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THE IMPORTANCE OF HYDROLOGICAL SIMULATIONS IN THE CLIMATE CHANGE CONTEXT: TIETE RIVER BASIN STUDY CASE

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Abstract

In the follow decades the world will face a huge challenge with the climate changes. Many are the studies that show changes in the variability of precipitation and temperature in the XX century. In this context, some countries present great vulnerability and more intense studies are necessary to better understand and predict the future events, as as the occurrence of drougths, floods and water availability. Brazil is one of these countries because of its agriculture economy, the depedency of hydropower plants in its energetic system and the presence of intense population agglomerates next to coastal areas and in regions with vulnerability to drougths and floods. There is still some challenges in predict the impacts in this territory and the use of hydrological models with a better resolution are fundamental. In this context, a model developed in Politecnico di Milano, the FEST-WB was used to made preliminar simulations in Tiete River Basin. It was possible to reach some conclusions and understand better the main challenges of making such studies.

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1. INTRODUCTION

On December 12nd, 2015, a new agreement was launched for dealing with climate change worldwide. After 12 days of intense negotiation in Paris during the 21st Conference of Parties (COP21), in the United Nations Climate Change Conference, this environmental challenge became part of the planning and management of 195 countries. The agreement recognizes that "climate change represents an urgent and potentially irreversible threat to human societies and the planet and thus requires the widest possible cooperation by all countries, and their participation in an effective and appropriate international response..." (UNITED NATIONS, 2015). For the first time, the actual impacts and the risks of rising global temperatures were included in an international agenda.

In this context, Brazil plays an important role because of its standing as an emerging country of great influence in negotiations and in other countries' actions. Given its large proportions of land, climatic diversity and an economy greatly dependent on agriculture variables, the country is extremely vulnerable to any possible climate change. The possibilities of changes in temperature and in the rainy season could pose drastic impacts on biodiversity, agricultural activities and on the natural biomes, besides directly affecting water availability (SILVA DIAS, 2007).

The fourth report (AR4) of the Intergovernmental Panel for Climate Change (IPCC) shows that, for a period of 25 years (1979-2005), there was an increase of up to 1.10° C/ decade in Southeast South America. For the same region, analyses of river flows pointed to an increase of between 2-30% in the Paraná River Basin and neighboring regions, consistent with the rainfall trend analysis in this area (MARENGO, 2007).

The project "Characterization of current climate and definition of climate change for Brazil over the twenty-first century" was a study financed by the Project for Conservation and Sustainable Use of Brazilian Biological Diversity - PROBIO and with the support of MMA / IBRD / GEF / CNPq and the Global Opportunity Fund -GOF of UK. The study collected temperature data from 22 stations that passed for a quality control, with the removal of heterogeneity follow by the esteem of linear trends. On the most of the regions is observed the increase of the maximum annual average temperature with values up to 0.6 °C /decade (~2.5 °C / 40 years old) that are statistically significant over a large part of Brazil, except the South region. In the Figure 1 is observed the trends of the average temperatures from 1961 to 2000 (°C /decade) (MARENGO, 2007).

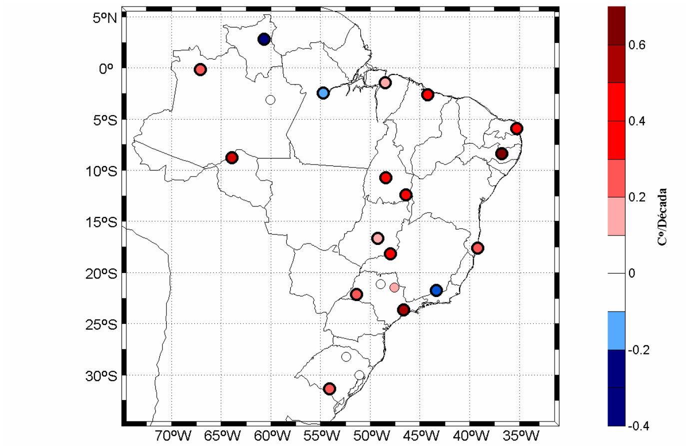


Figure 1 Trend of annual average temperature (1961-2000) in °C / decade.

Scientific studies of these climate change impacts on certain territories are still scarce and generally inconclusive. Reproducing or modeling future impacts of human activity on the climate is an extremely complex task (JUSTINO, 2007). Few studies have been done on the impact of climate change on agriculture. A first attempt to identify the impact of climate change in regional production was done 1989 and 2001 where it was simulated the effects of increases in temperatures and rainfall in the coffee zoning of the states of São Paulo and Goias. There was a drastic reduction in the areas with agro-climatic suitability, condemning the coffee production in these regions (MARENGO, 2006).

Nowadays, the main problems found for the forecasts are the spatial resolution and the interaction between aerosols, radiation and the microphysics of clouds. Small-scale resolutions are inaccurate because the scenario changes much depending on the ground slope and convective systems present in the area. On the other hand, case studies based on large-scale environments produced by future scenarios with high resolution (from the order of few kilometers) may provide relevant information about the changes in the life cycle and the associated extreme events (SILVA DIAS, 2007).

The Brazilian experience in this area shows the need to adjust the applicable methods to climate change scenarios resulting from global models to regional scope projections or location. This adjustment would be useful for studies of climate change impacts in fields such as management of water resources, ecosystems, agricultural activities and even the spread of diseases. A highest resolution obtained in regional or local scope models is essential for a more realistic prediction of extreme change and a substantial improvement in the assessment of the vulnerability of countries to climate change and their capacity to adapt (JUSTINO, 2007).

With the recent agreement in the Conference of Parties, the world recognizes that the union is important to fight these limitations. The present thesis is aligned with this tendency and aims at joining the efforts and advances in the study of climate change effects between two countries: Brazil and Italy. Besides the great geographic distances, both countries present similar cultural aspects, which reflect an historical interaction. In this work, a hydrological model developed at Politecnico di Milano will be used for make preliminary simulations in a very populated Brazilian basin, located in the country Southeast. Some limitations as the availability and reliability of data and the needs of the model adaptations were found and indicate the challenges that the Brazilian science will face in the following years of development regarding climate change simulations.

A Brazilian basin with high importance in the southeast economy and history was chosen as case study to illustrate the importance of such studies: the Tiete Basin. Making part of the most densely populated region in the country, the Tiete river was responsible for the transportation of colonizers that occupied the countryside and for the production and logistic of goods of great economic value. Moreover, its valleys were explored to provide sand, gravel and clay for the civil and dams construction. The consequence was the development of the richest region of the country and of the one of the biggest cities in the world, Sao Paulo. However, the pollution, the floods and availability of water are still huge challenges to be faced in the basin, and these aspects can become worse due to the climate change effects.

This work presents firstly a general description of the management of water resources in Brazil and a brief overview of the studied basin, with its main characteristics and aspects related with the water resources availability and management. In this section, the economic and social importance and vulnerability of Tiete basin is highlighted, with a description of the existent main uses of water and problems related. Then, there will be a brief overview of hydrological models and a description of the model used for input the basin data and calculates some parameters, the FEST-WB model. The follow section explains the input data collected and its sources. Finally, the main results are shown and analyzed and some conclusions are reached.

Besides indicating possible hydrologic impacts of past climate change to support research and decision-making, this study proposes an approach and more intense attention to a theme that must be academically improved in Brazil and considered in the construction of public policies. The integration of such studies is necessary to the development of mitigation and adaptation strategies to face possible adverse changes in clime and to minimize its consequential losses and damages.

2. AREA OF STUDY

1.1. Management of water resources in Brazil

Brazil is a federal republic formed by the Union, 26 states, 1 Federal District and 5,561 municipalities. The municipalities have administrative autonomy in relation to water supply and sanitation services, but the management of water resources is restricted to states and union. (BRAGA et al, 2008). To conduct a situational analysis of water resources, the Brazilian territory was divided into river basin districts, as shown in Figure 2.

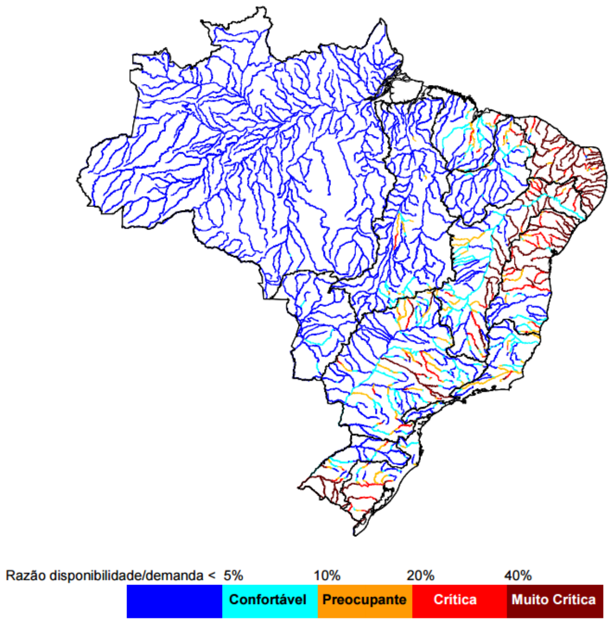
Source: ANA

Figure 2 Hydrographic regions and the Brazilian states

In 1997, it was created the Federal Law 9.433, called water law, which establishes the National Policy of Water Resources. This policy has as main pillars that water is a public good and the management of water resources should provide multiple uses and be decentralized, including the participation of the Government, users and communities. As policy instruments, there are the plans of water resources, aimed at defining the priority uses and the investment program for development, sustainable use, restoration and conservation of water resources of the basin, the charge for the use of water resources and the information system on water resources (SIRH). It was created also the river basin committees, which brings together representatives of government, users and non-governmental organizations. The information system aims to produce, systematize and disseminate data and information that characterize the water conditions of the basin in terms of water quantity and quality in its various uses (Braga et al, 2008). There is a portal that reunites all information available concerning the water resources in the country, as the situation of reservoirs, georeferenced maps, quantitative and qualitative data and all related legislation. There are still some missing information and inadequate accessibility in some cases, but there is an effort to improve and develop better solutions to turn it more useful for researches and the management of water resources.

The main agencies that carry out the hydrological monitoring in Brazil are ANA, the National Water Agency, created to implement the national system of water management, the Department of Water and Energy of the State of Sao Paulo (DAEE) and the CEMADEN, National Center for Monitoring and Alerts of Natural Disasters.

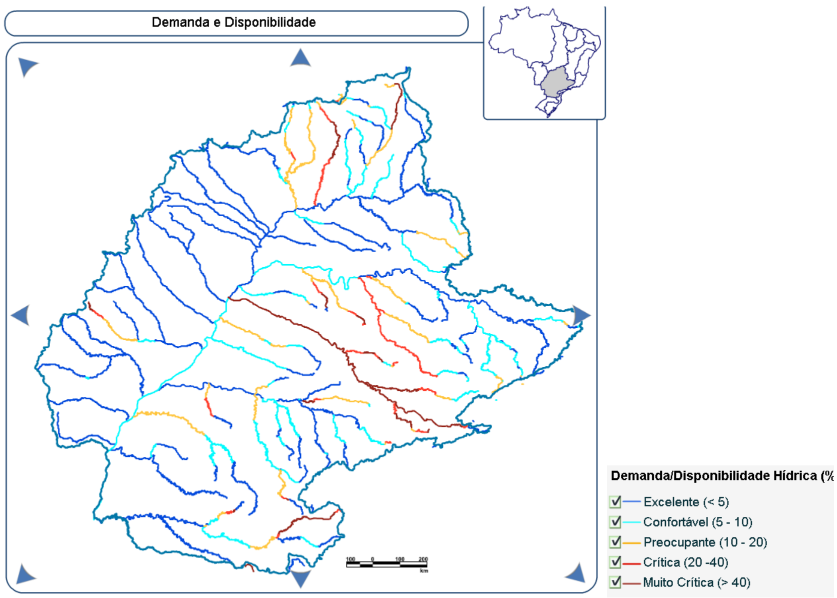
The ANA elaborates studies of demand and water availability for the Brazilian territory. The demand is estimated from water uses authorizations and availability is the flow regulated by the upstream reservoir system with 100% guarantee, plus the flow with 95% remaining in the stretch not regularized. Figure 3 shows the qualitative classification of the main water bodies in Brazil regarding demands and availabilities.



Source: ANA, 2007

Figure 3 Relation between water availability and demand in the main water bodies. The rivers in red and dark red indicates critical and very critical situation, respectively

In the figure is possible to observe that one of the critical regions are located in the Parana River basin. Looking more closely, Figure 4 shows the criticality of the rivers. Tiete River has the worst classification, being classified as extremely critic.

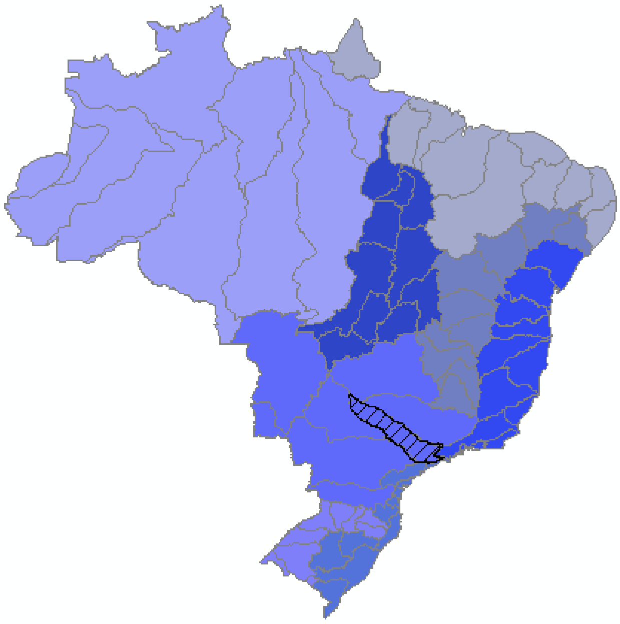


Source: ANA, 2007

Figure 4 Classification of the demand divided by availability of water of the main rivers in Parana River basin

1.2. Tiete River Basin

The follow work will use as case study the Tiete River Basin, which is inserted in the Paraná River hydrographic region. This basin is located between the meridians 45-52°W and the parallels 20-24°S, almost completely within the Sao Paulo state, in the Brazilian Southeast. Figure 5 shows the basin location in the territory and the division of hydrographic regions in Brazil.



Source: ANA

Figure 5 Tiete Basin location in Brazil.

Sao Paulo is the most populated state in Brazil, with 41 million inhabitants and responsible to almost one third of the Brazilian gross national product (GNP). The state is characterized for different uses of land. In the southeast, there are very densely populated urban areas and in the northeast, the predominant use is agriculture. Although with lower share in GDP, agriculture is vital to the state's economy, because since its urbanization in the early 1950s, farmers deliver agricultural products to consumers and local and other states food industries as well as for export (SAO PAULO, 2013). The Figure 6 indicates the position of the Sao Paulo state in Brazil.

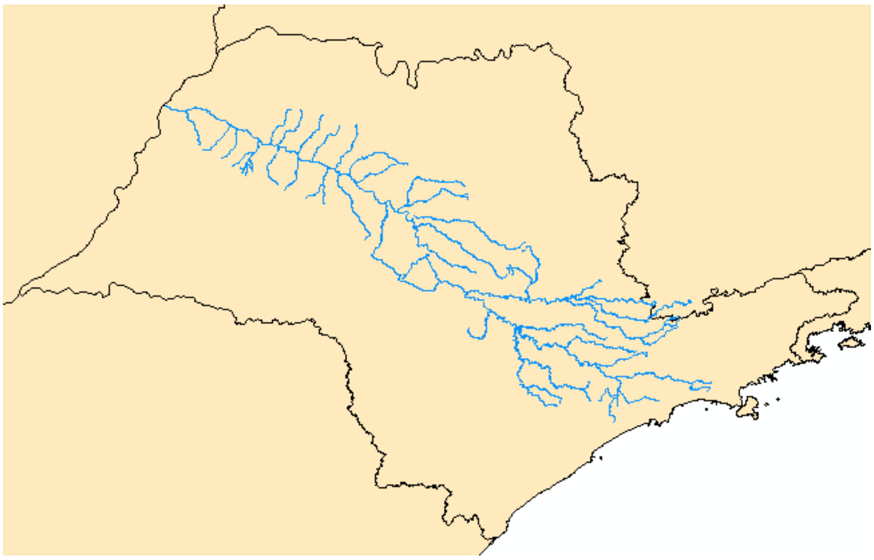
Figure 6 Sao Paulo state location in Brazil

Since 1991, the state of Sao Paulo has an integrated system of water resources management (SIGRH in Portuguese) that joins the government and members of civil society. The territory then, is divided into hydrographic regions and unities of management, the URGHIs (Unidades de Gerenciamento de Recursos Hídricos). Figure 7 shows this division, with the URGHIS in red contained in Tiete Basin: 05-Piracicaba/Capivari/Jundiaí (PCJ), 06-Alto Tiete (AT), 10-Sorocaba/ Médio Tiete (SMT), 13-Tiete/Jacaré (TJ), 16-Tiete-Batalha (TB) e 19-Baixo Tiete (BT) (SAO PAULO, 2011).

Source: São Paulo (2011)

Figure 7 Water management divisions in Sao Paulo state

Tiete is the longest river in the State, with approximately 1,100 kilometers and an east-west direction, as illustrated in Figure 8. Its source is located in the municipality of Salesopolis, very close to the "Serra do Mar", a long system of mountain ranges and escarpments next to Atlantic sea. Following the opposite direction of the most part of rivers, it flows to the countryside rather than the sea, pouring its waters into the ocean only at the end of a journey of 3,500 km, after joining the Paraná River in a discharge of 600 m^3/s (GANHITO, 2005). This characteristic was very important for the country occupation and development.



Source: ANA

Figure 8 Position of Tiete River and its affluents that form the Tiete Basin.

By leaving the highlands, formed by hard rocks, Tiete advances on the sedimentary basin of São Paulo, a region where prevail hills, some protruding spikes and extremely flat areas - the valley bottoms. The original vegetation of the Tiete basin was quite varied: the river starts in the middle of vigorous Atlantic Forest flora and in its original path, then crossed tropical broadleaf semidecidual forests, riparian forests and wetlands, in addition to *cerrado*, the Brazilian tropical savanna (MAURO,1991). Due to this variety of vegetation, there is a great biological diversity. Nevertheless, with the occupation and deforestation, the areas have been reduced and several species become extinct. Today, there is only 8,661 square kilometers of natural vegetation in the basin area.

The average Tiete river flow is 656 m^3/s and the minimum value of the flow considered for preserve the local ecosystem is 187 m^3/s (SAO PAULO, 2012). The Basin's clime is characterized by a dry season in the winter, during the months of June, July and August. The yearly rainfall value is about 1,400 mm, most of which is concentrated in the summer season, in the months of December, January and February and can reach a monthly average of 270 mm.

According to some authors, because of its importance, the indigenous groups who inhabited the Tiete river banks gave its name because of the meaning as "real river" in Tupi (the language spoke by local indigenous groups). The first settlement formed by Portuguese colonizers In the XVI century and at the river bank would become later the largest city in Latin America, Sao Paulo. Through the river, expeditions were carried out to explore and populate the countryside. During centuries, it was used for the mineral exploitation, development of coffee crops and sugar industry. The river then had a strategic role not only as provider of water, the essential resource for support the activities, but also as transportation and logistics of such goods.

With these activities, and especially with the coffee cultivation, there was a major expansion of the São Paulo's economy. Around 1785, there was the advance of industrialization and with it, the attraction of immigrants. However, this process was carried out in an unplanned way, and the result was the disorderly occupation of the river banks and the disposal of pollutants from homes and industries without any treatment. In 1900 there were more than 150 companies throwing waste in Tiete, including textile industries, metallurgy, beverage plants and joinery (GANHITO, 2005)

Nowadays, the river passes by 62 municipalities as shown in Figure 9, including the state's capital, São Paulo. Its basin occupies an extension of 73.400 km², with an elevation range of 800 m above sea level (SAO PAULO, 2012).

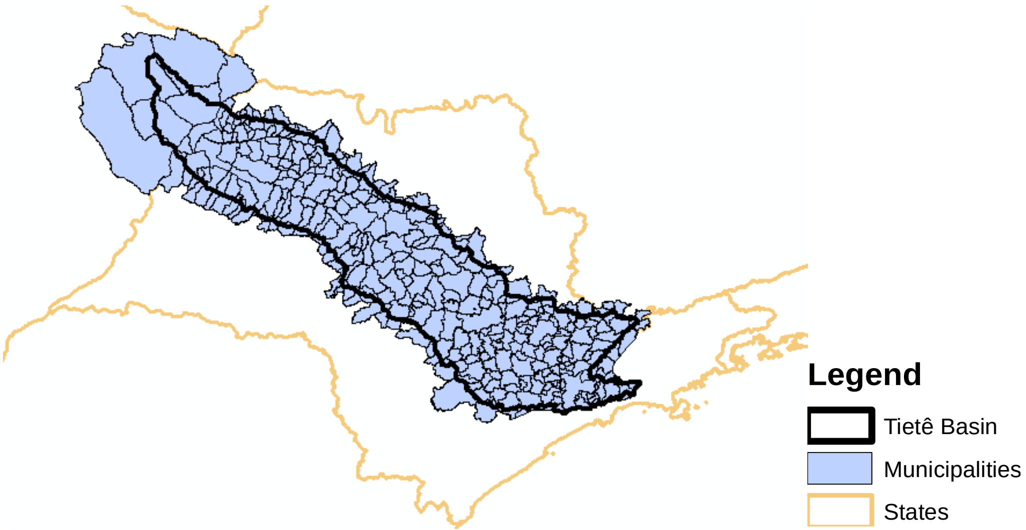


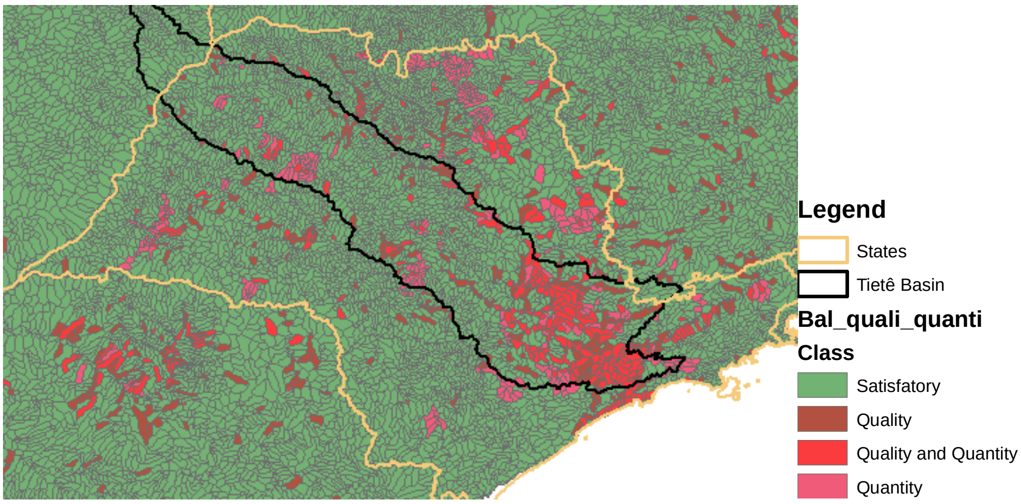
Figure 9 Tiete Basin area and municipalities

The basin counts with a total population in 2012 of almost 30 million people, in which 95% is urban. This area represents around 80% of the state GDB and 71% of the state population. In 2011, the sectors of agriculture and livestock, industry and services represented respectively, 0.97%, 26.79% and 72.25% of the total. The main agricultural activities are sugar cane and citrus fruits (SAO PAULO, 2012). Figures 10 and 10 illustrate the presence of agriculture and livestock, activities that depends on the availability of water in the basin.

Source: fotografiasaereas.com.br

Figures 10 and 11 Agricultural activity in the municipality of "Dois Corregos" in Sao Paulo and lifestock activity in the Barra Bonita reservoir, respectively.

Because of this different uses, the basin suffer many pressure and conflicts in its water resources. Some areas are characterized by great domestic and industrial water consumption, besides the growth production of effluents and waste. For instance, only 89.2% of the sewage in the basin is collected (SAO PAULO, 2012). Subsequently, the water quantity and quality are impacted and not enough to attend the population. Figure 12 shows the balance of water quality and quantity in the state, with the region belonging the Tiete basin the most critics, both in quality and quantity.



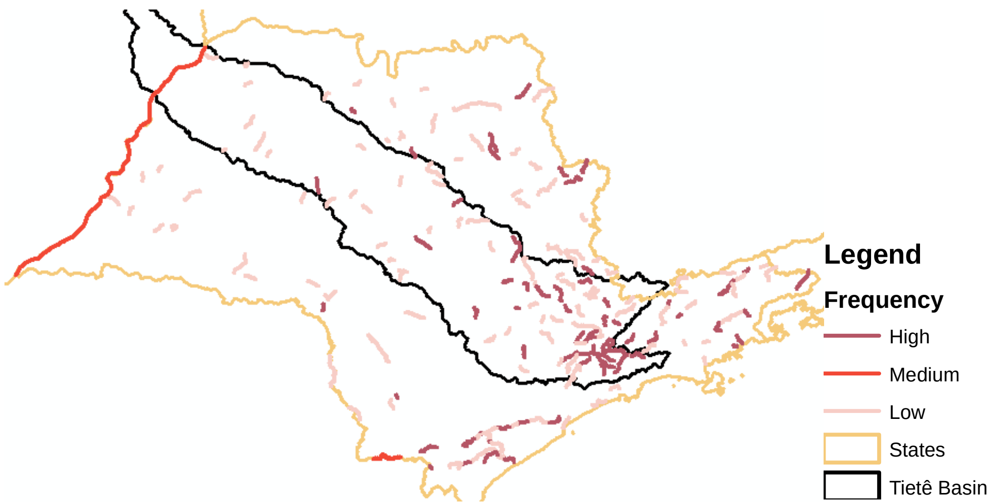
Source: ANA

Figure 12 Balance of the water resources situation in São Paulo and in the Tiete Basin in terms of quality and quantity.

The summer is characterized by strong rains in this region. During this period, there was always river overflow and river floodplain in the history's Basin occupation. Then, besides invading the villages, the river's water formed polluted lakes and became a diseases transmitter. In the 30's, for resolve this problem, the government studied and projected the river's canalization and rectification in the urban zone.

However, in the urban areas, the cases of flood are still frequent and cause multiple damages and losses every year. The Figure 13 shows the frequency of flood events in the rivers of São Paulo state and those of Tiete Basin. It is possible to note that this basin has a critic situation with many rivers characterized by constant floods, especially in the metropolitan region of São Paulo, the most densely populated one.

This is consequence of an irregular occupation, with high levels of pollution and soil sealing, which difficult the drainage in the rainfall events. In the city of São Paulo, express avenues in its margins were constructed as show in Figure 14. Having an intense traffic, these marginal ways also contribute with the flow events and are vulnerable to great economic losses.



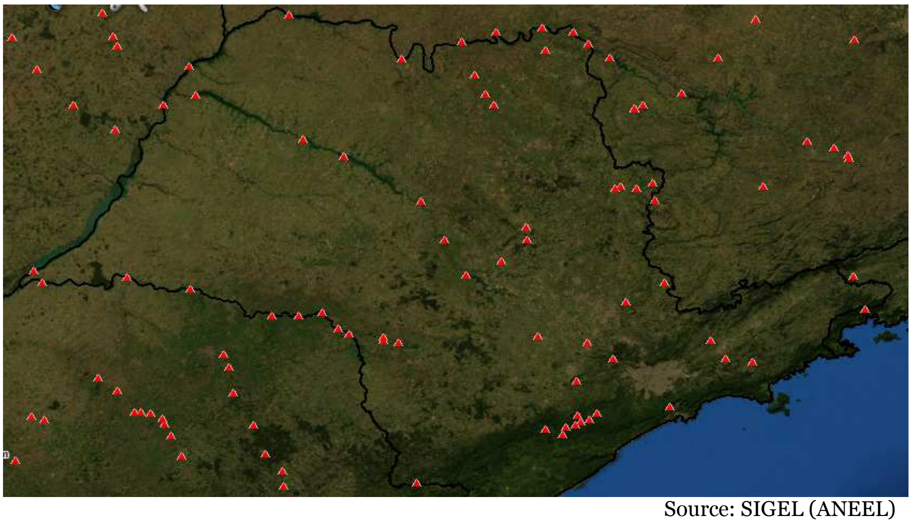
Source: ANA

Figure 13 Frequency of flood events in São Paulo state

Source: fotografiasaereas.com.br

Figure 14 Tiete River inside the metropolitan region of São Paulo

Another important water use in the Basin is the production of energy. Throughout the river, there are many hydroelectric power plants and dams. Around 20% of all energy generated in the country is produced in São Paulo state. The hydroelectric power plants existent in the state of São Paulo are shown in Figure 15. As the majority of dams are from hydroelectric power plants, the river flow is controlled by operations. Then, the natural river flow is not preserved, which consist in a difficulty for hydrological simulations in the basin. The hydrological model used must consider the operational rules or the reconstitution of natural flows, calculated by the National Operator of Energetic Systems, the ONS.



Source: SIGEL (ANEEL)

Figure 15 Red triangles representing the existent hydroelectric power plants in São Paulo State

The navigation was always very important also, since the strategic position of the river and the logistic of goods transportation. The primitive intense uses of this way of transport before the construction of highways and railways favored the development of many cities around the river (GANHITO, 2005). This factor and the process of urban sprawl that is occurring in the last decades contribute to an intense occupation of the riverbank, as show in Figures 16 and 17.

Source: fotografiasaereas.com.br

Figures 16 and 17 Tiete River next to its spring in Itaquaquecetuba with irregular occupation in the river banks and the silting and deforestation caused by it, respectively.

To face the problems of inundations, the city of Sao Paulo has a flood warning system, the *Sistema de Alerta a Inundações de Sao Paulo, SAISP*, nonstructural measure implemented in 1977 to perform the surface monitoring automatically and in real time. The system monitors rain, level of water bodies and flow, pressure, humidity, temperature, wind direction and speed and quality of water. A meteorological radar covers an area of the city and has good accuracy predictions with the production of rain forecast and accumulated rain maps.

3. HYDROLOGICAL MODELS

3.1 Brief overview of hydrological models

Models are simplified representations of the real system that is aimed to be analyzed. They are used for better understand how the systems work, to communicate ideas and to provide results that will influence decisions. There are many criteria to choose the model to be used, as the precision, which indicates how close to reality is the representation, the simplicity, with a reduced and sufficient number of parameters and variables and the transparency, having the possibility to introduce changes by the user.

Hydrological models are conceptual representations of the hydrological cycle and are used to better know and predict hydrological process, as evapotranspiration and runoff. Within a hydrological model is important to choose the type of the model to be used. The hydrological models can be classified as physically-based models and black box or input-output models. Physically-based models use mathematic equations with parameters directly obtained by measurements or estimated indirectly, depending on the availability of a data source. In the Black Box models, the equations are simple transformation functions that connect the outputs with the inputs renouncing to describe physically the process. The models can be classified also as concentrated or distributed, depending on the space range. Distributed models consider the heterogeneity of the territory characteristics and the parameters are estimated for each cell. They have higher resolution but are limited by the uncertainty and availability of parameters. On the other hand, in the concentrated models, the spatial variability is not considered and the basin, for instance, is contemplated as a single cell. This type of model requires less data and processing time.

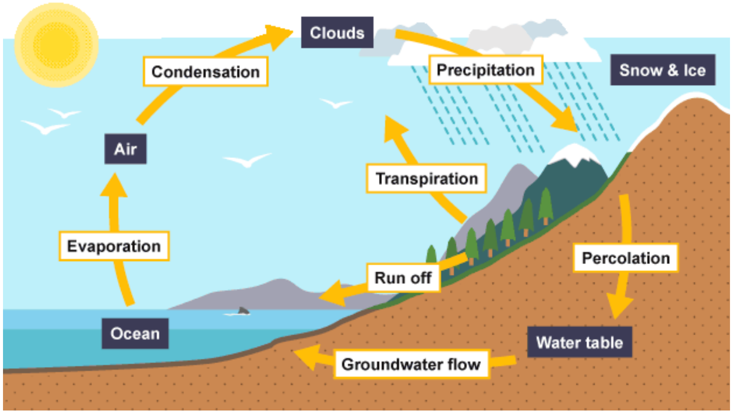


Figure 18 Water cycle

The hydrological cycle processes can be stochastic or deterministic, but in general are a combination of both. The deterministic ones are those that directly apply the laws of Physics, Biology and Chemistry. However, in the nature, most part of the hydrological cycle processes are stochastic, governed by laws of probability for containing random components, which overlap the regularities optionally explained, such as the seasons or the variations of the solar radiation. For instance, there are the precipitation, evaporation and the surface and sub-surface runoff. Thus, events such as floods, droughts and extreme events are hard to predict because of the difficult in identify and measure accurately all causal factors and their interdependencies (Naghettini and Pinto, 2007). Considering these factors, many are the technological developments and advances to better understand the hydrological processes to be used in hydrological models.

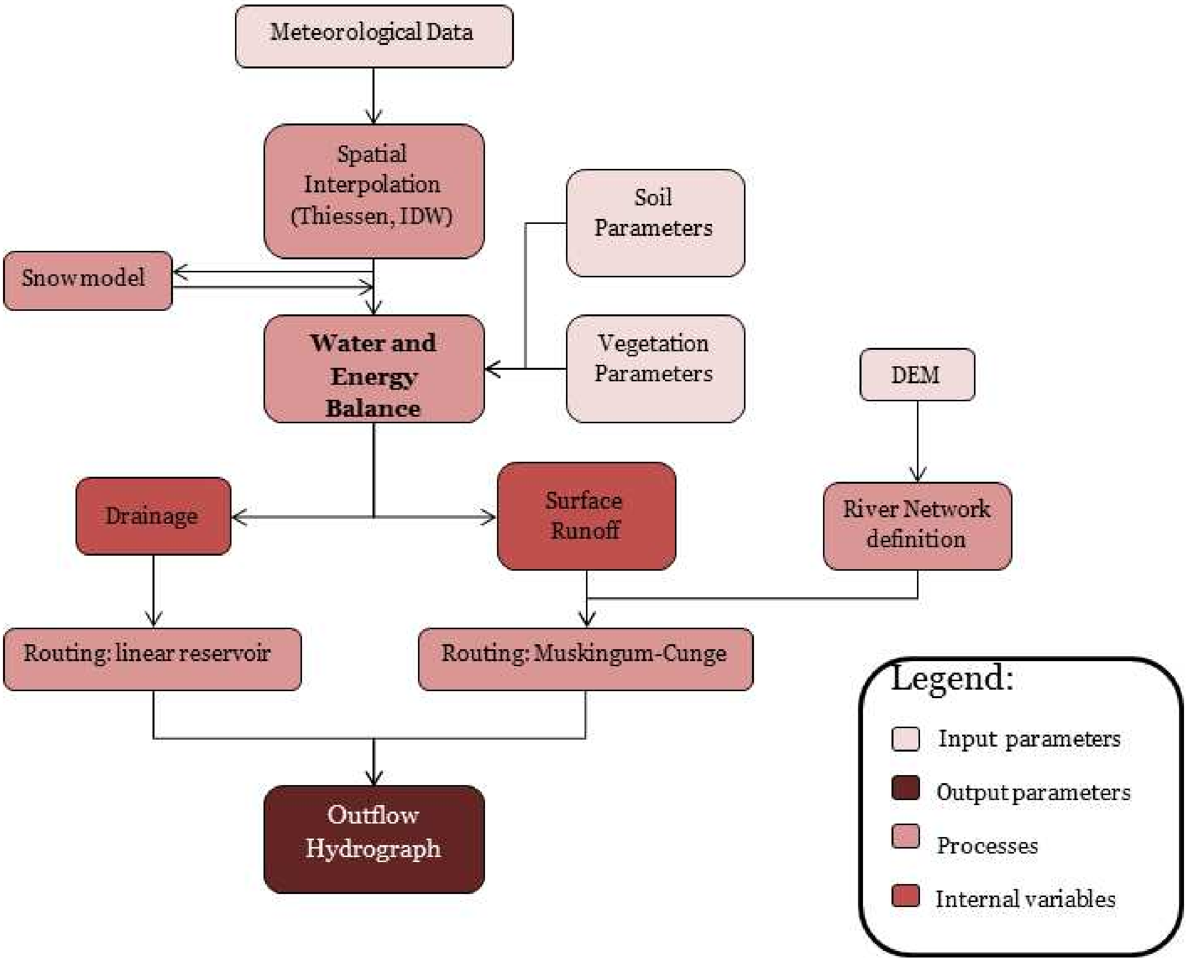
In Brazil, one of the most used hydrological models is the SMAP (Soil Moisture Accounting Procedure), a deterministic model of hydrologic simulation of the type conversion rainfall-runoff. It was developed in 1981 by Lopes J.E.G., Braga B.P.F. and Conejo J.G.L., and published by Water Resources Publications (1982). The model is used for stream flow forecasting and as a system for real time planning and operation of hydropower systems. For the calculations, it uses two reservoirs, four transfer functions and four calibration parameters. Its simplified form permits to be used for various hydropower plants in cascade.

3.2 Hydrological model FEST-WB

The distributed hydrological balance model FEST-WB is a hydrological simulation model, which stands for "Flash flood Event-based Spatially-distributed rainfall-runoff

Transformation-Water Balance". The model was entirely developed at Politecnico di Milano and started in the nineties.

The model can be classified as physically based and distributed and uses meteorological physical parameters and soil characteristics to simulate the flow of a river. This simulation is made through the balance of mass and energy involved in the main hydrological cycle's processes, such as evapotranspiration, infiltration, surface runoff, subsurface flow, flow routing and snow dynamics. It considers the temporal and superficial variability, using a raster format to calculate and join all information. Thus, it is necessary to use a great quantity of data as input. Each cell contains and calculates all parameters needed, which, multiplied by the number of cells, provide a large amount of information for processing. This detailing ensures great precision, especially in the spatial scope.



Source: Adapted from Ceppi (2011)

Figure 19 FEST-WB model's structure diagram

Five main components can be identified in the FEST-WB model (CEPPI, 2011):
(a) the flow paths and channel network definition;
(b) the spatialization of site measured meteorological forcings;
(c) the snow pack dynamics;
(d) the runoff calculation;
(e) the overland and subsurface flow routing.

The first component – the flow paths - is determined from the digital elevation model (DEM) by using an algorithm. The channel network is built using the constant minimum support area concept, which consists of selecting a constant critical support area that defines the minimum drainage area required to initiate a channel (MONTGOMERY AND FOUFOULA-GEORGIOU, 1993). With the values of the average height of each cell, it is possible to obtain the geomorphological parameters such as the slope, the direction of the runoff and the albedo.

For the second component, the model spatially interpolates the existing data related to precipitation and to the air average, maximum and minimum temperatures (CEPPI, 2011) of the ground stations. The interpolation is achieved by using the inverse distance weighting (IDW) technique and the temperature data is interpolated to different altitudes by using a fix gradient of -0.0065 °C/m. In this method, phenomena of thermal inversion are neglected.

The third component considers the snow dynamics simulation, including snow melt and snow accumulation dynamics. Since this study is developed for a subtropical area without the formation of snow (the minimum temperatures stays between 5°C and 7°C), this component was not considered in the calculation.

The fourth component – the runoff calculation – is computed for each elementary cell according to a modified SCS-CN method extended for continuous simulation (RAVAZZANI et al., 2007). This calculation is done in a few steps, determining for each cell and period of time: the effective evapotranspiration, the soil moisture, the degree of saturation and, finally, the maximum potential of retention of the soil (S).

1) Esteem of the effective evapotranspiration

The evapotranspiration rate (ET), represents the sum of the phenomena of evaporation and transpiration. The process of evaporation is determined by the energy needed for the liquid water present in rivers, lakes and soil to turn into steam. This energy is provided by the solar radiation, temperature of the environment, wind velocity and humidity of air.

The transpiration, on the other hand, is the evaporation of the water present in the vegetation, which is controlled by the aperture of the stomata, the regulatory organs present in the leaves. Thus, it depends on temperature, wind velocity, air humidity, gradient of saturated steam and the capacity of the plant in transport water from the soil to the leaves.

In order to obtain the evapotranspiration rate, it is necessary first to estimate the value of reference evapotranspiration (ET_0). The reference value is defined as the potential evapotranspiration of a hypothetical green grass surface with uniform height, actively growing, completely shading the ground, and adequately watered.

The Food and Agricultural Organization of the United Nations (FAO) recommended the Penman-Monteith equation (FAO-56 PM) as the standard for estimating reference evapotranspiration (RAVAZZANI ET ALL, 2012). This method requires measurement of: air temperature, air relative humidity, solar radiation and wind speed. However, the availability of stations and reliable data of these parameters are very limited in the most part of the globe, which restrains the applicability of studying some specific river basins. Considering this difficulty in obtaining data, Hargreaves and Samani (1985) developed an alternative equation using only the maximum and minimum temperature daily data. The HS method for calculating daily ET_0 is:

$$ET_{0,HS} = HC \times R_a \times (T_{max} - T_{min})^{HE} (\frac{T_{max}+T_{min}}{2} \qquad \text{Eq. (1)}$$

Where

- $ET_{0,HS}$ = ET_0 estimated by the HS equation (mm/day)
- Ra = extraterrestrial radiation (mm/day), tabulated according to the month of the year and the local latitude;
- T_{max} = daily maximum air temperature (°C);
- T_{min} = daily minimum air temperature (°C);
- HC = empirical coefficient (HC = 0.0023);
- HE = empirical exponent (HE = 0.5);
- HT = a factor needed to convert units of Fahrenheit to Celsius (HT = 32/1.8 = 17.8)

The Centre Commun de Recherche of the European Economic Community (1992) made a study comparing twelve ET_0 equations, using lysimeter ET and synoptic climatic data, with the Penman equation as standard method. The HS equation was selected as the one with the closest results to the classic Penman (HARGREAVES, 1994).

However, the soil has limitations of water availability and the theoretical value is not always reached. The effective evapotranspiration (ET_{eff}) thus, can be calculated by splitting it into the soil effective evaporation (E_s) and the vegetation effective transpiration (T_s). Both depend on the ET_0 and on two coefficients α and β, which are function of the soil humidity (θ), as expressed in the following equations:

$$E_s = \alpha(\theta) \times ET_0 \times (1 - f_v)$$ Eq. (2)

$$T_s = \beta(\theta) \times ET_0 \times f_v$$ Eq. (3)

Where f_v is the relative quantity of vegetation present in the territory.

$$\alpha(\theta) = 0.082 \times \theta + 9.17 \times \theta^2 - 9.185 \times \theta^3$$ Eq. (4)

$$\beta(\theta) = \frac{\theta - \theta_W}{\theta - \theta_W}$$ Eq. (5)

Finally, the effective evapotranspiration can be calculated by the equation:

$$ET_{eff} = Es + Ts$$ Eq. (6)

2) Determination of the degree of saturation

The method calculates the maximum retention *S* for each cell using a linear function of the degree of saturation, which depends on the saturation soil moisture (θ*sat),* the residual soil humidity (θ*res)* and of the soil humidity (θ*t)* calculated with the equation 8.

$$\frac{\partial\theta}{\partial t} = \frac{1}{Z}(P - R - D - ET)$$ Eq. (7)

Where:
R = surface runoff flux,
D = drainage flux,
ET = evapotranspiration rate,
Z = soil depth

The equation that calculates the degree of saturation is:

$$\varepsilon_t = \frac{\theta_t - \theta_{res}}{\theta_{sat} - \theta_{res}}$$ Eq. (8)

3) Calculus of the maximum potential of retention S

Finally, considering all the values previously determined, it is possible to calculate the potential maximum retention (*S*), with S_1 being the maximum value of *S* when the soil is dry (AMC 1).

$$S = S_1(1 - \varepsilon)$$ Eq. (9)

The value of S_1 is determined by using the SCS-CN method (Soil Conservation Service – Curve Number) adapted to continuous simulations (RAVAZZANI et al. 2007). The SCS-CN method distinguishes three levels of antecedent moisture condition (AMC I, AMC II, and AMC III), depending on the total rainfall in the 5 days preceding a high rainfall event (MONTALDO et al., 2007). In the modified version of the model, the value of humidity used is not the equivalent of five days previous to the event, but the correspondent to the beginning of the rainfall event. For each cell, the FEST-WB model applies the modified method using hydrological balance. To calculate this value, the CN_I is obtained from CN_{II} by using the following empiric equation.

$$CN_I = \frac{4{,}2 \times CN_{II}}{10 - 0{,}058 \times CN_{II}}$$ Eq. (10)

The values of CN for the AMC II condition are tabulated by the Soil Conservation Service on the basis of soil type and land use (MONTALDO ET AL, 2007). At that point, S_1 can be calculated with:

$$S_1 = 254 \times \left[\left(\frac{100}{CN_I}\right) - 1\right]$$ Eq. (11)

The last component determines the runoff routing by using the Musking-Cunge method in its non-linear form with celerity varying in time, which is calculated as a function of soil saturated conductivity (MONTALDO et al, 2007).

4. INPUT DATA

The model uses georeferenced maps in GIS format with information of the soil use, elevations and vegetation, besides daily meteorological data of different stations. To obtain the value of each cell, the model interpolates the existing data using the method IDW (Inverse Distance Weighted Method).

4.1 Rainfall

The rainfall data used for the simulation was obtained from the Hidroweb platform, an interface that gathers meteorological stations historical data of the mainly hydrographic basins in Brazil, and is managed by the National Water Agency, the *ANA (Agencia Nacional de Águas)*.

The historical data from 1970 to 2011 of 198 stations was organized in a standard format, specific for the model input and in a text file nominated as pioggia.txt. The major information is in Figure 20:

- parameter's name. In this case*, pioggia* (rainfall in Italian);
- number of stations;
- time period in which the measurements were made. As the data available had a daily time step, the dt is equal to 86,400 seconds;
- list with name, code and coordinates of each station;
- historical series of rainfall, starting in 01/01/1970 and finishing in 12/31/2011 of each station, identified by the code;

```
PIOGGIA
anagrafica
198      stazioni
86400    cadenze misure  [s]
-999.9   dato nullo

stazione          codice   x                y            z
INOCENCIA         1951005 -5193611         -1973639      502
CRUZEIRO          2049011 -4995000         -2050000      470
SEBASTIANOPOLIS   2049018 -4995000         -2063330      470
MONTE_APRAZIVEL   2049019 -4970000         -2076670      480
MACAUBAL          2049022 -4996670         -2080000      510
BADY_BASSIT       2049027 -4945000         -2091670      520
```

Figure 20 Input text file of rainfall historical data from stations located in the Tiete Basin

The spatial information of the stations was in a geographic coordinate system titled South America Datum – 1969. In order to be used in the model, it was necessary to convert the coordinates to WGS-1984. Annex A contains the Geographic distribution of all rainfall stations in the studied area.

4.2 Temperature

The FEST model interpolates data of maximum, minimum and average temperature of local stations to provide information for the entire Tiete basin. The temperature data for this basin was very difficult to obtain and usually presented missing information. Hence, different sources were consulted to gather consistent data of 12 stations. The information of the Institute of Astronomy, Geophysics and Atmospheric Science (IAG), located in the University of Sao Paulo, was the only station with full data regarding all years used for the simulations. This information was acquired directly with the Institute. The data from other stations, on the other hand, were obtained from Hidroweb, INMET (Brazilian National Meteorological Institute) and DAEE-SP (Department of Water and Electrical Energy of Sao Paulo State) websites. The data organization format to use as input in the FEST model is similar to the rainfall format.

Table 1 presents the name, code, height (z) and coordinates of latitude and longitude for each station, while Figure 21 shows the location of them within the Tiete Basin.

Tabela 1 Stations of temperature data

Code	Name	Z (m)	Latitude	Longitude
83781	SAO_PAULO_MIR_de_SANTANA	792	-23.50	-46.61
83851	SOROCABA	645	-23.48	-47.43
83726	SAO_CARLOS	856	-21.96	-47.86
81000	IAG	780	-23.65	-46.63
110	BIRITIBA_MIRIM	880	-23.63	-45.95
59	BOTUCATU	873	-22.95	-48.43
35	BORACEIA	445	-22.15	-48.75
28	BARRA_BONITA	456	-22.52	-48.53
112	RIO_CLARO	600	-22.37	-47.60
108	ANALANDIA	680	-22.12	-47.67
72	BRAGANCA_PAULISTA	860	-22.95	-46.53
111	IBITINGA	385	-21.75	-49.00

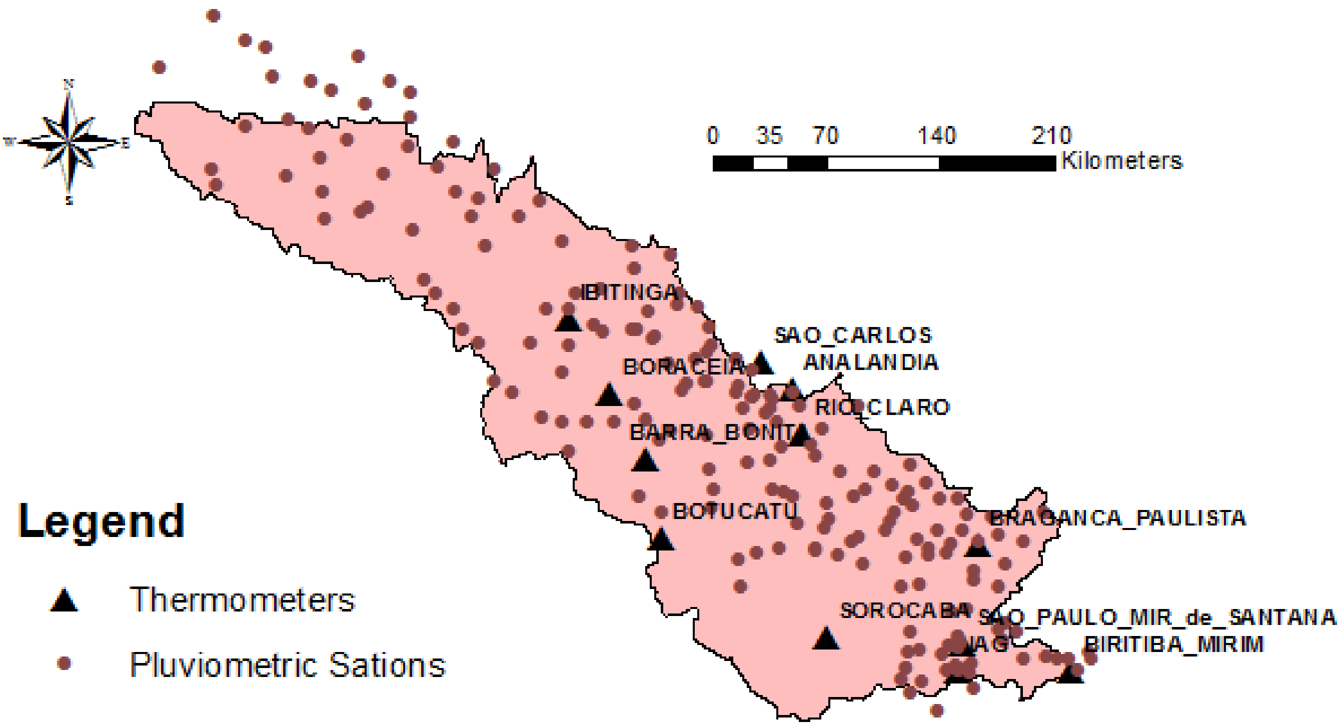


Figure 21 Distribution of the rainfall and temperature stations in Tiete Basin

4.3 Digital Elevation Model

One of the main maps GIS used was the Digital Elevation Model (DEM) that provides the average elevation value for each elementary cell present at the Tiete Basin area. For the simulations it was used the geographic database of topographically derived data sets of HYDRO1k, developed at the U.S. Geological Survey`s (USGS) EROS Data Center. The HYDRO1k was derived from GTOPO30, the 30 arc-second (approximately 1 km) digital elevation model (DEM) of the world and is used in hydrological processes, organization and evaluation. This DEM is processed for the hydrological use to remove elevation anomalies and to ensure the correct movement of water across its surface.

The HYDRO1k package provides, for each continent, a suite of six raster and two vector data sets. The raster data sets are: the hydrologically correct DEM, derived flow directions, flow accumulations, slope, aspect, and a compound topographic (wetness) index. The derived streamlines and basins are distributed as vector data sets. (U.S. GEOLOGICAL SURVEY'S)

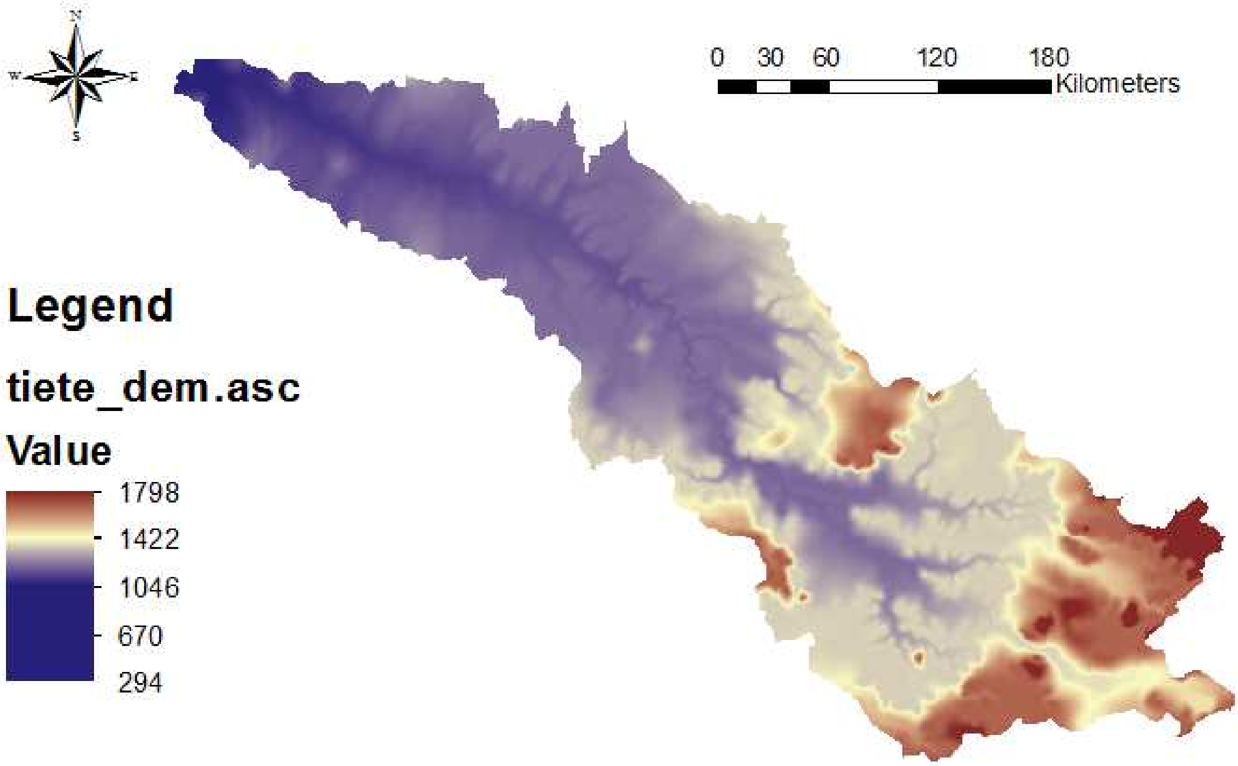


Figure 22 Digital Elevation Model (DEM) of the study area

4.4 Soil Texture

The hydrologic cycle is influenced by the predominant type of soil, which is conditioned by the size of its grains, aggregation, shape and arrangement of particles. These characteristics determine the infiltration capacity of different soils.

The soil texture information used in the simulations was obtained from the Harmonized World Soil Database (HWSD), a global database released in July 2008. This database was framed within a Geographic Information System (GIS) and contains up-to-date information on world soil resources. It gathers more than 16,000 different soil maps from existing national and regional updates of soil information and the information contained within the 1:5,000,000 scale FAO-UNESCO Soil Map of the World. The HWSD is of immediate use in the context of the Climate Change Convention and the Kyoto Protocol for soil carbon measurements and for the FAO/IIASA Global Agro-ecological Assessment studies (GAEZ, 2012).

According to the HSDW documentation, most of the areas covered by Soil and Terrain Databases (SOTER) are considered to have the highest reliability (Southern and Eastern Africa, Latin America and the Caribbean, Central and Eastern Europe). The main study used was the FAO/UNEP/ISRIC/CIP 1998, Soil and terrain digital database for Latin America and the Caribbean at 1:5 million scale.

The information is available in a 30 arc-second (approximately 1 km) raster map, in which each grid cell in the database contains commonly used soil parameters, such as: organic carbon, pH, water storage capacity, soil depth, cation exchange capacity of the soil and the clay fraction, total exchangeable nutrients, lime and gypsum contents, sodium exchange percentage, salinity, textural class, and granulometry.

The FEST model used only basic parameters related to the soil texture classification as clay, loan and sand. The hydrological parameters are defined for 7 classifications, as indicated in TABLE 2 (MAIDMENT, 2001)

Table 2 Parameters correspondent with the soil texture

Class	**Type**	**Ksat (m/s)**	**θ residuo [-]**	**θ saturo [-]**	**Brooks&Corey [cm]**	**Wilting point [-]**	**Field capacity [-]**	**Bubbling pressure**
1	Gravel	1.00E-04	0.006	0.417	1.09	0.007	0.018	0.0136
2	Sand	6.94E-05	0.02	0.437	0.694	0.033	0.091	0.0726
3	Loamy Sand	1.39E-05	0.035	0.437	0.553	0.055	0.125	0.0869
4	Sandy Loam	6.94E-06	0.041	0.453	0.378	0.095	0.207	0.1466

5	Loam	4.17E-06	0.027	0.463	0.252	0.117	0.27	0.1115
6	Clay	1.11E-07	0.09	0.475	0.165	0.272	0.396	0.373
7	Stone		0.195	0.523	0.293	0.336	0.466	1.872

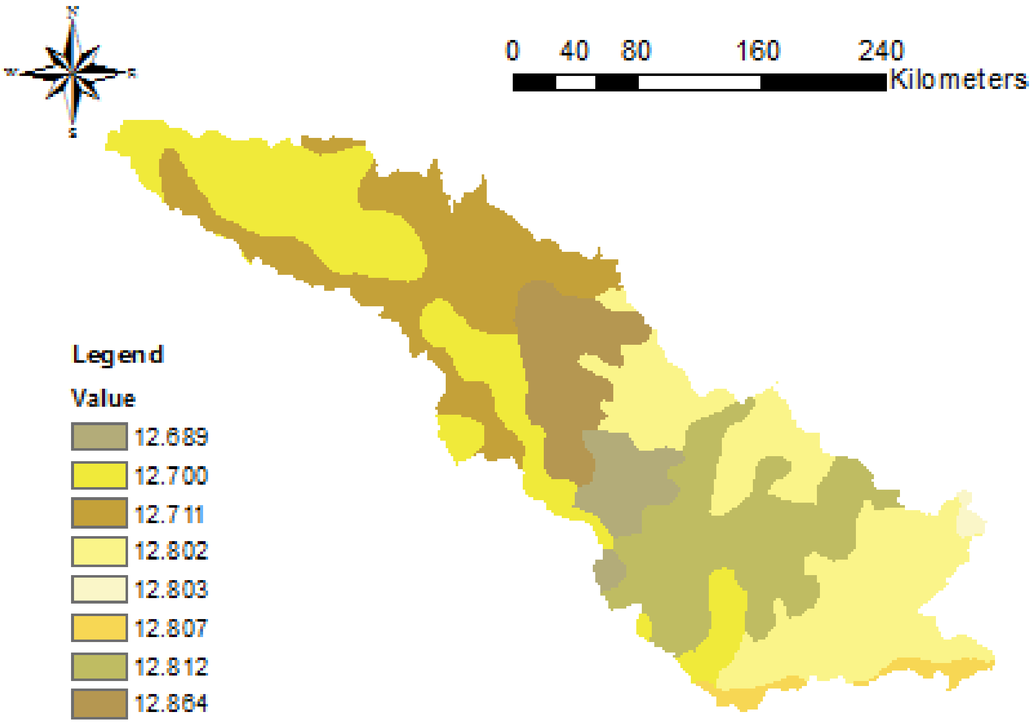


Figure 23 GIS Map of soil texture for the Basin area

The raster map with the codes relative to the soil types is in Figure 23. Table 2 Parameters correspondent with the soil texture indicates the topsoil fractions for each code.

Table 3 Topsoil texture for the soil types present in the Tiete Basin

Code	**12689**	**12711**	**12700**	**12864**	**12802**	**12812**	**12807**	**12803**
Dominant Soil Group	AR - Arenosols	LX - Lixisols	FR - Ferralsols	FR - Ferralsols	FR - Ferralsols	FR - Ferralsols	CM - Cambisols	LP - Leptosols
Topsoil Sand Fraction (%)	92	91	84	13	52	88	31	64
Topsoil Silt Fraction (%)	3	3	4	25	7	2	27	10
Topsoil Clay Fraction (%)	5	6	12	62	41	10	42	26

Topsoil USDA Texture Classification	sand	sand	loamysand	clay (heavy)	sandyclay	loamysand	clay (light)	sandyclayloam

The studied area presents a predominant sand soil texture, with some areas marked by the incidence of relevant clay fractions. This means that the topsoil has, in general, a relatively good permeability.

4.5 Land cover

The soil use has direct impacts in the hydrological cycle. The soil sealing, common in urban areas, reduces infiltration and increases the speed of flow, with the consequence of large flood peaks. The agriculture, on the other hand, causes the reduction of the organic matter in soil and of the porosity, resulting in decreased infiltration and consumption of water by plants.

The information about land cover was obtained with the GlobCover project. The GlobCover is an initiative from the European Space Agency (ESA) that aims at developing and making land cover maps available. This is accomplished by using observations from the 300 meters MERIS sensor located on the ENVISAT satellite mission.

The GlobCover project used for FEST Simulations was the GlobCover 2009, which presents the following land cover classification:

Table 4 GlobCover legend for world land cover

Value	GlobCover global legend	
11	Post-flooding or irrigated croplands	
14	Rainfed croplands	
20	Mosaic Cropland (50-70%) / Vegetation (grassland, shrubland, forest) (20-50%)	
30	Mosaic Vegetation (grassland, shrubland, forest) (50-70%) / Cropland (20-50%)	
40	Closed to open (>15%) broadleaved evergreen and/or semi-deciduous forest (>5m)	
50	Closed (>40%) broadleaved deciduous forest (>5m)	
60	Open (15-40%) broadleaved deciduous forest (>5m)	
70	Closed (>40%) needleleaved evergreen forest (>5m)	
90	Open (15-40%) needleleaved deciduous or evergreen forest (>5m)	
100	Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)	
110	Mosaic Forest/Shrubland (50-70%) / Grassland (20-50%)	
120	Mosaic Grassland (50-70%) / Forest/Shrubland (20-50%)	
130	Closed to open (>15%) shrubland (<5m)	
140	Closed to open (>15%) grassland	
150	Sparse (>15%) vegetation (woody vegetation, shrubs, grassland)	
160	Closed (>40%) broadleaved forest regularly flooded - Fresh water	
170	Closed (>40%) broadleaved semi-deciduous and/or evergreen forest regularly flooded - Saline water	
180	Closed to open (>15%) vegetation (grassland, shrubland, woody vegetation) on regularly flooded or waterlogged soil - Fresh, brackish or saline water	
190	Artificial surfaces and associated areas (urban areas >50%)	
200	Bare areas	
210	Water bodies	
220	Permanent snow and ice	

This classification makes possible to define the areas with natural vegetation, croplands and human occupation: for each type of land coverage, a CN (Curve Number) is determined. This information will be used for the characterization of the vegetation dynamics and for the calculation of the infiltration with the SCS-CN method, as explained in the FEST-WB model explanation.

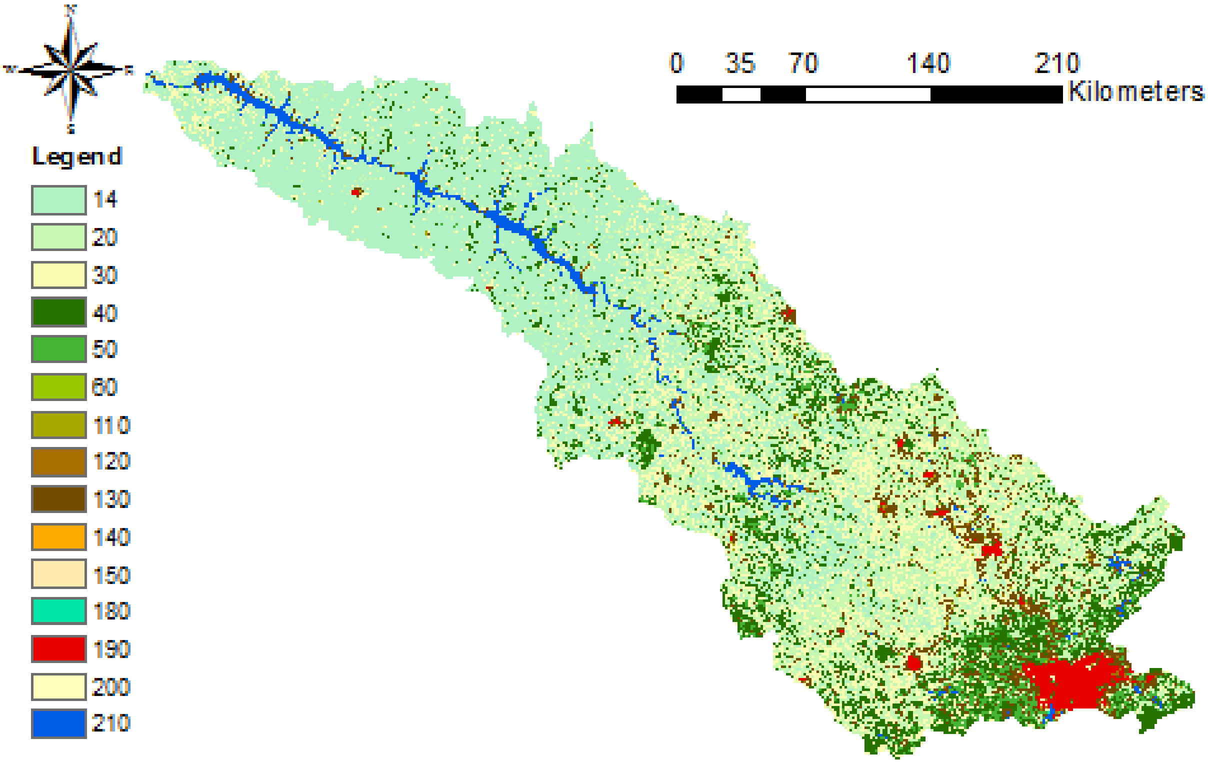


Figure 24 Land cover map for the Tiete Basin

Figure 24 Land cover map for the Tiete Basin presents the land cover for the Tiete Basin area. It is possible to notice that the area has a predominant cover of rainfed croplands (14), with significant presence of mosaic vegetation and croplands (20 and 30). In red, it is possible to identify some dense urban areas, as the Metropolitan Region of Sao Paulo located in the Southwest.

5. RESULTS AND ANALYSIS

With all data gathered and processed, it is possible to start the simulations using the FEST model. After interpolating the data collected for each cell to obtain distributed values for the basin area, the average daily values of the air temperature, precipitation and evapotranspiration were collected and analyzed graphically.

5.1 Coefficient of saturation (ks) and Curve Number (CN)

According to the input soil texture, it was possible to construct a GIS Map representing the coefficient of saturation (ks) distribution for the entire Tiete Basin, as show in Figure 25. This information is important for the determination of the Curve Number (CN).

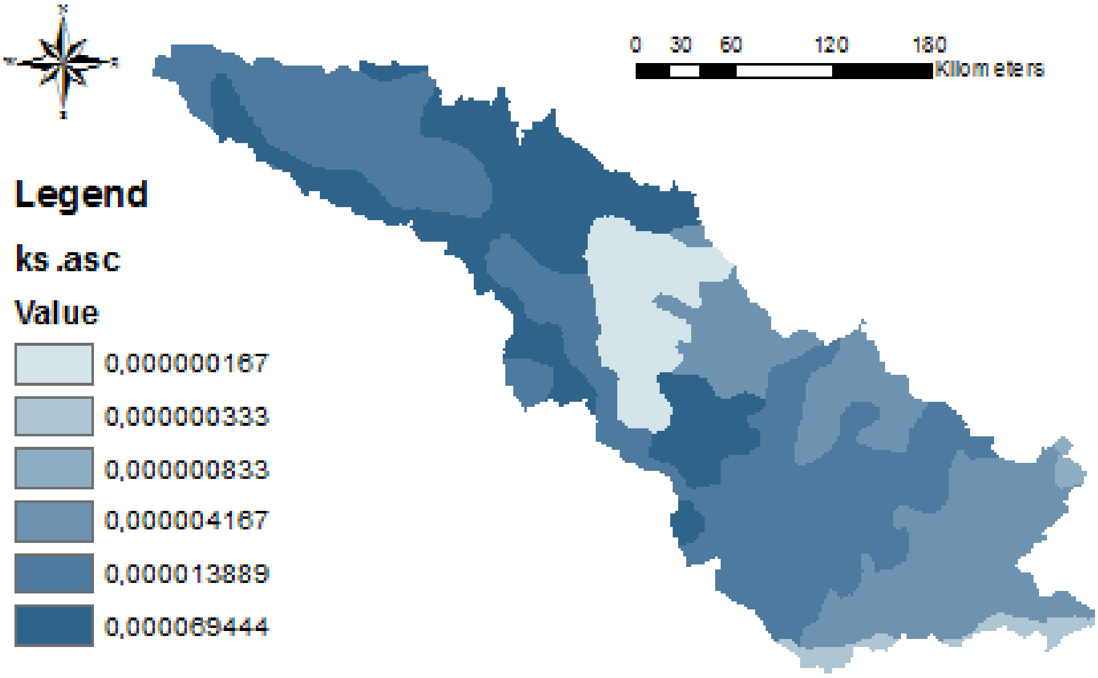


Figure 25 ks distribution for Tiete Basin

The soil type and the land use are also important to determine the Curve Number parameter, which decrease with the soil permeability. The map with the CN distribution in the Basin is in Figure 26

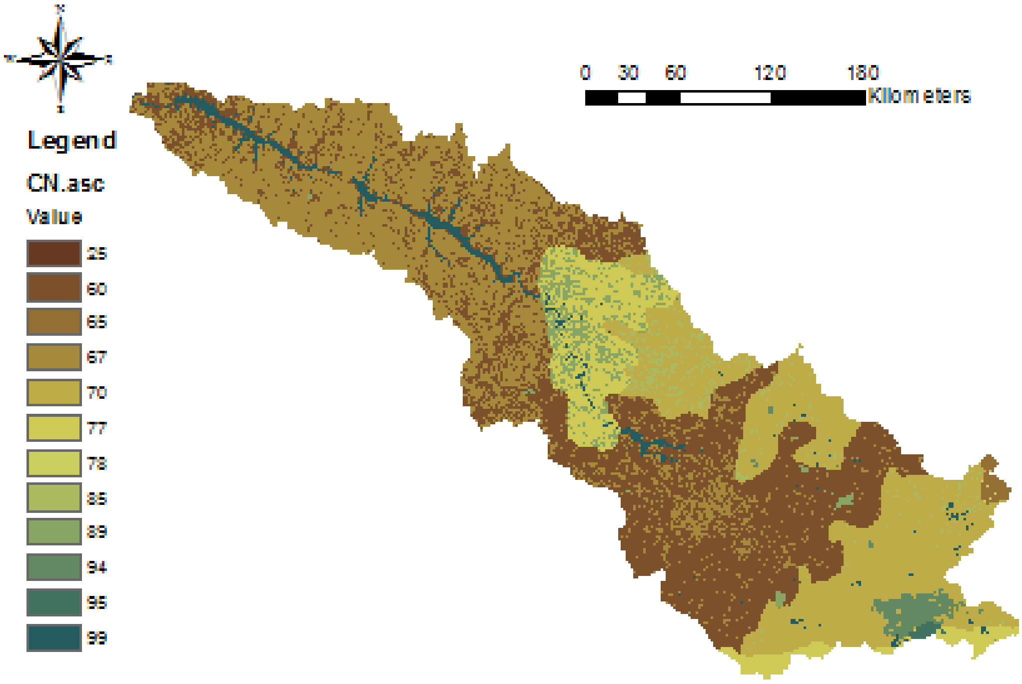


Figure 26 CN distribution for Tiete Basin

5.2 Air temperature, Precipitation, Soil Moisture and Evapotranspiration

The annual average of each variable and the total annual rainfall were obtained from the daily averages and the total daily precipitation. The air temperature average in the Tiete Basin for each day and in an altitude of 2 meters is represented in the Figure 27From the graphic, it is possible to note a linear growth trend on the average temperature. The average increased almost 1.5°C when using the linear trend to compare the values of January, 1970 with January, 2011.

This phenomenon can be attributed to several factors, as the climate changes occurring in a global scale or influences of local aspects as soil use changes and air pollution. In fact, during the period analyzed, there was a significant and intense process of urbanization in the study area, which can be an important element that triggered the temperature increase.

A research conducted in one of the stations used in this work, the IAG, revealed that the air temperature increased 2.1°C in a period of 70 years, from 1936 to 2005. It is suggested that theses climate changes are due to regional and global anthropic sources. The former is related to changes in the microclimate due to a reduction in vegetation cover, increase in urbanization and air pollution. The latter, less significant, is related to global greenhouse effects (PEREIRA et al, 2007).

Since this station is located in the city of São Paulo, the most urbanized portion of the basin and the one that suffered the most significant changes in the last decades, its results probably influenced significantly the simulation results for the entire basin. The daily average temperature found was 17.9°C, with a maximum of 29.2°C and a minimum of 5.6°C.

This increase in the temperature is already affecting some agricultural fields. Areas of unfitness for the coffee culture in terms of maximum temperatures supported by plants - 23°C annual average - significantly increased by the end of the century, shifting the culture gradually to the south of the country and higher areas in the Southeast, in search of cooler climes (PINTO et al, 2007). The temperature increase reduces the growing period and increases maintenance respiration rate in most cultures, thus causing a negative impact on productivity (LONG et al. 2005; SLINGO, et al., 2005).

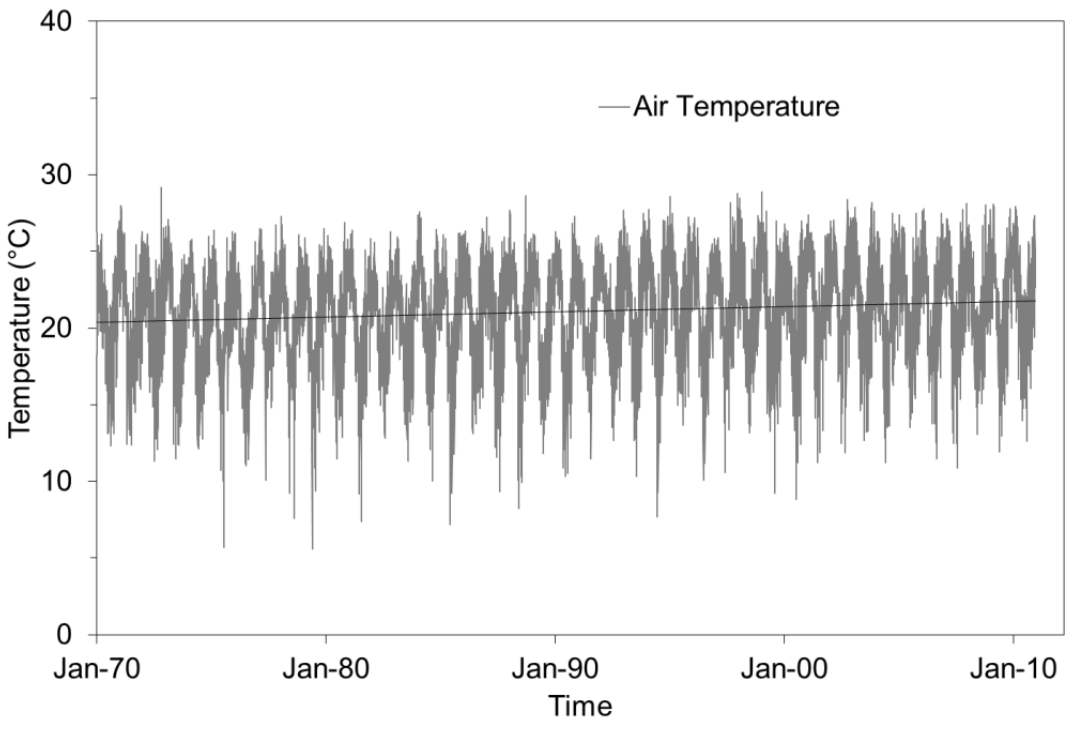


Figure 27 Temperature variation from 1971 to 2010 in Tiete Basin

Despite the increased temperature, the linear trend of precipitation in the basin did not present significant changes during the period analyzed. The results are presented in the follow graphic, with the linear trend and the cumulated precipitation. The average daily precipitation value was 4.2 mm, with a maximum of 79.45 mm. This result is in agreement with the studies contained in the IPCC fourth report, which demonstrated that in the Latin America Southeast, the total annual rainfall appears to have suffered no noticeable change in the last 50 years.

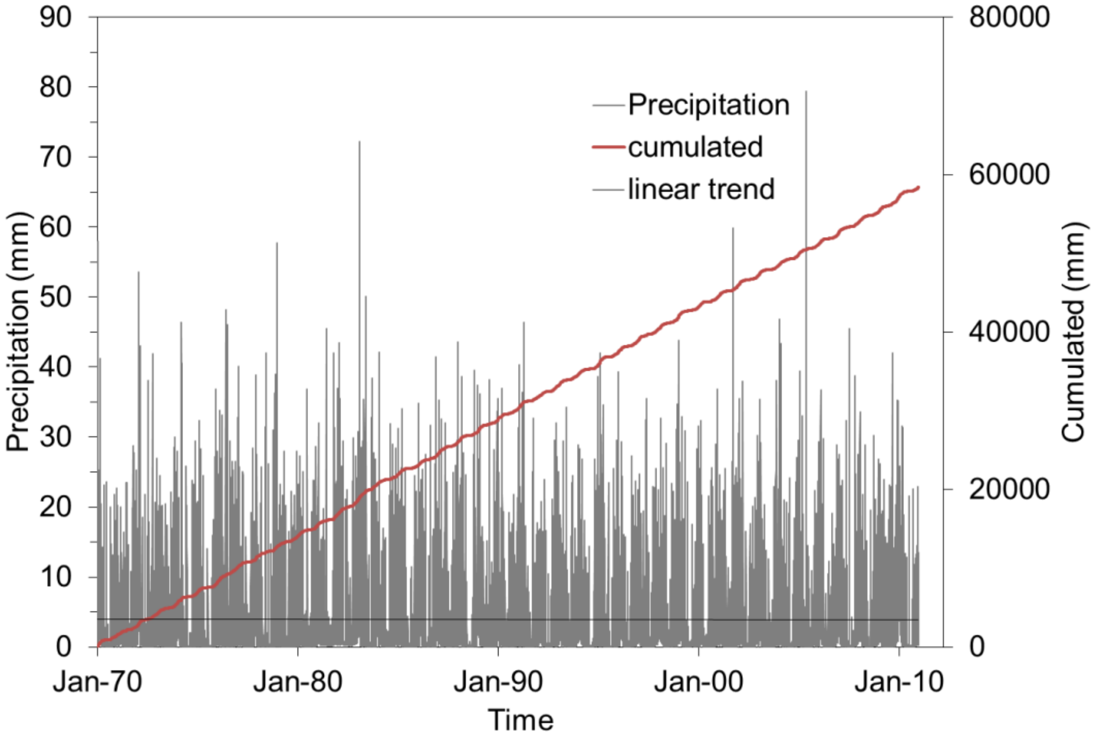


Figure 28 Precipitation variation from 1971 to 2010 in Tiete Basin

The potential evaporanspiration linear trend obtained from the simulations also didn't present an increased or decreased rate. Despite the dependence of temperature on the potential evapotranspiration calculation, the linear trend behavior of the two parameters was different. This is because it doesn't depend on average temperature, but on the maximum and minimum temperatures instead. The average value of the potential evapotranspiration stayed at 3.85 mm, with a maximum of 7.78 mm.

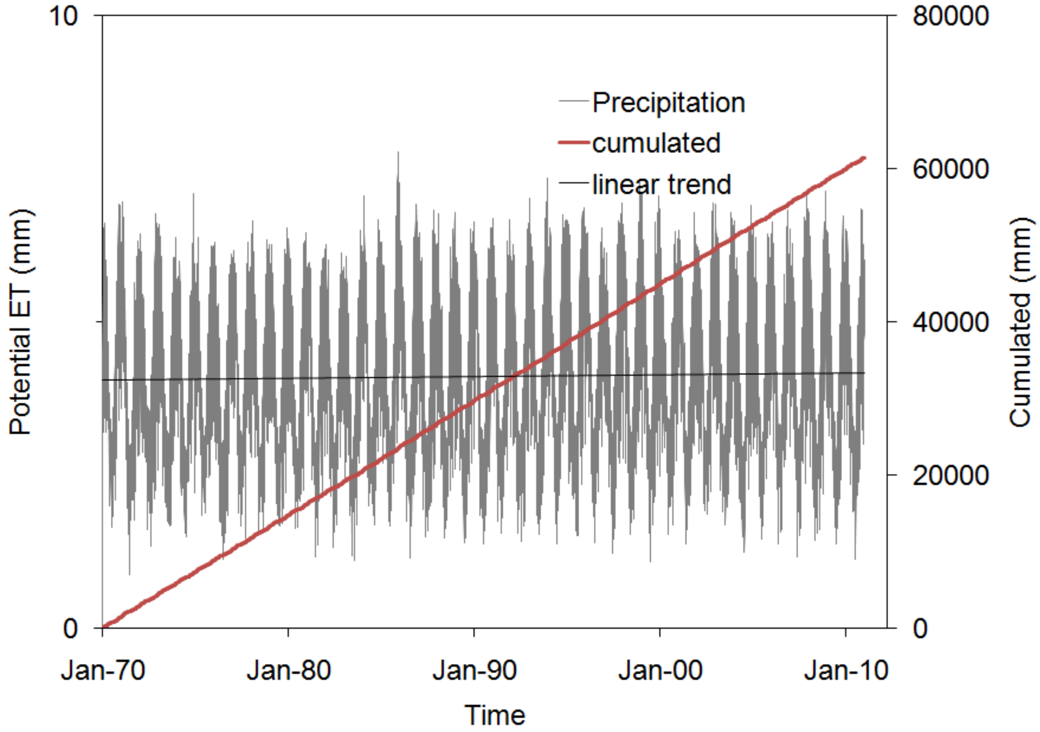


Figure 29 Potential Evapotranspiration variation from 1971 to 2010 in Tiete Basin

A similar behavior was found when analyzing the linear trend of the effective evapotranspiration, showed in Figure 30. This result was expected, whereas the E_{ff} depends on the soil moisture and on the presence of vegetation. The first was another output of the simulations and did not present changes in the linear behavior during the simulated period, as can be observed on the graphic of the Figure 31. The second, the quantity of vegetation, was considered constant, since it derives from the land cover GIS map, considered unchangeable for simplification reasons.

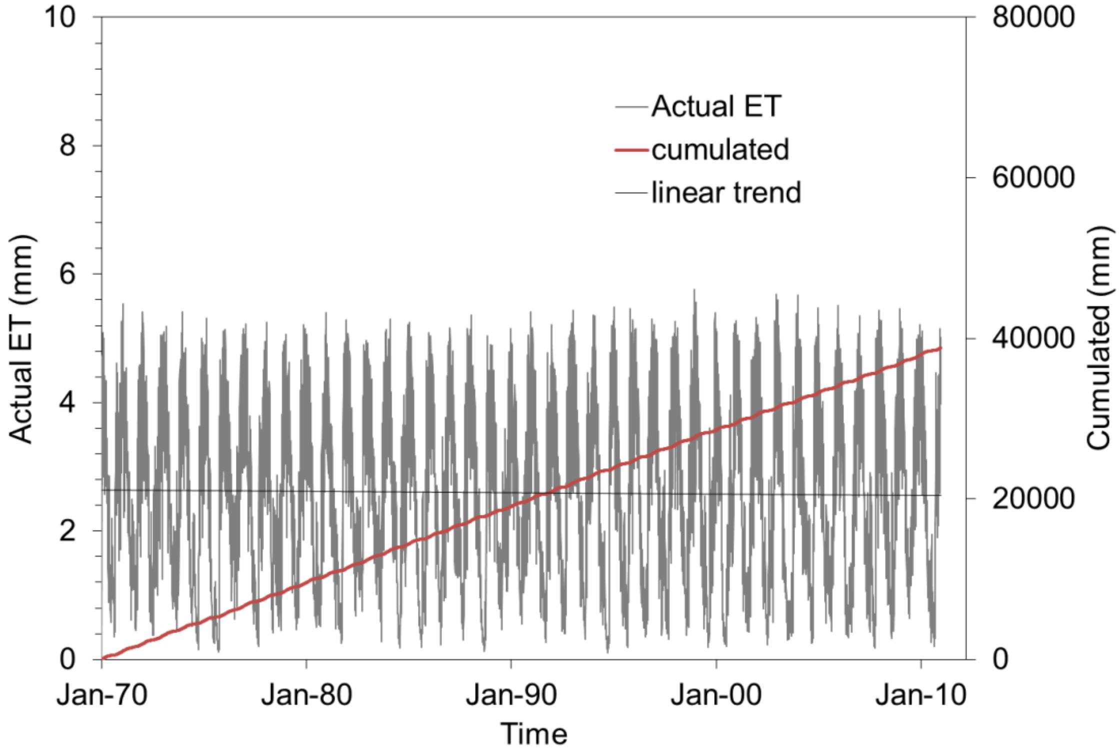


Figure 30 Actual evapotranspiration variation from 1971 to 2010 in Tiete Basin

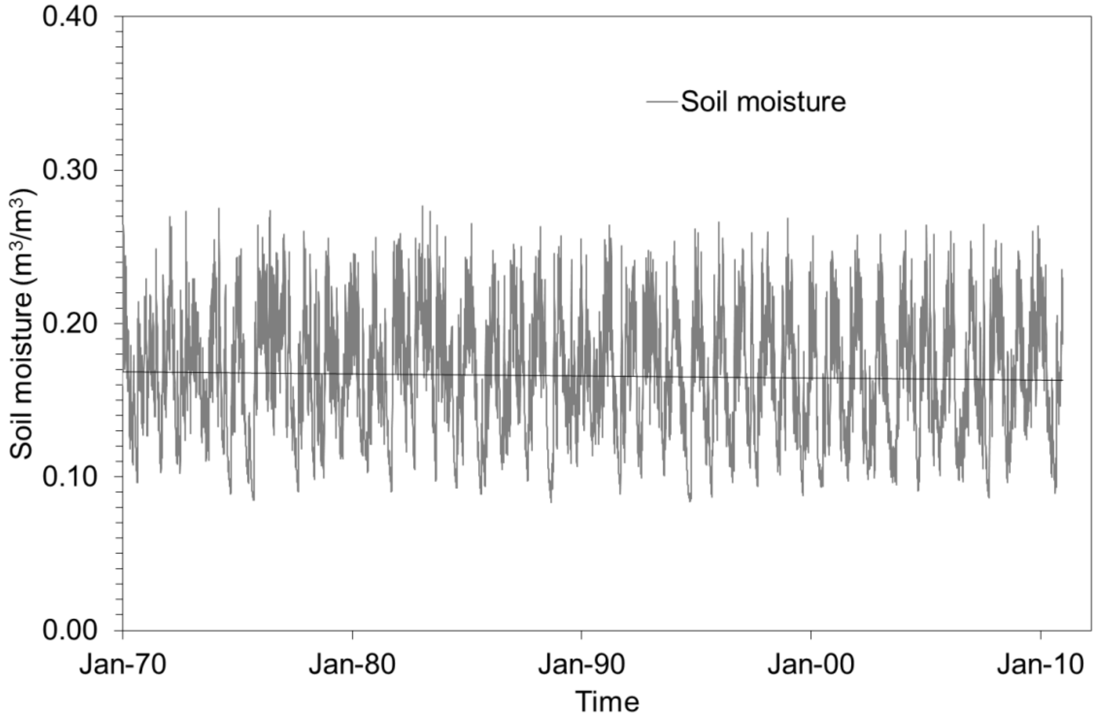


Figure 31 Soil moisture variation from 1971 to 2010 in Tiete Basin

The yearly averages of temperature, precipitation, soil moisture and evapotranspiration for each decade were confronted and presented in Table 5. The temperature has increased in a rate of 0.5°C per decade since the 80's. The effective evapotranspiration, the soil moisture and the precipitation, however, decreased in the same period of time. This could be related with the intense urbanization that occurred during these decades.

Table 5 Averages of precipitation, temperature, ET, ETP and Soil Moisture for the decades regarding the period1971-2010 in Tiete Basin

Decade	**Precipitation (mm/year)**	**Temperature (°C)**	**ET (mm/year)**	**ETP (mm/year)**	**Soil Moisture**
1971-1980	1394.68	20.60	968.71	1470.96	0.1709
1981-1990	1473.81	20.78	970.95	1496.92	0.1719
1991-2000	1436.77	21.28	961.23	1523.62	0.1682
2001-2010	1385.67	21.74	955.40	1500.91	0.1677

Comparing the decade of 2001 – 2010 with the 1971-2000 averages, it is possible to identify these trends and to evaluate significant variations. The temperature increased 4.08% and the precipitation decreased 3.44%. For the others parameters, there were not significant variations. The graphics in Figure 32, Figure 33, and Figure 34 illustrate these variations.

Table 6 Averages of precipitation, temperature, ET, ETP and Soil Moisture for the periods 1971-2000 and 2001-2010 in Tiete Basin

Decade	**Precipitation (mm/year)**	**Temperature (°C)**	**ET (mm/year)**	**ETP (mm/year)**	**Soil Moisture**
1971-2000	1435.09	20.89	966.97	1497.16	0.1703
2001-2010	1385.67	21.74	955.40	1500.91	0.1677
Variation (%)	-3.44	4.08	-1.20	0.25	-1.56

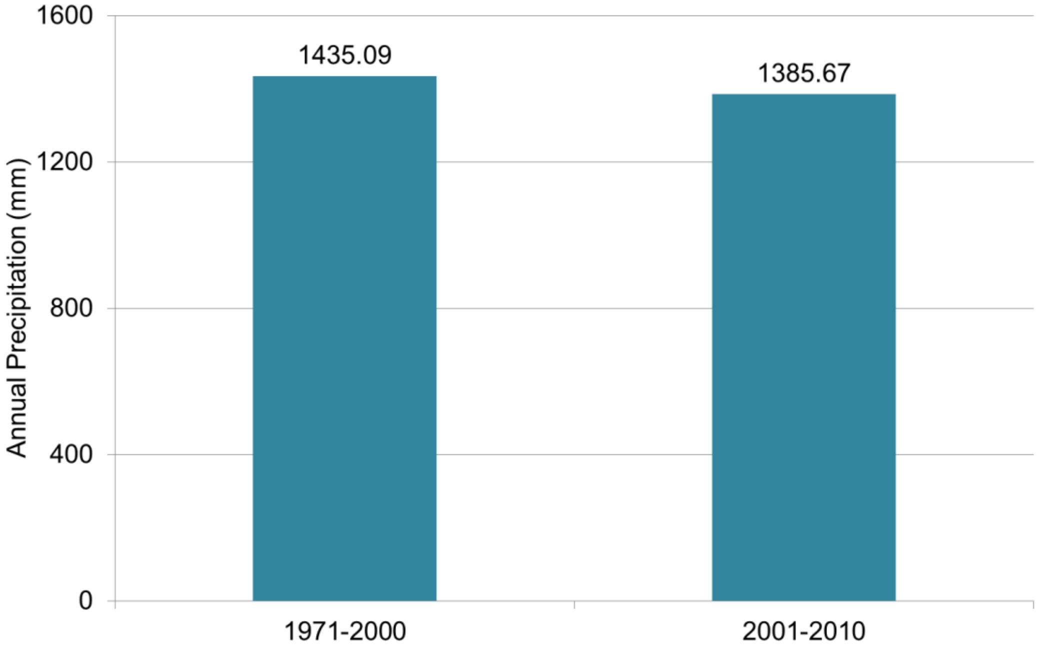


Figure 32 Confront of the average annual precipitation for 1971-2000 and 2001-2010 in Tiete Basin

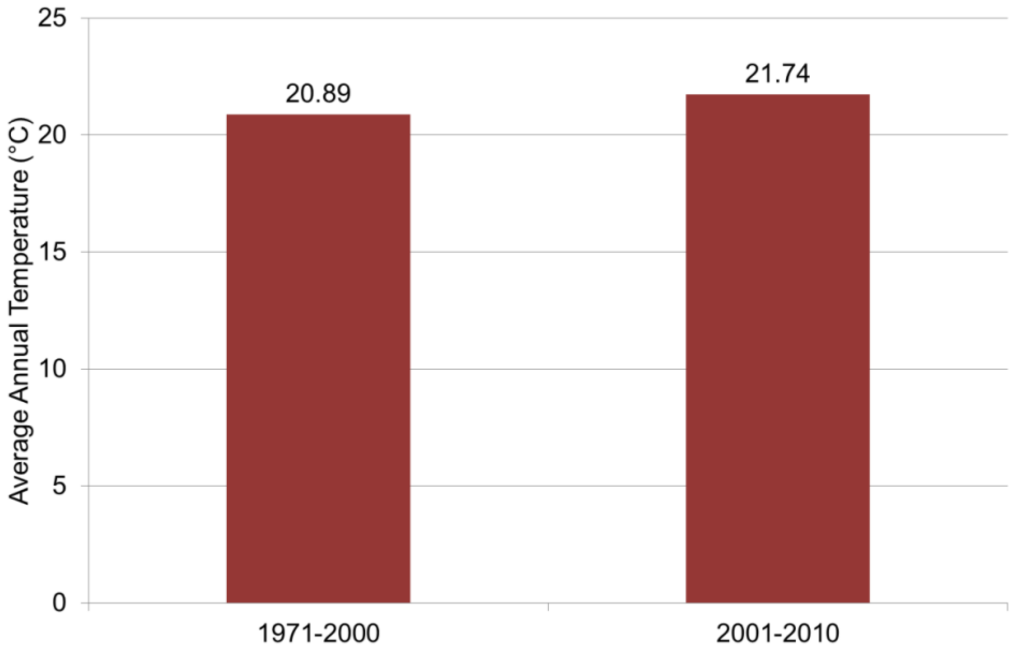


Figure 33 Confront of the average annual temperature for 1971-2000 and 2001-2010 in Tiete Basin

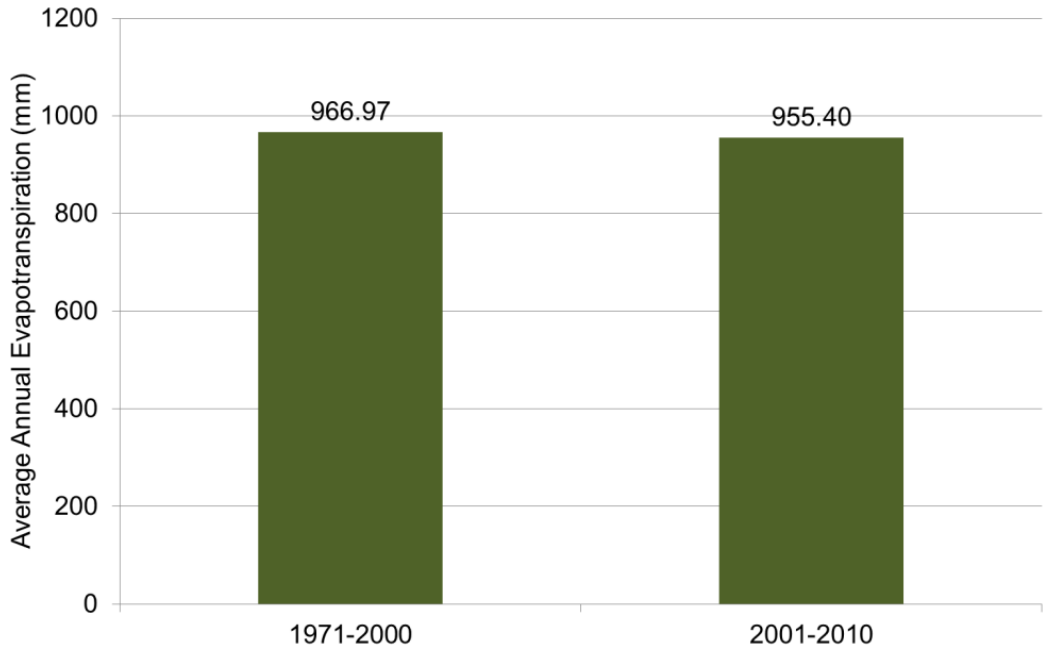


Figure 34 Confront of the average annual evapotranspiration for 1971-2000 and 2001-2010 in Tiete Basin

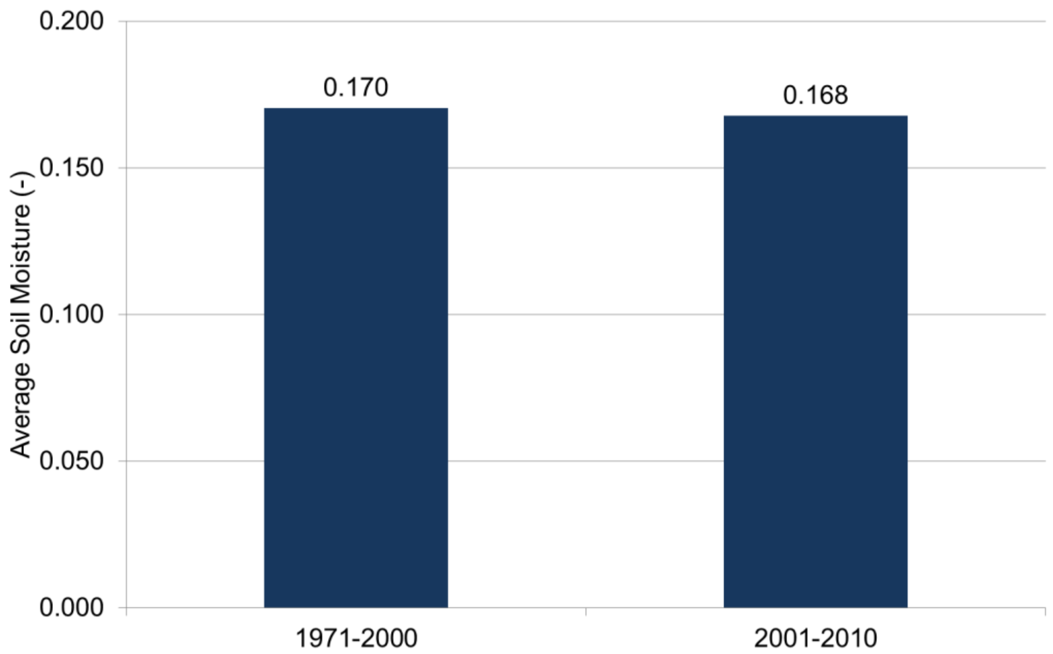


Figure 35 Confront of the average Soil Moisture for 1971-2000 and 2001-2010 in Tiete Basin

Another analysis was held considering the monthly variation; therefore, anomalies can be identified through monthly average confrontation. For temperature values, for instance, the average increase was regular in all months. The maximum difference was 7.16% in June, as can be seen in the Table 7.

Table 7 Monthly average Temperature variation in Tiete Basin

Month	Temperature 1971-2000	Temperature 2001-2010	Difference (%)
January	23.73	23.98	1.06
February	23.90	24.45	2.30
March	23.20	24.14	4.03
April	21.34	22.66	6.20
May	18.88	19.30	2.25
June	17.35	18.60	7.16
July	17.30	18.27	5.60
August	18.65	19.67	5.45
Setember	19.67	20.82	5.82
October	21.29	22.35	4.97
November	22.29	22.96	3.01
December	23.04	23.67	2.76

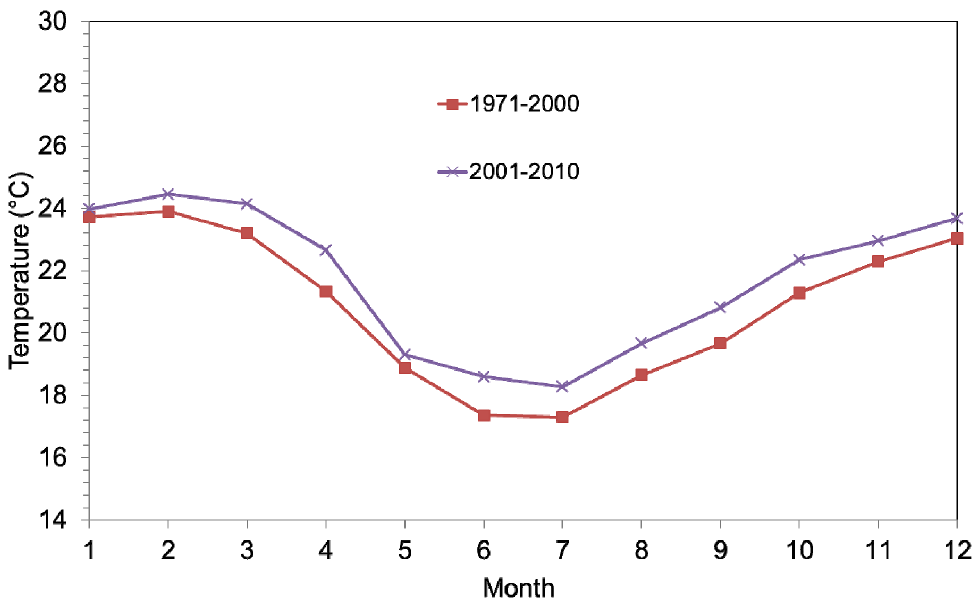


Figure 36 Monthly Temperature averages for 1971-2000 and 2001-2010 in Tiete Basin

However, the precipitation trend of 2000-2010 presented significant variations over the months, which was not noted in other decades. The Figure 36 shows the temperature evolution over the months for each decade and for the 1971-2000 average. All decades, except the most recent, showed an evolution pattern, with the monthly precipitation decreasing from December or January to August and then increasing towards the rain season.

For the 2001-2010 decade, however, there were two months with a different behavior. From April to May and from June to July, the precipitation increased instead of decreasing as in the other decades. Such trend changes demonstrate an increase in the variability, which could be very harmful for vulnerable environments and tend to affect human activities such as agriculture and water consumption.

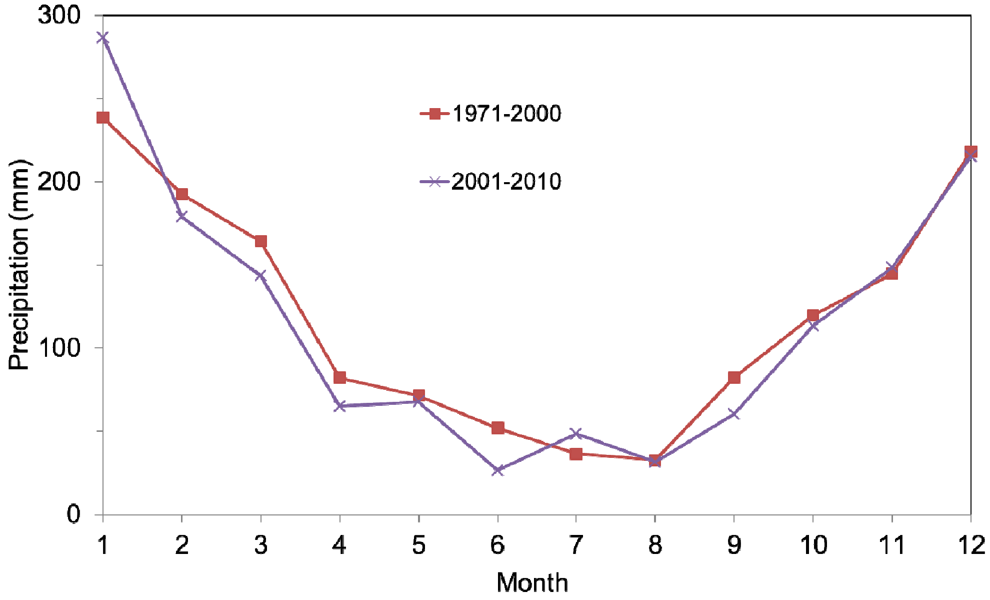


Figure 37 Monthly Precipitation averages for 1971-2000 and 2001-2010 in Tiete Basin

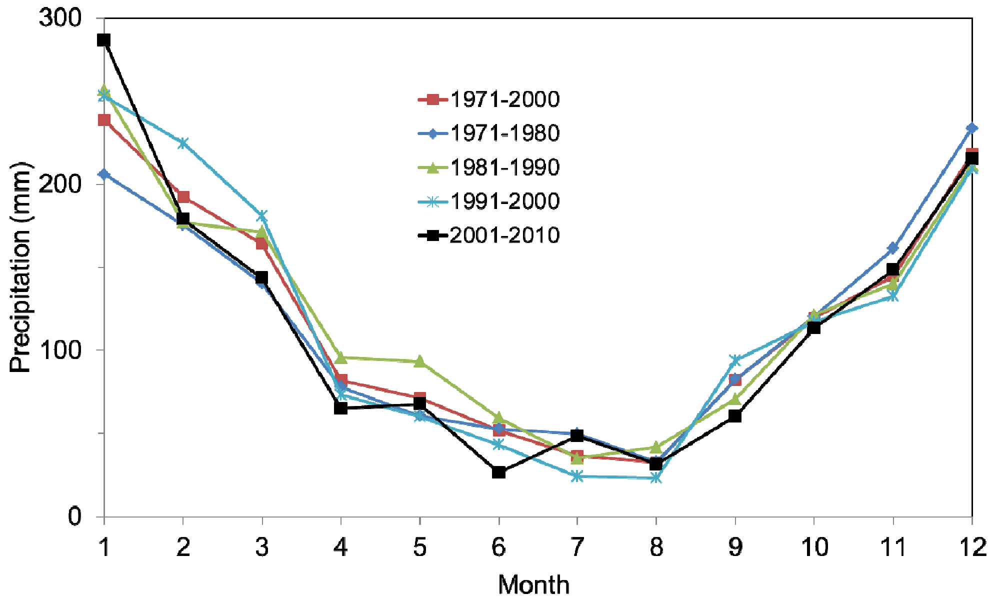


Figure 38 - Monthly Precipitation averages for different decades in Tiete Basin

With less variations and not significant differences, the soil moisture and evapotranspiration trends are showed in Figure 39 and Figure 40, respectively.

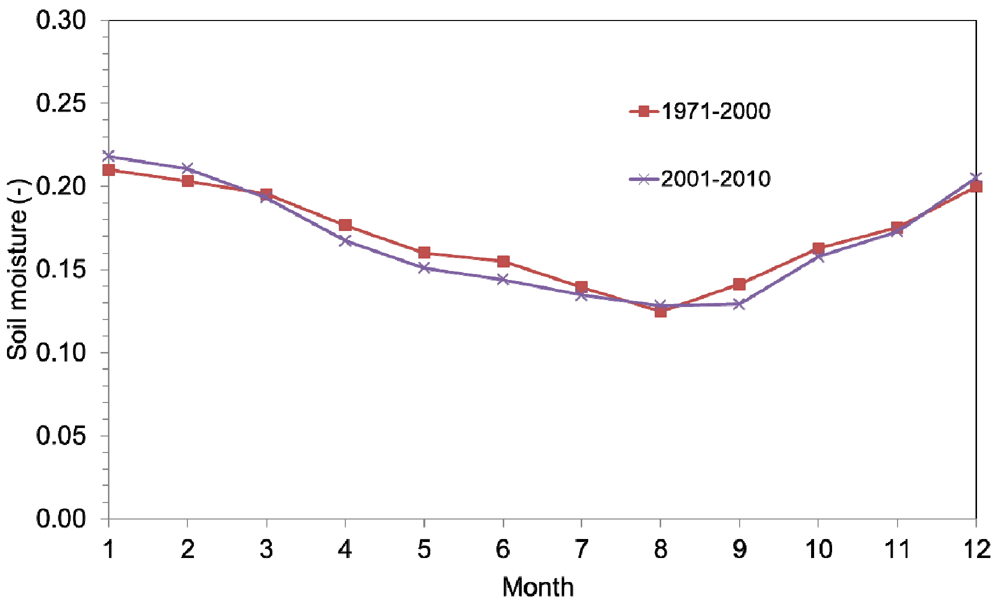


Figure 39 Monthly Soil Moisture averages for 1971-2000 and 2001-2010 in Tiete Basin

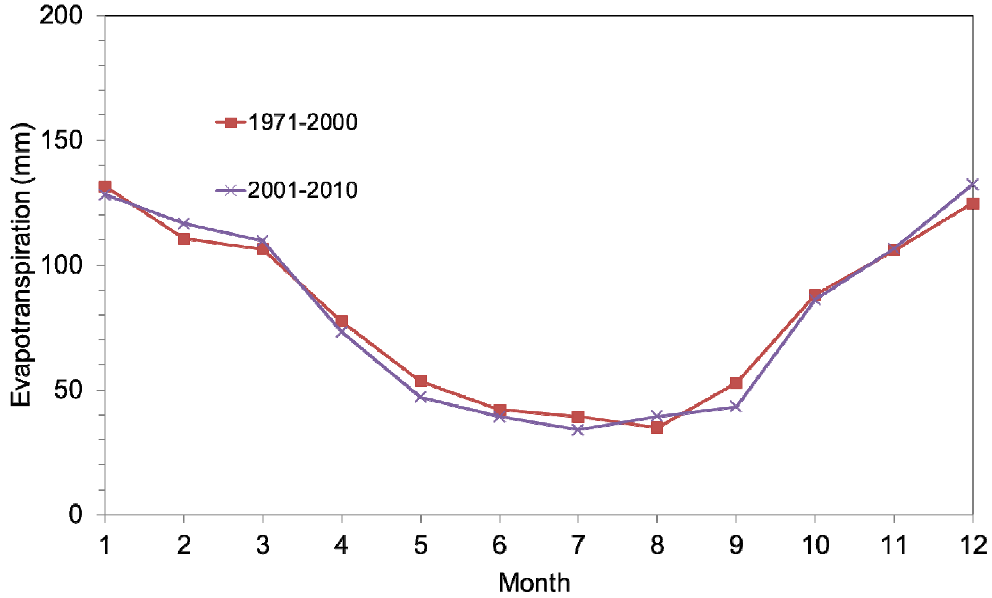


Figure 40 - Monthly Evapotranspiration averages for 1971-2000 and 2001-2010 in Tiete Basin

CONCLUSIONS AND OUTLOOK

Brazil is a country of great proportions and with a socioeconomic and physical huge variety. The existing problems in infrastructure and the social inequality are dependent of local characteristics, like concentration of population, economic activities, physical and climatic conditions. The challenge of water management in Brazil, therefore, is linked both to the management of demand and to increase and guarantee the supply of water in river basin districts with low availability and improvement of water quality with reduced domestic and industrial pollution. Considering also an economy and energetic system extremely dependent of climatological conditions, the country has a critical vulnerability to climate change. Recent studies predict a future period characterized by changes in the hydrological cycle, with longer droughts and more intense floods. The management of water resources will face further challenges and is necessary to develop resilient systems and better mechanisms for planning the use of resources. Science and technology, then, must to support decisions made with greater background knowledge and responsibility, causing smaller losses. One of the instruments necessary for improve the understanding of the systems is the regional study of the possible impacts of climate change using accurate hydrological models.

The recent advances in the production of studies on climate change and its repercussions on water resources are significant, but many uncertainties persist, particularly for models, time and adopted spatial horizons. In the course of this work, some of these difficulties were encountered. One of them was to find reliable data and organize them in a coherent way and able to be used in the model. Many data were found in different agencies, in a dispersed manner and unwieldy formats, often being incomplete. The lack of resolution of some data was also an important factor. The georeferenced files of the use and soil types were made available by global surveys with an inaccurate resolution. The adaptation of the model was another important factor, since it was developed in a very distinct region with very different climatic characteristics. Snow, for example, is a factor considered in the water balance of the FEST-WB, but non-existent in the analyzed basin. Even with these limitations, it was possible to prepare the files as input in the model and perform the necessary adjustments to perform the hydrological simulations.

After the simulations, the results were analyzed and some conclusions reached. It was possible to note a significant temperature increase in the period considered and throughout the basin. However, the precipitation, resulted of historical series of daily measurements, did not change its seasonality during the period analyzed (from 1970 to 2014), even with the temperature changing. Both the results are according to the IPCC's fourth report, released in 2007 that presented studies of global models using historical series in South America.

In hydrology, as there are many system variables, climate change would be one more factor that would influence the behavior of the historical series. Due to the complexities of the climate system, it is not possible to say that the increase in temperature was caused only by the growth in global temperature, but should also be considered the influences of urbanization and changes in land use, which were intense in the analyzed basin. The other variables did not suffer major changes during this period, showing some seasonality.

Since only one land use scenario was used in the simulations, which is recent and already represents the transformed and more intense urbanized territory, some changes in the results could occur, such as the evapotranspiration ones, which depend on the ground cover.

In its report on the effects of climate change on Brazilian water resources and the resulting management challenges, the National Water Agency, lists main activities to face the possible impacts of climate change, as the recovery of existing historical series of hydrological variables, strengthening and improvement of hydrometeorological monitoring and the progress in the improvement and predictability of hydro-climatic models. In this study, the only station with historical series of hourly measurements was the one controlled by the Institute of Astronomy, Geography and Atmospheric Sciences of University of São Paulo, the IAG. Its methodology must be expanded and used for more stations to get a better quantity of reliable data. A more modern monitoring system with constant maintenance and a higher frequency of variables measurement is essential as a basis for the development and calibration of the hydrological models. The predictions then can become more precise with the increase of the input data reliability.

This work can be continued through the inclusion of regionally forecast scenarios for changes in precipitation and temperatures using meteorological downscaling projections from global models and subsequent simulation of possible changes in the regime of basin flow. These results could serve as a base for the development of structural and nonstructural actions to mitigate the damage of possible long-term impacts on the basin. It is through better understanding the uncertainties of the consequences of changing hydrological regimes and water availability, mapping existing vulnerabilities, surveying and evaluating systems and tools for management and adaptation and constant monitoring the observed effects of climate change that is possible to reduce the risks caused by it.

Bibliografy

AGÊNCIA NACIONAL DE ÁGUAS - ANA. Portal das Mudanças Climáticas. Available in: <http://www2.ana.gov.br/Paginas/portais/MudancasClimaticas/mudancasclimaticas.aspx> Accessed in: January, 2016.

AGÊNCIA NACIONAL DE ÁGUAS (ANA). Portal Hidroweb. Available in: <http://hidroweb.ana.gov.br/> Accessed in: September to November, 2015.

AGENCIA NACIONAL DE ÁGUAS (ANA). Portal de metadados geoespaciais. Projeto GeoNetwork opensource. Available in: <http://metadados.ana.gov.br/geonetwork/srv/pt/main.home> Accessed in: September to November, 2015.

AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA (ANEEL). Sistema de Informações Georreferenciadas do Setor Elétrico. Available in: <http://sigel.aneel.gov.br/sigel.html> Accessed in: January, 2016.

BRAGA, BENEDITO P. f. et al. Pacto federativo e gestão de águas. Estud. av., São Paulo , v. 22, n. 63, p. 17-42, 2008 . Available from <http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0103-40142008000200003&lng=en&nrm=iso>. access on 15 July 2016.

CEPPI, A. Real Time flood forecasts coupling meteorological and hydrological models. 2011. Phd thesis - Politecnico di Milano, Milan, Italy. 2011.

CEPPI, A. et al. Real time drought forecasting system for irrigation management. **Procedia Environmental Sciences**, v. 19, p. 776–784, 2013.

CEPPI, A. et al. Effects of temperature on flood forecasting: Analysis of an operative case study in Alpine basins. **Natural Hazards and Earth System Science**, v. 13, n. 4, p. 1051–1062, 2013.

DAS, T. et al. Increases in flood magnitudes in California under warming climates. **Journal of Hydrology**, v. 501, p. 101–110, 2013.

DEFOURNY, P. et al. GLOBCOVER 2009 Products Report Description and Validation Report. p. 53, 2011.

DEPARTAMENTO DE ÁGUAS E ENERGIA ELÉTRICA DO ESTADO DE SÃO PAULO (DAEE). Portal de dados da rede de hidrometereologia. Available in: <http://www.daee.sp.gov.br/index.php?option=com_content&view=article&id=744%3Ahidrometeorologia-&catid=43%3Ahidrometeorologia&Itemid=30>
Accessed in: September, 2015.

FREIRE, P. D. G. Relator: Lauro Tadeu Guimarães Fortes. **INMET**. p. 1–18, 2007. Available in:
<http://www.inmet.gov.br/portal/css/content/informacoes/videos/Relatorio_Mesa_Redonda_2.pdf > Accessed In: January 2015.

FAO/IIASA/ISRIC/ISS-CAS/JRC. Harmonized World Soil Database (version 1.2). FAO, Rome, Italyand IIASA, Laxenburg, Austria. 2012

GANHITO, R; SPLIATTI, S. Tietê: o rio de São Paulo. São Paulo: Abooks, 2005.

HARGREAVES, G. H.; SAMANI, Z. A. Reference crop evapotranspiration from temperatur. **Transaction of ASAE**, v. 1, n. 2, p. 96–99, 1985.

HARGREAVES, G. Defining and using reference evapostranspiration. **Journal of Irrigation and Drainage Engineering**, v. 120, n. 6, p. 1132–1139, 1994.

INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS (INPE). Centro de previsão de tempo e estudos climáticos. (CPTEC). Temperature database. Available in: <http://bancodedados.cptec.inpe.br/#> Accessed in: September, 2015.

IPCC. IPCC Fourth Assessment Report (AR4). **IPCC**, v. 1, p. 976, 2007.

JUSTINO, F.; AMORIM, M., C. Projeções do clima da América do Sul segundo o cenário “b1” do IPCC adotando um modelo acoplado oceano- atmosfera vegetação-gelo marinho. **Boletim da Sociedade Brasileira de Meteorologia.** v.31, n.1, p.29-35, 2007

KROL, M. S.; BRONSTERT, A. Regional integrated modelling of climate change impacts on natural resources and resource usage in semi-arid Northeast Brazil. **Environmental Modelling and Software**, v. 22, n. 2, p. 259–268, 2007.

LONG, S.P., AINSWORTH, E.A., LEAKEY, A.D.B., MORGAN, P.B. Global food insecurity. Treatment of major food crops with elevated carbon dioxide or ozone under large-scale fully open air conditions suggests recent models may have overestimated future yields. **Phil. Trans. R. Soc.**, B 360: 2011- 2020, 2005

MAIDMENT, D. R. Handbook of Hydrology. New York: McGraw-Hill, 2001.

MARENGO, J. A. O quarto relatório do IPCC (IPCC AR4) e projeções de mudança de clima para o Brasil e América do Sul. **Boletim da Sociedade Brasileira de Meteorologia.** v.31, n.1, p.23-28, 2007.

MARENGO, J. A. Mudanças climáticas globais e seus efeitos sobre a biodiversidade: caracterização do clima atual e definição das alterações climáticas para o território brasileiro ao longo do século XXI. Brasília: MMA, 2006.

MAURO, J. E. M.; OHTAKE, C. R. O Livro do Rio Tiete.. 1. ed. SAO PAULO: Estúdio Ro, 1991. v. 1.

MONTGOMERY, D. R.; FOUFOULA-GEORGIOU, E. Channel Network Source Representation Using Digital Elevation Models. **Water Resources Research**, v. 29, n. 12, p. 3925–3934, 1993.

MONTALDO, N.; RAVAZZANI, G.; MANCINI, M. On the prediction of the Toce alpine basin floods with distributed hydrologic models. **Hydrological Processes**. v. 21, p. 608–621, 2007.

NAGHETTINI, M.; PINTO, E. J. A. Hidrologia estatística. Belo Horizonte: CPRM, 2007

PEREIRA, A. J.;DOS SANTOS P. M.; CAMARDO, R. D. Impactos antrópicos no clima da região metropolitana de São Paulo. **Boletim da Sociedade Brasileira de Meteorologia.** v.31, n.1, p.48-56, 2007.

PINTO, H. S.; ZULLO, J. JUNIOR, ASSAD, E. D.; EVANGELISTA, B. A. O aquecimento global e a cafeicultura brasileira. **Boletim da Sociedade Brasileira de Meteorologia.** v.31, n.1, p.65-72, 2007.

RAVAZZANI, G. et al. An integrated Hydrological Model for Assessing Climate Change Impacts on Water Resources of the Upper Po River Basin. **Water Resources Management**, v. 29, n. 4, p. 1193–1215, 2014.

RAVAZZANI, G. et al. Modified Hargreaves-Samani Equation for the Assessment of Reference Evapotranspiration in Alpine River Basins. **Journal of Irrigation and Drainage Engineering**, v. 138, n. 7, p. 592–599, 2012.

RAVAZZANI, G.; MANCINI, M.; GIUDICI, I.; AMADIO, P. Effects of soil moisture parameterization on a real - time flood forecasting system based on rainfall thresholds. In Quantification and Reduction of Predictive Uncertainty for Sustainable Water Resources Management, Proc. Symposium HS 2004 at IUGG 2007. *IAHS Publ.*, p. 407-416, 2007

SALATI, T., SCHINDLER, W., VICTORIA, D.C., SALATI, E., SOUZA, J.C.S., NOVA, N.A.V. Economia das Mudanças Climáticas no Brasil. Estimativas da Oferta de Recursos Hídricos no Brasil em Cenários Futuros de Clima. Fundação Brasileira para o Desenvolvimento Sustentável, 2008. 80 p.

SANGHI, A.; MENDELSOHN, R. The impacts of global warming on farmers in Brazil and India. **Global Environmental Change**, v. 18, n. 4, p. 655–665, 2008.

SAO PAULO (Estado). Secretaria de Agricultura e Abastecimento e Secretaria do Meio ambiente. Coordenadoria De Assistência Técnica Integral. Anexo 1 – Informações gerais da agropecuária do Estado de São Paulo. **Manual Operacional: Projeto de Desenvolvimento Rural Sustentável Microbacias II – Acesso ao mercado**, São Paulo, 2013.

SAO PAULO (Estado). Secretaria de Saneamento e Recursos Hídricos; Coordenadoria de Recursos Hídricos. Relatório de Situação dos Recursos Hídricos do Estado de São Paulo, São Paulo: SSRH/CRHi, 2011.

SAO PAULO (Estado). Secretaria de Saneamento e Recursos Hídricos; Coordenadoria de Recursos Hídricos. Relatório de Situação dos Recursos Hídricos do Estado de São Paulo, São Paulo: SSRH/CRHi, 2012.

SEO, S. N.; MENDELSOHN, R. An analysis of crop choice: Adapting to climate change in South American farms. **Ecological Economics**, v. 67, n. 1, p. 109–116, 2008.

SILVEIRA,C. S. ; SOUZA FILHO, F. A., LÁZARO, Y.M.C. Avaliação de Desempenho dos Modelos de Mudança Climática do IPCC-AR4 Quanto a Sazonalidade e os Padrões de Variabilidade Interanual da Precipitação Sobre o Nordeste do Brasil, Bacia do Prata e Amazônia. ***Revista Brasileira de Recursos Hídricos*****,** ABRH, Porto Alegre, RS, v. 18, n. 1, p. 177-194, 2013.

SILVA DIAS, M., A., F; SILVA DIAS, P., L. As incertezas regionais nos cenários de mudanças climáticas globais. **Boletim da Sociedade Brasileira de Meteorologia.** v.31, n.1, p.12-17, 2007.

SLINGO, J.M., CHALLINOR, A.J., HOSKINS, B.J. AND WHEELER, T.R.Introduction: food crops in a changing climate. **Phil. Trans. R. Soc**., B 360, 1983-1989, 2005.

SOIL CONSERVATION SERVICE (SCS). “Section 4: Hydrology.” U.S. National Engineering Handbook, U.S. Department of Agriculture, Washington, DC. 1956

Tiete River Photos. Available in < https://www.fotografiasaereas.com.br/>. Accessed in: February, 2016.

UNITED NATIONS. Adoption of the Paris Agreement. **Conference of the Parties on its twenty-first session**, v. 21932, n. December, p. 32, 2015.

U.S. GEOLOGICAL SURVEY'S (USGS). EROS Data Center. HYDRO1k Documentation ReadMe. Available in: <https://lta.cr.usgs.gov/HYDRO1KReadMe> Accessed in: October, 2016.

ANNEX A
LIST OF PLUVIOMETRIC STATIONS

CODE	NAME	LATITUDE (°)	LONGITUDE (°)	Z (m)
2049011	CRUZEIRO	-20.50	-49.95	470
2049018	SEBASTIANOPOLIS	-20.63	-49.95	470
2049019	MONTE_APRAZIVEL	-20.77	-49.70	480
2049022	MACAUBAL	-20.80	-49.97	510
2049027	BADY_BASSIT	-20.92	-49.45	520
2049028	NIPOA	-20.92	-49.78	460
2050007	SANTANA_DA_PONTE PENSA	-20.25	-50.80	430
2050011	VALENTIM_GENTIL	-20.43	-50.07	480
2050012	PALMEIRA_DOESTE	-20.42	-50.77	430
2050013	PONTALINDA	-20.43	-50.53	380
2050015	AURIFLAMA	-20.70	-50.55	450
2050016	SUD_MENUCCI	-20.68	-50.92	390
2050017	NOVA_CASTILHO	-20.77	-50.32	440
2050019	MAJOR_PRADO	-20.87	-50.48	415
2050021	FAZENDA_ARACANGUA	-20.97	-50.68	350
2050023	SANTA_FE_DO_SUL	-20.22	-50.92	410
2050024	FERNANDOPOLIS	-20.30	-50.25	520
2050037	TURIUBA	-20.95	-50.10	435
2050045	GUZOLANDIA	-20.65	-50.67	450
2050047	SAO_FRANCISCO	-20.57	-50.22	420
2051032	SEGUNDA_ALIANCA	-20.93	-51.12	420
2148027	GUARIROBA	-21.47	-48.62	520
2148031	ITAPOLIS	-21.58	-48.82	480
2148033	MATAO	-21.60	-48.35	560
2148036	FAZENDA_LARANJAL	-21.70	-49.00	420

2148038	IBITINGA	-21.78	-48.85	510
2148041	ARARAQUARA	-21.78	-48.17	670
2148043	USINA_SANTA_FE	-21.80	-48.60	490
2148044	SITIO_ESPERANCA	-21.82	-48.80	420
2148048	USINA_TAMOIO_BELA_VISTA	-21.92	-48.18	560
2148060	PCH_GAVIAO_PEIXOTO_MONTANTE	-21.85	-48.50	487
2148061	USINA_CHIBARRO	-21.88	-48.15	580
2148079	BUENO_DE_ANDRADA	-21.67	-48.23	680
2148086	IBATE	-21.95	-48.00	830
2148106	CANDIDO_RODRIGUES	-21.33	-48.63	600
2148121	ARARUBA	-21.70	-48.53	520
2148124	BOA_ESPERANCA_DO_SUL	-21.98	-48.40	500
2148126	USINA_REYNALDO_GONCALVES	-21.60	-48.97	430
2148128	FAZENDA_BARREIRINHO	-21.90	-49.00	450
2149002	JOSE_BONIFACIO	-21.05	-49.68	430
2149005	MENDONCA	-21.18	-49.58	490
2149006	URUPES	-21.18	-49.30	420
2149007	USINA_AVANHANDAVA	-21.27	-49.93	400
2149008	ITAJOBI	-21.32	-49.05	460
2149010	FAZENDA_BEM_TE_VI	-21.35	-49.50	440
2149017	GUAICARA	-21.62	-49.80	460
2149018	FAZENDA_SAO_PEDRO	-21.70	-49.68	480
2149019	FAZENDA_ANO_BOM_DO_TIETE	-21.70	-49.13	390
2149021	CAFELANDIA	-21.82	-49.63	440
2149023	REGINOPOLIS	-21.88	-49.23	380
2149064	GUARANTA	-21.88	-49.53	450
2149069	PROMISSAO	-21.53	-49.87	420
2149078	TERMAS_DE_IBIRA	-21.10	-49.18	420
2150001	DESTIVALE	-21.05	-50.47	320
2150008	FAZENDA_SAO_JOAO	-21.17	-50.23	370
2150010	ARACATUBA	-21.20	-50.45	390
2150090	CORREGOSECO	-21.13	-50.20	370
2151053	GRANJA_YUBA	-21.02	-51.10	420
2246015	MARTIM_FRANCISCO	-22.52	-46.95	590
2246020	FAZENDA_CHAPADAO	-22.62	-46.85	760
2246021	FAZENDA_DA_BARRA	-22.67	-46.97	570
2246022	MONTE_ALEGRE_DO_SUL	-22.70	-46.67	750
2246025	PINHALZINHO	-22.78	-46.60	880
2246028	PEDREIRA	-22.75	-46.93	590
2246034	MORUNGABA	-22.88	-46.78	750
2246035	VARGEM_(US_FLORES_CPFL)	-22.90	-46.42	940

2246036	BRAGANCA_PAULISTA	-22.93	-46.53	800
2246037	PCH_SALTO_GRANDE_JUSANTE	-22.93	-46.90	684
2246087	BARREIRO	-22.95	-46.70	770
2246090	JOANOPOLIS	-22.93	-46.27	920
2246095	PEDRA_BELA	-22.80	-46.45	1090
2247002	VILA_CARMEM	-22.02	-47.90	820
2247004	ANALANDIA	-22.13	-47.67	660
2247006	VISCONDE_DE_RIO_CLARO	-22.15	-47.80	740
2247008	USINA_DO_LOBO	-22.17	-47.90	690
2247010	CORUMBATAI	-22.22	-47.62	600
2247012	ITIRAPINA	-22.23	-47.80	790
2247015	GRAUNA	-22.30	-47.75	610
2247018	FAZENDA_SAO_JOSE	-22.33	-47.48	600
2247020	RIO_CLARO	-22.42	-47.55	600
2247021	IPEUNA	-22.43	-47.72	630
2247022	SANTA_GERTRUDES	-22.48	-47.52	620
2247024	CHARQUEADA	-22.52	-47.78	600
2247025	SAO_PEDRO	-22.53	-47.92	600
2247027	LIMEIRA	-22.57	-47.37	640
2247028	FAZENDA_HOLAMBRA	-22.63	-47.05	600
2247031	USINA_ESTER	-22.67	-47.22	560
2247032	ARTEMIS	-22.68	-47.77	470
2247039	FAZENDA_SAO_PEDRO	-22.75	-47.45	540
2247041	FAZENDA_MONTE_D'ESTE	-22.78	-47.03	600
2247042	BARAO_GERALDO	-22.83	-47.07	630
2247044	RIO_DAS_PEDRAS	-22.87	-47.62	615
2247046	CAMPINAS_IA	-22.88	-47.08	710
2247050	BAIRRO_PAVIOLI	-22.93	-47.25	610
2247052	USINA_BOM_RETIRO	-22.88	-47.45	570
2247075	UHE_AMERICANA_JUSANTE	-22.70	-47.28	521
2247094	PIRACICABA_(SEMAE)	-22.72	-47.65	500
2247100	ARTUR_NOGUEIRA	-22.57	-47.17	640
2247103	FAZENDA_SAO_LUIZ	-22.83	-47.43	560
2247110	CAPIVARI	-23.00	-47.50	500
2247113	SANTA_EREZINHA	-22.68	-47.70	500
2247206	FAZENDA_SANTA_BARBARA	-22.10	-47.98	780
2248005	RIBEIRAO_BONITO	-22.08	-48.18	590
2248008	FAZENDA_SAO_PEDRO	-22.10	-48.30	690
2248009	DOURADO	-22.13	-48.32	700
2248012	JAU_(CPEF)	-22.30	-48.53	500
2248014	BARRA_MANSA	-22.32	-48.72	450

2248015	GUAIANAS	-22.32	-48.88	480
2248016	DOIS_CORREGOS	-22.37	-48.38	700
2248019	AGUDOS	-22.48	-48.98	620
2248023	SANTA_MARIA_DA_SERRA	-22.57	-48.15	470
2248025	FAZENDA_DO_BARREIRO_RICO	-22.68	-48.12	560
2248026	SAO_MANUEL	-22.73	-48.57	710
2248028	ANHEMBI	-22.78	-48.13	480
2248029	FAZENDA_S. JOAO_MORRO_VERMELHO	-22.82	-48.43	780
2248045	PCH_TRES_SALTOS	-22.38	-48.17	720
2248079	MINEIROS_DO_TIETE (CPEF)	-22.42	-48.45	680
2248107	POUSO_ALEGRE	-22.22	-48.60	460
2249002	JACUBA	-22.05	-49.03	500
2249010	VAL_DE_PALMAS	-22.30	-49.15	580
2249012	BAURU_(PDV)	-22.32	-49.03	540
2249069	PRESIDENTE_ALVES	-22.10	-49.43	580
2249070	AVAI	-22.17	-49.33	500
2345047	SALESOPOLIS	-23.53	-45.85	770
2345049	PONTE_NOVA	-23.57	-45.97	800
2345076	CASA_GRANDE	-23.63	-45.92	820
2346001	ITATIBA	-23.02	-46.83	780
2346002	BAIXO_COTIA	-23.55	-46.87	730
2346003	VINHEDO	-23.03	-46.97	700
2346007	ATIBAIA	-23.15	-46.55	770
2346010	NAZARE_PAULISTA	-23.18	-46.40	790
2346014	ERMIDA	-23.20	-46.98	730
2346020	MAIRIPORA	-23.32	-46.58	800
2346021	FRANCO_DA_ROCHA_(HOSP. JUQUERI)	-23.33	-46.68	740
2346025	BAIRRO_FAZENDA_VELHA	-23.38	-46.35	760
2346029	FAZENDA_SAO_BENTO	-23.43	-46.28	690
2346030	BOM_SUCESSO	-23.42	-46.40	770
2346032	HORTO_FLORESTAL	-23.47	-46.63	790
2346033	SANTANA_DE_PARNAIBA	-23.45	-46.92	720
2346040	MONTE_BELO	-23.48	-46.37	790
2346041	SANTANA	-23.50	-46.62	760
2346045	LUZ_(ESTACAO)	-23.53	-46.63	730
2346046	AGUA_BRANCA	-23.52	-46.68	730
2346048	CAPIXINGA	-23.57	-46.10	750
2346049	FAZENDA_SANTO_ANGELO	-23.58	-46.23	750
2346051	VILA_PROSPERIDADE_(GM)	-23.62	-46.55	730
2346052	CACHOEIRA_DA_GRACA	-23.65	-46.95	880
2346053	SAO_CAETANO_DO_SUL	-23.63	-46.58	740

2346054	CONGONHAS_(AEROPORTO)	-23.63	-46.65	800
2346056	RUDGE_RAMOS	-23.67	-46.57	780
2346057	SANTO_AMARO	-23.65	-46.70	764
2346059	OBSERVATORIO_DO_IAG	-23.65	-46.63	780
2346060	PEDRO_BEICHT	-23.72	-46.97	920
2346064	ITAPECERICA_DA_SERRA	-23.72	-46.85	910
2346068	RECALQUE_ABC	-23.75	-46.53	840
2346071	ALDEINHA	-23.78	-46.92	860
2346287	ROSELANDIA	-23.57	-46.93	735
2346329	FAZENDA_PRIMAVERA	-23.00	-46.72	730
2347002	FAZENDA_VISTA_REDONDA	-23.00	-47.72	570
2347004	ELIAS_FAUSTO	-23.03	-47.37	580
2347006	PEREIRAS	-23.07	-47.97	510
2347007	INDAIATUBA	-23.08	-47.22	630
2347017	CESARIO_LANGE	-23.22	-47.95	610
2051046	APARECIDA_DO_TABOAO	-20.07	-51.10	375
2051045	SELVIRA	-20.36	-51.42	348
2050022	GENERAL_SALGADO	-20.48	-50.42	340
2148164	IBATE	-21.95	-48.00	830
2148166	FAZENDA_EXPERIMENTAL	-21.66	-48.35	460
2148167	GAVIAO_PEIXOTO	-21.84	-48.49	490
2148168	GUARAPIRANGA	-21.96	-48.25	739
2148169	USINA_SANTA_FE	-21.80	-48.63	520
2148173	FAZENDA_SANTO_ANTONIO	-21.39	-48.40	640
2149060	NOVA_ITAPIREMA	-21.08	-49.55	450
2246023	AMPARO	-22.71	-46.77	670
2246033	RIO_ABAIXO_(FAZ_CACHOEIRA)	-22.88	-46.63	760
2246038	ITATIBA	-22.98	-46.83	690
2246057	CAMANDUCAIA	-22.76	-46.15	1040
2247055	JAGUARIUNA	-22.71	-46.99	570
2247058	MONTE_MOR	-22.96	-47.30	560
2247059	CAPIVARI	-23.01	-47.50	500
2247121	CAMPO_ALEGRE	-22.20	-47.27	870
2247180	ITIRAPINA	-22.25	-47.83	739
2247182	RIBEIRAO_DO_FEIJAO	-22.15	-47.89	676
2247184	ITAQUERI_DA_SERRA	-22.34	-47.92	894
2247185	FAZENDA_CAMPO_ALEGRE	-22.15	-48.00	733
2247196	CRHEA_BROA	-22.17	-47.90	732
2247197	EST. FERROVIARIA_CAMPO_ALEGRE	-22.24	-47.96	747
2247198	FAZENDA_PEQUENA_HOLANDA	-22.18	-47.78	780
2248110	RIBEIRAO_BONITO (2)	-22.08	-48.18	486

2345048	USINA_SALESOPOLIS	-23.57	-45.83	790
2346094	PIRACAIA	-23.05	-46.37	790
2346095	ATIBAIA	-23.10	-46.56	730
2346097	JUNDIAI	-23.19	-46.88	700
2346101	BIRITIBA_MIRIM	-23.58	-46.04	760
2346395	EMBURA	-23.88	-46.75	780
2347005	LARANJAL_PAULISTA	-23.03	-47.85	490
2346047	CTH_CIDADE_UNIVERSITÁRIA.	-23.57	-46.73	760
1951005	INOCENCIA	-19.74	-51.94	502