SÃO PAULO CITY GREEN BELT BIOSPHERE RESERVE – WATER SECURITY AND HUMAN WELL-BEING

Rodrigo Antonio Braga Moraes VICTOR[1], Elaine Aparecida RODRIGUES[2], Gustavo Casoni da ROCHA[3], Edgar Fernando de LUCA[4], Jean Paul METZGER[5], Amanda Rodrigues de CARVALHO[6], Denise BICUDO[4]

KEYWORDS

Water security; Urban water supply; Territorial planning; Megacities; Ecosystem services; Global climate change; Ecological Infrastructure

ABBREVIATIONS

ANA National Agency of Water and Basic Sanitation
BAT Alto Tietê Hydrographic Basin
CBH-BS BaixadaSantista Hydrographic Basin Committee
CO2 Carbon dioxide
DAEE Department of Water and Electricity
GHG Greenhouse gases
HA Hectare
IBGE Brazilian Institute of Geography and Statistics
IPCC Intergovernmental Panel on Climate Change
MEA Millennium Ecosystem Assessment
UN United Nations
GBBR São Paulo City Green Belt Biosphere Reserve
M^3/S Cubic meters per Second
M^3/H Cubic Meters per Hour
SMA Metropolitan Area of BaixadaSantista
SPMA São Paulo Metropolitan Area
SABESP São Paulo State Water Company
UGRHI Unidade de Gerenciamento dos RecursosHídricos
UN - DSDG Division for Sustainable Development Goals
UN - HABITAT United Nations Human Settlements Programme
UNEP United Nations Environment Programme
UNESCO

[1]FundaçãoFlorestal (São Paulo, Brazil) - Email:

[2]Instituto de Pesquisas Ambientais do Estado de São Paulo (Brazil) / Instituto de Pesquisas Energéticas e Nucleares - IPEN / Universidade de São Paulo - USP (Brasil).

[3]Fundação Florestal (São Paulo, Brazil)

[4]Instituto de Pesquisas Ambientais do Estado de São Paulo (Brazil)

[5]Universidade de São Paulo - USP (Brasil)

[6]Universidade de Brasília - UnB (Brazil)

ABSTRACT

The green belt surrounding São Paulo and Santos metropolises, designated by UNESCO as the São Paulo City Green Belt Biosphere Reserve - GBBR (1994), encompasses a population of 25,4 million people in a region responsible for nearly 20% of Brazilian GDP. With approximately 2,33 million hectares, the biosphere reserve and its inner urban area (220 thousand hectares) are host to expressive terrestrial and marine biodiversity, typical to the Atlantic Forest and Cerrado biomes. This paper presents the biosphere reserve as a water security territory: it provides around 90% and 100% of the water flows supplying São Paulo and Santos metropolises, respectively. Representing only 7,36% of São Paulo State territory, the GBBR harbors over 70% of the state´s volume for public supply. Spatial analysis shows that most of this volume comes from a few protected areas that act as hydric hotspots. During 2013-2015 Southeastern Brazil and especially São Paulo faced a severe shortage in rainfall that posed threats to the metropolitan water supply, leading to important reflections about the region´s hydric vulnerability. Combining classical built infrastructure with ecological infrastructure (conservation, restoration and sustainable use of its ecosystems) is paramount to ensure the population's water security in the medium and long terms. In this sense, the geographical and conceptual frameworks constituted by the GBBR can provide integrated land management solutions for improving water supply in quantity and quality for such a complex and critical territory.

1 INTRODUCTION

The world's largest urban agglomerations, which concentrate more than ten million inhabitants, are designated as megacities, and stand out for their continuous growth in population and economic power, as well as for their global environmental impact (Forberth et al., 2015; United Nations, 2019; MEA, 2005). These regions present multiple and complex challenges related to the Sustainable Development Agenda (UN-DSDG, 2020). Growing population, per capita consumption and the intensification of urbanization processes magnify environmental changes, bringing along local, regional and global impacts. The degradation of natural ecosystems and the consequent loss of their benefits and biodiversity significantly compromises human well-being.

The benefits that nature can provide, the so-called "ecosystem services" (MEA; 2003;) or "nature's contributions to people" (DIAZ et al., 2018), include provisioning services (e.g., water, wood, fibers, fruits), regulation (climate, water, pollination, pest, disease, flood and landslide control, among others) and cultural (recreation and physical activity, contemplation and aesthetic appreciation, spiritual experience) (MEA, 2003).

In a world with fast urbanization processes, with 55% of the population occupying 1% of the planet's territory (United Nations, 2019), large and megacities lead to the increasing depletion of ecosystem services, especially those related to freshwater, by concentrating the demand of millions of people in small areas. Aggravated by the impact of climate change, the availability and supply of water has become a key challenge worldwide (Ahmadi et al. 2020; Adeel, 2017) and has severely impacted the Southeast region of Brazil between 2013 and 2015, a period with rainfalls well below the normal average (Buckeridge and Ribeiro, 2018; Faro et al., 2018; Milano et al., 2018; Jacobi et al., 2018; Victor et al., 2018).

The low rainfall over such a long period brought a series of consequences for the quality of life of 21 million people living in the São Paulo Metropolitan Area (SPMA) - the fourth largest urban settlement in the world (IBGE, 2020; United Nations, 2019). With its drinking water reservoirs reduced to 5% of their capacity, the region faced a severe crisis in water supply, a direct result of variations in historical rainfall patterns, aggravated by the great vulnerability of the region's water governance systems.

Because ecosystem services that benefit the metropolis of São Paulo are provided by ecosystems that are located, in significant part, beyond its geographical limits, to understand the processes of water security that affect the SPMA it is necessary to analyze a broader geographical framework which corresponds to its surrounding green belt. Composed by a vast peri-urban and rural area, with predominance of large extensions of forests, water springs, cultivated areas, tourism/leisure areas and less densely populated human occupations, this territory was designated a UNESCO biosphere reserve in 1994 (São Paulo City Green Belt Biosphere Reserve - GBBR) (Victor et al., 2018; Rodrigues et al., 2020).

The GBBR fully encompasses São Paulo Metropolitan Area, nearly all Santos Metropolitan Area, and partially the metropolitan areas of Sorocaba, Campinas, Vale do Paraíba and Litoral Norte, São José dos Campos and the administrative region of Registro, in a total of 78 municipalities, enclosing a population of 26.19 million inhabitants in a territory of 2,331,715 hectares (land and marine areas, excluding dense urban areas) (Rodrigues et al., 2020).

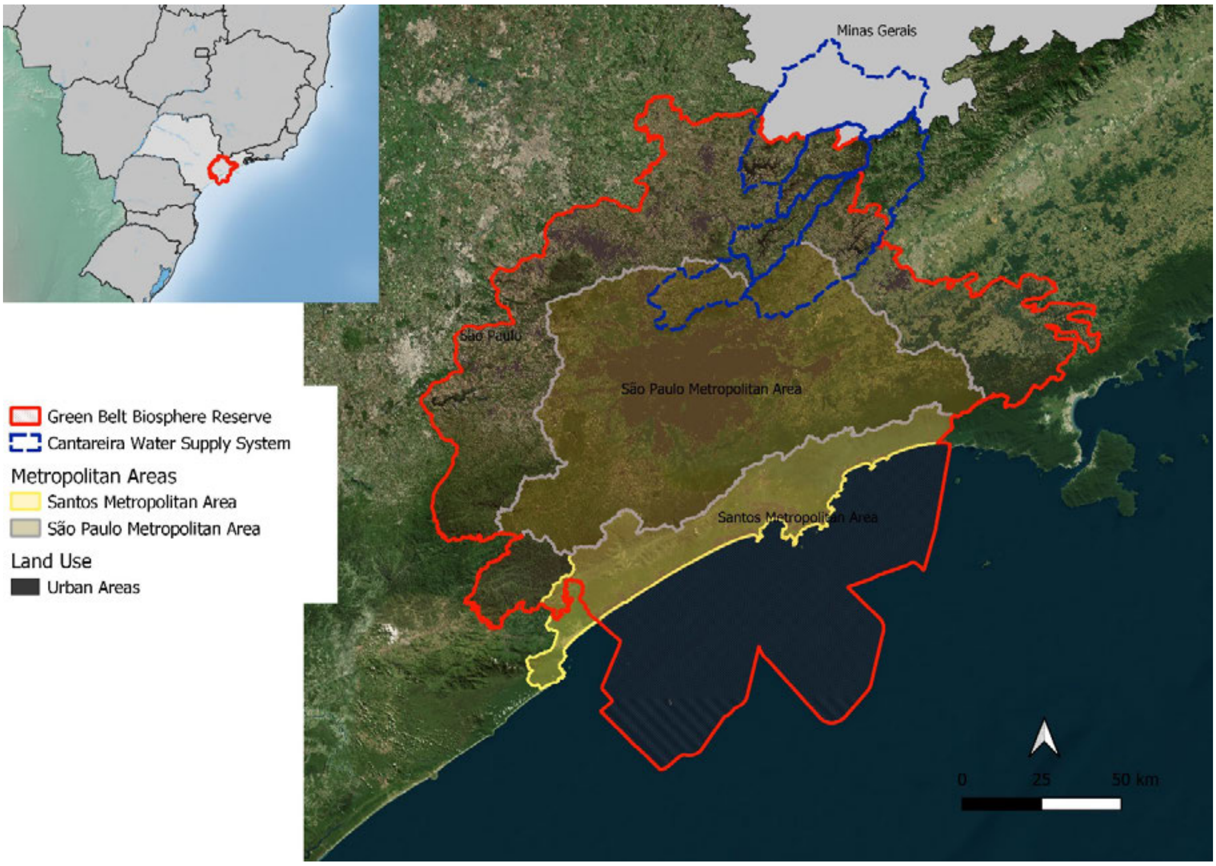
The density of urbanization in São Paulo, the trend of expansion of this urban spot and the severity and extent of the water scarcity process that occurred in the region between 2013-2015, led this study to the search for proposals for the water sustainability in those metropolises. Thus, this article aims to assess the hydrological importance of GBBR and its contribution to the water supply and the stability of this service over time. In a first moment, we discuss the relation between megacities, climate change and urban water supply. Next, we highlight the water shortage in São Paulo and the importance of adopting the GBBR as an appropriate territorial framework for the integrated management of a water security territory on both state and national scales.

2 METHODS

Study Site

The area under study is the GBBR, designated by UNESCO in 1994, which covers 78 cities, including SPMA (39 municipalities), Santos Metropolitan Area (SMA - 9 municipalities) and other 30 municipalities. Altogether, GBBR encompasses urban areas that are home to 25,4 million people, generating a GDP equivalent to 63% of the state of São Paulo´s and 19.5% of Brazil´s (IBGE, 2019), with emphasis on SPMA, the fourth largest megacity in the world (United Nations, 2019; IBGE, 2020) (figure 1).

Figure 1 - Location of GBBR, its main metropolitan regions and the Cantareira Water Supply System, with its headwaters in the state of Minas Gerais.



The Cantareira Water Supply System (hereinafter called Cantareira System), at the north of the GBBR, is the largest water supplying system for the SPMA. With six reservoirs connected by underground tunnels and channels, it supplies 35,7 % of São Paulo metropolis. The system transposes two watersheds, importing water from the Piracicaba River basin (ANA, 2020). The other systems supplying São Paulo metropolis are shown in Table 4. Santos Metropolitan Area, with its nine municipalities, is supplied by three supplying systems (Pilões-Cubatão; Mambu; Melvi) and by isolated systems totaling 24 surface springs, and by water transfers from the Billings reservoir located in the SPMA (ANA, 2010).

Water Assessment Methodology

To assess the hydrological importance of the GBBR and the conservation state of its supplying basins and systems, four different methodological approaches were used:

1) Bibliographic review and primary data survey in the State Water Company database (SABESP, 2020-2021) of the basins and hydric systems supplying São Paulo and Santos metro areas, before and after the water crisis of 2013-2015 (table 1), to: ***i)*** assess how much of this water provisioning ecosystem service is provided by the biosphere reserve territory, both in terms of water flow and reservation; ***ii)*** consequently analyze if the GBBR is self-sufficient in supplying these two metropolises.

2) Multiscale Analysis of water use permits in the GBBR and protected areas within it (table 2): In Brazil, all water use modality between 15 and 25 m³ / hour is subject to a permit granted by federal (ANA) and state agencies (in São Paulo, by DAEE) (BRAZIL, 1997; DAEE, 2017). The

grant to use the water resource aims at ensuring the quantitative and qualitative control of the various water uses and the effective right to access the resource.

The present analysis used spatial data of surface water use permits from DAEE to three modalities in the GBBR: public supply (for households, offices etc), industrial and irrigation uses, in order to compare GBBR data with the São Paulo State ones. While topic 1 analyzes overall basins and water systems flows, water use permits allows for assessing water flows from individual withdrawal spots. In all, 12.510 spots were analyzed. Water use permits are indicators of basin flow (and the hydric ecosystem services provided by the basin) demanded for human use. It is an easier way to provide primary data for a given territory to which bibliographic data is not available, like the case of protected areas whose boundaries do not coincide with the basin´s. Unlike in topic 1, that considers basins and systems supplying two metropolises, the water use permit analysis covers the whole GBBR territory.

3) Analysis of three protected areas and their buffer zones within the biosphere reserve that concentrate the highest water volumes granted for the public supply modality. Building on the biodiversity hotspots concept (Myers, 2000), they are called in this paper hydric hotspots protected areas (relatively small areas supplying a significant percentage of water volume for public supply) (table 3).
4) Land use and cover analysis of ***i)*** Alto Tietê water basin, ***ii)*** the portion of the Cantareira System within the GBBR (226.000 out of 371.000 ha), both supplying São Paulo metro area, and ***iii)*** Baixada Santista water basin. Data was collected from the MapBiomas 4.1 database (MAPBIOMAS, 2020), for the years 1994 (GBBR designation) and 2018 (table 4).

3 RESULTS

Table 1. Water supply systems for the SPMA in 2013 and 2020 and SMA in 2013 and 2018 and the contribution in water flow and reservation of the São Paulo City Green Belt Biosphere Reserve.

Water supply system	**Water flow (m^3/s) (% from total)[a]**			**% of the water flow from within the GBBR territory (2020)**	**% of the water stored in reservoirs within the GBBR territory (2020)**	**Reservoirs that constitute the water supply systems**
	São Paulo Metropolitan Area					
	2013 [b]	2020 [c]	Sep-2020 Sep-2021 [c]			
Cantareira	33,0 (45,2%)	24,4 (38,4%)	22,6 (35,7%)	70,2%	100%	Jaguari/Jacareí, Cachoeira, Atibainha, Castro Paiva, Águas Claras, Jaguari (CESP)
Alto Tietê	15,0 (20,5%)	14,2 (22,3%)	13,2 (20,9%)	100%	100%	Paraitinga, Ponte Nova, Biritiba, Jundiaí, Taiaçupeba, Biritiba (Dique)
Guarapiranga	15,0 (20,5%)	12,8 (20,1%)	13,7 (21,7%)	100%	100%	Guarapiranga, Capivari, Bilings
Rio Grande	4,8 (6,6%)	4,5 (7,1%)	4,7 (7,3%)	100%	100%	Rio Grande, Ribeirão da Estiva

Rio Claro	4,0 (5,5%)	3,7 (5,8%)	3,6 (5,7%)	100%	100%	Ribeirão do Campo
São Lourenço	-	2,8 (4,4%)	4,6 (7,3%)	100%	100%	Cachoeira do França
Alto Cotia	1,2 (1,7%)	1,2 (1,9%)	0,9 (1,4%)	100%	100%	Pedro Beicht, da Graça, Isolina
Total	73,0	63,6	63,2	88,6%	100%	
Santos Metropolitan Area						
	2013 [d]	2018 [d]				
Pilões/Cubatão Mambu; Melvi	19,4	18,4		100%	100%	

Notes: [a]Flow withdrawn from the following Water Treatment Stations: Cantareira = ETA (Water Treatment Station) Guaraú; Alto Tiete = ETA Taiaçupeba; Guarapiranga = ETA ABV; Rio Grande = ETA Rio Grande + ETA Ribeirão da Estiva; Rio Claro = ETA Casa Grande; São Lourenço = ETA São Lourenço; Alto Cotia = ETA Alto Cotia; [b]Marins et al. (2019); [c]SABESP (2021); [d]CBH-BS (2019).

Table 2. Water flow granted for public supply, industrial and agricultural uses in different geographical scales - (1000m3.h-1), in August 2020. *Source*: Elaborated based on SABESP (2020)

Site	Public Supply		Industrial Use		Agricultural Use		Sum Total
	Q (1 mil $m^3.h^{-1}$)	**%**	**Q (1 mil $m^3.h^{-1}$)**	**%**	**Q (1 mil $m^3.h^{-1}$)**	**%**	**Q (1mil $m^3.h^{-1}$)**
São Paulo State	1.448	100	403	100	1.715	100	3.568
GBBR	1.039	72%	72	18%	93	5%	1.205
Hydric Hotspots Protected Areas	738	51%	16	4%	15	1%	770

Tabela 3. Hydric Hotspots Protected Areas

Protected Areas and Their Buffer Zones	Total Area	% within GBBR	Overlaps
Sistema Cantareira Environmental Protection Area (SC-EPA)	254.092 ha	100%	711ha with CSP 21.912ha with CSPBZ
Cantareira State Park (CSP)	7.619 ha	100%	711ha with SC-EPA
Cantareira State Park buffer zone (CSPBF)	35.712ha	100%	21.912ha with SC-EPA
Serra do Mar State Park (SMSP)	322.296 ha	57%	none
Serra do Mar State Park buffer zone – (SMSPBZ)	294.960ha	55%	none

Table 4. Land use and cover in the 3 water basins/systems within the GBBR supplying São Paulo and Santos Metro Areas

Land Use and Cover Modalities	Baixada Santista Water Basin		Alto Tietê Water Basin		Cantareira Water Supply System		GBBR	
	1994	2018	1994	2018	1994	2018	1994	2018
Native vegetation	83.9%	84.1%	41.1%	38.6%	45.8%	45.4%	47.9%	47.0%
Afforestation (Eucalyptus/Pinus)	1.2%	1.5%	3.0%	4.7%	2.6%	7.6%	2.4%	4.6%
Crop/Pasture	6.3%	4.4%	27.3%	23.1%	50.5%	45.4%	35.2%	31.3%
Urban area	8.0%	9.6%	28.3%	33.4%	0.9%	1.3%	11.1%	13.8%
Other non-natural areas	0.6%	0.4%	0.3%	0.3%	0.2%	0.2%	3.4%	3.3%

4 DISCUSSIONS

Between 2013 and 2015, the SPMA faced a severe water supply crisis as a direct result of variations in historical rainfall patterns. As water supply reservoirs depend on the rainy season for their filling, the droughts and high temperatures that have occurred from 2013 have caused their level to reach critical volumes in 2014. The most impacted supply system was Cantareira, the main water supplier for SPMA, which at the time catered for more than 8 million people (Braga and Kelman, 2016; Ambrizzi and Coelho, 2018; Buckeridge and Ribeiro; 2018; Milano et al., 2018; Braga,).

As the main water supply system for the SPMA, Cantareira System contributes to around 35% of the water consumed by the region. The Alto Tietê and Guarapiranga systems are equivalent, each account for about 20%. The other systems have lower shares, varying between 7,3% and 1,4% (September 2020-Sepetmber 2021) (table 1), with decrease in the flow withdrawn in the period from 2013 to 2020-2021 - greater decreases for the Cantareira system (31,5%) and Alto Tietê (12%). On the other hand, the flow withdrawn from São Lourenço system increased by 64% in the 2020-2021 period. The geospatial analysis conducted for this study showed that all the supplying systems are fully within in the GBBR territory, with the exception of approximately 40% of the Cantareira system, whose headwaters are in the southern region of the Minas Gerais state (MAPBIOMAS, 2020). In 2018, with the beginning of water transposition from the Paraíba do Sul River and the transfer of 7.8 m3/s in 2020, there was a dilution in the percentage of water coming from Minas Gerais State into the SPMA area (30% of the Cantareira system -; around 7,27 m^3/s) (ANA, 2020).

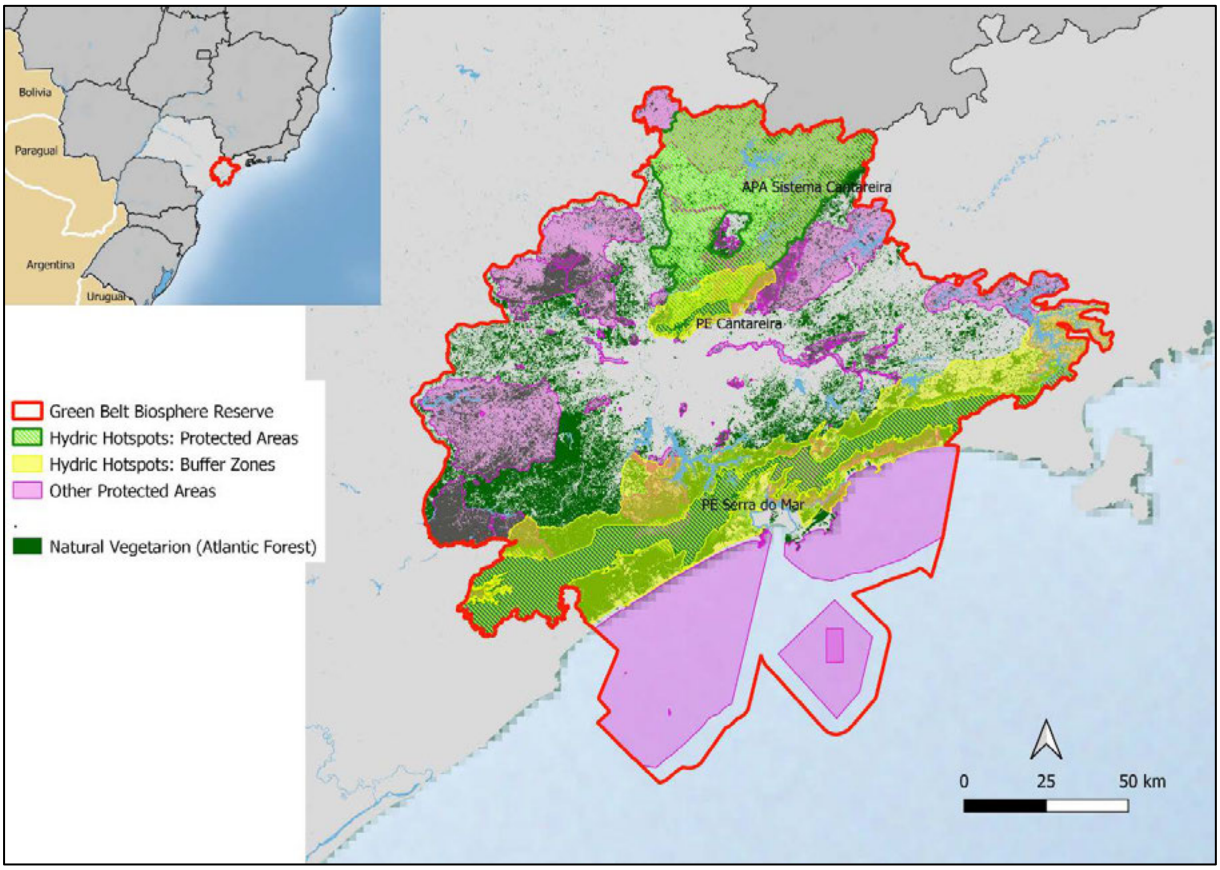
From the figures above it can be noticed that the GBBR is almost self-sufficient in supplying water to the SPMA (88,6% of the required flow, with 11,4% coming from southern of Minas Gerais State) and self-sufficient in supplying the SMA (100% of the required flow) . Concerning reservation, all volume from all systems is stored in reservoirs within the GBBR

Data shows that 72% of the state's drinking water volume is obtained from the GBBR, which in surface corresponds to only 7,36% of the São Paulo State territory. Considering that those water sources are not replaceable at the short and medium terms, this water extraction rate within the biosphere reserve places it as a critical water security territory, crucial for the water security of 25,4 million people. Table 2 presents data on water use permits granted by the State Water and Electric Energy Authority for public supply, industrial and agricultural uses at the following boundaries: a) São Paulo State; b) São Paulo City Green Belt Biosphere Reserve - GBBR; c) *hydric hotspots* protected areas (plus buffer zones).

The GBBR also supplies 18% of the state water volume for industrial use, a figure not as expressive as the public supply´s one but quite relevant as São Paulo is the most industrialized state in Brazil, with an industrial GDP amounting to US$ 68,7 billion/yr (31,6% of the national industry), employing 2,85 million people (CNI, 2020). The water volume granted for agricultural use, while small at the state level (5%), is important for a few thousands of small and medium-scale producers on the agricultural green belt. As for the hostpots protected areas (table 3), they are: a) just 2.6% of São Paulo State surface while supplying 51% of state´s granted volume for public water supply; b) 35,2% of the biosphere reserve surface while supplying 71% of the reserve´s granted volume for public water supply. They can be grouped as follows (figure 2):

- *Hydric hotspot* 1: Cantareira System Environmental Protection Area (IUCN category V) and Cantareira State Park (IUCN category II) plus its buffer zone.
- *Hydric hotspot* 2: Serra do Mar State Park (IUCN category II) plus its buffer zone.

Figure 2: Hydric hotspots for human supply in the GBBR territory.



Analysis of the state of conservation of the basins supplying São Paulo and Santos metropolises over the years is crucial to support sound planning strategies for water security in the GBBR. There are many factors associated with water security. Some of them are determined at other scales and are consequently out of local governance, like rainfall pattern and other climatic factors. Sanitation levels are also critical for water supply and is still an issue in developing countries like Brazil. Built infrastructure for water supply can provide systems that are robust and capable of delivering water in quantity and good quality even during a drought.

However, wise land management, with special focus on conservation and restoration of natural ecosystems is paramount to ensure water security. Ecosystems provide cities with fresh water for drinking and other human uses, and secure storage and controlled release of water flows. Vegetation cover and forests in the city catchment influences the quantity of available water (Gómez-Baggethun et al., 2013).

Considering the basins and systems providing water to São Paulo and Santos metro areas, there are different situations concerning land uses and cover (table 4). The Alto Tietê basin, where 5 out of the 7 water supplying systems for São Paulo Metro Area sit, is a highly urbanized area (33,4%) and the one which lost most of the natural vegetation since the eighties. Current forest cover (38,6%) is very unevenly distributed, concentrated in the outskirts of the urban area. It is the basin exposed to most of the deforestation pressures and pollution from urban sources. Cantareira System is better than Alto Tietê basin in terms of natural vegetation cover (45,4%), with net deforestation rates close to zero (deforestation is equivalent to regeneration). Although many of the threats to water and other ecosystems are associated with agriculture, in recent years urbanization is posing increasing pressures on them. Baixada Santista basin is the most environmentally preserved one, with current vegetation cover around 84%. This high conservation rate has a lot to do with relief and the presence of large strictly protected areas like Serra do Mar State Park, the biggest park in the Brazilian Atlantic Forest. Like in all basins in the biosphere reserve, urban sprawl is a major driver of ecosystem change. However, the region´s high vegetation cover is still an important element to ensure the basin´s resilience to secure natural water flows.

The water crisis of 2013-2015 brought to wide public discussion the many dimensions of the problem and possible solutions, among them the need to: *i)* increase hydric input by drawing water from additional neighboring basins, what was actually put in place with the beginning of the São Lourenço System operations (2,8 m^3/s) and the water transposition from Paraíba do Sul basin to Cantareira System (7,8 m^3/s) (SABESP, 2020); *ii*) decrease water leakage and losses in the distribution systems, which is around 20% for São Paulo Metro Area (WRI, 2018); *iii)* change the population´s water consumption habits, which decreased by 15% in 2018 (AKATU, 2020) compared with the pre-crisis figures.

Less attention, however, was given to land management issues and the importance of ecological and natural infrastructures, what was, to some extent, a lost opportunity. The concept of ecological infrastructure captures the role that water and vegetation in or near the built environment play in delivering ecosystem services at different spatial scales. It includes all green and blue spaces that may be found in urban and peri-urban areas (Gómez-Baggethun et al., 2013).

Natural infrastructure investment analysis in the Cantareira System (Green-Gray Assessment) demonstrated that ecological restoration can reduce silting control costs and secure water flows; the restoration of 4.000 hectares in critical areas would cost US$ 21,75 million and generate an economy of US$ 61,8 million in energy use, chemical products and equipment depreciation, with net benefits of US$ 40 million in 30 years. Natural infrastructure reduces soil erosion by 36%. Additional benefits of natural infrastructure include climate change mitigation by CO2 removals, increase of community resilience for climate change, amelioration of human health and well-being, rural economy and productivity (WRI, 2018).

The GBBR boundaries were designed to encompass green areas and water basins that directly contribute to São Paulo and Santos Metro Areas, and a number of associated ecosystem services (Rodrigues et al., 2020). Within the GBBR there are classical land and water institutional management frameworks like cities, water basins, protected areas, and metropolitan areas (whose development plans have not yet been adopted). However, none of them, but the GBBR, entirely embraces the watersheds and systems supplying water to São Paulo and Santos Metro Areas (with the small exception of the Cantareira System headwaters, as discussed). The GBBR management system involves stakeholders from several public institutions, municipalities, civil society, scientific community, among others, and an action plan with several integrated management strategies to reconcile socio-economic development with conservation and sustainable use of its ecosystems.

The GBBR actions, over the years, have placed a lot of emphasis on local development projects, including ecological restoration, land analysis for designation of new protected areas and ecosystem services assessments, to name a few, all connected with water conservation. Nevertheless, the biosphere reserve´s potential for territorial integrated management has not been implemented. Being a more comprehensive management framework, it offers tools to integrate metropolitan, cities, protected areas and watershed management/master plans, for a more robust land and water governance. By bringing the analyses and discussions on how the GBBR territory connects with water security for two important metropolises, this paper also seeks to call the attention of decision-makers to the fact that the reserve: *i)* must be considered a water security territory for all management purposes (Victor et al., 2018) *ii)* is in a position to provide a powerful platform for discussions and actions aiming at water sustainability in the medium and long terms, especially in the fields of biodiversity conservation, ecological infrastructure, strategic planning, participatory management and promotion of eco-job markets for the social inclusion and well-being of local communities.

CONCLUSIONS

In view of scenarios depicting futures with increasing urbanization towards water conservation critical areas and the various impacts of climate change, like alteration in rainfall patterns with occurrence of further severe droughts, robust policies, planning and actions must be put in place to ensure water supply in the São Paulo City Green Belt Biosphere Reserve, as a critical water security territory. Sound built infrastructure must come along with investments in ecological infrastructure to enhance ecosystems resilience and their intrinsic capacity to ensure water provision with good quality. Future disturbances in water supply has great potential to affect the well-being of over 25,4 million people and ultimately the Brazilian economy. The management framework provided by the GBBR should be used in a more effective way to allow for policies integration at different scales and promotion of ecosystem-based solutions.

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