CONTRIBUTIONS TOWARD A MUNICIPAL APPROACH TO WATER FOOTPRINT: CASE STUDY IN A BRAZILIAN COASTAL CITY

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Introduction

Water resources are limited and have an important role in the economic and social development of a region. Advances in water management require knowledge of the availability and demand of water resources in order to define priority actions in water conservation. Amid discussions on the efficient use of water, the Water Footprint concept appeared in 2002 as a tool for water resources management that encourages the responsible use of water and it has been applied worldwide since then. Furthermore, as pointed out by Hoekstra *et al.* (2011), as a fresh water use indicator, it provides information not only about the direct, but also the indirect water consumption of consumers and producers. It can be considered an indicator of global water resources appropriation.

According to Hoekstra *et al.* (2011), Water Footprints can be blue, green or grey. Blue water footprints relate to the consumptive use of surface and groundwater, whereas green water footprints refer to the use of rainwater that ends up as runoff and does not replenish underground water supplies. Grey water footprint is an indicator of the level of freshwater pollution associated to a stage of a particular process. It is defined as the freshwater volume required to assimilate the pollutant load, given the natural background concentration and existing ambient water quality standards.

The Northern Coast of the State of São Paulo deserves special attention with regard to both its water supply and quality. This region encompasses the municipalities of Ubatuba, Caraguatatuba, Ilhabela and São Sebastião and it is situated between the Serra do Mar mountain range and the Atlantic Ocean.

This region is of strategic importance in terms of the conservation of the Atlantic Rainforest biome. However, property speculation and accelerated and uncontrolled growth caused by tourism have intensified environmental degradation in the area (Pereira *et al.*, 2009). Furthermore, in Brazil, a number of infrastructure projects related to the oil exploration industry have been planned, starting operations within the next few years, in particular in the São Paulo State's Northern Coast region. These projects involve new

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ports, roads, railways and dams with sufficient capacity to alter the social, economic and environmental dynamic of an entire country (Carmo *et al.*, 2012; Teixeira, 2013).

IBGE [Brazilian Institute of Geography and Statistics] census revealed a significant increase in the São Paulo's Northern Coast population between 1970 and 1990 (Figure 1), in particular in Caraguatatuba where the population increased 489.23% from 1970 to 2007 (Luchiari, 1999; IBGE, 2012), almost five times the growth rate of the Brazilian population during the same period.

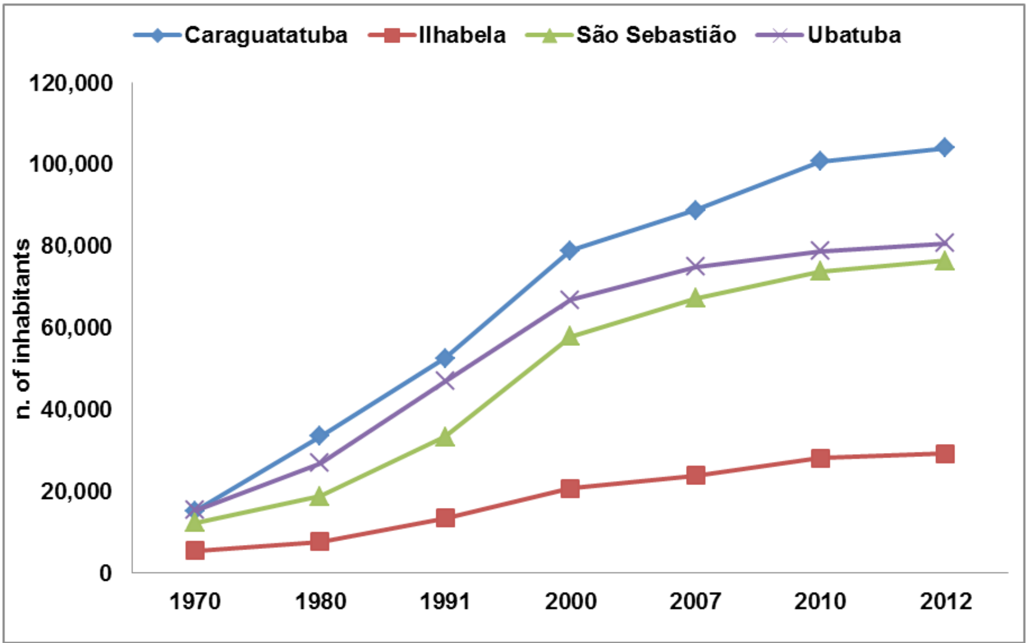

Figure 1: Population growth in São Paulo's Northern Coast municipalities. Source: Adapted from IBGE (2012), produced by the author.

Furthermore, the expansion of infrastructure associated to the exploration of the pre-salt reserves may further stimulate the population boom in the Northern Coast region (Teixeira, 2013), leading to direct and indirect impacts on water demand, increasing the pressure on the municipalities' basic sanitation and water supply systems.

The strong urban growth which has taken place in the region since the 1970s was not accompanied by the adequate implementation of sanitation infrastructure.

According to a report produced by SABESP [São Paulo State Sanitation Company], regarding projections for the resident and seasonal populations in the four Northern Coast municipalities, the settled population of Caraguatatuba could reach 154,040 by 2040. This is an increase of 48% compared to 2012. Furthermore, the peak population - that is, the settled population in addition to that which frequents the city during weekends and the summer season – could reach almost half a million by 2040 (SABESP, 2010).

The Brazilian National Water Agency (ANA) Report (ANA, 2011) points to a critical situation in the region in terms of water quantity and quality, mainly due to the existing high demand for water and the large quantities of organic mass released into the rivers. In this context, a more dynamic property sector, together with the development of logistic activities tend to enhance the attractiveness of the region and drive population growth, resulting in an increase in the municipality's water footprint.

Given the forecasts of a reduced supply and the degradation of water quality, the situation is likely to deteriorate, in particular in Caraguatatuba which has felt the negative impacts of social expansion associated to pre-salt exploration. The use of the water footprint concept as a tool for estimating the appropriation of water resources in the region could lead to actions and initiatives to mitigate existing impacts in terms of the maintenance of water supply for the future and, ultimately, it could also promote its sustainability. The present study aimed to conduct a full water footprint assessment of Caraguatatuba, a coastal Brazilian municipality, in 2012.

Materials and methods

Study area

Caraguatatuba is the gateway to São Paulo's Northern Coast, situated only 182 km from the state capital. It has a population of 104,150 inhabitants and is the largest municipality in the Northern Coast with approximately 485.4 km^2 (IBGE, 2012). It is worth pointing out that, of the four cities which make up the region, Caraguatatuba has the lowest percentage of remnant natural vegetation, that is, 73%, whilst Ilhabela, São Sebastião and Ubatuba have an average of 84% (SOS Mata Atlântica and National Institute for Space Research [INPE], 2009).

According to a study by Pereira *et al.* (2009), assessing the level of human impact in the São Paulo's Northern Coast by using geo-processing techniques and taking into account the political, spatial, cultural, ecological, economic and social dimensions, Caraguatatuba has been highly affected by human activities. Figure 2 shows the location of the municipality in the state of São Paulo.

Water footprint accounting

The total water footprint of the municipality in 2012 was calculated based on its main water uses. The total water footprint was reached by adding the urban water supply footprint to that of the pasture fields of Fazenda Serramar, (the largest farm in the region, occupying 9% of the total area of the municipality), together with the water footprint for cattle-farming in Serramar farm and the water footprint for the sewage produced in the municipality, according to the Equation 1 (units in m^3/year).

$$WF_{total} = WF_{urban\ supply} + WF_{pasture} + WF_{cattle\text{-}farming} + WF_{sewage} \qquad \text{(Equation 1)}$$

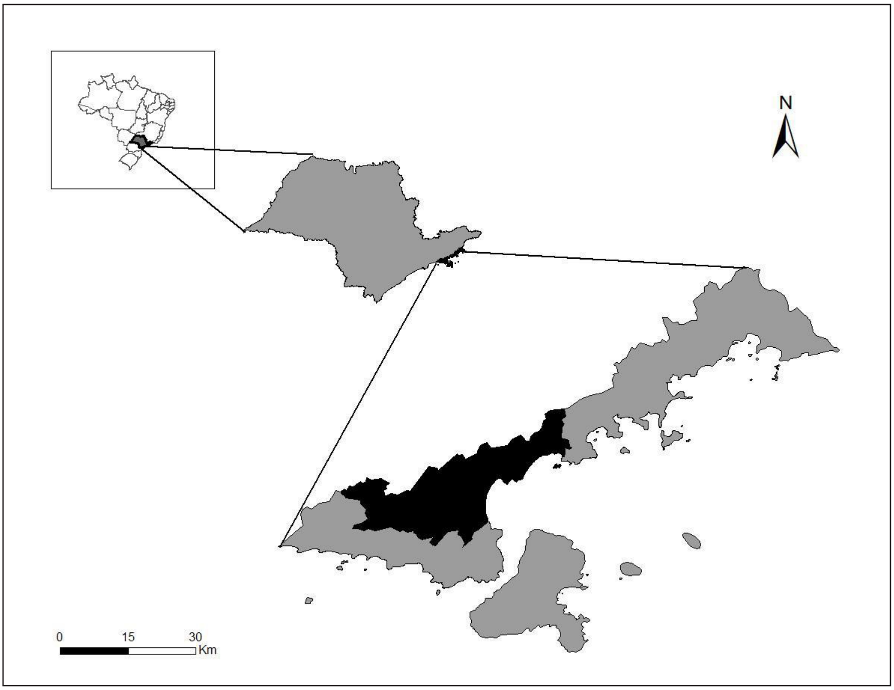

Figure 2: Location of Caraguatatuba municipality, SP, shown in black (source: produced by the authors).

Where:
WF_{total} = Caraguatatuba's total water footprint;
$WF_{urban\ supply}$ = urban water supply footprint;
$WF_{pasture}$ = Fazenda Serramar's pasture water footprint;
$WF_{cattle\text{-}farming}$ = cattle-farming water footprint;
WF_{sewage} = water footprint of the sewage produced in Caraguatatuba.

Urban water supply

The urban water supply footprint was calculated based on data provided by SABESP which supplies water to 98.3% of the urban population (Brazil, 2012). With information on the micro-measured volume - the volume of water that is consumed in the city - during 2012, it was possible to estimate the volume of blue water consumed by the municipality's industrial, commercial and domestic sectors.

Given the total volume of water used in the municipality refers to the macro--measured volume - the volume produced in the four Water Treatment Plants which supply the urban areas - the micro-measured volume underestimated the final amount of water supplied to Caraguatatuba. Therefore, the rate of water loss in the supply systems' distribution, 39.6%, (Brasil, 2014) was taken into account in order to incorporate the amount of water "lost" in the distribution network prior to reaching consumers.

Fazenda Serramar pasture area

The water footprint of the Fazenda Serramar pasture area was estimated by calculating the water balance in the pasture planted in 4,440 ha of the property. The actual evapotranspiration was indirectly calculated by applying the Climatological Water Balance method (Rolim *et al.*, 1998) and all evapotranspiration was classified as green water.

The actual evapotranspiration for the pasture was estimated by using the monthly average temperatures and the total precipitation in Caraguatatuba. This data was obtained from the Department for Water and Electricity - DAEE and the Integrated Centre for Agro-Meteorological Information - CIIAGRO. In addition, a figure of 100 mm relating to Available Water Capacity (AWC) of the type of crop cultivated was used, in accordance to Sentelhas *et al.* (1999).

Cattle-farming

The water footprint for cattle-farming was calculated based on information on the herd supplied by Fazenda Serramar's administration. Information was gathered regarding the size of the herd and its different stages of development, its feeding and supplement consumption daily routines. Once this data was compiled, the blue and green water footprints for this activity were calculated. In this study, it was decided not to compute the grey water footprint for cattle-farming because it is a diffuse form of pollution requiring a more complex calculation. Furthermore, not enough information was available on the physical and chemical characteristics of the farm's soil and the leaching rate of the pollutants associated with the manure produced.

In order to calculate the blue water volume, the average weight of the cattle was estimated for each development stage so as to calculate the herds' water needs. Table 1, produced by EMBRAPA [Brazilian Agricultural Research Agency] and other institutions, was used. It contains the average daily water consumption values for bovine cattle.

Table 1: Farm's cattle according to development stage, average weight and average water demand for 2012.

Animal Category	Number of animals	Average weight (kg)	Water consumption (L/animal/day)
Reared	5,500	480	46
Calves	3,000	245	18
Bull-calves	1,200	330	32
Fattening	1,500	450	46

In order to calculate the green water footprint, information regarding the herd's daily consumption of silage was calculated. According to the data provided by Fazenda Serramar's administration, the bull-calves and fattening cattle categories are fed on 15 kg of corn silage/animal/day during winter which lasts from April to September. Silage used to feed cattle is produced from corn planted in the property with a productivity of 30 t/ha. With this information, both the amount of silage necessary to feed the herd for a year and the total area cultivated with corn needed to supply this production were calculated. For a total of 7,290 t/year of silage consumed and a productivity of 30 t/ha, the area needed for cultivation was estimated to be 243 ha.

Once the cultivated area was estimated, the amount of green water was calculated by applying the Climatological Water Balance method to find out the water balance of 243 ha (Rolim *et al.*, 1998) using the same climatological data employed to calculate the actual evapotranspiration of the pasture area in Fazenda Serramar.

Sewage

The total grey water footprint for the municipality was calculated by adding together the treated pollutant load LTreat and untreated pollutant load LNTreat, divided by the difference between the maximum acceptable concentration cmax and the natural concentration cnat of the selected pollutant (Hoekstra *et al.*, 2011), according to Equation 2 (units in m^3/year).

$$WF_{grey\ municipal} = \frac{LTreat + LNTreat}{(Cmax - Cnat)} \qquad \text{(Equation 2)}$$

Where:
LT_{reat} = treated pollutant load (mg/s);
LNT_{reat} = untreated pollutant load (mg/s);
C_{max} = maximum acceptable concentration (mg/L);
C_{nat} = natural concentration of selected pollutant (mg/L).

The volume of water needed to assimilate the pollution generated in the municipality was calculated taking into account the sewage percentage treated by SABESP, the sewage percentage receiving primary treatment in septic tanks and the sewage percentage discharged in the bodies of water without treatment (*in natura*). The potential pollutant load was monitored by SABESP and data regarding the concentration of each pollutant was considered.

Treated Sewage

The estimated pollutant load generated by the Sewage Treatment Plants (STP) was based on information regarding the quality of the treated effluent at all four STP in the municipality during 2012. The parameters selected for creating the different contamination scenarios were BOD5, Total Phosphorus and Ammonia Nitrogen. Once these three parameters were chosen for analysis, data was compiled and the average monitored concentrations were calculated in mg/L throughout the year for all parameters in each of the four treatment stations. Subsequently, the average concentration for each parameter was multiplied by their respective outflow rate at each plant, in L/s. The total pollutant load of the treated portion was given by adding the treated pollutant load for all four treatment plants, according to Equation 3.

$$L_{treat} = \sum (C_{treat} \times Q_{outflow}) \quad \text{(Equation 3)}$$

Where:
L_{treat} = treated sewage pollutant load, in mg/s;
C_{treat} = parameter concentration in treated sewage, in mg/L;
Q_{exit} = each treatment plant outflow, in L/s.

Subsequent to estimating the pollutant load of Caraguatatuba's treated sewage, taking into account BOD5, Phosphorus and Ammonia Nitrogen, the grey water footprint for each of these parameters was calculated, based on the maximum concentration allowed and the natural concentration of each of these parameters. Once the grey water footprint results were analyzed, it was decided that only one reference parameter would be used to calculate the pollutant load of the untreated sewage percentage in the municipality. The parameter requiring the largest quantity of water for its assimilation was chosen, namely BOD5.

Untreated Sewage

Regarding untreated sewage, that is, the quantity released *in natura* into water bodies, the pollutant load was calculated based on characterization data of the raw sewage entering the treatment plants. As explained in the previous chapter, the parameter used to calculate the pollutant load of untreated sewage was BOD5. First, the average BOD5 concentration found in raw sewage was calculated for each STP in 2012, in mg/L, based on monitoring data supplied by SABESP. Subsequently, the BOD5 concentration average of the four STP averages was calculated and used as the BOD5 concentration value for a standard untreated effluent.

In order to calculate the volume of untreated sewage discharged into the rivers, the per capita water consumption in the municipality and the percentage of the population without access to the sewage system network were employed. A return rate equivalent to 80% of the volume of distributed water was used, in accordance with Von Sperling (1996). After analyzing the data provided by SABESP, the BOD5 concentration of a standard raw effluent was found to be 175.85 mg/L. This value was then multiplied by the estimated volume of untreated sewage. The total pollutant load of the untreated portion was given by the product of pollutant concentration in a standard effluent, multiplied by the sewage produced by the municipality's inhabitants without access to the sewage system network, as according to Equation 4.

$$LN_{treat} = 0.8 \times C_{water} \times POP_{NServ} \times C_{standard} \quad \text{(Equation 4)}$$

Where:
L_{Ntreat} = untreated sewage pollutant load, in mg/s;
C_{water} = per capita water consumption in the municipality, in L/inhab.day;
POP_{NServ} = population outside the sewage system, in n. of inhabitants;
$C_{standard}$ = BOD5 concentration of a standard raw effluent (175.85 mg/L).

Part of the percentage of sewage not treated in the STPs includes what is treated in septic tanks. This reduces the pollutant concentration in the effluents, in comparison with sewage that receive no treatment at all. Due to the lack of available information regarding septic tank treatment in the region and after consulting with the municipality's sanitation experts, members of the Northern Coast Basins Committee and members of the community in general, an arbitrary figure of 50% was reached to represent the percentage of sewage not collected by the municipality that receives primary treatment in septic tanks. Jordão and Pessoa (2009) highlight that a BOD5 average of 35% to 65% is removed by septic tanks with multiple chambers in series. The results of experiments conducted by Metcalf and Eddy (2003) show that septic tanks have BOD removal efficiency rates of between 33% and 63%. Borges (2007), who analyzed BOD5 removal efficiency in septic tanks in the city of Araguari-MG, found efficiency rates of 52%. Based on these studies, an efficiency rate of 50% for BOD5 removal in septic tanks was used.

Maximum Pollutant Concentration allowed in water bodies

In the São Paulo Northern Coast, river sections falling in the 50 metres above sea level quota are described as Class 1, and river sections below this quota are described as Class 2 (São Paulo State Decree n. 10.755, 1977). For Class 2 rivers, the quality standards adopted must comply with the Conama [National Environmental Commission] Resolution n. 357, 2005 (BRASIL, 2005). In the Caraguatatuba study, all water bodies analyzed fall under Class 2. Therefore, with regard to the amount of BOD5 in water bodies, the CONAMA legislation's quality standards were followed. The maximum concentration permitted in a water body (cmax) for BOD5 is 5 mg/L, according to Brasil (2005).

Estimate of the Natural Concentration in a reference water body

Research regarding the natural concentration of BOD5 in a water body in the region was carried out by selecting a location with low human impact. In order to select this location, eight points monitored by CETESB [São Paulo State Environmental

Company] in Caraguatatuba were analyzed. The monitoring point showing the lowest BOD5 values was chosen.

The water body chosen for defining the reference value was the Claro River, an affluent of the Juqueriquerê River. The chosen point is located in the SABESP catchment area in the Baixo Claro River and is monitored by CETESB between 2007 and 2012, every two months (CETESB, 2013). The values adopted for *cnat* were equal to the averages recorded for this 6-years interval. The natural BOD5 concentration was 2.36 mg/L.

Availability versus Water Demand in Caraguatatuba

The "volumetric" water footprint of a location cannot be directly compared with the water footprint for another location because the opportunity costs and impacts associated to each form of consuming water are different. The "size" of the water footprint cannot tell us the whole story about the costs and benefits associated to water usage. Therefore, it is necessary to analyze water footprint within its own context, both in terms of time and geography, by comparing water availability and consumption in the municipality in 2012.

In order to conduct a monthly analysis of water footprint sustainability in Caraguatatuba, the monthly percentage rate as part of the total water footprint was calculated, based on the average monthly water consumption recorded by SABESP in the last six years. Thus, the monthly water footprint was calculated according to the average monthly water consumption.

Results

The Urban Population Supply Water Footprint

Given we are addressing surface water use, the water footprint of the urban supply was classified as blue water. According to the data provided by SABESP, the micro--measured volume of water in Caraguatatuba in 2012 was 8,383,861 m^3. Considering a rate of loss in the distribution network of 39.6%, the urban supply water footprint was 11,703,870 m^3.

Pasture Area Water Footprint

Given that the pasture area is supplied only with water from natural precipitation, evapotranspiration, water was classified as green water. As already discussed above, the agriculture activities in the municipality of Caraguatatuba are mainly the extensive cattle--farming undertaken at Fazenda Serramar. Therefore, it is the main locus for the rural areas' water footprint accounting.

The actual evapotranspiration for the pasture area, calculated by using the Climatological Water Balance method in accordance with Rolim *et al.* (1998), was 1,052.6 mm/year. Taking into account the 4,440 ha pasture area in the farm, the pasture water footprint was calculated to be 46,735,440 m^3 of water per year.

Water Footprint of Cattle-farming

Subsequent to calculating all the water necessary for each development stage of the herd, the blue water footprint was found to be 151,256 m^3 of water for 2012.

The actual evapotranspiration of the corn crop necessary to feed the herd in the farm during 2012 was equivalent to 1,052.6 mm^3. Given that the area cultivated with corn was 243 ha, after all the necessary unit conversions, the green water footprint for cattle-farming was found to be 2,736,865.3 m^3 of water/year.

The total, arrived at by adding the blue and green water footprints for cattle-farming, was 2,888,122 m^3/year, where 95% is green water and 5% blue water.

Grey Water Footprint

The result of calculating the grey water footprint of the treated sewage showed that the parameter with the greatest contamination potential was BOD5, which has a grey water footprint of 216,606,129 m^3/year. This parameter was, therefore, used in the final calculation. With regard to untreated sewage, by considering the percentage of the population outside the sewage system, it was possible to estimate the raw sewage pollutant load for Caraguatatuba. The calculated *per capita* consumption value for the municipality was 221 L/inhab.day, taking into account a resident population of 104,150 in 2012 and a total annual water demand of 8,383,861 m^3. Considering that the rate of sewage system provision in the municipality is 63.5%, the number of residents estimated to be outside the system is 38,015. The average concentration of BOD5 in a standard raw effluent was 175.85 mg/L in 2012.

The grey water footprint for the untreated sewage, therefore, was 81,701,689 m^3/year. The portion of sewage not treated in the STPs, but which receives primary treatment in septic tanks was found to be 40,850,845 m^3/year. Thus, the grey water footprint for the sewage not treated in Caraguatatuba's STPs was equivalent to 122,552,534 m^3/year.

Therefore, after adding the grey water footprints of treated and untreated sewage, the total grey water footprint of sewage in the municipality was 339,158,663 m^3/year.

Total Water Footprint

After calculating the blue, green and grey water footprints for the municipality of Caraguatatuba in 2012, the total water footprint was found to be 400,486,095 m^3 of water/year or approximately 400 Mm^3/year. Green water footprint is equivalent to 12% of the total water footprint and the remainder is blue water footprint. The volume of water calculated for each water footprint component and per activity can be seen in Tables 2 and 3, respectively.

Table 2: Caraguatatuba's Water Footprint in 2012 - by component.

Component	Water Footprint (m³/year)
Blue	11,855,127
Green	49,472,305
Grey	339,158,663
Total	400,486,095

Table 3 - Caraguatatuba's Water Footprint in 2012 - by activity.

Activity	Water Footprint (m³/year)
Supply	11,703,870
Pasture	46,735,440
Cattle-farming	2,888,122
Sewage	339,158,663
Total	400,486,095

When considering the specific water footprint of each activity analyzed in the municipality, the sewage system has the greatest share of the total water footprint. The water footprint for Pasture, Cattle-farming and Water Supply were equivalent to 12%, 0.7% and 3%, respectively.

As can be observed in Figure 3, the largest percentage of water footprint in the municipality comes from grey water, representing 85% of the total footprint.

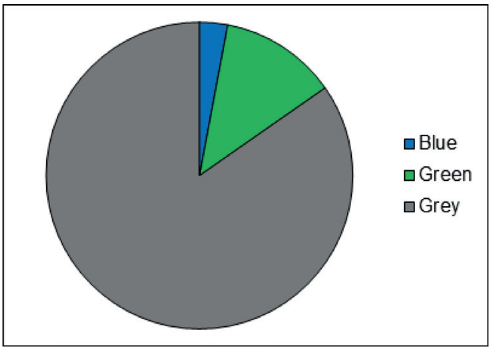

Figure 3: Different Components' share (%) of the total water footprint for Caraguatatuba in 2012.

According to the results obtained in this study, it is clear that the sewage contamination of water courses exerts the largest amount of pressure on the water resources in Caraguatatuba, given the large volume of water needed to assimilate this pollution. The rivers crossing the urban areas of the municipality are most affected by sewage discharge and by a gradual loss of water quality. The share of the population served by SABESP's sewage system is considered to be one of the main quality indicators in sanitation management.

Therefore, improving these values is one of the municipal administration's greatest challenges. Reasons for the lack of access to the system relate mainly to the increase in population size, the fluctuating population in the region during week-ends and holidays, as well as to illegal and uncontrolled occupation of areas, all of which have a negative impact on the implementation of an adequate public sanitation system.

Discussion

The Total Water Footprint of municipalities

A pioneer study, recently developed by the *Huella de Ciudades* Project team, involved a full assessment of the water footprint of three cities in Latin America: Quito in Ecuador, Lima in Peru and La Paz in Bolivia. This project calculated the carbon and water footprint of the municipal governments and the cities themselves in 2012 in order to foster mitigation and adaptation measures through pilot initiatives and actions plans to reduce the municipal footprint (Proyecto Huella de Ciudades, 2014).

The methodology used to calculate the water footprint of these cities was the *Water Footprint Assessment* described by Hoekstra *et al.* (2011). The quality parameter used to calculate the grey water footprint was also BOD5, and the maximum concentrations allowed for La Paz and Quito were 30 mg/L and 15 mg/L for Lima, respectively. It is important to note that the BOD5 limit for Caraguatatuba was 5 mg/L, six times lower than that permitted for La Paz and Quito and three times lower than the value for Lima. As Empinotti *et al.* (2013) show, countries with tougher environmental laws tend to be "penalized" in terms of water footprint accounting. Often, a high water footprint value indicates neither greater consumption nor pollution, but stronger legislative restrictions regarding the discharge of pollutants in the water.

The grey water footprint in the three cities represented more than 95% of the total water footprint value. The residential sector was responsible for over 80% of water usage in cities, reaching 96% in Lima (Proyecto Huella de Ciudades, 2014).

The total water footprint for Caraguatatuba was almost double that of La Paz and approximately half that of Quito. However, the population of Caraguatatuba in 2012 was 104,150 whilst the population of La Paz was 840,207 and that of Quito 2.3 million. In terms of water footprint *per capita*, Lima with its almost 8.5 million inhabitants, consumed 751 m^3/inhab.year, followed by Quito, with 464 m^3/inhab.year and La Paz with 260 m^3/inhab.year (Proyecto Huella de Ciudades, 2014).

Although the water footprint for Caraguatatuba was not as high as those of Quito and Lima, its water footprint per capita was greater than that observed in all three Latin

American cities studied: 3,845.3 m^3/inhab.year, taking into account only the settled population for 2012 (104,150 inhabitants). Although the context needs further analysis - the Latin American cities studied have a restricted water supply, reflected by their population's water consumption - the data reveal the potential for reducing both blue water use and the generation of grey water in Caraguatatuba, either by changing the behaviour of the city's inhabitants, or by expanding the sewage treatment infrastructure.

Grey water is sometimes disregarded in water footprint studies of geographical areas because of a lack of data about pollutant amounts discharged in water bodies. Therefore, very few studies address grey water footprint accounting using sewage system data. Almost all water footprint studies address grey water as the volume of water needed to assimilate the pollution generated by fertilizers and pesticides used in agricultural crops (Aldaya and Hoekstra, 2010; Van Oel *et al.*, 2009). Grey water footprint is calculated based on the amount of contaminant infiltration in the soil. The methodology used in this study, to some degree, differs from that of other studies given it does not include the water footprint of agricultural crops. This is because of the small share of these activities vis-à-vis the income generated in the municipality. By contrast, it analyzes in detail the volume of treated and untreated sewage discharged in the region's river.

Water footprint sustainability analysis

In the State of São Paulo, the availability of surface water is given by Q 7.10 or by a basin's stabilized water flow when there are hydrological structures for this purpose (CBHLN [Northern Coast River Basin Committee], 2013). Thus, according to the guidance available in the CRH [São Paulo State Water Resources Council] n. 62, 4th September 2006, the water availability of a particular watershed is given by 50% of the Q 7.10 value.

Therefore, in order to carry out a full water balance, the total volume of surface water captured must be calculated and compared with 50% of Q7.10. In this way, the water availability considered in this study was 3.52 m^3/s, equivalent to 50% of Q 7.10 specified as 7.04 m^3/s (CBHLN, 2013).

A comparison between water availability and its corresponding water footprint for each month during 2012 can be observed in Figure 4.

According to Figure 4, the total water demand is greater than the minimum flow for the municipality, revealing the unsustainability of Caraguatatuba's water footprint in 2012. If we compare water consumption and the pollution generated with the amount of water available for developing activities and services for the Caraguatatuba population, it is possible to see that the volume "extracted" is greater than the volume available. This analysis places Caraguatatuba in a very critical scenario in terms of water usage, in particular during the high tourist season when the city's population grows considerably.

Water availability is gradually reducing, a reflection of the population growth and the high Geometric Annual Growth Rate of the Northern Coast municipalities (CBHLN, 2013). Therefore, the considerable abundance of water in the region needs to be carefully observed: First, the geographical relief of the Northern Coast means that surface

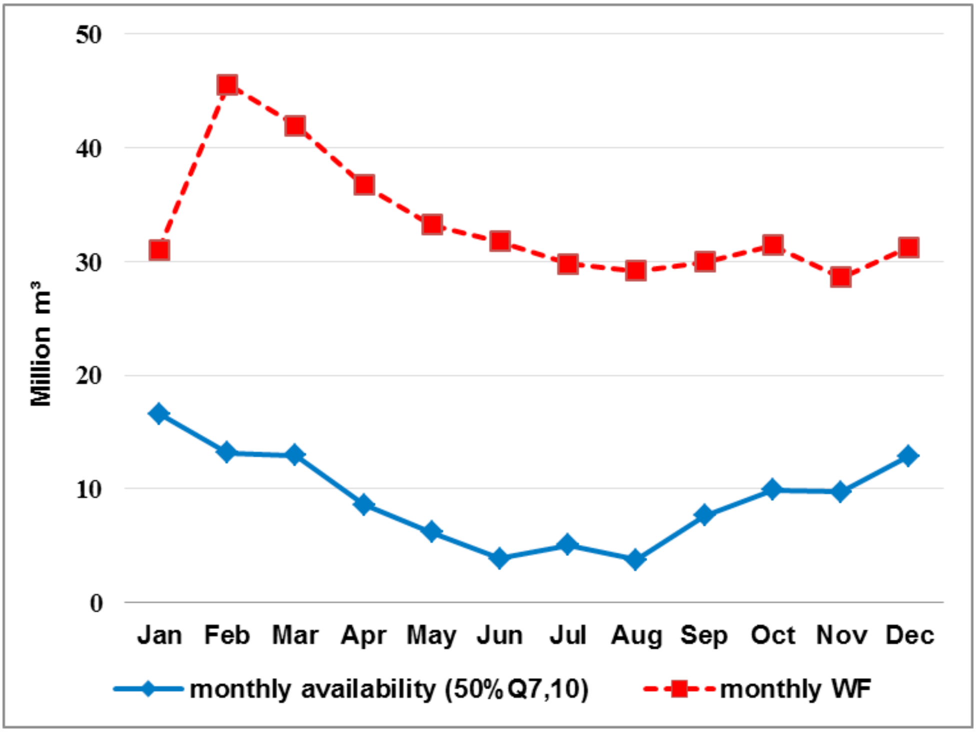

Figure 4: Comparative Analysis between monthly water availability and monthly water footprint in Caraguatatuba in 2012.

runoff occurs in small independent river basins (and not sub-basins). Thus, the period of time water remains in the basin is relatively short in comparison with the large river basins and water availability varies from basin to basin. Furthermore, water criticality is influenced by water availability and consumer demand for water in each basin. Second, it is important to highlight the presence of the fluctuating population, and occasional and peak water usage, which reduces *per capita* water availability. These factors, together with a tendency to raise the *per capita* volume, indicate potential conflicts due to water usage (CBHLN, 2013).

Alternative measures for reducing the water footprint

Based on the results obtained, it is clear that in order for the Caraguatatuba authorities to reduce the water footprint, it must address a critical issue, namely, basic sanitation and in particular, sewage, so as to reduce the discrepancies between the capacity of the system and demographic growth.

The most important measure for reducing the municipality's total water footprint, particularly with regard to grey water, is the expansion of the sewage system network, given sewage is the key factor threatening the quality of water resources in the region. However, in order to expand the sewage network and adjust the sanitation system to the new population size of the municipality so that it can work effectively, a number of measures must be adopted beforehand. Some are cited in the CBHLN (2013) and may be adapted:

- Identify the areas not served by the sewage network, pinpointing the reasons why they remain outside the system (illegal land occupation and risk areas, isolated communities, etc.);
- Carry out awareness and monitoring campaigns to connect properties to the sewage system;
- Register properties so that alternative sewage treatments can be formalized.

In addition to measures to improve the municipal sewage system, it is important to highlight that the development of an integrated water resource management system, the consequent reduction in consumption rates and the increase in water use efficiency can only be achieved if the city's database is expanded. Therefore, other CBHLN (2013) measures should also be adopted:

- Implement hydrometric monitoring of the main rivers in the region in order to know their real flow, given that currently river flow is calculated using theoretical values;
- Stimulate actions to reduce losses in the water supply system;
- Promote registration of water usage concessions at Water Authority (DAEE) in order to assess the real demand for the basin's water.

The use of water footprint as a tool to assist water governance at a national or regional level is still incipient, but will tend to become more prevalent with the potential escalation of conflicts regarding future water usage. Population growth, an increase in agricultural production to achieve the food security of the planet and imminent global changes require the joined-up effort of global society as a whole so that the supply of water resources does not collapse.

Therefore, as well as measures which should be adopted by the municipal authorities, river basin committees and the water regulatory and monitoring bodies, it is crucial that the population becomes more aware of the need for using water sustainably and consciously. In this way, water footprint can be a very useful tool to highlight the key issues that need to be considered in the integrated management of water resources and warn to the potential consequences of the inappropriate use of water and water wastage.

Final considerations

The São Paulo Northern Coast is undergoing a period of intense economic, social and environmental transformations driven by the expansion of infrastructure associated to the exploration of the pre-salt oil reserves. Furthermore, this region is also facing the challenge of addressing urban development and resulting population boom, whilst conserving the Atlantic Rainforest biome and preserving local natural resources. Despite the fact that this coastal region is known for its high water availability, rapid population growth and the inappropriate use of this resource are threatening water quality.

The findings of this study point to a total municipal water footprint of approximately 400 Mm^3 of water/year in 2012. Grey water represents the largest share, that is, 85% of the total water footprint. Grey water reflects the volume of water which would be necessary to assimilate the total amount of sewage discharged in the region's rivers, with or without prior treatment. Thus, the high proportion of grey water footprint in the total calculation of the municipality's water consumption makes it clear that the greatest pressure on local water resources comes from the disparity between the capacity of the sewage network system and the demands of a population that continues to grow.

From the environmental point of view, the total water footprint of Caraguatatuba in 2012 was not sustainable because it exceeded the amount of water available in the region. Therefore, the environmental liability created by the lack of sustainability is incorporated into the marine environment as an externality. This indicates that this region, once thought of as having abundant water resources, may suffer from rationing and conflicts associated to water usage if society at large continues to view this resource as inexhaustible.

Breaking down water footprint into its different components enables us to better identify management targets, in this case, the city's sewage system. This tool can be of help to decision-makers and can be extremely useful for implementing measures towards a more sustainable use of water in the region.

A preliminary comparison between the results of this work and that conducted in other municipalities, as in the case of Quito, Lima and La Paz, shows that it is essential to have an analysis which considers in more detail the context in which studies are conducted. They also demonstrate the potential for reducing blue and grey water in Caraguatatuba, either by changing people's behaviour or by expanding the infrastructure for treating effluents, both of which should be addressed through local public policies.

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CONTRIBUTIONS TOWARD A MUNICIPAL APPROACH TO WATER FOOTPRINT: CASE STUDY IN A SÃO PAULO STATE COASTAL CITY

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Abstract: Advances in water management require knowledge of the availability and demand of water resources to define priority actions for water conservation. The aim of this study is to support the development of municipal initiatives involving Water Footprint, based on a case study of Caraguatatuba, using 2012 data. The following water footprints were considered: a) the urban water system; b) sewage production; c) cattle-farming; and d) rural water uses. Results showed water footprint levels of approximately 400 Mm^3/year, where grey water represents the largest share (85 %). Furthermore, results showed that the increased pressure on local water resources results from the disparity between the sewage system in relation to the demands of a growing population. This study can contribute to improve Water Footprint methodology, promoting comparative studies and supporting water management policies in this socio-political field.

Keywords: Water consumption, Caraguatatuba, Urban expansion

Resumo: Os avanços na gestão da água exigem o conhecimento da situação dos recursos hídricos como subsídio para definição de ações prioritárias para a conservação da água. Este trabalho teve como objetivo subsidiar o estabelecimento de uma abordagem municipal para a Pegada Hídrica a partir do estudo de caso de Caraguatatuba, com dados de 2012. Foram consideradas as pegadas hídricas: a) do sistema de água urbana; b) da produção de esgoto; c) da pecuária; e d) da água utilizada no meio rural. A pegada hídrica encontrada foi de 400 Mm^3/ano, com uma contribuição de 85% da água cinza. Esse resultado mostrou que a maior pressão sobre a água advém da defasagem do sistema de esgoto em relação às demandas de uma população crescente. O estudo pode contribuir para o aprimoramento da metodologia da Pegada Hídrica com este recorte, permitindo estudos comparativos e subsidiando políticas de gestão das águas neste nicho sócio- político.

Palavras-chave: Consumo hídrico, Caraguatatuba, Expansão urbana

Resumen: Los avances en la gestión del agua requiere el conocimiento de la situación de los recursos hídricos como un subsidio para las acciones prioritarias para la conservación del agua. Este estudio tuvo como objetivo apoyar el establecimiento de um abordaje municipal de la Huella Hídrica del estudio de caso de Caraguatatuba, com datos de 2012. Se consideraron las huellas hídricas de: a) el sistema urbano de agua; b) la producción de alcantarillado; c) el ganado; y d) el agua utilizada en las zonas rurales. Los resultados mostraron una huella hídrica de 400 Mm^3/año, con la contribución de 85% de las aguas grises. Este resultado muestra que el aumento de la presión sobre los recursos hídricos locales proviene de la brecha de la red de saneamiento en relación con las demandas de una población creciente. El estudio puede contribuir a la mejora de la metodologia de la huella hídrica, permitir estudios comparativos y subvencionar las políticas de gestión del agua en este nicho sócio-político.

Palabras clave: Consumo del agua, Caraguatatuba, Expansión urbana