Treated wastewater application in agriculture: potential assessment in the State of Santa Catarina/Brazil

Aplicação de esgoto tratado na agricultura: avaliação de potencial no Estado de Santa Catarina/Brasil

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ABSTRACT

This study aimed to evaluate the potential of using treated wastewater in the irrigation of 7 crops produced in the State of Santa Catarina by assessing the current demand for irrigation water in the study area and the future production of treated wastewater. Food production data were collected from the most significant public agricultural institution in the study area to calculate their blue water footprint, given the amount of food harvested. Future wastewater production data were gathered from official reports which present the sanitation plans to be performed by 2035. Geographic Information System tools and risk assessment approaches were used to present and discuss results from quantitative and qualitative perspectives. Results show that the amount of wastewater to be produced in 2035 could not only supply the current irrigation water demand for the selected crops but also allow agriculture to expand without consuming more potable water.

Keywords: Ecological Sanitation. Irrigation. Reuse. Crops. Circular Economy.

RESUMO

Este trabalho teve como objetivo avaliar o potencial de utilização de esgoto tratado na irrigação de sete culturas produzidas no estado de Santa Catarina, avaliando a demanda atual de água para irrigação na área de estudo e a produção futura de esgoto tratado. Os dados de produção de alimentos foram coletados por intermédio da instituição agrícola pública mais importante presente na área de estudo para calcular sua pegada hídrica azul, dada a quantidade de alimentos colhidos. Os dados de produção futura de esgoto tratado foram recolhidos a partir de relatórios oficiais que apresentam os planos de saneamento a serem executados até 2035. Ferramentas de sistema de informação *geográfica e princípios de avaliação de risco foram utilizados para apresentar e discutir resultados de perspectivas quantitativas e qualitativas. Os resultados mostram que a quantidade de esgoto tratado a ser produzida em 2035 poderia não apenas suprir a demanda atual de água para irrigação das culturas selecionadas, mas também permitir a expansão da agricultura sem consumir mais água potável.*

Palavras-chave: Saneamento Ecológico. Irrigação. Reúso. Culturas Agrícolas. Economia Circular.

1 INTRODUCTION

It is estimated that the global population will achieve 9.6 billion people in 2050, requiring a 70% increase in food production (HECKENMÜLLER; NARITA; KLEPPER, 2014). Agriculture accounts for 85% of the global blue water consumption, representing the volume of underground or superficial water used to complement precipitation to grow crops (MEKONNEN; HOEKSTRA, 2011). Another side effect of population growth is more wastewater to be dealt with appropriately. According to WHO and Unicef (2017), 39% of the global population did not have access to ideal sanitation facilities, and the excreta from 4,5 billion people was disposed into the environment without any treatment in 2015. Moreover, 870 thousand deaths related to the lack of sanitation and hygiene occurred worldwide in 2016 (WHO, 2018).

The ecological sanitation and circular economy approach bring potential solutions to these issues. Whereas sanitation by-products, such as treated wastewater, are considered waste or contaminants in the traditional sanitation mindset, they are resources in the view of ecological sanitation, presenting opportunities to be applied in different contexts (WIELEMAKER *et al*., 2018). Several authors recommend the benefits of sanitation by-products reuse, such as Courault *et al*. (2017), Jössom *et al*. (1997), Magri *et al*. (2013), and Moazeni *et al*. (2017).

Nonetheless, despite having several benefits, the reuse of sanitation products raises concerns regarding the presence of pathogens and their potential negative impacts on human health (COURAULT *et al*., 2017; MOAZENI *et al*., 2017). However, these risks should not be seen as impediments to recycling sanitation by-products but as important key points to be studied and managed to achieve the benefits of ecological sanitation and preserve human and environmental health simultaneously (OWAMAH, 2014).

In Brazil, agriculture employs 15 million people and covers 351 million ha. In addition, research indicates a 48% increase in agricultural irrigation demand and a 5% increase in the agricultural area compared to 2006 (IBGE, 2017). Besides that, sanitation coverage in Brazil varies considerably throughout its territory. Considering all 26 states in Brazil, 3 have over 70% of wastewater collection by sewers, 8 are between 40-70%, and the other 15 are under 40%. Moreover, Brazil (2019) shows that, among the 4.050 cities studied, 996 presented less than 20% and 574 more than 80% of their wastewater treated.

Although Brazil has yet to update legal instruments with minimal quality standards guiding the application of sanitation by-products in the soil, recent Brazilian legislation meets the importance of this practice. The Ministry of Science, Technology, Innovation, and Communication of the Brazilian government, in the document MCTIC No 1.122 of March 19th, 2020, which sets the priority areas of research in science, technology, innovation, and communication, prioritised the development of innovation regarding sanitation, life quality, treatment of pollution, environmental preservation, health, sanitation, water safety, among others. Moreover, Brazilian law No 14.026 of July 15th, 2020, which refers to the new Brazilian basic sanitation legal framework, brings the word reuse repetitively as long as it meets environmental restrictions and public health concerns (BRASIL, 2020).

Given that, mapping the agricultural water demand and the possible supply of treated wastewater makes it possible to identify locations with greater potential of reusing sanitation by-products, allowing for a more assertive study of the risk involved and recommending good hygiene and prevention practices, as carried out by Barbagallo *et al*. (2012), Mara *et al*. (2007), and OMS (2006). Furthermore, potential and quality assessment studies provide a starting point for logistics and economic evaluation to implement specific solutions to high-potential areas and foment the creation of legislation to guide reuse practices. Therefore, the study of the application of treated wastewater in agricultural irrigation covers not only food production and water saving but an alternative to the disposal of this sanitation by-product, meeting the multi-barrier approach proposed by the World Health Organization (WHO). The study herein presented aims to evaluate the potential of treated wastewater use in agricultural irrigation in the State of Santa Catarina, located in southern Brazil, by assessing the current demand for irrigation water in the study area and the future production of treated wastewater. Food production data were collected from the most significant public agricultural institution in the study area. They covered historical series from 2016 to 2020 to calculate their blue water footprint, given the amount of food harvested from selected crops. Wastewater production data were gathered from official reports, which present the sanitation plan to be performed by 2035, the number of wastewater treatment plants (WWTP), served population, flow rate, type of treatment, and load discharged. Geographic Information System (GIS) tools and risk assessment approaches were used to present and discuss results in quantitative and qualitative perspectives, providing data that allow future studies to assess specific areas in further detail, fomenting ecological sanitation and assisting decision-makers.

The study herein presented aims to evaluate the potential of treated wastewater use in agricultural irrigation in the State of Santa Catarina, located in southern Brazil, by assessing the current demand for irrigation water in the study area and the future production of treated wastewater. Food production data were collected from the most significant public agricultural institution in the study area. They covered historical series from 2016 to 2020 to calculate their blue water footprint, given the amount of food harvested from selected crops. Wastewater production data were gathered from official reports, which present the sanitation plan to be performed by 2035, the number of wastewater treatment plants (WWTP), served population, flow rate, type of treatment, and load discharged. Geographic Information System (GIS) tools and risk assessment approaches were used to present and discuss results in quantitative and qualitative perspectives, providing data that allow future studies to assess specific areas in further detail, fomenting ecological sanitation and assisting decision-makers.

2 METHODS

2.1 STUDY AREA

The State of Santa Catarina is located in southern Brazil and has an area of 95.736 km² and a current population of over 7 million people. Agriculture activity is present throughout most of its territory, and despite not having an arid or semi-arid climate, the study area has experienced periods of drought, which generated negative impacts on food and energy production, in addition to bringing attention to reducing water consumption to provide security and stability to its water supply.

The study area has 16.214 agricultural establishments totalising 167.243 ha of irrigated area (IBGE, 2017) and under 40% of wastewater collection through sanitary sewers (BRASIL, 2019), indicating that most of the wastewater produced is either treated in loco or discharged without any quality control. However, Santa Catarina had the 6th biggest investment in sanitation between 2016 and 2018 among all the Brazilian States and intends to increase its number of WWTP by 2035 (ANA, 2013).

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2.2 ASSESSMENT AND DATA COLLECTION

2.2.1 AGRICULTURAL IRRIGATION WATER DEMAND

At first, 23 crops were pre-selected. Data from the Agricultural Research and Rural Extension Company of Santa Catarina (Epagri) were collected regarding the production of vegetal crops and their respective harvests performed between 2016 and 2020 in different municipalities.

Given the lack of local irrigation requirements databases, data collection considered the report entitled The Green, Blue and Grey Water Footprint of Crops and Derived Crop Products (MEKONNEN; HOEKSTRA, 2010), produced by the Institute for Water Education of Unesco, which provides information about water footprints of different crops in distinct locations, including the study area. Moreover, Mekonnen and Hoekstra (2010) provide details regarding blue water consumption in agriculture, which equals zero in non-irrigated crops. This approach to irrigation water footprint has also been used by Rost *et al*. (2008) and Seckler *et al*. (1998). Given that, this study considered that a crop's respective blue water footprint is equivalent to its irrigation needs once it complements the precipitation volume, represented by green water. The crops with blue water footprint values equal to zero were excluded from the study. The calculation of the irrigation water demand for the remaining crops and the municipalities that produce them was carried by the multiplication between the amount of food (t $year^{-1}$) and the required amount of irrigation water needed to produce one ton of one specific crop (m^3 t^{-1}), resulting in the necessary volume of irrigation water per year (m^3 $year^{-1}$). Afterwards, these results were transformed into people equivalent to facilitate their comprehension by dividing the results by the average water consumption (m^3 year $inhab^{-1}$) of 2016, 2017, and 2018 in the study area (BRASIL, 2018), achieving a value in inhabitants per year. Municipalities that irrigated volumes equivalent to less than 1.000 inhab were excluded from the study. Therefore, considering the criteria applied, the scope of this study covered 7 crops (rice, onions, garlic, cavendish, banana, potatoes, tomatoes, and chunky banana) grown in, respectively, 85, 18, 7, 6, 2, 2, and 1 cities that irrigate more than the equivalent to the water consumption of 1.000 inhabitants.

2.2.2 TREATED WASTEWATER PRODUCTION AND INVESTMENTS IN SANITATION

Data provided by the Brazilian government (ANA, 2013) were collected for the municipalities selected regarding their planned WWTP by 2035. Data collection covered the names of the WWTP, population served, type of treatment, flow rate, and BOD load discharged, as well as the investments planned for future sanitation coverage expansions.

Besides, information regarding bacteria concentrations in the treated wastewater produced was gathered and further used to discuss the risks related to irrigating crops with treated wastewater. Data collection was performed by identifying the technologies chosen for the WWTP planned and using their efficiency and removal data presented by Von Sperling (2007). Equivalence between faecal coliform (FC) and E. coli concentrations was considered, given the data available in different databases.

2.3 AGRICULTURAL IRRIGATION POTENTIAL WITH TREATED WASTEWATER AND RISK ASSESSMENT

The potential of agricultural irrigation with treated wastewater was calculated to indicate how much of the current irrigation demand could be covered by the future production of treated wastewater. Moreover, load discharge data were assessed to present the percentage resealed into water bodies that could be avoided if the municipalities studied used all of their potential to irrigate the current food production scenario.

The qualitative evaluation performed aimed at presenting the tolerable health risks for different irrigation scenarios, besides discussing the reduction of pathogens necessary to achieve such tolerable risks and determining how the necessary reduction of pathogens can be achieved. This approach became possible after the Disability Adjusted Life Years (DALY) parameter was introduced by WHO in 1993, which calculates the time of life lost due to the practice of a risk activity when compared to a disease-free life, as presented by Mara *et al*. (2007) and WHO (2006).

Given that different crops have different levels of restriction regarding the quality of the effluent that can be used in their irrigation, onion and garlic crops were chosen once they are cultivated under the soil, representing the worst possible situation. In addition, this choice allowed us to evaluate unrestricted and restricted irrigation of some of the highest water-demanding crops among the ones studied. Onions presented the second-highest irrigation demand, with an average annual production of approximately 533.673 tons. Besides, despite having the third greatest irrigation demand among the crops evaluated, garlic crops present a water requirement per ton produced approximately 9 times higher than onions, with an annual production of around 72.123 tons.

The reference values adopted for the acceptable risk of rotavirus infection per person per year (pppy) agree with the ones proposed by Mara *et al*. (2007) and presented by WHO (2006), being between 10^{-2} and 10^{-3}, meaning that between 0,1 and 1,0% of the exposed population gets ill every year. Thus, it was possible to evaluate scenarios with different levels of restriction and regulation, simulating more and less conservative guidelines with regard to the minimum quality standards required for the practice of agricultural irrigation with treated wastewater.

The qualitative evaluation of onion crops' unrestricted irrigation considered a scenario with pppy equal to 10^{-3}, which implies a maximum concentration of 10^{3} E. coli/100mL in the effluent used to irrigate, meeting the recommendations of Mara *et al*. (2007) and the epidemiological studies carried out by WHO (2006), since onions develop underground and can be eaten raw by end consumers.

The evaluation of garlic crops considered two restricted irrigation scenarios to study the risks to farmers involved in its production. The scenarios evaluated considered the WHO recommendation for pppy equal to 10^{-3} in different types of agriculture: 1) more restrictive labour-intensive agriculture, which implies a maximum concentration of 10^{4} E. coli/100mL in the effluent used to irrigate, 2) scenario of highly mechanised agriculture, less restrictive, which implies in a maximum concentration of 10^{5} E. coli/100mL in the effluent used to irrigate.

The criteria considered in these scenarios followed the ones from the research and epidemiologic studies performed by Mara *et al*. (2007), being the consumption of 100g of raw onion per person per week over five months and 1-5 mL of sewage remaining in 100g of onion after irrigation. Regarding the garlic crops scenarios, they considered 150 and 300 days of annual exposure with 10^{-100} mg of soil consumed per exposure for labour-intensive agriculture and 100 days of annual exposure with 1^{-10} mg of soil consumed per exposure for highly mechanised agriculture.

Moreover, health protection measures suggested by WHO (2006) were used to discuss the results obtained and present good practices to increase the safety of production and consumption of the crops studied.

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3 RESULTS AND DISCUSSION

3.1 AGRICULTURAL IRRIGATION WATER DEMAND

Data regarding blue water footprints and the agricultural irrigation water demand of each crop studied are presented in Table 1. Figure 1 shows the distribution of agricultural irrigation water demand in the study area.

Table 1| Annual yield, blue water footprint, and irrigation demand for the selected crops

Crop	*Product Code (Faostat)*	*Total Yield per year (t year-1) (1)*	*Average Blue Water footprint for Santa Catarina/Brazil (m^3 t^{-1})*	*Agricultural Irrigation water demand (m^3 $year^{-1}$) (1)*
Rice	27	1.156.461	500	578.230.263
Onions	403	533.673	12	6.404.081
Garlic	406	18.041	110	1.984.496
Cavendish Banana	486	620.148	2	1.240.296
Potatoes	116	114.839	9	10.331.552
Tomatoes	388	164.569	3	493.708
Chunky Banana	486	115.959	2	231.917

Values cover all of the municipalities that produce the crops studied, including those that irrigate less than the equivalent of 1.000 inhab.

Source: Epagri (2022), Mekonnen and Hoekstra (2010).

3.2 TREATED WASTEWATER PRODUCTION AND ITS POTENTIAL TO IRRIGATE AGRICULTURE

Data regarding the investments in sanitation are presented in Table 2. Moreover, information about agriculture, irrigation, and sanitation in the study area is shown in Table 3. Figure 2 presents the distributions and ranges of treated wastewater production in the study area, whilst Figure 3 shows the potential of agricultural irrigation with treated wastewater by municipality and crop.

Table 2| Investments planned to improve sanitation until 2035 in the cities that produce the crops studied

Crop	*Investments planned until 2035 (BRL) (1)*			*Population served*	*Investment per inhab*		*Population served with WWTP*
	Collection	*Treatment (2)*	*Collection and Treatment*		*BRL*	*USD (3)*	
Rice	5.053.715.068	1.377.865.163	6.431.580.231	3.343.905	1.923	350	91%
Onions	367.906.000	109.715.566	477.621.566	216.335	2.208	401	90%
Garlic	268.478.483	90.121.898	358.600.381	173.552	2.066	376	90%
Cavendish Banana	345.385.261	107.444.075	452.829.336	258.048	1.755	319	92%
Potatoes	96.565.696	26.835.179	123.400.876	49.470	2.494	454	90%
Tomatoes	136.977.087	38.573.286	175.550.374	80.432	2.183	397	90%
Chunky Banana	11.783.082	3.036.959	14.820.041	5.990	2.474	450	90%

1| Corrected values to January 2022 given IPCA (Brazilian National Broad Consumer Price Index)

2| Most common solutions planned: Conventional and Advanced secondary treatment

3The exchange rate between BRL and USD considered in this study was 5,50 BRL to 1 USD

Source: ANA (2013), Brasil (2018).

Table 3| Agriculture, irrigation, and sanitation information regarding the crops and municipalities studied

Crop	No. of cities (1)	Agriculture information		Irrigation water consumption		WWTP information				Agricultural irrigation potential range (%)	Load discharge avoided (%) (5)
		Cultivated area (ha)	Yield (t $year^{-1}$) (2)	Irrigation Water (m^3 $year^{-1}$) (3)	Irrigation water: People equivalent (inhab)	No. of WWTP	Population served	Inlet flow (m^3 $year^{-1}$)	Load discharged (kg BOD day-1)		
Rice	85	283.888	1.155.996	577.997.917	10.445.620	100	3.349.170	130.978.469	36.814	0 - 2.685	74
Onions	18	72.922	494.532	5.934.390	107.247	24	216.335	7.089.293	1.977	15 - 642	59
Garlic	7	8.239	2.002	453.778	8.201	13	152.856	3.954.614	886	17 - 3.082	49
Cavendish Banana	6	28.254	434.879	869.759	15.718	8	258.048	9.460.800	2.836	231 - 6.351	8
Potatoes	2	3.350	43.250	389.250	7.035	2	49.470	567.648	562	86 - 367	30
Tomato	2	2.920	72.145	216.436	3.911	5	80.432	2.570.184	472	571 - 1.659	10
Chunky Banana	1	5.000	32.500	65.000	1.175	1	5.990	394.200	129	(4)	40

1|10 municipalities produce two crops, and 2 municipalities produce 3 crops in their territory. The remaining cities produce only one of the crops studied.

2| The yield was calculated by the division of the total yield produced by the number of harvests performed between 2016 and 2020 in the municipalities that produce the crops studied and irrigate more than the equivalent of 1.000 inhab.

3| The presented volumes cover only the municipalities that produce the crops studied and irrigate more than 1.000 inhab.

4| No range presented once this crop was produced by 1 municipality.

5| Potential percentage of load discharged directly into water bodies that could be avoided if the municipalities studied used all of their agricultural irrigation potential to irrigate the current food production scenario.

Source: ANA (2013), Brasil (2018), Epagri (2022), The Authors.

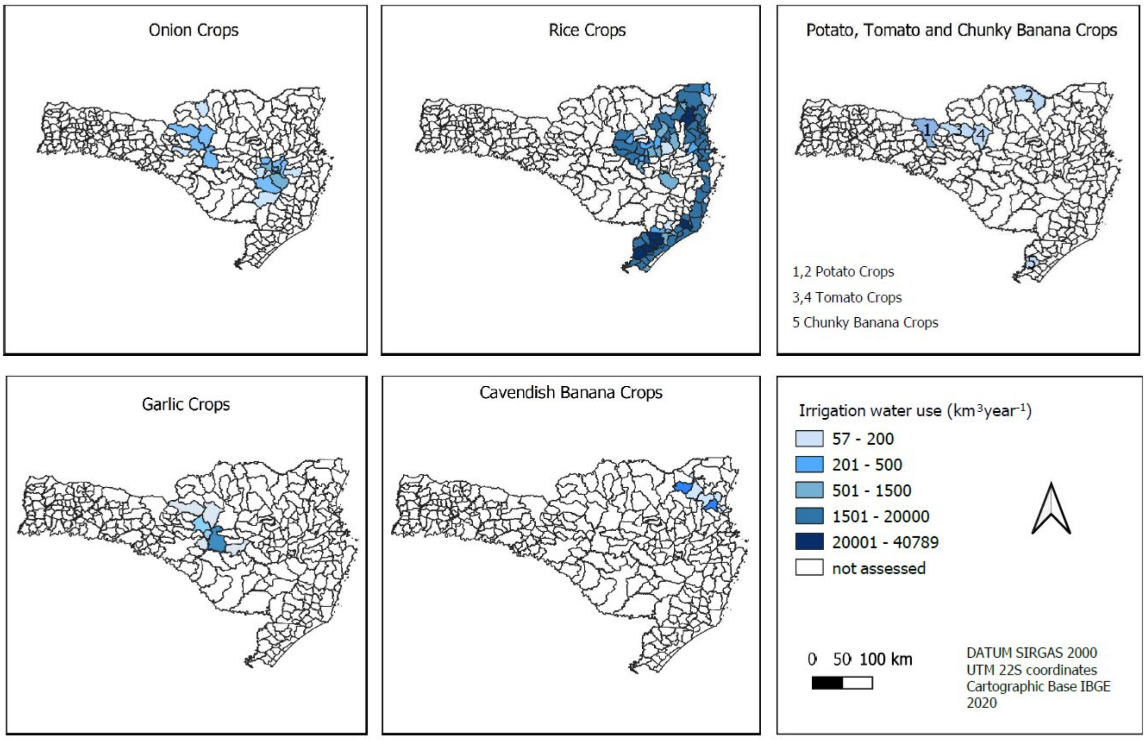

Figure 1| Agricultural water demand by municipality and crop

Source: The authors.

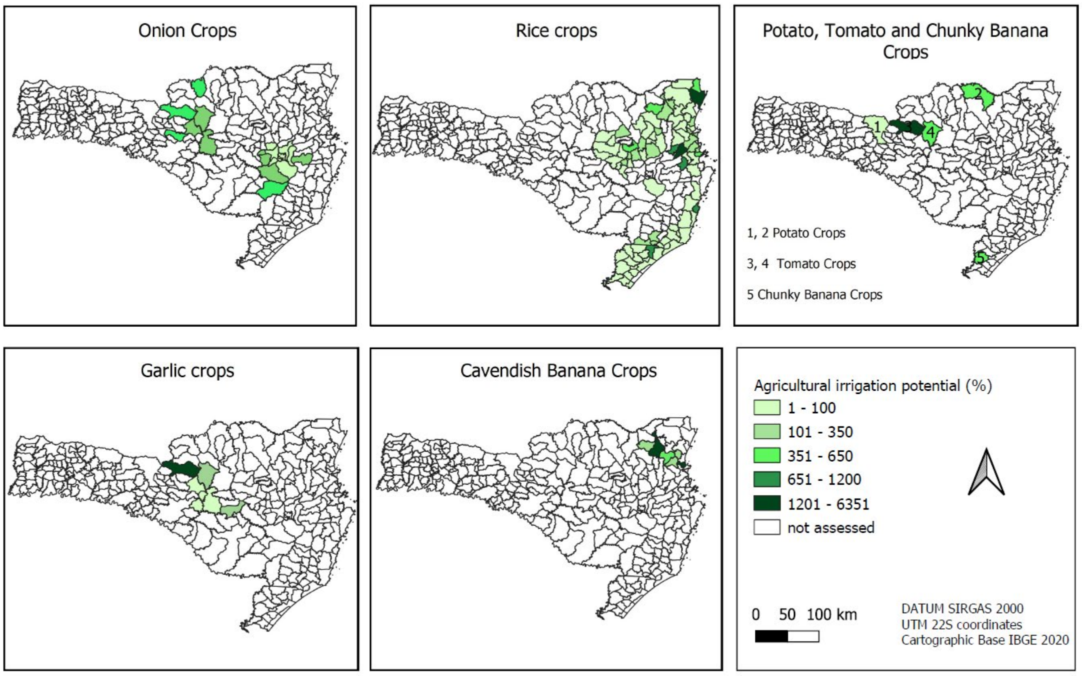

Figure 2 | Treated wastewater production by municipality and crop

Source: The authors.

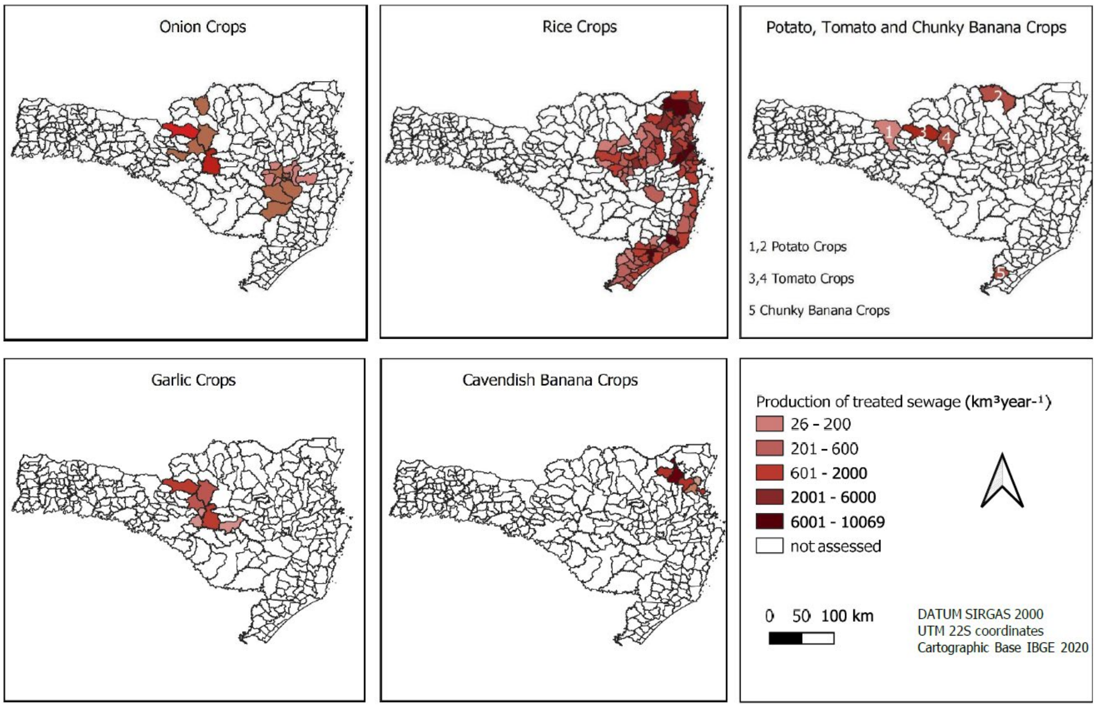

Figure 3 | Potential of agricultural irrigation with treated wastewater by municipality and crop

Source: The authors.

It is possible to observe that most of the municipalities that produce rice are located on the coast side of the study area, having the biggest irrigation water consumers in the north and south regions of the state. Most of the cities studied consumed irrigation water volumes above 501 km^3year^{-1}, reaching values up to 40.789 km^3year^{-1}. Future wastewater production in the cities that most irrigated rice was not enough to provide the highest agricultural irrigation potential values, once none of the top 10 cities in terms of irrigation water volumes were among the top 10 highest agricultural irrigation potentials, mainly due to their low population when compared to the amount harvested. However, 34 out of the 84 rice-producing municipalities presented potentials over 80%. The cities with the highest agricultural irrigation potentials were Brusque (2.685%), São Francisco do Sul (2.348%), Criciúma (1.154%), Guabiruba (1.125%), Garopaba (654%), and Porto Belo (597%), totalising 1.894 km^3year^{-1}, being equivalent to 34.228 inhab per year. The total irrigation water demand related to rice production was equivalent to over 10 million inhabitants, which is higher than the current population of Santa Catarina.

Onion production occurred in two distinct regions, with municipalities irrigating between 65 and 1.441 km^3year^{-1}. Half of the top 10 cities in terms of irrigation water volumes were among the top 10 highest agricultural irrigation potentials, and 13 out of 18 onion-producing municipalities presented potentials over 80%. The cities with the highest agricultural irrigation potentials were Caçador (642%), Tangará (540%), Irineópolis (532%), Urubici (473%), and Curitibanos (289%), totalising 759 km^3year^{-1}, being equivalent to 13.718 inhab per year. Onion crops had the second highest irrigation water demand in terms of people equivalent, around 107 thousand inhabitants.

The seven municipalities that produce garlic were concentrated in the same region in the study area, with irrigation water volumes ranging from 66 to 750 km^3year^{-1}. Four cities presented potentials over 80%, those being Caçador (3.082%), Lebon Régis (320%), Ponte Alta (224%), and Curitibanos (81%), totalising 925 km^3year^{-1} or 16.721 inhab per year.

All the six cities that produce cavendish banana were located in the north of the study area and had agricultural irrigation potentials over 200%. The cities Jaraguá do Sul and Balneário Piçarras presented potentials of 6.351% and 2.394%, respectively. Given that, all of the necessary irrigation water volume could be supplied by treated wastewater, given the scope of this research, which would totalise 870 km^3year^{-1}, equivalent to 15.718 inhab per year.

The cities that produce potatoes were Água Doce and Mafra, which presented potentials of 86% and 367%, respectively. The amount of irrigation water used by both cities to irrigate potatoes is 389 km^3year^{-1}, equivalent to 7.035 inhab per year.

Tomatoes are produced in Caçador and Lebon Régis, which presented potentials of 1.659% and 571%, respectively. The amount of irrigation water used by both cities is 123 km^3year^{-1}, equivalent to 2.216 inhab per year.

Jacinto Machado, the only producer of Chunky banana considered in this study, presented 606% of agriculture irrigation potential. The irrigation water volume used in this crop is 65 km^3year^{-1}, equivalent to 1.175 inhab per year.

In relation to the WWTP planned until 2035, the most common types of solutions are conventional and advanced secondary treatment. Among the treatments planned, anaerobic reactors, activated sludge and anaerobic and aerobic filters stand out. The average adopted efficiency for the WWTP present in the cities that produce rice, onions, garlic, cavendish banana, potatoes, tomato, and chunky banana are, respectively, 73%, 72%, 78%, 76%, 84%, 79%, and 60%.

Regarding load discharge, if all the municipalities studied used all their agricultural irrigation potential to irrigate the current scenario of food production, the amount of BOD not discharged directly into water bodies, considering rice, onions, garlic, cavendish banana, potatoes, tomato, and chunky banana producers, would be, respectively, 27.240, 1.160, 436, 214, 169, 49, and 129 kg BOD day^{-1}. The total load discharge avoided would be around 60% of the one from the biggest WWTP in Latin America, located in the state of São Paulo, which has a current capacity to treat over 40 thousand litres per second (ANA, 2013). Considering the study area, its biggest WWTP, located in the capital of the State of Santa Catarina, discharged 231.2 kg BOD day^{-1} in 2013 and has an estimated load discharge of 468.3 kg BOD day^{-1} after improvements planned until 2035 (ANA, 2013).

The results found make it possible to visualise the big picture of all the municipalities and crops considered in the scope of this research, in addition to analysing individual data of each city and the crops they produce. As an example, there is the city of Caçador, which presented the highest agricultural irrigation potential for Onions (642%), Garlic (3.082%), and Tomatoes (1.659%). In fact, its planned yearly treated wastewater production in 2035 can still cover 403% of the annual irrigation demand of the present production of all those three crops.

Moreover, Figure 1, Figure 2 and Figure 3 show that different municipalities with high demand for irrigation water and elevated treated wastewater production are grouped in clusters along the State of Santa Catarina, which indicates the possibility of cooperation among those cities. This increases the success rate of using treated wastewater to irrigate crops grown in the study area once it allows the centralisation of complementary treatment that may be necessary in order to meet quality standards imposed by the government and other regulatory institutions, as well as facilitating quality control, distribution, management, among other important factors to be considered.

Besides, it is important to highlight the importance of treated wastewater quality to safely use it to irrigate different crops, as well as taking other logistical, economic, and risk-related aspects into consideration. For instance, future studies should address the presence of family farming in the study area, as it is responsible for 23% of the farmed area in Brazil, Santa Catarina being the 8th State in terms of family farming presence out of 26 States in the country (IBGE, 2017). Furthermore, other water footprints must be assessed to fully understand the dynamics of crop irrigation with treated wastewater, such as the green water footprint, which is the rainwater used, and the grey water footprint, which refers to the amount of freshwater used to dilute pollution.

Ultimately, the data collection performed in this study considered information provided by the national government, representing a plan for improving sanitation by 2035. That being said, the authors here express that they intended to indicate potential and point out which crops and locations in the study area have a higher tendency to implement agricultural irrigation with treated wastewater, fomenting further research.

3.3 HEALTH SAFETY IN AGRICULTURAL IRRIGATION WITH TREATED WASTEWATER

Given the scenarios evaluated for onion and garlic crops, the qualitative evaluation performed allowed identifying the tolerable health risks for different irrigation scenarios, besides presenting the necessary reduction of pathogens to achieve such tolerable risks.

Among the 18 municipalities that produce onions, 16 have only one planned WWTP. Two presented more than one proposed WWTP, representing, respectively, 33% and 15% of the total population served by all evaluated WWTP. In addition, it should be noted that another city, despite having only one WWTP, is responsible for 16% of the total population served, which shows the concentration of production of treated wastewater in some locations. There was only one municipality that presented treatment via Waste Stabilization Ponds (WSP) with anaerobic followed by facultative and maturation ponds, reaching an average effluent quality between 10^{2}-10^{4} FC/100mL, which requires only produce washing before eating to ensure infection risk equal to 10^{-3} pppy, once this practice has the potential of reducing 1 log (OMS, 2006). However, considering that onions are usually peeled before consumption, such a measure already implies a potential reduction of 2 logs. Therefore, the traditional consumption of onion can be safe, given the scope of the scenario assessed.

The remaining onion-producing cities have 15 WWTP planned with sewage treatment via anaerobic reactor, 1 via UASB followed by submerged aerated biofilters, 4 via conventional activated sludge, 1 via UASB reactor followed by anaerobic filters, and 2 via UASB followed by high-rate trickling filters. According to Von Sperling (2007), these types of treatment produce effluent with concentrations between 10^6-10^8 FC/100mL. The effluent from these solutions requires a reduction of 3-5 logs in its bacteria concentration to ensure its safe application, given the scenario considered. Possible health protection measures and cooking technics can contribute to achieving such logs reductions, e.g., washing with clean water (1 log), produce disinfection (2 logs), and peeling (2 logs). Combinations of good practice are possible. Besides, in addition to being eaten raw, onions usually go through cooking processes, which have the potential to reduce 6-7 logs (WHO, 2006).

Among the 7 selected municipalities that produce garlic, 5 have one WWTP planned. The other 2 concentrate 68% of the total population served by all WWTP evaluated in garlic-producing cities. Another city, despite having only one WWTP, is responsible for 23% of the total population served, which also shows the concentration of treated wastewater production. There are 7 WWTP planned with treatment via anaerobic reactor, 3 via conventional activated sludge, 1 via UASB reactor followed by anaerobic filters, and 2 via UASB followed by high-rate trickling filters. According to Von Sperling (2007), these types of treatment produce effluent with FC concentrations between 10^6-10^8/100mL. The effluent from these solutions requires a reduction between 1-4 logs to ensure the safety of farmers who will work in irrigated fields with treated wastewater, depending on the type of agriculture practised. This reduction can be achieved through the implementation of complementary treatment units in order to reach the minimum quality of 10^4 and 10^5 E. coli/100mL, for labour-intensive and highly mechanised agriculture, respectively, as recommended by WHO (2006).

It is important to emphasise that the qualitative evaluation applied to garlic crops refers to the practice of restricted irrigation and, therefore, did not address the safety of the final consumer. Mara *et al*. (2007) and WHO (2006) recommend a concentration of $\leq 10^3$ E. coli/100mL for unrestricted irrigation of root crops and, as an example of a potential combination of health protection measures, indicate effluent treatment (reducing 4 logs), followed by the death of pathogens up to consumption (reducing 2 logs), ending with washing the product at home under running water (reducing 1 log). This combination applies to vegetables and salads irrigated with treated sewage. However, garlic is commonly cooked before eaten, which can reduce 6-7 logs.

It should be noted that different types of agriculture and crops imply different risks associated with the recycling of treated wastewater in irrigation. Therefore, it is necessary to continue researching more specific scopes in Brazil, once, despite labour-intensive agriculture being common in developing countries, Brazil is a reference country in agribusiness and, therefore, applies different types of technology in its agriculture. Besides, it is necessary to expand data collection and complementary evaluation of the proposed wastewater treatment solutions, addressing the systems as a whole by including all their treatment units in the evaluation.

Furthermore, Mara *et al*. (2007) indicate the possibility of reducing pppy requirements from 10^{-3} to 10^{-2} for both restricted and unrestricted irrigation, considering the global incidence of diarrheal diseases. The authors recommend concentrations $\leq 10^5$ E. coli in 100mL for labour-intensive agriculture, as long as farmers adopt good hygiene practices, and that the maximum concentration is reduced to $\leq 10^4$ E. coli in 100mL if people under the age of 15 are exposed. The authors suggest changing quality standards for highly mechanised agriculture from $\leq 10^5$ to $\leq 10^6$ E. coli in 100mL. Moreover, they agree with $\leq 10^3$ E. coli in 100mL for unrestricted irrigation of root crops grown underground and eaten raw. For crops that grow above ground level, they suggest changing from $\leq 10^3$ to $\leq 10^4$ E. coli in 100mL.

Furthermore, it is necessary to understand the particularities of each context when defining quality standards to be followed to guarantee the safety of farmers and end consumers without jeopardising the technical and economic feasibility of recycling sanitation by-products. As presented by Mathers *et al*. (2002), the incidence of diarrheal diseases in developing countries is higher than the risk that their legislation aims to contain. Bearing in mind that one of the main causes of this type of disease is the lack of access to adequate sanitation services, it is necessary to reflect on whether the allocation of efforts should be in highly restrictive regulations or in the education, research and identification of alternative solutions that gather the expansion of sanitation coverage and food production.

4 CONCLUSIONS

The present study reports the wastewater irrigation potential in agriculture in the State of Santa Catarina/Brazil. The results regarding agricultural irrigation potential present the presence of many municipalities over 100%, going up to more than 6.000%, showing that the amount of wastewater to be produced in 2035 could not only supply the current irrigation water demand but also allow agriculture to expand without consuming more potable water to do so. Cooperation among different municipalities is possible, and the organic load discharge avoided is substantial.

The effluent quality produced by most of the planned WWTP requires further treatment or, at least, the application of hygiene and cooking methods to prevent infection risks. Given that most of these WWTP still need to be in operation, changes may be implemented to provide better quality effluent to irrigate crops.

Further research is necessary regarding economic evaluation, risk analysis, and other viability assessment key factors. Given that these aspects are very site-specific, they have not been taken into account in this study but can be applied in future research regarding the potential crops and cities hereby presented. Aspects regarding green and grey water footprints, as well as the presence of family farming, must be addressed in order to understand the dynamics of crop irrigation with treated wastewater fully and to foment the achievement of the Sustainable Development Goal 6, which focuses on ensuring access to water and sanitation for all.

Furthermore, the train of thought used in this study can be applied to perform similar assessments in other locations, considering their particularities.

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