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Research Paper

Priority areas for the use of solar water disinfection (SODIS) in Brazil: a spatial approach

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ABSTRACT

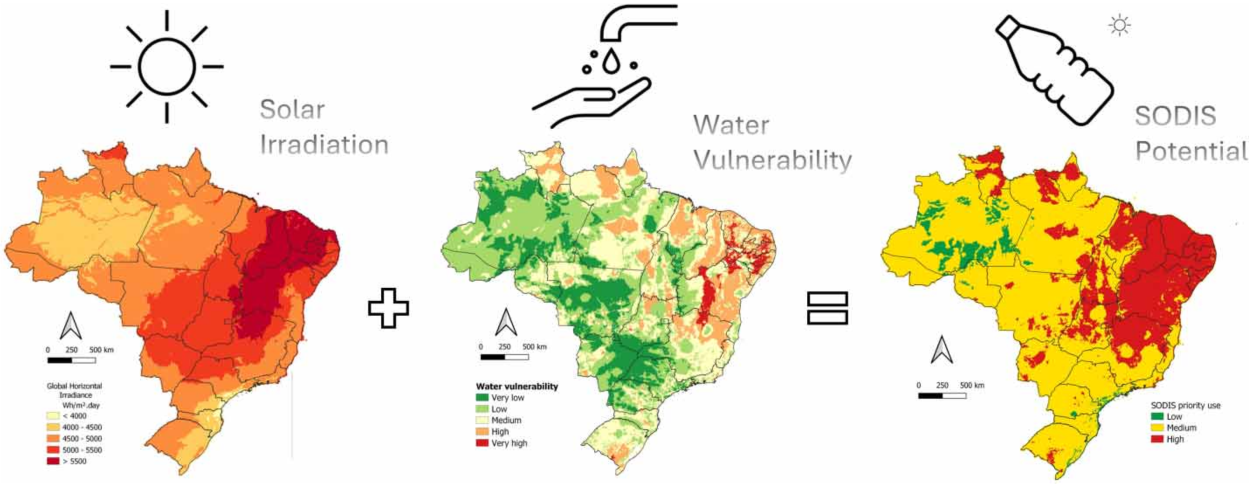
This paper presents a methodology for the development of a potential and priority use map for the application of the solar water disinfection (SODIS) method in Brazil. The assessment of solar radiation was conducted, with a particular focus on the annual average global horizontal irradiance (GHI). The water vulnerability index (WVI) and the economic-social-ecosystemic (ESE)-WVI were developed and employed as indicators to define the priority regions for the application of SODIS. The combination of the GHI and WVI maps yielded a SODIS usage potential index (SUPI). The combination of the SUPI map with information pertaining to the human, economic, and ecosystem dimensions of water vulnerability (ESE-WVI) yielded the SODIS usage priority index. The analysis revealed that the country exhibits favorable levels of solar radiation, making the implementation of SODIS a viable option, particularly in the Northeast region. Furthermore, the study identified regions with greater water vulnerability, such as the semi-arid region and some parts of the Amazon, as priorities for the application of SODIS. In conclusion, SODIS represents a viable water treatment technique for various regions in Brazil, particularly those with abundant solar radiation and concerns regarding water security.

Key words: global horizontal irradiance, solar water disinfection, water quality, water vulnerability

HIGHLIGHTS

- A systematic approach to evaluate the potential for solar water disinfection (SODIS) is presented using a SODIS usage potential index (SUPI) based on solar radiation and natural water vulnerability data.
- A map of priority sites for the use of SODIS in Brazil is presented based upon the SUPI and the economic-social-ecosystemic water vulnerability index.
- SODIS projects should be prioritized for application in the Brazilian semi-arid regions.

GRAPHICAL ABSTRACT



INTRODUCTION

The present situation is such that all sectors of society, including domestic, agricultural, and industrial, are experiencing an increase in demand for water as a consequence of population growth (Roshan & Kumar 2020). According to estimates produced by the United Nations (2020), there is a consistent annual growth in demand of approximately 1%. This trend could result in a water deficit of up to 40% by 2030.

However, climate change creates uncertainties regarding water availability. Extreme weather events are becoming more frequent, exacerbating water scarcity in various regions (Lazaro *et al.* 2023). Countries that are already facing challenges related to water scarcity or high water demand are deeply concerned about the potential impacts of climate change on water supplies for human, agricultural, and industrial use (Hristov *et al.* 2021; Tijjani *et al.* 2022; Huang *et al.* 2023; Molénat *et al.* 2023; Karimi *et al.* 2024).

Even in a country such as Brazil, which is renowned for its abundant water resources, the population, as well as the agricultural and industrial sectors, are already experiencing the impacts of water scarcity (Lazaro *et al.* 2023). The challenges in water supply for densely populated urban centers in Brazil are attributed to the distribution of water resources, which are concentrated in less populated regions of the country (Lazaro *et al.* 2023). Two abnormal drought periods occurred in Brazil, particularly in the Southeast region, the most populous and industrialized, in 2014 (Empinotti *et al.* 2019) and 2021 (Getirana *et al.* 2021). Furthermore, the semi-arid region in the Northeast of the country is noteworthy for its history of low rainfall and chronic water scarcity issues. In times of water scarcity, the search for new water sources becomes a natural course of action due to the competition for water resources.

In this scenario, the implementation of low-cost water treatment methods is increasingly necessary, particularly in impoverished areas or remote communities. Solar disinfection is a low-cost and environmentally sustainable method used, especially, in low-to-medium-income-countries with high solar radiation incidence (Khedikar & Tembhurkar 2016; Al-Gheethi *et al.* 2019; Nair *et al.* 2023). Recent studies aim to scale up solar water disinfection (SODIS), increasing both the treated volume and its efficiency. Notable approaches for wastewater treatment include the use of large-volume containers, solar collectors, and low-cost reactors such as the raceway pond reactor or high-cost photoreactors such as tubular photoreactors equipped with compound parabolic collectors (Gandhi & Prakash 2023).

SODIS technology has been known for over 30 years. The technique involves using transparent plastic or glass bottles filled with water that are exposed to sunlight for a period of 6–48 h, depending on solar intensity and the sensitivity of pathogens present in the water. The disinfection mechanism combines the heat generated from sunlight (pasteurization) with ultraviolet (UV)-A radiation from the sun (McGuigan *et al.* 2012). Various types of thermoplastics can be used for this purpose. According to García-Gil *et al.* (2020), polymethylmethacrylate, polypropylene, polycarbonate, and polyethylene terephthalate (PET) are more suitable as they transmit sufficient solar radiation to eliminate pathogens and offer a viable production cost-durability relationship under sun exposure.

Solar radiation can be used as a disinfection element under certain meteorological conditions. The incidence of solar radiation is identified as a key factor for SODIS performance. According to general guidelines, an exposure time of 6 h on cloudless days or up to 48 h on cloudy days is recommended (McGuigan *et al.* 2012). Experiments conducted by Johansson *et al.* (2022) to assess the scaling up of treatment and by Karim *et al.* (2021) to verify the efficiency of different containers under varying climatic conditions support the suggested exposure times.

The potential use of SODIS can be evaluated from two perspectives: (i) the more appropriate treatment conditions, considering the solar radiation incidence and (ii) the need for use, considering the water security conditions. Based on this, it is proposed to create a map of the potential use of SODIS in Brazil and a map of priority SODIS application areas for use by the public and the scientific community. This map would provide information to identify priority areas for investment and promotion of SODIS techniques.

METHODS

Brazil is a country with continental dimensions, covering an area of over 8.5 million km^2. It is politically and administratively divided into 27 federal units, comprising 26 States and one Federal District (Figure S1 – Supplementary Material). These units are further grouped into five major regions: North, Northeast, Center-West, Southeast, and South, each with its distinct physical, political, and socio-economic characteristics. More information on Brazil can be found in Section S.2. of the Supplementary Material.

This study considers the political and administrative regions of Brazil as the basis for analysis. A basic understanding of biomes (Figure S1 – Supplementary Material) is required to understand water availability and scarcity issues. To develop the map of the potential use of SODIS, we employed various databases containing information on solar radiation, water security, and the distribution of tubular wells for groundwater use.

The incident solar radiation was assessed using the database from the second edition of the Brazilian Solar Energy Atlas (LABREN 2017; Pereira *et al.* 2017), which is a collaborative product involving various research organizations and universities in Brazil (INPE/DIIAV 2021). The Atlas was originally designed to provide information on the potential use of solar energy in Brazil. It shares data on the annual and monthly averages of total daily global horizontal irradiance (GHI), diffuse, direct normal, inclined plane, and photosynthetically active radiation in Wh/m^2.day (INPE/DIIAV 2021).

To create the potential SODIS use map, we selected data on the daily annual average GHI. GHI (Equation (1)) data represent the sum of direct and diffuse solar radiation, which is a suitable indicator of incident solar radiation for SODIS potential studies (Moreno-SanSegundo *et al.* 2021).

$$\mathrm{GHI} = \mathrm{DHI} + \mathrm{HDI} \text{ or } \mathrm{GHI} = \mathrm{DHI} + \mathrm{DNI} \cdot \cos(\theta z) \tag{1}$$

where (definitions from Pereira *et al.* 2017):

- GHI is the rate of total energy per area incident on a horizontal surface;
- DHI (horizontal diffuse irradiance) is the rate of energy incident on a horizontal surface per unit area, resulting from the scattering of the direct solar beam by atmospheric constituents;
- HDI (horizontal direct irradiance) is the rate of energy per unit area of the direct solar beam on a horizontal surface;
- DNI (direct normal irradiance) is the rate of energy per unit area coming directly from the Sun, which is incident perpendicular to the surface;
- θz is the solar zenith angle.

The irradiation data are provided by the SONDA network (http://sonda.ccst.inpe.br/) coordinated by Brazil's National Institute for Space Research (Instituto Nacional de Pesquisas Espaciais (INPE)), with the support of several Brazilian research institutes and universities. The network comprises 17 observation stations, which collect GHI and DHI data using pyranometers. Eight of these stations also acquire DHI and DNI data with the aid of solar trackers, and HDI data with pyranometers. The pyranometers exhibit a nearly flat response curve across the spectral range of 300–3,000 nm. They can be utilized with two distinct shading techniques, namely the shading ring and the shading sphere with a solar tracker. Pyrheliometers are linked to the solar tracking system and exhibit a flat response curve for wavelengths between 300 and 2,800 nm, encompassing the entire shortwave range of the solar spectrum (Pereira *et al.* 2017).

The daily annual average of GHI in Brazil ranges between 3,500 and 5,500 Wh/m^2.day, subdivided into 5 classes (Table 1) for comparison of potential in different areas within the Brazilian territory.

This study considers water security as an aspect that indicates areas with a greater need for domestic water treatment techniques, particularly due to the pressure on water resources. The indicator used is the water vulnerability index (WVI), which is categorized into five classes (refer to Table 1). The WVI was developed based on the resilience dimension (item S.3.6 – Supplementary Material) of the water security index (WSI) from the Brazilian National Water Agency (Agência Nacional de Águas (ANA)) Water Security Plan (ANA 2023).

The WSI is an index developed as part of National Water Security Plan of Brazil. Its purpose is to assess the current conditions and future forecasts of water security issues in the country. In order to do so, it considers four dimensions: human, economic, ecosystem, and resilience. Furthermore, it incorporates the concept of risk to water use (Brito *et al.* 2022). WSI represents the potential of natural (surface and groundwater) and artificial water stocks in Brazil and their spatial renewal capacity through precipitation, as defined by ANA (2023).

Each dimension is constituted by one or more indicators (Table 2), which, in turn, are constituted by a combination of measurable variables or attributes. The indicators are assigned values within a five-point gradation band, with natural numbers from 1 to 5 used to normalize them. The calculation of each dimension of the index is based on the weighted average of its respective indicators. The weights assigned to each indicator were based on the input of experts and an assessment of their alignment with empirical reality. Further details of the methodological structure are presented in the Supplementary Material to this article (item S.3) and can be accessed in full at ANA (2019).

The WVI proposed in this study is represented by the inversion of the values assigned to the resilience dimension of WSI. The objective of this transformation (Table 3) is to represent vulnerability, as opposed to water security, in a manner that differs from that of the original index proposed by the Brazilian National Water Agency.

Table 1 | Representation of the classes used for the elaboration of the maps of GHI and WVI in Brazil

Class	GHI (Wh/m^2.day)	WVI (range)
0	–	0–1
1	3,500–4,000	1–2
2	4,000–4,500	2–3
3	4,500–5,000	3–4
4	5,000–5,500	4–5
5	$>$ 5,500	–

Table 2 | Indicators used to generate the WSI

Dimension	Indicator
Human	Guaranteed water supply Water supply coverage
Economic	Guaranteed water for irrigation and livestock farming Guaranteed water for industrial activities
Ecosystem	Adequate quantity of water for natural uses Adequate water quality for natural uses Safety of mining tailings dams
Resilience	Artificial reservoir Natural reservoir Underground storage potential Rainfall variability

Source: ANA (2019).

Table 3 | Rules for transforming the resilience dimension of the $\mathrm{WSI}_{\mathrm{resilience}}$ into the WVI

$\mathrm{WSI}_{\mathrm{resilience}}$	WVI
0	5
1	4
2	3
3	2
4	1
5	0

Finally, a map was developed to show the potential use of SODIS in Brazil. The map was created by overlaying the solar radiation map (map of the reclassified GHI) and the WVI map, which was obtained (Equation (2)) by summing their respective class (Table 1). In order to facilitate the utilization of map algebra, the WVI map, in vector format, was transformed into matrix format through the utilization of the QGIS software. Subsequently, a specific class value was attributed to each pixel in each map, and these values were subsequently added together. The resulting map represents a SODIS usage potential index (SUPI) on a scale from 1 to 9. The higher the value, the greater the potential for SODIS use due to solar radiation incidence and a higher need for the technique due to water vulnerability characteristics.

$$\mathrm{SUPI} = \mathrm{GHI}_{\mathrm{reclassified}} + \mathrm{WVI}_{\mathrm{reclassified}} \tag{2}$$

The economic-social-ecosystemic (ESE)-WVI was developed for Brazil. It takes into account the characteristics of guaranteed water supply, water availability for the agricultural and industrial sectors, and the environmental vulnerability of multiple-use springs. The index draws on indicators from the human, economic, and ecosystem dimensions (items S.3.3, S.3.4, and S.3.5 – Supplementary Material) of the WSI in the Brazilian National Water Agency's (ANA) Water Security Plan (ANA 2023). The objective of these three dimensions is to evaluate the risk of water shortages in response to human, agricultural, and environmental demands, as well as the risk of water source contamination due to the disposal of domestic sewage and mining waste. Following the logic of the WVI, the ESE-WVI is calculated as the average of the inverse values (Table S.2 – Supplementary Material) of the three dimensions mentioned in the WSI (Equation (3)). The ESE-WVI is also classified into five categories, following the WSI pattern presented in Table 1.

$$\mathrm{ESE\_WVI} = \frac{\mathrm{Economic} + \mathrm{Social} + \mathrm{Ecosystemic}}{3} \tag{3}$$

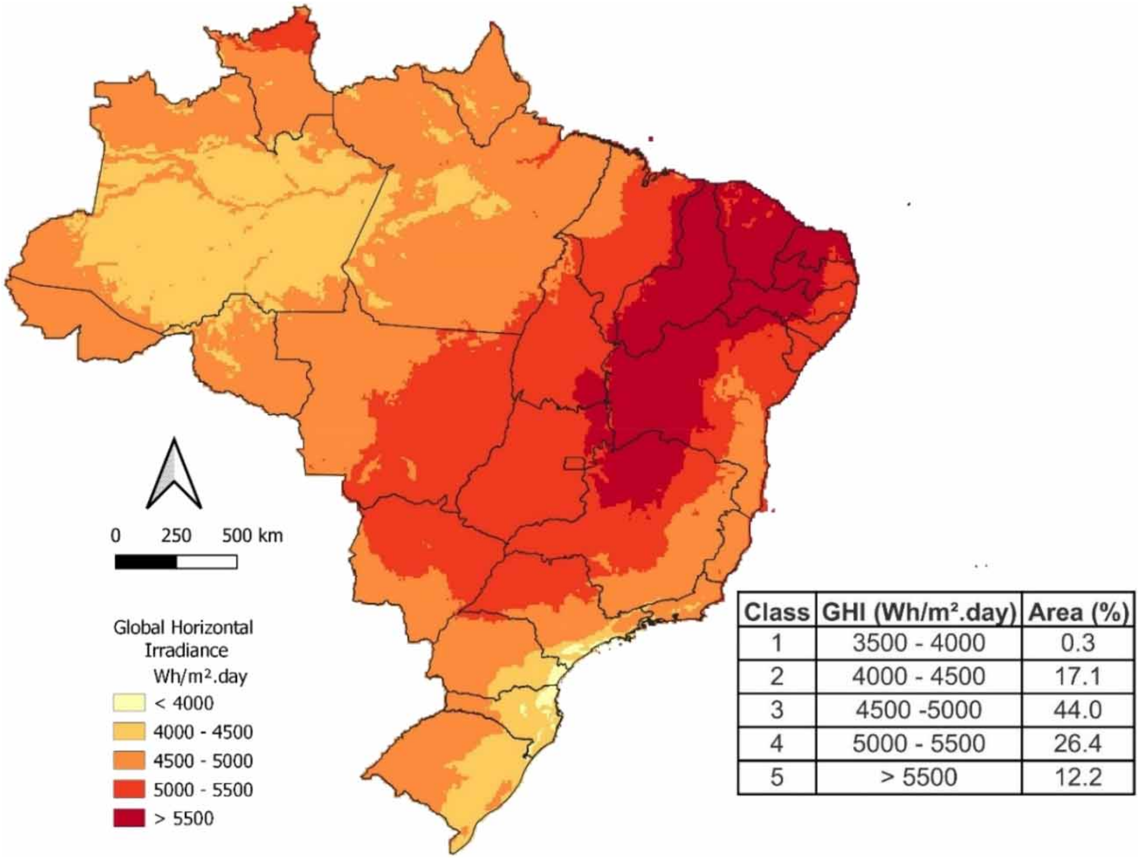
Finally, a SODIS use priority map was created in Brazil by overlaying the map of potential SODIS use with the ESE-WVI map. The map of potential SODIS use was reclassified into four categories (1, 2, 3, and 4 representing 1–3; 3–5; 5–7; and 7–9, respectively), and the resulting values were added to the ESE-WVI values (Equation (4)). The map shows the SODIS use priority index (SUPrI) on a scale of 1–8. Higher values indicate areas that should be prioritized for SODIS deployment initiatives.

$$\mathrm{SUPrI} = \mathrm{Potential\ SODIS}_{\mathrm{reclassified}} + \mathrm{ESE\_WVI} \tag{4}$$

All maps were created using QGIS Desktop software, version 3.28.15, and map algebra was performed using the software's native tools. The authors will make all the maps created for this study available to interested parties upon request.

RESULTS

Figure 1 shows the map of GHI in Brazil, with the legend representing the five reclassification categories derived from the spatialized database of the Brazilian Solar Energy Atlas (LABREN 2017; Pereira *et al.* 2017). Additionally, the map displays the percentages of the Brazilian territory occupied by each established class. The region most suitable for SODIS use is from the northeastern part of the country to the central region, covering a significant portion of the Southeast region, particularly



Class	GHI (Wh/m².day)	Area (%)
1	3500 - 4000	0.3
2	4000 - 4500	17.1
3	4500 -5000	44.0
4	5000 - 5500	26.4
5	> 5500	12.2

Figure 1 | Map of GHI in Brazil. Database source: LABREN (2017) and Pereira *et al.* (2017).

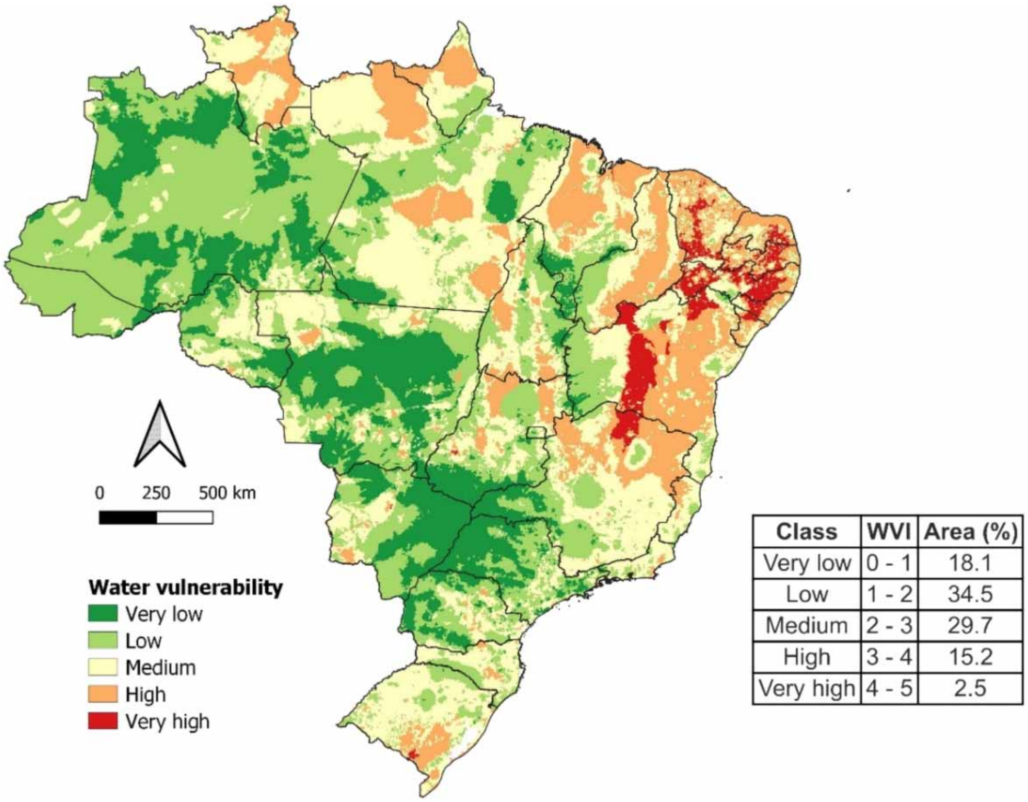
the states of São Paulo and Minas Gerais. These states are responsible for the highest and third-highest gross domestic product (GDP) in Brazil, respectively (IBGE 2024). Regions with higher probabilities of cloud cover, such as the Amazon region and the mountainous areas in the Southeast and South of Brazil, exhibit lower indices of GHI. It is worth noting that the northern part of the state of Roraima, in comparison to other states in the Amazon region, presents higher GHI values.

Overall, the entire country has favorable solar radiation indices for implementing SODIS, although some regions experience higher incidence. This aligns with findings from studies (Moreno-SanSegundo *et al.* 2021) which indicate that the most suitable regions are located between latitudes 35°N and 35°S. The areas between latitudes 15°S and 35°S, as well as 15°N and 35°N, are notable for receiving direct solar radiation, with low cloud cover and precipitation. In contrast, regions closer to the Equator, between latitudes 15°N and 15°S, experience intense scattered radiation due to high cloud cover, despite still receiving significant incident radiation. Brazil's territory spans approximately between latitudes 5°N and 33°S, which is predominantly within the most favorable area for SODIS application.

It is important to note that a solar radiation dose of at least 555 W.h/m^2 (in the UV-A and violet light range, 350–450 nm) is required for a 3-log reduction of *Escherichia coli*, given a water temperature of around 30°C (Wegelin *et al.* 1994). This information is pertinent to the decision-making process regarding the implementation of SODIS systems.

A further pertinent consideration in the deployment of SODIS is the number of days per year on which sunshine is present in each region. The Brazilian Climatological Normal (1991–2020), published by INMET (2022), indicates that the stations in the northeastern region of Brazil receive, on average, 2,600 h of sunshine per year, with a monthly distribution that varies little, averaging 223 $\pm$ 21 h of sunshine per month. In contrast, the northern region of the country has an average of approximately 2,200 h of sunshine per year, with notable fluctuations across the months, including a considerable decline in sunlight between December and April.

Figure 2 shows the map of water vulnerability in Brazil, with the scale ranging from class 1 (very low) to class 5 (very high). The percentage of Brazilian territory for each category is also presented in Figure 2. The Northeast region of Brazil, extending



Class	WVI	Area (%)
Very low	0 - 1	18.1
Low	1 - 2	34.5
Medium	2 - 3	29.7
High	3 - 4	15.2
Very high	4 - 5	2.5

Figure 2 | Map of the WVI in Brazil.

north to the state of Minas Gerais, exhibits the most critical vulnerabilities. Other significant areas of vulnerability in Brazil include the southern state of Rio Grande do Sul, and the northern states of Roraima and Amapá in the North Region, which demonstrate vulnerability levels ranging from moderate to high, despite being in regions considered to have good water availability.

Figure S3 (Supplementary Material) presents the map of potential regions for the implementation of SODIS, along with the percentage of Brazilian territory for each of the nine classes. The map reflects the observations made in the WVI map, with a particular emphasis on the semi-arid regions and the northern part of the Amazonian region. The implementation of alternative technologies using solar energy in these areas is possible due to their higher levels of global solar radiation incidence. Public policies for the implementation of SODIS should prioritize these regions.

To improve the visualization of the potential map for the implementation of SODIS systems, the map was reclassified into three categories: low (values from 1 to 3), medium (values from 4 to 6), and high (values from 7 to 9). Figure 3 shows this reclassified map, which indicates that most of the Brazilian territory has a medium potential, confirming the findings presented in Figure S3.

However, other regions in Brazil could strategically plan the implementation of SODIS. This could be due to the potential driven by solar radiation intensity, as observed in the central region of the country, or due to pressing needs, as exemplified in the southern part of the State of Rio Grande do Sul. These locations are also prominently featured on the map and could be classified as a secondary priority. The highlighted regions are notable not only for their solar potential but also for the abundance of tubular groundwater wells, as shown in Figure S4 (Supplementary Material). Although many of these wells may be used for industrial water supply purposes, their presence highlights the increased pressure on water resources.

To confirm the research findings, Figure 4 shows the map of water vulnerability related to ESE aspects. The vulnerability in the northeastern region of Brazil is confirmed, and ESE water vulnerability is considered high in the northern region of Brazil, particularly in the state of Amazonas. More than 44% of Brazil's territory can be classified as having high or very high water vulnerability.

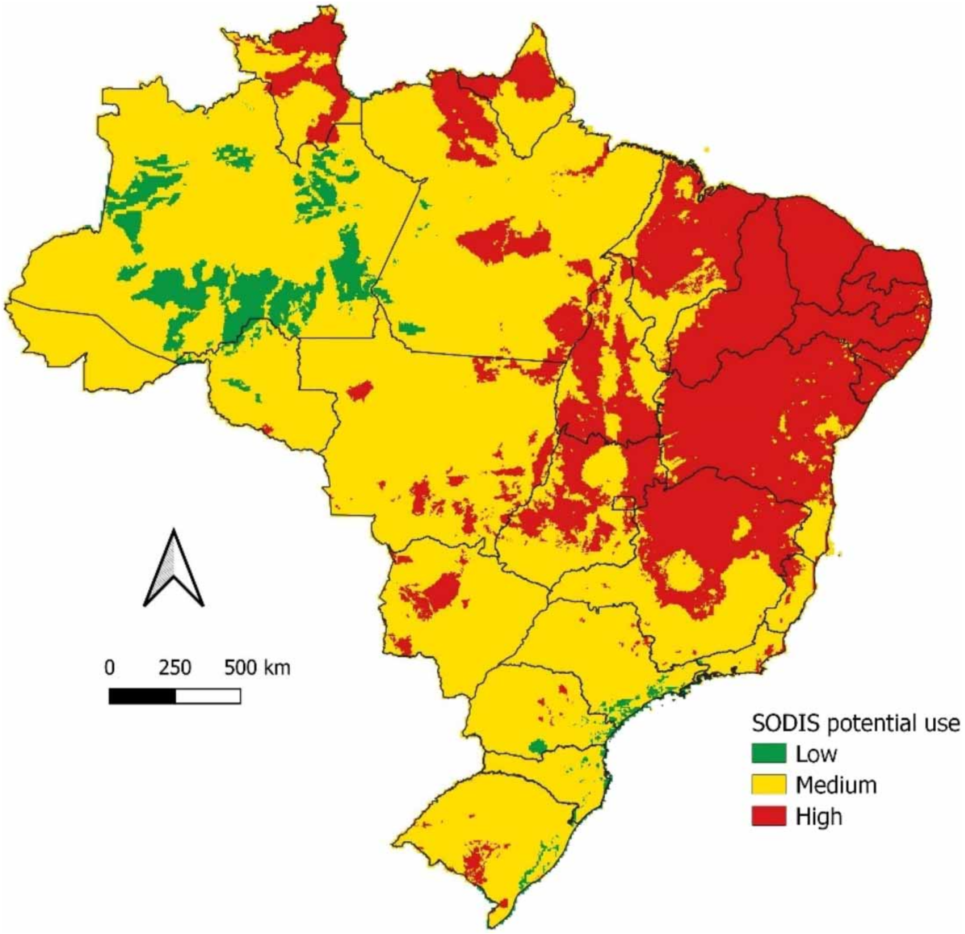
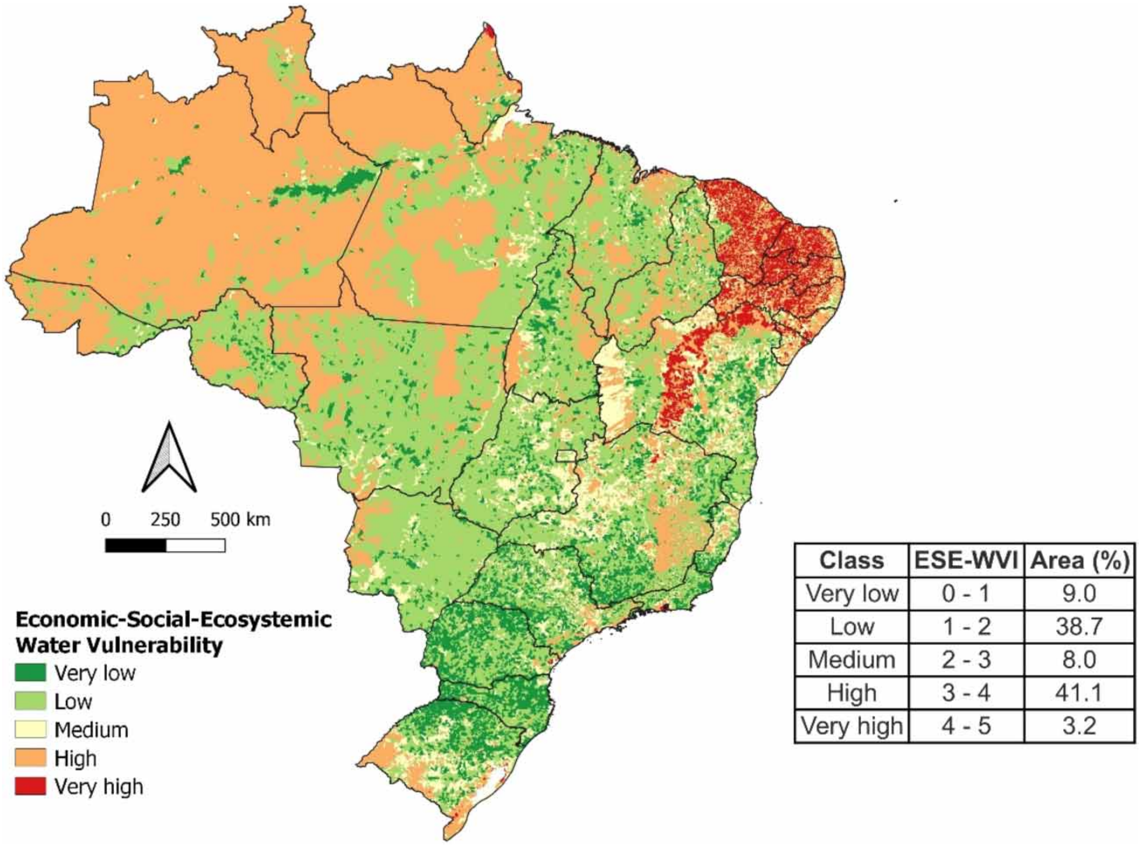


Figure 3 | Reclassified map of potential SODIS use in Brazil.

Although the Amazon region has high water availability, this may seem inconsistent with the results shown in Figure 4. However, data can help to explain this aspect. Despite having approximately 71% of the country's water resources (EBC 2017), the northern region has a water supply service index of only 64.2%. This means that over 35% of the population does not have access to treated water in their homes (SNIS 2022). Furthermore, the sewage service coverage in this region is only 14.7%, which is significantly lower than the national average of 56% (SNIS 2022). This low coverage rate means that the local population has to resort to using water from the region's rivers, which is often carried in buckets (EBC 2017) and may not be safe for consumption due to possible contamination by sewage. Additionally, the indigenous reserves in the region also encounter challenges in accessing quality water.

A new map was generated to represent the priority areas for the application of SODIS in Brazil (Figure S5 – Supplementary Material). The map was created by overlaying the potential use of SODIS with the ESE water vulnerability map. The visualization of the map clearly shows two major priority areas for the application of SODIS. The northeastern region of Brazil is characterized by scarcity, long periods of drought, and unfavorable socio-economic conditions. Similarly, the northern region of Brazil is characterized by low water supply despite its abundance, risk of contamination of the consumed water, and also unfavorable socio-economic conditions.

Figure 5 shows the results of the map presented in Figure S5, reclassified into three categories for ease of visualization. The northeastern region has over 87% of its territory classified as high and medium priority for the implementation of SODIS, with 44% of the area classified as high priority. The northern region has over 74% of its territory classified as high or medium priority, with more than 67% being medium priority. Given the reality of these two regions, it can be considered that the implementation of SODIS policies and projects should prioritize these areas.



Class	ESE-WVI	Area (%)
Very low	0 - 1	9.0
Low	1 - 2	38.7
Medium	2 - 3	8.0
High	3 - 4	41.1
Very high	4 - 5	3.2

Figure 4 | Map of ESE-WVI in Brazil.

DISCUSSION

A potential limitation of this study is the necessity for a considerable amount of secondary information to be sourced in order to produce the maps. The data presented here have been sourced from a variety of sources (see Supplementary Material), with varying resolutions and undergoing certain transformations (vector to raster) prior to being submitted to map algebra. This may result in an underestimation of the significance of the results obtained. However, given the fragmentation of sources and limitations in obtaining data from all over the country, this approach was deemed the most viable alternative for developing the methodology. In comparison to the findings of Moreno-SanSegundo *et al.* (2021), the results of this study demonstrate the production of coherent maps. The aforementioned authors constructed a world map of potential for the use of the SODIS method, using criteria including radiation incidence and the number of sunny days.

As with the findings of this study, the map produced by Moreno-SanSegundo *et al.* (2021) indicates a heightened potential for the implementation of SODIS in the northeastern region of Brazil, with a particular focus on inland areas. In comparison, the regions in closer proximity to the Sahara Desert, the Middle East, India, and the Australian Outback exhibit a greater potential for utilizing SODIS than the northeastern region of Brazil, as illustrated in the map presented by Moreno-SanSegundo *et al.* (2021).

The northeastern semi-arid region of Brazil has a long history of water scarcity and prolonged droughts. Tomaz *et al.* (2023) highlight the challenges faced by families in this region, particularly during extended drought periods. They emphasize the impact of water supply issues on social relations and human development within communities.

In Brazil, the Instituto Melhores Dias (Inmed Brasil) implements initiatives in disadvantaged communities in collaboration with local governments, facilitating the delivery of resources and tools to enhance the health and education of children, families, and communities. Inmed Brasil facilitates the transfer of SODIS technology to impoverished communities in rural Brazil through the delivery of workshops and lectures in educational institutions. Since 2010, Inmed Brasil has provided training to approximately 41,000 teachers, 10,000 school cooks, and 26,000 community health workers across 12 Brazilian

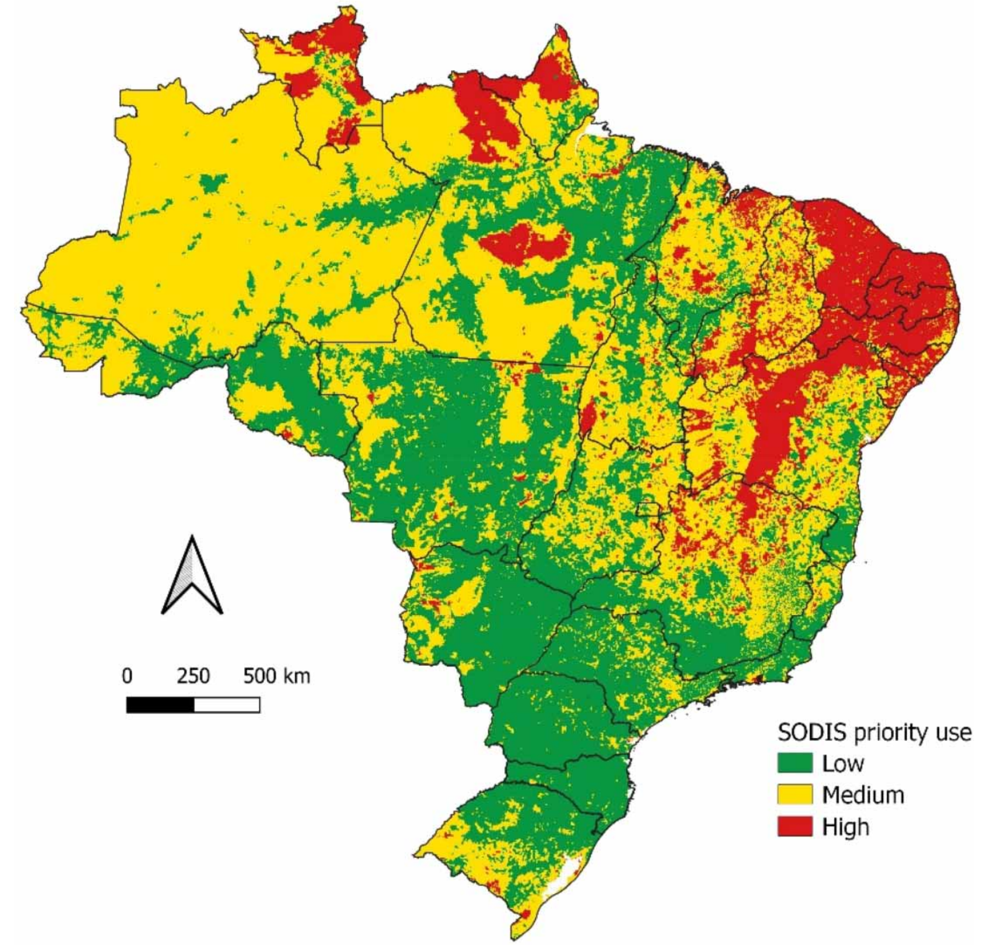


Figure 5 | Map of priority for the use of SODIS in Brazil.

states on the utilization of SODIS (BB Foundation, n.d.). Furthermore, it has implemented significant initiatives in states in the Northeast and North of the country, particularly in cities in the states of Maranhão, Tocantins, and Rondônia, which corroborate the areas identified as being in need in this study.

The WVI map effectively demonstrates the need for water treatment technologies in regions outside of the semi-arid zone. Populations in agricultural communities in the southern part of the country, indigenous territories, and isolated communities in the Amazon rainforest are facing increasingly limited access to quality water. These regions highlight the importance of implementing simple and cost-effective water treatment methods.

In the context of socio-economic challenges caused by drought in the semi-arid region of the northeast, implementing additional SODIS projects can help alleviate conflicts. This region has been described by Brito & de Almeida (2023) as facing socio-spatial, socio-economic, and political-institutional conflicts.

In the context of climate change and growing pressure on water resources, it is expected that larger segments of the population will experience episodes of water scarcity, both in terms of quantity and quality. Despite Brazil's perceived water abundance, it faces issues due to uneven distribution and areas with high population density. In areas with proven scarcity or even in urban areas, the population often relies on the use of water from underground sources to meet their needs. However, groundwater, like any water source, is susceptible to contamination (Saxena & Den 2022; Vijayakumar *et al.* 2022), particularly microbiological contamination (Silva *et al.* 2017). Contamination can occur in pipelines, water outlets, or collection containers, even when sourced from artesian wells.

Another important aspect of SODIS is its use as a simple and cost-effective alternative for water disinfection technology (Karim *et al.* 2021), mainly in tropical countries (Nwankwo *et al.* 2022). The World Health Organization (WHO) recommends SODIS as a suitable method for treating household water, especially in underprivileged, rural, or areas with limited access to clean drinking water (Karim *et al.* 2021; Johansson *et al.* 2022). By the end of the 2000s, SODIS was estimated to be used daily by over 2 million people in 28 low-to-medium-income-countries, including Kenya, India, and some Latin American countries (CDC 2008). Nevertheless, certain constraints must be acknowledged with regard to the utilization of SODIS. These include the restricted volume of water that can be processed on a daily basis, due to the inherent limitations of utilizing plastic bottles; the intermittent nature of sunlight availability; and the presence of turbidity, which, at levels exceeding 30 Nephelometric Turbidity unit (NTU), has the potential to compromise the efficacy of SODIS (Chaúque & Rott 2021).

In this context, it is relevant to consider additional aspects of SODIS implementation. Ongoing studies are investigating the potential migration of microplastics from bottles to water, which may be a cause for concern regarding the technique's use (Álvarez-Fernández *et al.* 2024). Additionally, research efforts should concentrate on evaluating and enhancing the technique to ensure satisfactory performance in inactivating more resilient microorganisms, such as protozoa (Chaúque & Rott 2021).

It is important to note that many experiments use total coliforms or *E. Coli* as indicator microorganisms (Amirsoleimani & Brion 2021; Brockliss *et al.* 2022; Juvakoski *et al.* 2022). However, protozoa are more resistant to the action of SODIS due to their protective forms (cysts and oocysts). Therefore, it is essential to conduct studies evaluating these organisms. Promising results were achieved for the inactivation of *Cryptosporidium parvum* and *Giardia muris* under laboratory conditions with solar simulator irradiation of 870 W/m^2, temperature above 40°C, and exposure times between 4 and 12 h (McGuigan *et al.* 2012). In a real-scale treatment study, O'Dowd *et al.* (2023) achieved a 3-log reduction in *C. parvum* after 48 h of solar exposure.

Although SODIS was initially conceived as a low-cost technique that utilizes simple and effective materials, such as PET bottles, some studies aim to expand its scale by implementing small-scale plants (Johansson *et al.* 2022). This application holds significant potential for areas with larger populations, even if it is not deployed on a large scale.

It is important to note that the expansion of SODIS usage presents a significant challenge. To ensure the continued efficacy of SODIS, it is essential to minimize the required exposure time of water to the Sun, while processing large volumes of water during the day. In light of the aforementioned challenges, current studies are seeking to develop continuous flow systems for solar water disinfection that: (i) combine the properties of solar pasteurization and SODIS; (ii) enhance the performance of solar radiation collectors, photo-thermal reactors, and heat exchangers; and (iii) integrate disinfection technologies based on photocatalytic and photo-thermal nanomaterials (Chaúque & Rott 2021).

CONCLUSIONS

The method employed to create maps of potential and priority areas for the use of SODIS was deemed suitable and can be replicated in other regions or countries. One potential limitation is the lack of data on natural, economic, and social water vulnerability, as well as the risk of water resource contamination. In such cases, it would be necessary to compile a database before implementing the method outlined in this paper.

To establish priority areas for the implementation of SODIS, it is necessary to consider information on socio-economic and environmental aspects. The SUPI alone, which is based on solar radiation and natural water vulnerability, cannot provide accurate decision-making.

The traditional SODIS technique is prioritized for application in the Brazilian semi-arid region and parts of the Amazon region. Other areas with agricultural and urban demand may consider implementing small-scale SODIS systems.

FUNDING

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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