ISSN 1808-8546 (ONLINE) 1808-3765 (CD-ROM)

SUSTENTABILIDADE DOS RECURSOS HÍDRICOS NA BACIA DO ALTO PARANAPANEMA-SP: UM ENFOQUE DE DINÂMICA DE SISTEMAS*

ALBA MARIA GUADALUPE ORELLANA GONZALEZ[1]; JOÃO CARLOS CURY SAAD[1], RODRIGO MÁXIMO SÁNCHEZ-ROMÁN[1]

[1] Department of Rural Engineering, Faculty of Agricultural Sciences, Universidade Estadual Paulista (UNESP), Avenida Universitária, n° 3780 – CEP 18610-034, Altos do Paraíso, Botucatu, SP, Brazil, E-mail:alba.maria@unesp.br; joao.saad@unesp.br; rodrigo.roman@unesp.br
**Article originating from Alba Maria Guadalupe Orellana Gonzalez's PhD thesis: “Assessment of impacts of climate change on agriculture and water resources in the Alto Paranapanema basin, São Paulo: a systems dynamics approach”. UNESP,2022.*

1 RESUMO

O setor agrícola é impactado diretamente pelas condições climáticas. Projeções de modelos de mudanças climáticas globais (MCG) indicam que o Brasil terá incrementos de temperatura e variações nas precipitações. Nesse cenário de alterações climáticas, torna-se cada vez mais necessária a compreensão do impacto que tais modificações terão sobre os recursos hídricos e a agricultura. Diante do exposto esta pesquisa teve como objetivo identificar os prováveis impactos na agricultura irrigada e nos recursos hídricos sob a perspectiva de diferentes cenários de mudança do clima na Bacia Hidrográfica do Alto Paranapanema (BH do ALPA), SP, avaliando suas prováveis repercussões. O modelo formulado permitiu avaliar os impactos causados por mudanças climáticas, manifestadas em alterações na pluviosidade, sobre a agricultura irrigada e os recursos hídricos da BH do ALPA. A avaliação foi feita usando os Índices de Falkenmark, Keller e de Sustentabilidade. Quando analisado o cenário *Bussiness as Usual* (BaU), os resultados indicam que o sistema de recursos hídricos da bacia, conserva ao longo do período de simulação (2016-2070), a sustentabilidade hídrica do sistema.

Palavras-chave: balanço hídrico, pensamento sistêmico, STELLA

ORELLANA-GONZALEZ, AMG; SAAD, JCC; SÁNCHEZ-ROMÁN, RM
WATER RESOURCE SUSTAINABILITY IN THE UPPER PARANAPANEMA-SP BASIN: A SYSTEMS DYNAMICS APPROACH

2 ABSTRACT

The agricultural sector is directly impacted by climate conditions. Global climate change (GCC) model projections indicate that Brazil will experience increases in temperature and variations in precipitation. In this climate change scenario, it is becoming increasingly necessary to understand the impacts that these changes will have on water resources and agriculture. Therefore, the aim of this research was to identify the probable impacts on irrigated agriculture and water resources from the perspective of different climate change scenarios in the Upper Paranapanema River Basin (BH of the ALPA), SP, by assessing their probable repercussions. The model made it possible to assess the impacts caused by climate change, manifested in

Recebido em 20/09/2022 e aprovado para publicação em 09/10/2023
DOI: http://dx.doi.org/10.15809/irriga.2023v28n4p602-613

changes in rainfall, on irrigated agriculture and water resources in the BH of the ALPA. The evaluation was carried out via the Falkenmark, Keller, and sustainability indices. When the business-as-usual (BaU) scenario is analyzed, the results indicate that the basin's water resource system maintains water sustainability throughout the simulation period (2016--2070).

Keywords: water balance, systems thinking, STELLA.

3 INTRODUCTION

Climate variations caused by the warming of the Earth are causing socioeconomic and environmental problems that are highly relevant to the planet in general. The assessment reports of the Intergovernmental Panel on Climate Change (IPCC) (2007, 2014, 2021) and many scientific studies suggest that the Earth's climate is changing and that this change has been caused by human activities. Research and assessments of climate change have experienced a series of advances that have allowed the generation of increasingly accurate climate models.

According to several IPCC studies, specifically those released in 2014 and 2021, variations in the Earth's temperature can range between 1.1°C and 6.4°C, with an average of 4°C by the end of the 21st century. In addition to the increase in air temperature, changes in the rainfall regime are expected, both spatially and temporally.

In Brazil, the agricultural sector and the water resources sector have attracted great attention because they are the most impacted by climate change. In the approach to climate aspects carried out by Cox *et al*. (2008), Marengo *et al* . (2008a, 2008b) and Marengo (2014), Brazil's vulnerability to climate variability is well known.

The scarcity of water resources, in quantity and quality, is already a reality in some regions of the country. In the state of São Paulo and throughout the Southeast Region, the most recent water shortages in 2013 and 2014 (Assad, 2015) had negative consequences for water supply services, energy generation in hydroelectric plants and agriculture.

The Brazilian agricultural sector is very diverse and plays a leading role in the economy. According to data from 2021 (Brazil, 2021), the sector contributes approximately 27% of the gross domestic product and generates approximately 35% of jobs. There are approximately 5 million rural properties where food and fiber are produced. Many of these products have been exported, and Brazil has occupied fourth place in the world as an exporter of agricultural products since 2008, characterizing the country as an important food provider worldwide (FAO, 2021).

The agricultural sector is directly impacted by weather conditions. Approximately 80% of fluctuations in sector productivity are due to variations in meteorological factors such as temperature, solar radiation, rain, air humidity, wind speed and water availability in the soil, and the other 20% of changes in productivity depend on social, economic, political and infrastructure factors (Brazil, 2016).

The IPCC (2021) projections formulated in different scenarios indicate that Brazil will experience increases in temperature and variations in precipitation.

In this climate change scenario, it becomes increasingly necessary to understand the impact that such changes will have on the agricultural sector and water resources.

The demand for research involving the impacts of climate change on the productivity of agricultural crops and water resources at the regional level is growing. Such research is necessary to support decision-making by the different affected actors and to formulate public policies that aim to reduce the adverse economic and environmental impacts caused by climate change.

This research aimed to identify the likely impacts on irrigated agriculture and water resources from the perspective of different climate change scenarios in the Alto Paranapanema Hydrographic Basin (BH of ALPA) SP, evaluating their likely repercussions.

4 MATERIALS AND METHODS

4.1 Location of the study area

This study was based on the Upper Paranapanema Hydrographic Basin, defined as the Water Resources Management Unit – UGRHI 14 (Figure 1), which is located in the Southwest Region of the state of São Paulo, between coordinates 23°00' and 24° 23' S and 49°42' and 47°22' W. To the north, it is limited by UGRHI 17 - Médio Paranapanema; to the south, it is limited by UGRHI 11 - Vale do Ribeira/Litoral Sul; to the east, it is limited by UGRHI 10 - Sorocaba/Médio Tietê; and to the west, it is limited to the northeast region of the state of Paraná (CBH-ALPA, 2020).

Figure 1. Location map of the Water Resources Management Unit (UGRHI) 14, Alto Paranapanema Hydrographic Basin, SP.

Source: Fundação Paulista Technological Center (2015).

4.2 Data analysis

With the help of the STELLA 10.1.2 *software for Windows*, a systems dynamics simulation model was developed to evaluate the impacts of climate change, manifested in changes in rainfall, on irrigated agriculture and water resources in BH of ALPA, SP. The model presented specific submodels, called the atmospheric level, surface level and underground level.

The scenarios developed were the business-as-usual (BaU) scenario BaU.1, in which precipitation was equivalent to 1,200 mm year^{-1}, and the BaU.2 scenario, in which annual precipitation data were present in the historical series of the period from 1947--2021. Notably, the other parameters of the model remained invariable between the scenarios. Using the model developed in the STELLA *software*, the scenarios were simulated for a period of 55 years, from 2016--2070.

Falkenmark, Keller and sustainability indices were applied.

The Falkenmark index defines the annual relationship between the total available water and the number of inhabitants in the basin (Falkenmark, 1989; Falkenmark *et al*., 2007). According to this index, a basin has an adequate supply of water if it is greater than 10,000 m^3 $inhabitant^{-1}$ $year^{-1}$. The basin suffers moderate problems if the index oscillates between 1,600 and 10,000 m3 $inhabitant^{-1}$ $year^{-1}$. Water stress occurs when the index varies between 1,000 and 1,600 m3 $inhabitant^{-1}$ $year^{-1}$. A basin is considered to have chronic water scarcity when the volume of water available is between 500 and 1,000 m3 ^{per} year. Values lower than 500 m^3 $inhabitant^{-1}$ $year^{-1}$ indicate that the basin exceeds the limit of water resource management capacity (Falkenmark *et al*., 2007).

The Keller index, proposed by Keller, Keller and Davids (1998), was applied to evaluate the development of the ALPA BH over time since this index depends on the relationship between the annual consumption by various demanders and the volume of annually available water. It classifies a river basin into different stages of development, which are as follows:

Exploration:
- Stage I: water use less than 40%
- Stage II: use of 40 to 60% of available water

Conservation:
- Stage III: water use from 60--80%
- Stage IV: use of 80--90% of available water
  Enlargement:
- Stage V: 90--95% water usage
- Stage VI: use more than 95% of available water

Closed System:

When there is no usable water, leaving the system beyond what is necessary to meet the minimum required flow and outflow requirements.

The sustainability index (SI) was proposed by Xu *et al*. (2002), was used to evaluate the sustainability of the use of water resources in the ALPA Basin. The IS is defined as the relationship between a possible water deficit and the corresponding supply in the same region (Equation 1).

$$IS = \begin{cases} (S-D)/S & S \rangle D \\ 0 & S \leq D \end{cases} \quad (1)$$

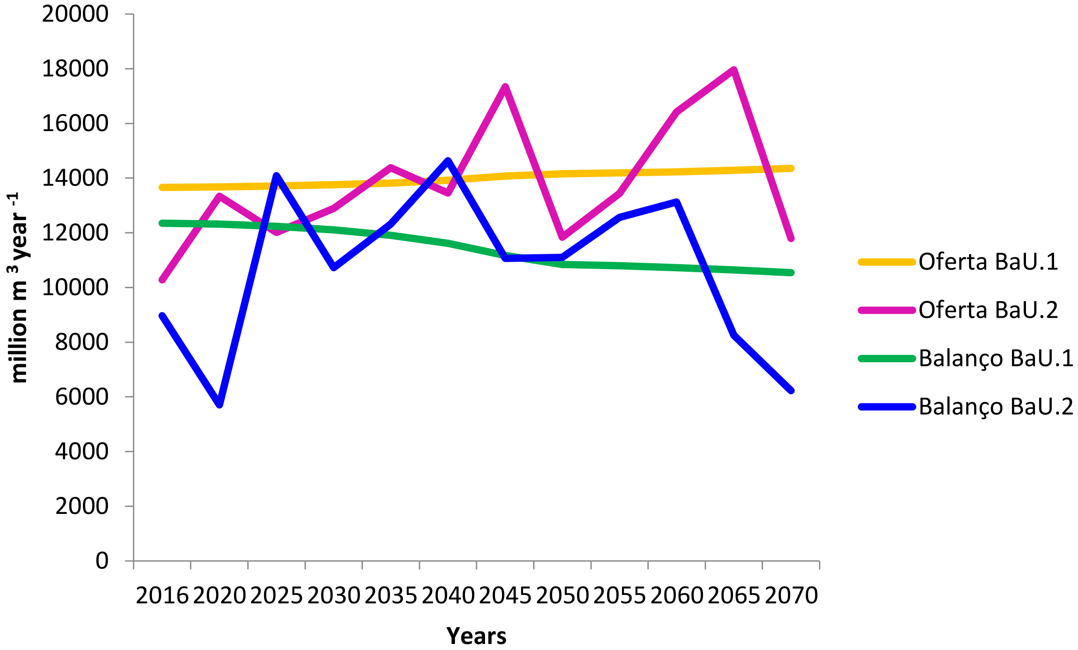
where D is the demand for water and S is the available supply of water.

If the IS value is greater than 0.2, this indicates low or no stress on the water supply, which means that the demand for water is less than or equal to 80% of the potential supply of this resource. IS values equal to or less than 0.2 reflect vulnerable conditions, which indicates that the water demand is greater than 80% of the potential water supply. An IS equal to 0 indicates that the water supply is unsustainable; that is, the demand for water is greater than the overall availability of water resources at the location.

5 RESULTS AND DISCUSSION

Figure 2 shows that, in the simulated period from 2016--2070, in the BaU.1 scenario, whose average annual precipitation was equal to 1,200 mm, the total water demand in ALPA BH in 2016 represented 10% of the available supply. In 2070, the final period of the simulation, this demand reached 27% of the available supply, which is equivalent to almost tripling its value over the simulation time.

Figure 2. Water supply and balance, in million m ^{3} year $^{-1}$, of the Alto Paranapanema Hydrographic Basin, SP, in the BaU.1 and BaU.2 scenarios



Legend: Offer BaU.1=water supply scenario BaU.1, Supply BaU.2= water supply scenario BaU.2, Balance BaU.1= water balance scenario BaU.1, Balance BaU.2= water balance scenario BaU. two.

The BaU.2 scenario, which uses precipitation from the 1947--2021 series, presented fluctuations in available supply due to variations in precipitation. In this scenario, total water demand in 2016 represented 13% of the available supply, whereas in 2070, the final period of the simulation, it reached 33% of the available supply, which is equivalent, as in the previous scenario, to almost tripling its value in the period simulated (Figure 2).

Table 1 presents a summary of the indices used to assess the sustainability of water resources in ALPA's BH in BaU.1, a scenario with an average rainfall of 1,200 mm, and in BaU.2, a scenario with rainfall from the 1947--2021 series.

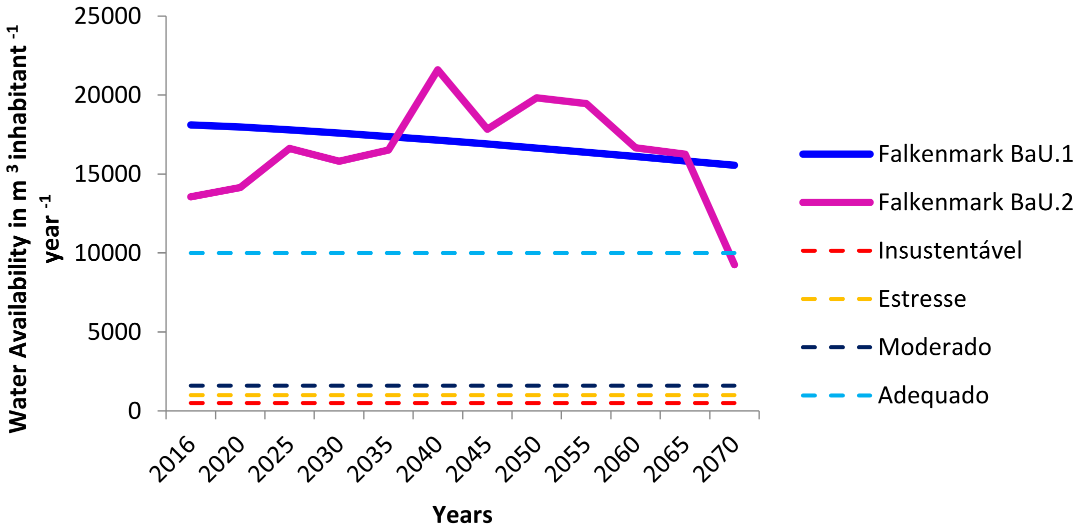
Table 1. Assessment indices for the sustainability of water resources in the Alto Paranapanema Hydrographic Basin, SP, in the BaU.1 and BaU.2 scenarios

	Falkenmark (m^3 inhab $^{-1}$ year $^{-1}$)		Keller (%)		IS*	
Years	**BaU.1**	**BaU.2**	**BaU.1**	**BaU.2**	**BaU.1**	**BaU.2**
2016	18,111	13,569	10	13	0.90	0.87
2020	17,978	14,143	10	13	0.90	0.43
2025	17,794	16,622	11	12	0.89	1.17
2030	17,592	15,804	12	14	0.88	0.83
2035	17,375	16,521	15	15	0.86	0.86
2040	17,145	21,602	18	14	0.83	1.09
2045	16,902	17,831	22	21	0.79	0.64
2050	16,648	19,825	25	21	0.77	0.94
2055	16,386	19,472	25	21	0.76	0.93
2060	16,116	16,666	26	25	0.75	0.80
2065	15,840	16,249	27	26	0.75	0.46
2070	15,559	9,257	28	48	0.73	0.53

Caption: IS= sustainability index**;** * dimensionless

Figure 3 shows that the value of the Falkenmark Index in ALPA's BiH in the BaU.1 scenario was 18,111 m3 inhabitant $^{-1}$ year $^{-1}$ in 2016. In 2050, it fell to 16,648 m3 inhabitant $^{-1}$ year $^{-1}$, reaching a value of 15,559 m3 within $^{-1}$ year $^{-1}$ in 2070, the end of the simulation period. With respect to this scenario, it can be concluded that the situation of water availability in m ^{3} inhabiting $^{-1}$ year $^{-1}$ is quite comfortable since, according to this indicator, a basin has an adequate supply of water if its index is greater than 10,000 m ^{3} inhabitants $^{-1}$ year $^{-1}$.

Figure 3. Falkenmark Index in the Upper Paranapanema Hydrographic Basin, SP, in the BaU.1 and BaU.2 scenarios

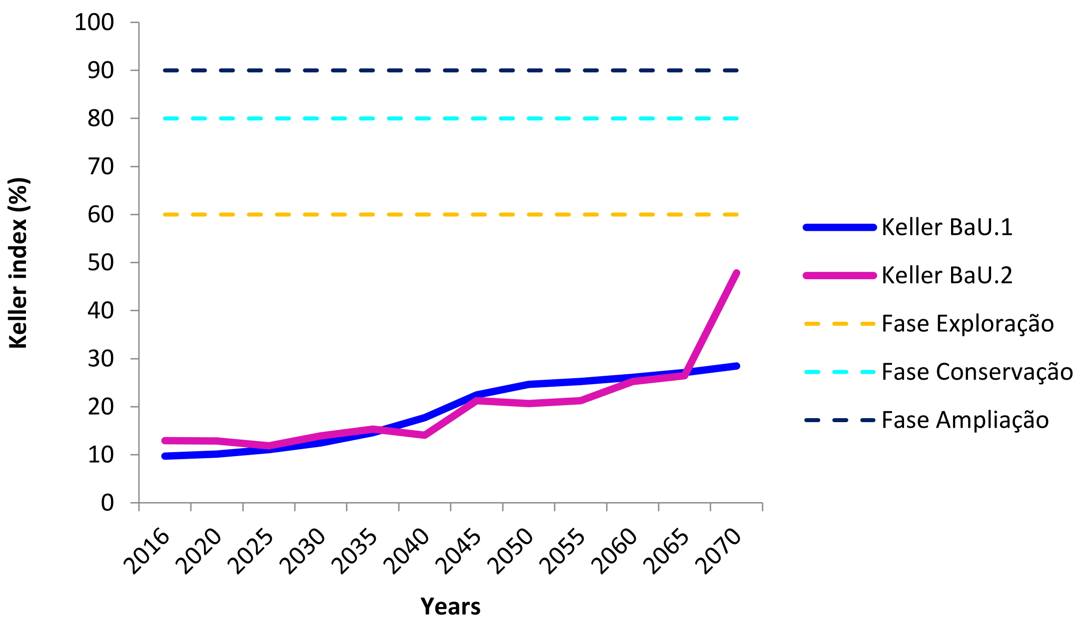


Legend: Falkenmark BaU.1=Scenario Falkenmark Index BaU.1, Falkenmark BaU.2=Scenario Falkenmark Index BaU.2; Unsustainable= less than 500 m ^{3} inhabitant $^{-1}$ year $^{-1}$; Stress= in the range of 500 to 1,600 m ^{3} inhabitant $^{-1}$ year $^{-1}$; Moderate= in the range of 1,600 to 10,000 m ^{3} inhabitant $^{-1}$ year $^{-1}$; Adequate= greater than 10,000 m ^{3} inhabitant $^{-1}$ year $^{-1}$.

The Falkenmark index showed fluctuations depending on precipitation, starting from 13,569 m ^{3} inhabitant $^{-1}$ year $^{-1}$ in 2016, passing through 19,825 m ^{3} inhabitant $^{-1}$ year $^{-1}$ in 2050 and reaching 9,257 m ^{3} inhabitants $^{-1}$ year $^{-1}$ in 2070. In this scenario, in the period from 2016--2065, the same is observed as in the BaU.1 scenario. Despite fluctuations in precipitation and the decrease in water availability in m ^{3} inhabitants $^{-1}$ year $^{-1}$, the system allows water to be supplied in an adequate quantity with respect to the population of the basin, since availability is above 1 0,000 m ^{3} inhabitants $^{-1}$ year $^{-1}$. However, this situation changed from 2070 onward, as the basin began to present moderate water problems, with the index showing a value lower than 10,000 m3 inhabitant $^{-1}$ year $^{-1}$ (9,257 m3 inhabitant $^{-1}$ year $^{-1}$) (Figure 3).

Figure 4 shows the Keller index for the ALPA BH in the BaU.1 and BaU.2 scenarios. This index allows analysis of the development of the basin. According to Keller, Keller and Davids (1998), the development of a basin depends on the relationship between the annual consumption by various demanders and the annual volume of water available.

Figure 4. Keller Index in the Upper Paranapanema Hydrographic Basin, SP, in the BaU.1 and BaU.2 scenarios



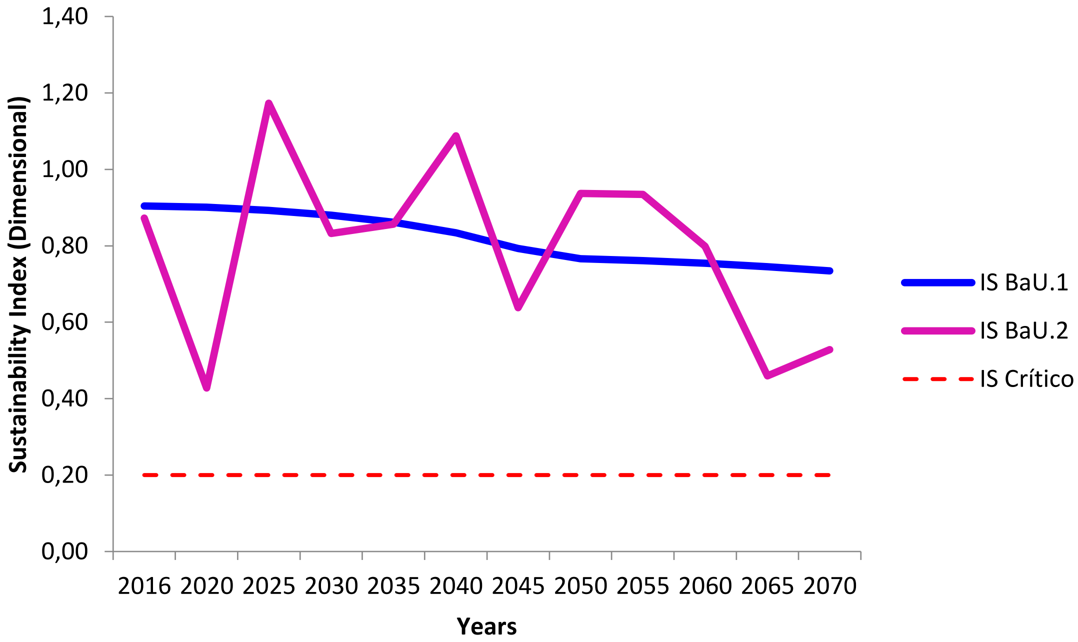
Legend: Keller BaU.1= Keller index scenario BaU.1; Keller BaU.2= Keller index scenario BaU.2; Exploration phase= the basin uses up to 60% of the water (stage I: the basin uses less than 40% of the water; stage II: the basin uses 40--60% of the water); Conservation phase= the basin uses 60--80% of the water; Enlargement phase= the basin uses more than 90% of the water.

According to the Keller index, the ALPA BH is, in 2016, in both scenarios, in stage I of the exploration phase, which means that the basin's water resource system is largely open (Figure 4). At this stage, the main means of satisfying the growing demand are simply to divert more supply and pump water from shallow groundwater aquifers, and there is no need to implement measures to reduce demand. This condition remains until the end of the BaU.1 scenario simulation period. However, in the BaU.2

scenario, in 2070, the ALPA BH passed from stage I to stage II of the exploration phase. At this stage, it is necessary to build water storage systems, expand the distribution system and pump from deep aquifers. Such measures are essential when the sum of the net flow withdrawn and the minimum instantaneous flow requirements in surface water bodies begin to exceed the available flow.

Figure 5 shows the sustainability index, proposed by Xu *et al.* (2002), for scenarios BaU.1 and BaU.2. This figure shows that, in 2016, the IS in the BaU.1 scenario was 0.90 and that it will reach 0.77 in 2050 and 0.73 in 2070. The BaU.2 scenario presents fluctuations that are dependent on changes in the supply of available water caused by variations in precipitation. The lowest IS values occurred in 2020 and 2065, with values of 0.43 and 0.46, respectively, and the highest values occurred in 2025, with values of 1.17, and in 2040, with values of 1.09.

Figure 5. Sustainability Index (SI) in the Alto Paranapanema Hydrographic Basin, SP, in the BaU.1 and BaU.2 scenarios



Caption: IS BaU.1=Sustainability Index scenario BaU.1; IS BaU.2= Sustainability Index scenario BaU.2; Critical IS= index equal to or less than 0.2 equivalent to water stress and vulnerability in the use of water resources.

In the SI calculation process, reused water was considered part of the water supply available in the ALPA BH. When the IS value is greater than 0.2, it indicates that there is low or no stress on the water supply, but when the IS value is less than 0.2, it reflects the vulnerability of water resources. Values equal to zero indicate that the supply is unsustainable. In both scenarios, the IS value is greater than 0.2, indicating that there is low or no stress on the water supply available in the local ALPA BH (Figure 5).

Xu *et al.* (2002), using the STELLA software, simulated the sustainability index for a subregion of the Yellow River Basin in China. In the BaU scenario, the authors found IS values equal to 0.67, 0.64 and 0.63 for the years 2010, 2020 and 2030, respectively, showing that, as well as for the ALPA BH (Figure 5), the basin studied did not present a situation of water stress.

Orellana González *et al.* (2008), in a study in the municipality of São Miguel do Anta (MG), evaluated the sustainability of water resources in the municipality on the basis of the sustainability index and reported that in the simulation period from 2003--2035, the SI approached 0.5, indicating that the municipality uses 50% of the available water. This finding indicates that, as with ALPA BH (Figure 5), the municipality studied did not present a situation of water stress.

Unlike what was found in the present study (Figure 5), Sánchez-Román, Folegatti and Orellana-González (2010) reported that for the Piracicaba, Capivari and Jundiaí River Basins in the BaU scenario, the IS was 0.2 in 2054, which indicates a situation of water stress in the evaluated basin. Likewise, Souza *et al*. (2010), when analyzing the hydrological behavior of the Entre Ribeiros stream basin, they reported that in the BaU scenario, the IS will reach a value of 0.2 in 2040, indicating that the basin will face water stress.

Ribeiro *et al*. (2022), considering the BaU scenario in the Palma River basin, Tocantins, evaluated, on the basis of the sustainability index, the water situation in the basin until the end of the 21st century. The results indicate that throughout the simulation period, it is possible to observe a reduction in water supply and increases in demand. Despite this, at the end of the simulation period, the IS was 0.88, indicating the sustainable use of the basin's water resources. This finding also corroborates the results of the present work, since it was verified through the IS that ALPA BH did not present in the simulated period, in both scenarios, situations of water stress or vulnerability (Figure 5), even with fluctuations in supply (Figure 2) and in agricultural, industrial, population and livestock demands (Table 2, Figure 6).

Table 2. Demand by user sector in millions of m ^{3} year $^{-1}$, in the Alto Paranapanema Hydrographic Basin, SP, in scenarios BaU.1 and BaU.2

Years	Agricultural	Environmental	Industry	Livestock	Populational	Total Demand
2016	149	804	58	102	196	1,309
2020	193	804	63	107	198	1,366
2025	297	804	74	118	202	1,494
2030	457	804	85	131	206	1,683
2035	703	804	99	150	210	1965
2040	1081	804	115	174	214	2,388
2045	1663	804	133	207	219	3,026
2050	1887	804	154	250	223	3,319
2055	1887	804	178	308	228	3,406
2060	1887	804	207	385	233	3,516
2065	1887	804	240	488	238	3,658
2070	1887	804	278	626	244	3,839

Figure 6. Demand by user sector in millions of m ^{3} year $^{-1}$, in the Alto Paranapanema Hydrographic Basin, SP, in scenarios BaU.1 and BaU.2

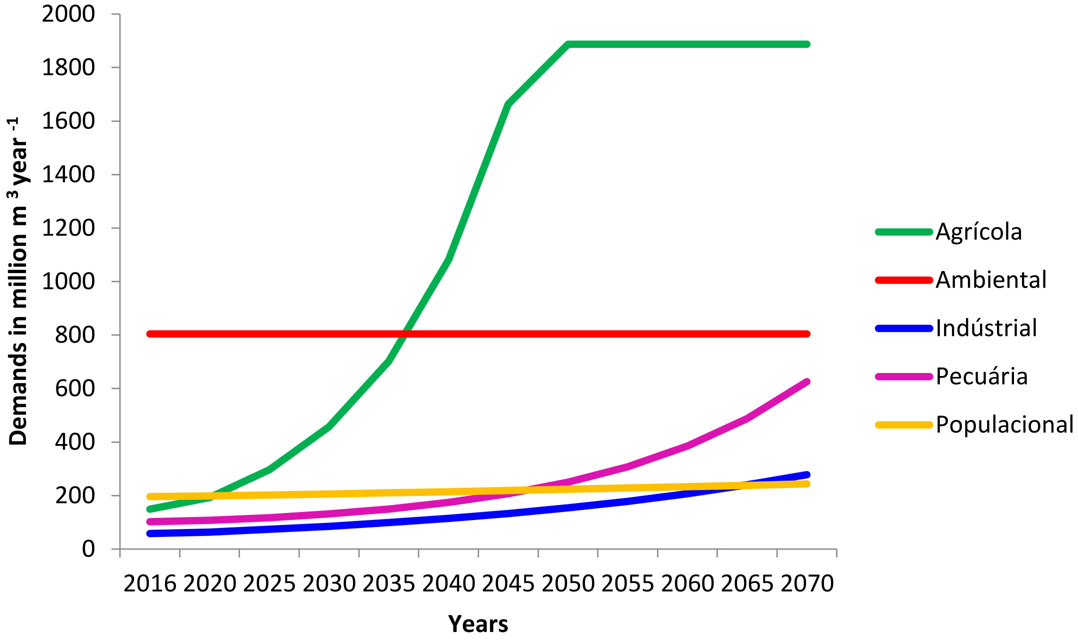


Table 2 shows that the environmental demand remains at 804 million m ^{3} year $^{-1}$, which is constant throughout the simulation period. The demand from the agricultural and livestock sector represented 19% of the total demand in 2016 and 64% in 2050, reaching 65% of the total demand in 2070. The demand from the industrial sector increased from 4% of total demand in 2016 to 7% in 2070, whereas the population demand decreased from 15% of total demand in 2016 to 6% in 2070 due to the low population growth rate in ALPA's BiH.

60% of the available water, and is considered an open basin, with no need to implement demand reduction policies; however, planning for the use of water resources is recommended. According to the sustainability index, the basin's water resource system does not present situations of stress or vulnerability, as the available water supply can meet the demand of different users (the demand is less than 80% of the available supply in the basin), maintaining the sustainability of water resources in the ALPA BH.

6 CONCLUSIONS

The results of this work allow us to conclude the following:

In the scenarios considered, the three indices evaluated indicate that there is an adequate supply of water in the ALPA's BiH to satisfy the population's demand (Falkenmark index). With respect to water use, the Keller index shows that within the development phase, the ALPA basin is in the exploration phase, stages I and II, uses up to

7 ACKNOWLEDGMENTS

The authors would like to thank the National Council for Scientific and Technological Development (CNPq) for granting a scholarship.

8 REFERENCES

ASSAD, E. Eduardo Assad says it is impossible to say when the drought will end [Interview given to] Alexandre Mansur.

Blog do Planeta , 2015. Available in: http://epoca.globo.com/colunas-e-blogs/blog-do-planeta/noticia/2015/02/beduardo-assadb-e-impossivel-dizer- Quando-seca-acabara.html. Accessed on: 20 April. 2022 **.**

BRAZIL. Ministry of Development, Industry and Foreign Trade. **AGROSTAT** - Brazilian Agribusiness Foreign Trade Statistics. Brasilia , DF, 2021. Available at: https://sistemasweb.agricultura.gov.br/pages/AGROSTAT.html. Accessed on: 13 April. 2022.

BRAZIL. Ministry of the Environment. **National Climate Change Adaptation Plan** . Brasília, DF: Ministry of the Environment, 2016.

TECHNOLOGICAL CENTER OF FUNDAÇÃO PAULISTA. **Upper Paranapanema river basin plan 2012/2015** . Lins: CEPTEC, 2015. Available at: http://www.sigrh.sp.gov.br/public/uploads/documents/8776/planodebaciacbhalpa.pdf. Accessed on: 5 Oct. 2022.

CBH-ALPA. **UGRHI-14 Water Resources Situation Report** – Alto Paranapanema – 2020 – Base Year 2019. Piraju: CBH_ALPA, 2020. Available at http://www.sigrh.sp.gov.br/public/uploads/documents//CBHALPA/12213/relatorio-de-situacao-2017_v_final.pdf. Accessed on: 22 Jan. 2022.

COX, PM; HARRIS, PP; HUNTINGFORD, C.; BETTS, RA; COLLINS, M.; JONES, CD; JUPP, TE; MARENGO, JA; NOBRE, CA Increasing risk of Amazonian drought due to decreasing aerosol pollution. **Nature** , United Kingdom, vol. 453, no. 7192, p. 212-215, May 2008.

FALKENMARK, M.; BERNTELL, A.; JÄGERSKOG, A.; LUNDQVIST, J.; MATZ, M., TROPP, H. **On the Verge of a New Scarcity** : A Call for Good Governance and Human Ingenuity . Sundbyberg : Stockholm International Water Institute, 2007.

FALKENMARK, M. The Massive Water Scarcity now threatening Africa - Why is n't it being addressed? **Ambio** , Stockholm , v. 18, no. 2, p. 112-118, 1989.

FAO. **The State of Food and Agriculture** : Making agrifood systems more resilient to shocks and stresses. Rome: Food and Agriculture Organization of the United Nations, 2021.

IPCC. **Climate Change 2007** : The Physical Science Basis . Cambridge: Cambridge University Press, 2007. Available at: https://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4_wg2_full_report.pdf. Accessed on: 23 April. 2022.

IPCC. **Climate Change 2014** : Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva: IPCC, 2014. 151 p. Available at: http://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full.pdf. Accessed on: 23 April. 2022.

IPCC. Summary for Policymakers. In: **Climate Change 2021** : The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. *In Press* . Available at: https://www.ipcc.ch/report/sixth-assessment-report-cycle/. Accessed on: 10 April. 2022.

KELLER, J.; KELLER, A.; DAVIDS, G. River basin development phases and implications of closure. **Journal of Applied Irrigation Science** , Germany, v. 33, no. 2, p. 145-163, 1998.

MARENGO, JA; NOBRE, CA; TOMASELLA, J.; OYAMA, MD; OLIVEIRA, GS de; OLIVEIRA, R.; CAMARGO, H.; ALVES, LM; BROWN, IF The Drought of Amazonia in 2005. **Journal of Climate** , Boston, v. 21, no. 3, p. 495-516, 2008a.

MARENGO, JA; NOBRE, CA; TOMASELLA, J.; CARDOSO, MF; OYAMA, MD Hydroclimatic and ecological behavior of the drought of Amazonia in 2005. **Philosophical Transactions of The Royal Society B** : Biological Sciences, London, v. 363, no. 1498, p. 1773-1778, 2008b.

MARENGO, JA The future climate of Brazil. **USP Magazine** , São Paulo, SP, v. 103, p. 25-32, 2014.

ORELLANA GONZÁLEZ, AMG ; SILVA-JUNIOR, AG; SÁNCHEZ-ROMÁN, RM; SILVA, E.; BRAGA, JL Water resources sustainability at São Miguel do Anta County, Minas Gerais, Brazil : a system dynamics approach. **Brazilian Journal of Biosystems Engineering** , Tupã, v. 2, no. 3, p. 231-241, 15 Dec. 2008.

RIBEIRO, CLC; DIOTTO, AV; THEBALDI, MS; RODRIGUES, JAM; VIOLA, MR Simulations of the climate change and its effect on water resources in the Palma River basin, Brazil. **Water Supply** , London, vol. 22, no. 5, p. 5494-5508, 2022.

SÁNCHEZ-ROMÁN, RM; FOLEGATTI, MV; ORELLANA-GONZÁLEZ, AMG Water resources assessment at Piracicaba, Capivari and Jundiaí River Basins: a dynamic systems approach. **Water Resources Management** , New York, vol. 24, p. 761-773, 2010.

SOUZA, MN; MANTOVANI, EC; ORELLANA GONZALEZ, AMG; SÁNCHEZ-ROMÁN, RM; SILVA, MAAS System dynamics and modeling using the STELLA program of water resources in the Rio Preto basin, a tributary of the Paracatu River. **Ibero-American Journal of Environmental Sciences** , Aquidabã, Sergipe , v. 1, no. 1, p. 16-42, 2010.

XU, ZX; TAKEUCHI, K.; ISHIDARA, H.; ZHANG, XW Sustainability Analysis for Yellow River Water Resources Using the System Dynamics Approach. **Water Resources Management** , New York, vol. 16, n.3, p. 239-261, 2002.