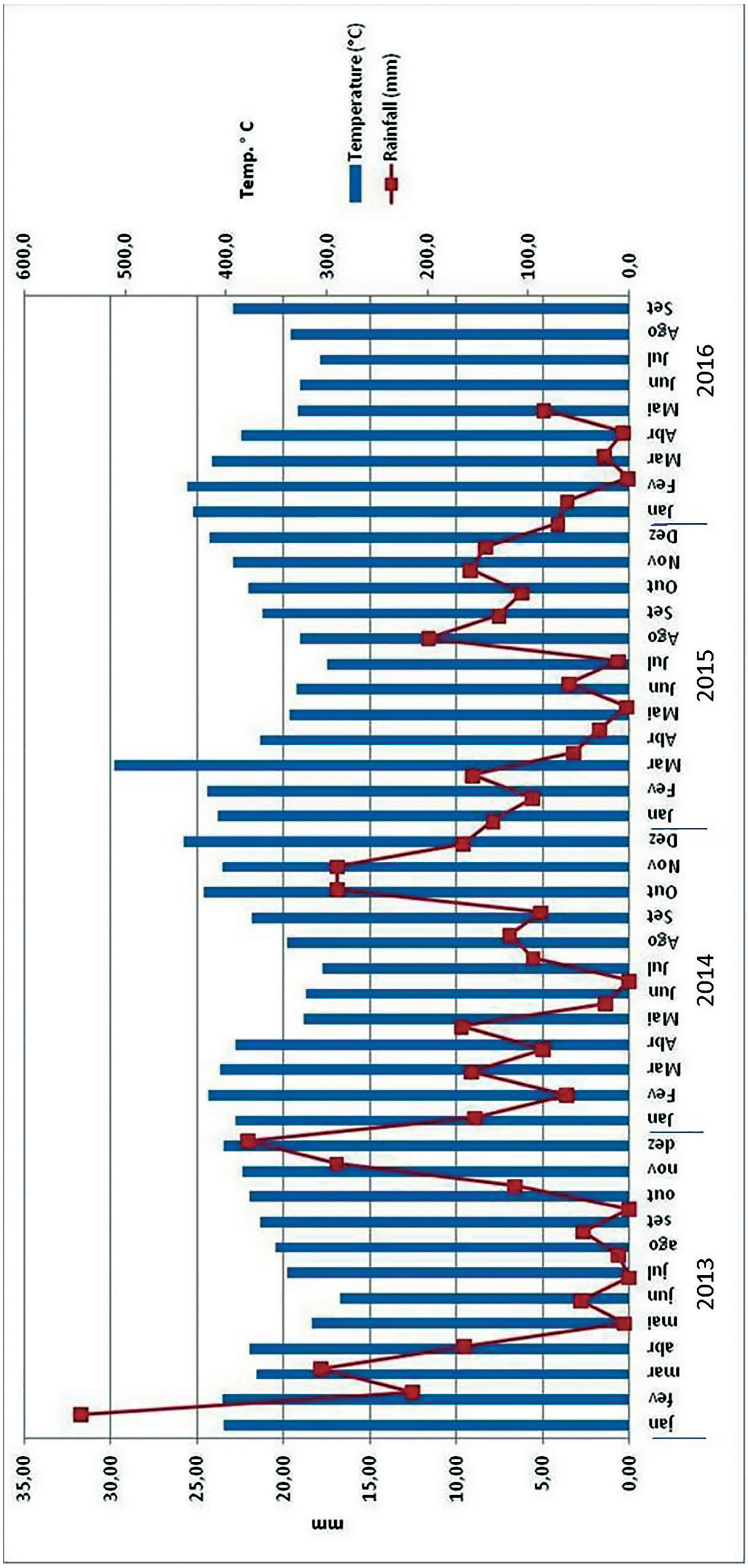

Figure 4 – Air temperature and rainfall from January 2013 to May 2016 at Itaqueri/Lobo watershed.

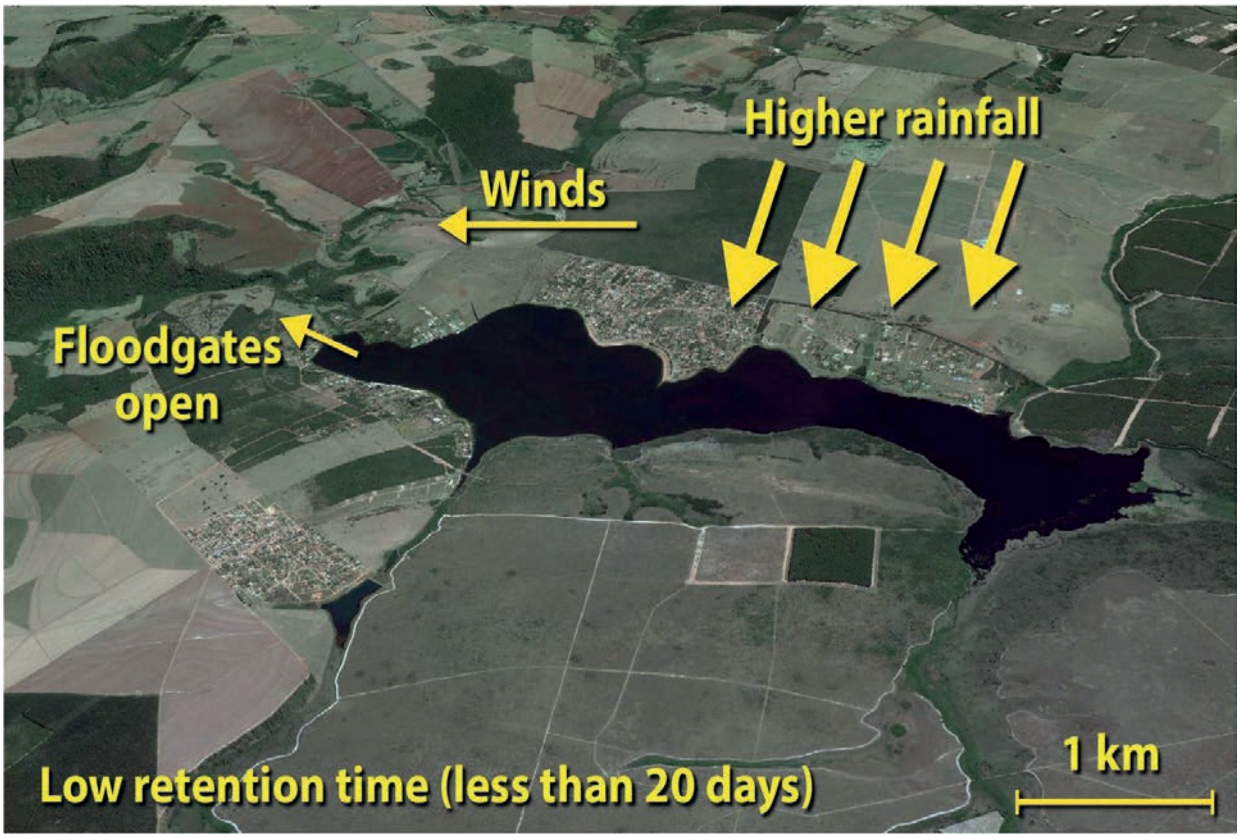

Figure 5 – Normal conditions at Itaqueri/Lobo watershed and reservoir.

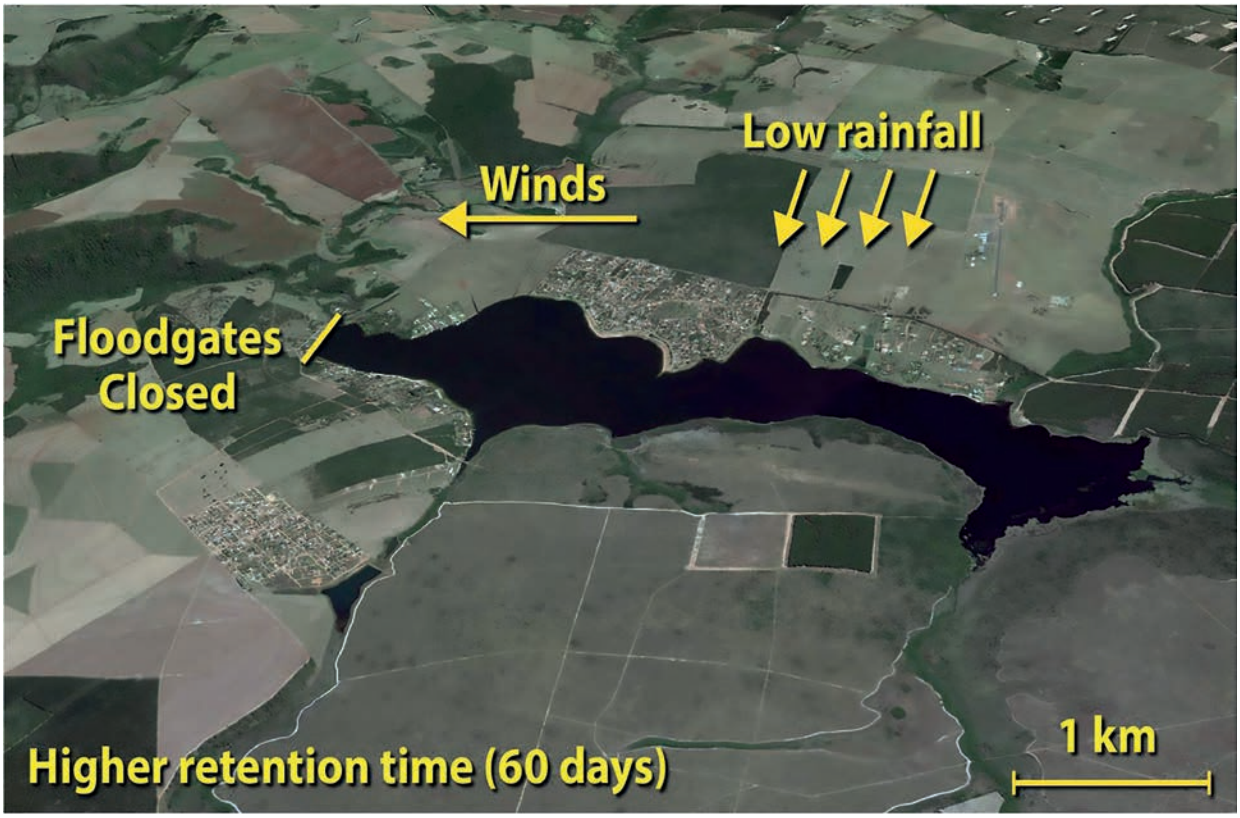

Figure 6 – Low retention time and low rainfall during period of climatic changes at Itaqueri/ Lobo watershed and reservoir.

The Cyanobacteria blooms linked to climatic changes present the following characteristics and responses:

- Hydrologic changes;
- Nutrient concentration in the water; inputs; availability of nutrients increase;
- Water residence time (an increase enhances Cyanobacteria growth);
- Water mixing conditions (low mixing enhances Cyanobacteria growth);
- Higher surface water temperatures;
- Synergic activity of climatic change with anthopogenic nutrient enrichment.

(Sources: SCHEFFER et al., 2001; PAERL; PAUL, 2012; WILSON; SARNELLE; TILLMANS, 2006; WAGNER; ADRIAN, 2009).

Dicussion

In the search for fundamental mechanisms that drive the structure and function of ecosystems, it is necessary to understand the role of the forcing function that are the key components of ecosystems dynamics.

In the case of Lobo/Broa reservoir climatological/hydrological forcing functions are the main drivers of the reservoir dynamic processes related to biological, chemical and physical responses. As stated by Kitchell et al. (1988), a major effort should be directed to understand the relationship between spatial/temporal relationships the response and the interactions of aquatic communities.

Lobo/Broa reservoir has two compartments distributed spatially in the horizontal axis: the upper region, a wetland dominated by aquatic macrophytes with high concentration of organic matter in the water and in the sediment; the lower region, the largest volume of the reservoir, turbulent, well mixed with predominance of phytoplankton as primary producer and a oxidized sediment due to continuous vertical mixing (TUNDISI, 2017).

The ecological dynamics of the reservoir is dependent of this horizontal gradient from the upper region to the dam site the vertical mixing promotes permanent instability, full oxygenation of the water column.

As for the temporal dynamics two main forcing functions are present in the reservoir: precipitation in the summer and wind during the winter. These two forcing functions establish the horizontal and vertical patterns of circulation in the reservoir.

As demonstrated by Granadeiro Rios (2003) Lobo/Broa reservoir respond rapidly to the climatological forcing functions such as wind and precipitation. Low retention time (approximately 20 days) in normal climatological periods, controls the vulnerability to external fluxes of nutrients and suspended material loads. As discussed by Straškraba (1999) retention time is a key factor in the ecological dynamics of the reservoirs. The wetland at the upper portion of the reservoir is also an important controlling factory since it functions as a buffer compartment retaining nutrients, and suspended matter (TUNDISI; MATSUMURA-TUNDISI, 2013).

Changes in this climatological and retention time conditions promote changes in the response of the reservoir. It must be emphasized that during the period of studies the reservoir showed very much predictable responses in terms of phytoplankton biomass and composition and zooplankton composition and succession. (TUNDISI; MATSUMURA- TUNDISI, 2013).

During 2013 and 2014 the forcing function dynamics changed. Lower precipitation lead to lower volume of the reservoir. Also a higher surface water temperature occurred (2ºC above average surface water temperature of 45 years). Higher retention time (approximately 60 days and not 20 days), higher nutrient concentration, presence of an invasive species *Cylindrospermopsis raciborskii*, of unknown origin produced drastic changes in the composition of phytoplankton community (from diatom/ Chlorophyte to dominance of Cyanobacteria). Lower diversity of phytoplankton and very high chlorophyll concentrations (80-120 mg $\times$ l $^{-1}$) demonstrated the change in the ecological dynamics (OGASHAWARA et al., 2017). Several species of zooplankton were not found at this stage.

The loss of control and feedback systems in related to abrupt changes in the forcing functions. The resilience of Lobo/ Broa reservoir was due to the stability in the climatological forcing functions and in the long term stability of the retention time. Once these conditions were lost the resilience was also lost. A major change in the forcing functions promoted a new step in the organization and ecological dynamics of the reservoir. This the “tipping point concept” applied to Lobo/Broa reservoir showed a change of status, a loss of resilience and feedback controls and a lower biodiversity. The links of the global expansion of harmful Cyanobacteria with climate change are at present well documented in several publications (PAERL; HUISMAN, 2008; PAERL; PAUL, 2012).

Mass development of Cyanobacteria increases turbidity, restricts ligh penetration; numerous planktonic species of cyanobacteria produce toxic peptides and alkaloids, that can produce neurological impairment, skin diseases and even death (CHORUS; BARTHRAN, 1999).

Global warming produce hydrologic changes affecting the physical – chemical environmental and biological processes such as metabolic growth rates and bloom function. (PAUL, 2008) Higher temperatures promote cyanobacterial growth. Global warning and changes in climate affects intensities, duration of precipitation and droughts with a consequence of increasing cyanobacteria dominance.

The effects of extensive *Cylindrospermopsis raciborskii* growth at Lobo/Broa reservoir showed strong interference with multiple uses such as: recreation, tourism, aquatic sports, fisheries.

In order to achieve a better control of the water quality and reduce the impact of changes in the climatological forcing functions it is necessary to better control human activities in the system. Fisheries, recreation, aquatic sports have to be controlled in order to reduce nutrient point and non point sources, and avoid eutrophication. Also the deforestation process should be stopped; thus a improvement of the control of impact on now point sources should be expected.

The "tipping point concept" applied to Lobo/Broa reservoir ecosystem could be also applied to other reservoir/lake ecosystems of tropical and subtropical latitudes. When we learn more about the general mechanisms that drive the structure and functions of ecosystems, and regulate their function, we are prepared to promote a "big picture" that will emerge, applied to many ecosystems we can resolve and/or understand complex problems and interactions (KITCHELL et al., 1988). These complex interactions involve multiple spatial and temporal scales, with biogeochemical, chemical and physical responses. Thus the exemple of Lobo/Broa reservoir should be useful as study case for other lake/reservoir ecosystems.

Acknowledgements

The authors acknowledge the support of FAPESP-PELD (Process 2012/51502-3) for this project. CNPq-PELD program (Process: 441564/2016) is also gratefully acknowledged.

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