AGRONOMY SCIENCE AND BIOTECHNOLOGY

REVIEW ARTICLE

Water rationalization in Brazilian irrigated agriculture

Felipe Jorge Viana[1], Fernando França da Cunha[1], Mayara Oliveira Rocha[1] and Job Teixeira de Oliveira[2,*]

[1]Departament Agricultural Engineering, Universidade Federal de Viçosa (UFV), Campus Universitário, Viçosa, MG, Brazil, CEP 36570-900. [2]Department Agronomy, Universidade Federal do Mato Grosso do Sul (UFMS), Campus CPCS, Chapadão do Sul, MS, Brazil, CEP 79560-000. *Corresponding author, E-mail: job.oliveira@hotmail.com

ABSTRACT

Freshwater, an essential asset for the life of living beings and one of the main resources for the development of nations. About 70% of the freshwater on the planet is used by irrigated agriculture. In view of the increasing population density for food production, considering the limitations of agricultural processes, countless producers are looking for viable alternatives that provide them with greater production, irrigation being one of them. This bibliographic review aims to summarize information on the topic: Rationalization of Water Resources and Environmental Impacts in Irrigated Agriculture, based on searches in books, scientific articles, and publications by reputable organizations related to the topic. In these, aspects related to water scarcity, the challenges of irrigated agriculture, contamination of water resources, the reuse of water for irrigation, the quality of reused water, and adequacy of water for irrigation are dealt with. The need for conservation of water resources and awareness of the irrigator regarding the rational use of water and the environmental impacts inherent to the irrigation process is evident, therefore, the intention is to consolidate increasingly sustainable agriculture.

Keywords: Agriculture, irrigation, water resources, rational use, hydrology, agricultural systems.

Citation: Viana, F. J., Cunha, F. F., Rocha, M. O., & Oliveira, J. T. (2022). Water rationalization in Brazilian irrigated agriculture. *Agronomy Science and Biotechnology*, 8, 1-15 https://doi.org/10.33158/ASB.r154.v8.2022

Received: October 06, 2021.
Accepted: November 25, 2021.
Published: February 25, 2022.

English by: Job Teixeira de Oliveira.

INTRODUCTION

One of the greatest challenges facing humanity in this century is to guarantee food security for all people, on a planet with great social, economic, and environmental differences. For this it is necessary to intensify agriculture in a sustainable way and improve the efficiency of agricultural systems, making them more productive. Sustainable irrigated agriculture includes its own practices, activities, interactions, and concepts, inherent to intensive regimes and relatively higher production costs, but with proportionally greater benefits (Borghetti, Silva, Nocko, Loyola, & Chianca, 2017).

Irrigation is constituted in complementing, through the rational application of water, the water needs of the crop, minimizing the impacts of the climate on its yield, in order to reach productions that are economically viable. Irrigation requires management that consists of defining how, how much and when to irrigate (Oliveira, Cunha, Oliveira, Silva Junior, & Bufon, 2020).

Thus, the use of irrigation brings increased crop productivity and social return, as well as financial return for rural people, including improved respect for ecosystems. In addition, it can establish new job opportunities with better qualifications, both in the production unit and outside it, as well as and especially in agribusiness, improving the income of rural communities and their quality of life (Rodrigues & Domingues, 2017).

In view of the above, this review aims to synthesize information on the topic: irrigation and environmental impacts associated with water use, briefly reporting the conceptual aspects related to the topic addressed.

The research is exploratory, where articles and books with related subjects were researched: “irrigation and environmental impacts associated with the use of water”. The research was carried out via the Google Scholar platform and in libraries.

The selection was made in articles with less than 15 years, giving preference to those with less than 5 years of publication.

About 68 publications were found, including books, articles, book chapters, reports, and technical notes on the subject, but filtering was carried out and 52 citations were used in this study.

WATER RATIONALIZATION

Current scenario of irrigated agriculture - water scarcity

Historically, in Brazil there has always been a culture of abundance of water resources. This was based on previously prevalent intuitions that treated water as an easily renewable and extremely abundant natural resource. The consequences of this misconception are the culture of misuse and waste, both in the processes of collection, distribution and use, without a greater concern with the necessary conditions for the sustainability of activities dependent on these resources (Rodrigues & Irias, 2004).

In agreement with Pimenta, Speroto, Costa and Dionizio (2021) the transformation in Brazilian agriculture is not spatially uniform and depends on local and regional factors. Specific characteristics of the local climate, such as the length of the rainy season and photoperiod, and other regional factors, including the type of biome, land suitability, availability of water resources and energy infrastructure for irrigation, are relevant aspects. Figure 1 shows the evolution of water withdrawal in Brazil and a forecast until 2030.

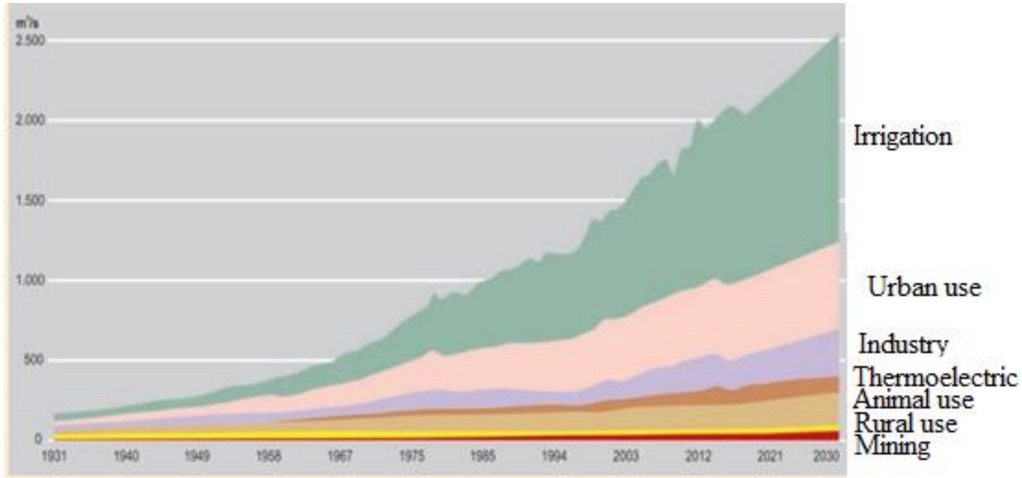

Figure 1. Evolution of water withdrawals in Brazil since 1931 and forecast until 2030, by user sector (1931 – 2030).
Source: Agência Nacional de Águas (ANA) (2019).

Changes in land use can have a strong influence on hydrological processes (Bosmans, Beek, Sutanudjaja, & Bierkens, 2017), which can contribute to flooding and drought, for example. Drought was defined as "a water deficit relative to normal conditions" Brazil has abundant freshwater resources. Considering the total volume of water in the country, we may have the false thought that it is enough to accommodate current and future demand. However, water availability is unevenly distributed (Duden et al., 2021; Hernandes, Bufon, & Seabra, 2014), and several sub-basins in the Southeast and Midwest regions of Brazil are facing water scarcity problems (Flach et al., 2016).

Specifically, the Cerrado biome, for which expansion in sugarcane production is expected, has periods of drought and soils with less water storage capacity than current sugarcane cultivation areas (Scarpare et al., 2016; Duden et al., 2021). Therefore, concerns have arisen about the potential impacts of the expansion of this culture in Brazil. Oliveira et al. (2020), highlight the feasibility of installing irrigation in sugarcane fields, but warn of the need for proper management of the use of water and electricity so that the enterprise can be successful.

Challenges of the rational use of water in agriculture

The growth of water scarcity and competition among water users (Figure 2) represents a serious challenge for water resource managers in different regions of the world. A relatively high per capita water availability covers serious regional and seasonal water availability problems as well as quality problems that compromise the various uses (Rodrigues & Domingues, 2017).

As attributed by Almeida and Costa (2014), the climate is considered a preponderant element when it comes to irrigated agriculture. It influences the natural factors of agricultural crops, through the rainfall regime present in a given area. Therefore, the interference that the climate exerts in agricultural practice is concrete, especially through the amount of rain that occurs in a certain location.

Practically way, irrigation projects must consider the social and ecological aspects of the region and seek to maximize productivity and water use efficiency and minimize costs. As well as improving or, at the very least, maintaining the physical, chemical, and biological conditions of the soil, which will undoubtedly greatly influence the project's useful life (Bernardo, 2008).

Among the various technologies developed to rationalize the use of water, there are those developed for the irrigation system, one of the most important processes for agricultural production and which consists of applying water to the soil in non-rainy seasons, so that it does not dry out and the plants dry out (Oliveira et al., 2021).

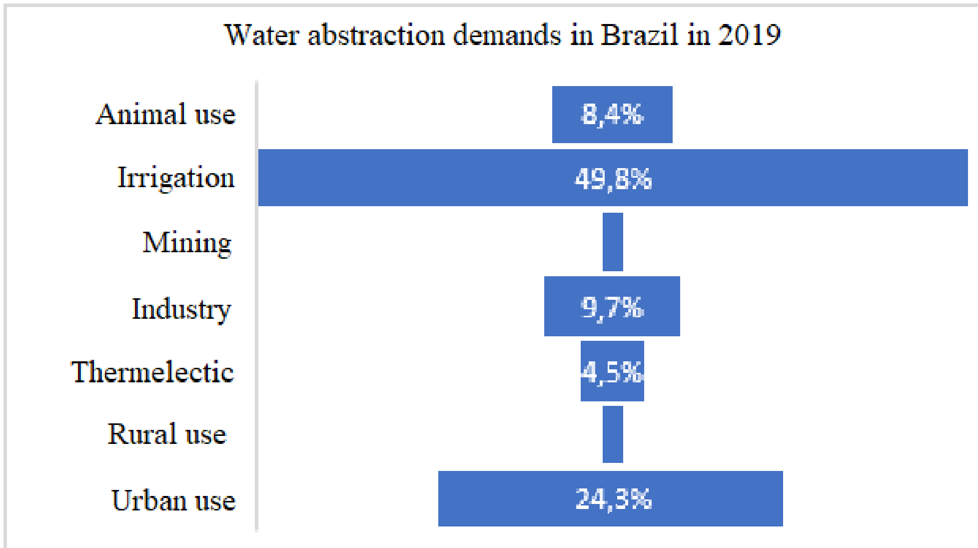

Figure 2. Evolution of water withdrawals in Brazil, by user sector (1931 – 2030).
Source: ANA (2019).

Under these aspects, Cunha and Augustin (2014) infer that current water problems can be solved by the scientific community, which is capable of bringing new technological and economic solutions. However, environmental problems are already at a stage where solutions cannot be left to specialists alone, it must encompass the entire society that must be sensitized to the importance of their role in the challenge of rational use of water.

In addition, Friesen, Sinobas, Foglia, & Ludwig, (2017) point out that currently one of the main concerns facing the water issue has been the availability, quantity, quality, distribution, limited allocation of water resources, and climate change. Water is the primary resource for all life, just as it is essential for agriculture in many regions of the world.

The increase in population density in urban centers linked to the growth of activities that demand a large volume of water triggers a gradual pressure on water resources. The history of the evolution of water use is linked to the process of urbanization and economic development in Brazil. The water demand in the country is growing, as in the last twenty years there has been a significant increase of approximately 80% in the total amount withdrawn. By 2030, withdrawal is expected to increase by 26% (ANA, 2019), as shown in Figure 1.

The challenges for efficient management of sustainable water use in the face of population growth are being faced gradually, however developing countries find it difficult to deal with the lack of infrastructure, increased demand for water, solve scarcity problems and manage conflicts between water users (Friesen et al., 2017).

Another constant concern is exposed by Vieira, Sandoval-Solis, Pedrosa and Ortiz-Partida (2020), who inform that the understanding of climate change associated with the effects of changes in land use is essential for the sustainable development of water resources in river basins. In this sense, actions that change land cover without proper planning, such as replacing native forests with pasture, increasing the planted area, expanding irrigated agriculture, result in changes to natural systems and consequently to the hydrological cycle, directly affecting the quality and amount of water available.

According to Bosmans et al. (2017), the anthropogenic impact on the global terrestrial hydrological system has many aspects. The climate, as well as more direct human interventions such as dam construction and water withdrawal (for domestic, industrial, and agricultural use, including irrigation) have a strong impact on future water availability, floods, and droughts (Winsemius et al., 2016; Veldkamp et al., 2017).

Contamination of water resources

The irrigated area in the world in 2013 reached 310 million hectares, 70% of which was located in Asia. India is the country with the largest irrigated area in the world, 66 million hectares, followed by China and the United States, with 62 and 27 million hectares, respectively. The irrigated area in Brazil has more than 8.2 million ha (ANA, 2021), ranking it among the ten countries with the largest irrigated area in the world (Carvalho et al., 2020a). Below table 1 with the irrigated areas in Brazil.

However, the availability of freshwater for use in agriculture is also declining, due to general population growth and increased demand for freshwater for residential and commercial use. As a result, the quality of the water used to irrigate crops (eg its pH, salinity levels, and content of different contaminants) is declining (Zandalinas, Fritschi, & Mittler, 2021).

Melo and Queiroz (2020) report that water unsuitable for agriculture, in addition to contaminating, can degrade the soil through salinization, sodicity, poisoning plants, corroding and clogging pipes, making agricultural production unfeasible, it can also lead to contamination of direct users and indirect (Almeida, 2010) and still reduce profits and even make the activity unfeasible.

The world agricultural production has grown between 2.5 and 3.0 times in the last 50 years, while the cultivated area has grown only 12%. Clearly, 40% of the increase in food production came from irrigated areas (FAO, 2011). However, the inadequate use of irrigation in intensive agricultural systems can negatively impact water quality due to the use of pesticides and other harmful substances (Darré, Cadenazzi, Mazzilli, Rosas, & Picasso, 2019).

Excess water applied to the irrigated area, which is not evapotranspiration by crops, returns to rivers and streams through both surface and subsurface runoff or goes to underground deposits, by deep percolation, carrying with it soluble salts, fertilizers (N, P, and nitrates), pesticide and herbicide residues, toxic elements, sediments, etc. Certainly, the contamination of water resources has caused serious problems for the supply of drinking water, both in rural areas and in urban centers (Bernardo, 2008).

The reliability of water resources is also a limiting factor for economic development in many water-scarce countries (Danso et al., 2015). With agriculture accounting for nearly 70% of all freshwater withdrawn and over 90% of total drinking water use, this will inevitably lead to "irrigation points" where agricultural water demand exceeds what is available (Perea, Daccache, Díaz, Poyato, & Knox, 2018).

Table 1. Irrigated area in the regions, states and Federal District, 2021.

Region/State	Irrigated Area (ha)
North	434.007
Acre	1.339
Amapá	53.57
Amazonas	71.06
Roraima	27.009
Rondônia	70.838
Tocantins	155.404
Pará	54.850
North East	**1.198.019**
Maranhão	69.889
Piauí	50.593
Ceará	71.810
Rio Grande do Norte	47.017
Paraíba	52.591
Pernambuco	155.858
Alagoas	180.016
Sergipe	58.072
Bahia	495.190
Southeast	**3. 862. 244**
Minas Gerais	1.144.428
São Paulo	2.418.298
Rio de Janeiro	38.905
Espírito Santo	260.613
South	**1. 568. 678**
Santa Catarina	184.506
Rio Grande do Sul	1.128.687
Paraná	255.485
Midwest	**1. 261. 053**
Mato Grosso	292.947
Mato Grosso do Sul	265.313
Goiás	669.912
Distrito Federal	33.358
Total Brazil	**8.195.391**

Adapted from Rodrigues and Domingues (2017).
Source: ANA (2019).

Agricultural pesticides were and are used in agriculture to eradicate/control bacteria, fungi, weeds, insects, rodents, and any organisms that can harm crops, reducing the quantity and quality of food products (Barbosa, 2014). Excessive use of chemical inputs can cause severe problems related to the contamination of biotic and abiotic components in certain spaces. The toxic substances present in these products can be incorporated into the food chain and, therefore, contaminate large amounts of living beings. In the case of fertilizers, for example, the phosphate and nitrate present in their chemical composition are the main responsible for the eutrophication of water due to the formation of favorable environments for the development and proliferation of algae, which consume aquatic oxygen (Queiroz, Alves, & Silva, 2021).

The imminent depletion of water resources has demanded that the water use regulation and inspection bodies have more rigor in order to ensure the sustainability of the activities. However, compliance with specific legislation has run into some institutional barriers, such as bureaucracy, slowness, high fee costs, and lack of awareness (Furquim & Abdala, 2019).

Water reuse for irrigation

Humanity has been affected by numerous crises, such as epidemics, food and oil. Unquestionably, the current ones are for energy and the availability of good quality water.

A projection points out that more than 9.5 billion people will inhabit the planet in 2050, agriculture will grow by approximately 60% and water consumption by approximately 20%; thus, if there are no significant changes in water management, global water security will be strongly compromised, affecting human, economic and social developments (Cantelle, Lima, & Borges, 2018; Ferreira et al., 2019).

This society/nature paradigm seeks to understand how anthropic actions modify the environment and use it for its development in the same way as the environment, formed by living beings, climate, relief, among other elements, can interfere in society.

Freshwater scarcity has become a growing problem around the world. According to González-Fragozo, Zabaleta-Solano, Devia-González, Moya-Salinas and Afanador-Rico (2020) wastewater has been used in agriculture for many years; in ancient Rome, it was used as a fertilizer. Currently, its use has increased due to the scarcity of freshwater. This reused water is mainly applied to crops that are processed before consumption, such as corn and rice and fruits that are consumed raw; to a lesser extent, in some industrial crops, such as cotton, in addition to timber and forage trees (Garzón, González, & García, 2016).

Some rainwater harvesting techniques, such as cisterns associated with sidewalks, roofs, and plastic surfaces for capturing low-cost irrigation systems, can mitigate the effects caused by irregular rainfall, increasing agricultural production and reducing production risks in periods of drought. Studies carried out in Brazil reveal that rainwater harvesting technologies promote increased crop productivity. Nevertheless, the stored water must be used in irrigation systems in a cautious way, proceeding with the correct choice and management of the irrigation method, so that the volume of water captured from the rain is sufficient to supply the need for water for the crop no waste (Brito, Moura, & Gama, 2012).

Alves, Lima, Dantas Neto, Lima Júnior and Melo Júnior (2021) understand that the use of low-quality water in irrigated production systems has been widely observed in several regions of the country. Crops such as nitrogen, phosphorus, potassium, and micronutrients, which can considerably reduce expenses with the acquisition and application of chemical fertilizers. Ensure the development and sustainability of the agricultural activity.

Oliveira, Maradini, Borges and Gava (2021b) address the issue of the feasibility of central pivot irrigation with reuse water from three different sewage treatments in a city. Thus, providing an excellent alternative for using water. There is central pivot irrigation equipment that has already been adapted for the application of wastewater. It is a PVC layer inside the galvanized steel piping, so that there is no corrosion of the equipment structure, as there is no direct contact between the residue and the steel. Vinasse water, which is the residual liquid from the fuel alcohol manufacturing process, is applied. Diluted liquid pig slurry is also applied. Therefore, alternatives for water reuse via irrigation exist, and it is a very important tool for improving the quality of river water since by applying wastewater to the soil with irrigation equipment, this water is prevented from coming to contaminate the rivers.

The use of effluents in agriculture can be not only a solution for water but also an important ally in mitigating the concentration of CO_2 in the atmosphere due to a load of organic matter present. Even so, in order to develop more systematically sustainable management practices and proposals, it is essential to have information about impacts on soils. Quantify their stocks of carbon, nitrogen, and other nutrients, caused by the incorporation of new resources and technologies in human activities, such as the treatment and reuse of domestic effluents in agriculture (Correia et al., 2020).

In agreement with Lucena, Santos, Silva., Costa and Lucena, (2018) focus that the reuse of effluent water can generate economic, social, and environmental benefits for the communities in which this practice is inserted.

As described by Ucker et al. (2013), the adequacy of water for irrigation is still very subjective, however, one should always try to identify and evaluate some parameters that could produce unpleasant effects on the water, plant, and soil relationship. For example, water may be considered adequate for a certain type of soil or crop, but inadequate for others. Therefore, it is always necessary to analyze: the physicochemical characteristics, the sanitary quality of the water, the soil characteristics, the tolerance of the crops to be used, the local climate, irrigation management, and drainage.

Quality of reused water

Proper management of irrigation water is essential to obtain high productivity, quality, cost reduction, and rational use of water. The proper management of irrigation cannot be considered an independent step within the agricultural production process, tending, on the one hand, to the efficient use of water, promoting the preservation of the environment, and on the other hand, the commitment to the productivity of the exploited crop (Padrón, 2021).

In recent years, as assured by Sales, Aguiar Netto, Monteiro and Carvalho, (2020), the theme of water resources in agricultural land has been discussed with greater frequency, focusing on the losses in quality and quantity when successive plantings are adopted. In this way, it threatens water sustainability, especially in arid and semi-arid regions. Due to the multiple uses of water without the correct environmental control, regularly evaluating water quality parameters becomes essential as a way to control pollution.

In this sense, water quality is therefore used as an indicator of the conditions of the aquatic system and to assess the state of pollution, degradation, or conservation of rivers, lakes, dams, estuaries, coastal waters, and wetlands (Souza et al., 2021). This assessment can be carried out using monitoring, which is the collection of regular information and the formation of a fundamental database for future actions related to management use, and conservation (Carvalho et al., 2017; Carvalho et al., 2020b).

Considering that the presence of some components that confer salinity to the water, combined with inadequate irrigation management, can accelerate soil degradation and, consequently, promote the decline of productivity in irrigated areas (Alves et al., 2021).

In this context, water quality is an aspect that must be considered in irrigation agriculture, because depending on its physicochemical and biological characteristics, its use may become limited or unfeasible. The main water quality parameters that directly or indirectly affect the irrigation system and the quality of irrigated water are pH, total iron, magnesium, calcium, hardness, bacteria, and algae (Rodrigues et al., 2020).

The different uses of water have different quality requirements. The waters with better quality allow the existence of more demanding uses, while waters with worse quality allow only the less demanding uses (ANA, 2019). Conama Resolution No. 357, of March 17, 2005, in Article 3, establishes that fresh, brackish, and saline waters in the National Territory are classified, according to the quality required for their predominant uses, in 13 quality classes. With the following classes of water intended for irrigation:

• Class 1 brackish water: irrigation of vegetables that are consumed raw and of fruits that grow close to the ground and ingested raw without removing the skin; and the irrigation of parks, gardens, sports, and leisure fields, with which the public may have direct contact (Rodrigues & Domingues, 2017).
• Class 2 freshwater: irrigation of vegetables, fruit plants, and parks, gardens, sports, and leisure fields, with which the public may have direct contact.
• Class 3 freshwater: irrigation of arboreal, cereal, and forage crops.

Carvalho et al. (2017) highlight that it is essential to identify water quality, as well as its vulnerability to human activity so that adequate management can be implemented, aiming at maintaining environmental resources. This is also important to identify the suitability of the main purposes within the processes of irrigated agriculture (Santi, Furtado, Menezes, & Keppeler, 2012).

Semi-arid regions, the climate is characterized by short periods of rain followed by long periods of drought, that is, there is a low concentration of water available in quality and quantity, with poor distribution and high atmospheric losses by evaporation and low precipitation rates (Gheyi, Paz, Medeiros, & Galvão, 2012).

It is of great importance to identify the quality of water, as well as to verify its vulnerability to human activity, so that adequate management of water resources is carried out, in particular regarding its management use, and conservation (Carvalho et al., 2017). The monitoring that determines planning actions for the conservation of the water resource is necessary, as the characteristics of water quality vary according to space and time, and can determine numerous water characteristics in different places and periods, which can lead to a large number of correlated information (Sales et al., 2020).

Adequacy of water for irrigation

Irrigation is a technique that allows for greater safety in crops, diversification of production, among other advantages. However, it requires implementation studies for a better choice of irrigation method and system with the same degree of importance, but with less diffusion are preliminary studies to assess the quality of irrigation water and its availability for use (Melo & Queiroz, 2020).

Bernardo (2008) highlights the importance of irrigation to increase the supply of food and fiber to the population. He also points out that there are serious problems regarding the environmental impacts that can be caused. This is because, since irrigation is an artificial way of applying water to the soil to meet the evapotranspirometric demand of crops, it represents a technological introduction modifying the environment.

Soil management is entirely linked to water management, being essential for the property, constituting adequate principles and procedures for the successful efficient use of water. Since inadequate water management causes numerous problems, such as lower productivity, lower quality fruits, environmental damage, soil erosion, and reduced air in the soil. It is common to note that the use of irrigation systems has been hampered by inadequate water management (Eerthal & Berticelli, 2018).

Water is dynamically interrelated with different strategic issues, such as food security, energy matrix, economic growth, sanitation, and sustainability. Faced with population growth, industrialization, energy generation, and agricultural production are under pressure due to increased consumption. Thus, the total amount of water resources required to meet such demands is growing, with the flow withdrawn for agricultural use standing out. However, efficient and effective technological alternatives for water management are already available, such as modeling, environmental information systems, simulation tools, and other computational technological innovations, which allow the management, through data sharing, monitoring, and evaluation of risks (Cantelle et al., 2018).

FINAL COMMENTS

The agricultural sector increasingly requires the inclusion of techniques that minimize production risks and increase productivity to meet the global demand for food. In this sense, irrigation is a great ally of producers.

The impacts generated by the incorrect use and/or management of irrigation systems must be considered, serving as a subsidy for the design of more efficient irrigation systems capable of optimizing the use of mobilized water resources, with to reduce the potential risk of environmental impact.

Emphasizing that, as reported in this research, irrigation can cause damage to agriculture, such as soil salinization, exaggerated and inadequate water consumption, which can cause a scarcity of the resource in times of drought.

Therefore, it is essential to raise awareness and train farmers in the proper use of water, not only thinking about quality and quantity means in production, but also thinking about the common good of all who use it.

Finally, there is a need for future research regarding the availability and use of water, as well as consultancy related to sustainable management and irrigation.

REFERENCES

Almeida, J. J. G., & Costa, F. R. (2014). Análise Dos Impactos Ambientais Da Agricultura Irrigada No Perímetro Irrigado De Pau Dos Ferros (Rn). *Geografares*, 22–44. https://doi.org/10.7147/geo16.4898

Almeida, A. O. (2010). *Qualidade da água de irrigação*. Cruz das Almas, BA: Embrapa Mandioca e Fruticultura.

Alves, A. D. S., Lima, V. L. A., Dantas Neto, J., Lima Júnior, B. C., & Melo Júnior, A. P., (2021). Quality of wastewater applied to banana tree culture. *Brazilian Journal of Animal and Environmental Research*, 4(1), 511–531. https://doi.org/10.34188/bjaerv4n1-045

ANA - Agência Nacional de Águas. (2019). *Levantamento da agricultura irrigada por pivôs centrais no Brasil* (2ª ed.). Brasília, DF: ANA.

ANA - Agência Nacional de Águas. (2021). *Atlas irrigação: uso da água na agricultura irrigada* (2ª ed.). Brasília, DF: ANA.

Barbosa, V. (2014). *A última gota*. São Paulo, SP: Planeta.

Bernardo, S. (2008). Impacto ambiental da irrigação no Brasil. (pp. 1-13). Rio de Janeiro, RJ: Winotec. http://www2.feis.unesp.br/irrigacao/imagens/winotec_2008/winotec2008_palestras/Impacto_ambiental_da_irrigacao_no_Brasil_Salassier_Bernardo_winotec2008.pdf

Borghetti, J. R. L. C., Silva, W., Nocko, H. R., Loyola, L. N., & Chianca, G. K. (2017). *Agricultura Irrigada Sustentável no Brasil: Identificação de Áreas Prioritárias*. Brasília, DF: FAO.

Bosmans, J. H. C, Beek, L. P. H., Sutanudjaja, E. H., & Bierkens, M. F. P. (2017). Hydrological impacts of global land cover change and human water use. *Hydrology and Earth System Sciences*, 21(11), 5603–5626. https://doi.org/10.5194/hess-21-5603-2017

Brito, L. T. L., Moura, M. S. B., & Gama, G. F. B. (2012). *Potencialiadades da água de chuva no semiárido brasileiro*. Petrolina, PE: Embrapa Semiárido.

Cantelle, T. D., Lima, E. C., & Borges, L. A. C. (2018). Survey of hydric resources worldwide and in Brazil. *Revista Em Agronegocio e Meio Ambiente*, 11(4), 1259–12. doi.org/10.17765/2176-9168.2018v11n4p1259-1282

Carvalho, D. F., Martins, R., C. F., Santos, J. J. S., Teles, G. C., Gentile, M. A. D., & Oliveira, M. S. (2020a). Evolution and current scenario of irrigated area in Brazil: Systematic data analysis. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 24(8), 505–511. https://doi.org/10.1590/1807-1929/agriambi.v24n8p505-511

Carvalho, L. L. S., Lacerda, C. F., Carvalho, C. M., Lopes, F. B., Andrade, E. M. & Gomes Filho, R. R. (2020b). Variabilidade espaço-temporal da qualidade das águas subterrâneas em área irrigada no semiárido brasileiro. *Research, Society and Development*, 9(8). https://doi.org/10.33448/rsd-v9i8.5786

Carvalho, L. L. S., Lacerda, C. F., Lopes, F. B., Carvalho, C. M., Gomes Filho, R. R., & Araújo Filho, R. N. (2017). Influence of Prolonged Drought on Groundwater Quality: Irrigated Perimeter of Lower Acaraú – State of Ceará– Northeast of Brazil. *Journal of Experimental Agriculture International*, 18(3), 1–14. https://doi.org/10.9734/jeai/2017/36480

Correia, M. M., Cavalcanti, M. C., Primo, D. C., Neto, F. C. F., Martins, J. M., Menezes, R. S. C., Antonino, A. C. D., Mendes, & Medeiros, L. R. S. Wastewater reuse in irrigation: short-term effect on soil carbon and nitrogen stocks in Brazilian semi-arid region, 6(1). https://doi.org/10.4136/ambi-agua.2623

Cunha, B. P., & Augustin, S. (2014). *Sustentabilidade ambiental e hídrica*. Caxias do Sul, RS: Educs.

Darré, E., Cadenazzi, M., Mazzilli, S. R., Rosas, J. F., & Picasso, V. D. (2019). Environmental impacts on water resources from summer crops in rainfed and irrigated systems. *Journal of Environmental Mangement*, 232, 514-522. https://doi:org/10.1016/j.jenvman.2018.11.090

Danso, O. E., Abenney-Mickson, S., Sabi, E. B., Plauborg, F., Abekoe, M., Kugblenu, Y. O., Jensen, C. R., & Andersen, M. N. (2015). Effect of different fertilization and irrigation methods on nitrogen uptake, intercepted radiation and yield of okra (Abelmoschus esculentum L.) grown in the Keta Sand Spit of Southeast Ghana. *Agricultural Water Managemen*t, 147, 34–42. https://doi: org/10.1016/j.agwat.2014.07.029

Duden, A. S., Verweij, P. A., Kraak, Y. V., Beek, L. P. H., Wanders, N., Karssenberg, D. J., Sutanudjaja, E. H., & Hilst, F. (2021). Hydrological impacts of ethanol-driven sugarcane expansion in Brazil. *Journal of Environmental Management*, 282 (2021), https://doi:org/10.1016/j.jenvman.2021.111942

Eerthal, E. S., & Berticelli, R. (2018). Sustentabilidade: agricultura irrigada e seus impactos ambientais*. Ciência e Tecnologia*, 2(1), 64-74.

Ferreira, D., M., Navoni, J. A., Araújo, A. L. C., Tinoco, J. D., & Amaral, V. S. (2019). Wastewater use in agriculture: Analytical limits of sewage for impact control in Brazil. *Revista Caatinga*, 32(4), 1048–1059. https://doi:org/10.1590/1983-21252019v32n421rc

Flach, M., Gans, F., Brenning, A., Denzler, J., Reichstein, M., Rodner, E., Bathiany, S., Bodesheim, P., Guanche, Y., Sippel, S., & Mahecha, M. (2016). Multivariate Anomaly Detection for Earth Observations: A Comparison of Algorithms and Feature Extraction Techniques. *Earth System Dynamics Discussions*, 8 (3), 677–696. https://doi:org/10.5194/esd-8-677-2017

Friesen, J., Sinobas, L. R., Foglia, L., & Ludwig, R. (2017). Environmental and socio-economic methodologies and solutions towards integrated water resources management. *Science of the Total Environment*, 581–582, 906–908. https://doi.org/10.1016/j.scitotenv.2016.12.051

Furquim, M. G. D., & Abdala, K. D. O. (2019). Sustentabilidade e expansão da agricultura irrigada: um olhar para o setor no estado de Goiás. *Natural Resources*, 9(1), 47–56. https://doi:org/10.6008/cbpc2237-9290.2019.001.0006

González-Fragozo, H. E., Zabaleta-Solano, C., Devia-González, J., Moya-Salinas, Y., & Afanador-Rico, O. (2020). Efecto del riego con agua residual tratada sobre la calidad microbiológica del suelo y pasto King grass. *Revista Actualidad & Divulgación Cientifica*. 23. https://doi:org/10.31910/rudca.v23.n2.2020.1513

Garzón, Z., González, Z., & García, B. (2016). Evaluación de un sistema de tratamiento doméstico para reúso de agua residual**.** *Revista Internacional de Contaminación Ambiental*. 32, 199-211. https://doi:org/10.20937/RICA.2016.32.02.06

Gheyi, H. R., Paz, V. P. S., Medeiros, S. S., & Galvão, C. O. (2012). *Recursos hídricos em regiões semiáridas: estudos e aplicações*. Cruz das Almas, BA: Universidade Federal do Recôncavo da Bahia.

Hernandes, T. A. D., Bufon, V. B., & Seabra, J. E. A. (2014). Water footprint of biofuels in Brazil: Assessing regional differences. *Biofuels, Bioproducts and Biorefining*, 8(2), 241–252. https://doi.org/10.1002/bbb.1454

Lucena, C. Y. D. S., Santos, D. J. R., Silva., P. L. S., Costa, E. D., & Lucena, R. L. (2018). O reuso de águas residuais como meio de convivência com a seca no semiárido do Nordeste Brasileiro. *Revista de Geociências do Nordeste*, 4 , 1-17. Obtido em https://periodicos.ufrn.br/revistadoregne/article/view/13321

Melo, M. T., & Queiroz, T. M. (2020). Disponibilidade e qualidade da água para irrigação no território indígena Rio Formoso, na transição cerrado/amazônia, Mato Grosso-Brasil. *Geosul*, 35(75), 461–480. https://doi:org/10.5007/1982-5153.2020v35n75p461

Oliveira, A. B., Dangui, E. A. S., Beretianski, N. D., & Piovezan, P. A. (2021a). Tecnologia na produção agrícola : o consumo racional dos recursos hídricos (pp. 180-201). São José dos Pinhais, PR: Faculdade da Indústria.

Oliveira, J. T., Maradini, P.S., Borges, A. C., & Gava, R. (2021b). Viabilidade da fertirrigação por pivô central com uso de efluentes tratados em diferentes níveis. *Nativa*, *9*(1), 23-29.

Oliveira, J. T., Cunha, F. F., Oliveira, R. A., Silva Junior, A. G., & Bufon, V. B. (2020). Economic analysis of two sprinkler irrigation systems for sugarcane and soybean crops in Brazil. *International Sugar Journal*, *122*(1464), 844-850.

Padrón, R. A. R. (2021). Manejo da Irrigação. In: Padrón, R. A. R. (Ed.). *Manejo, gestão e técnicas em irrigação.* Canoas, RS: Mérida Publishers. p. 8-61.

Perea, R. G., R., Daccache, A., Díaz, J. R. A., Poyato, E. C., & Knox, J. W. (2018). Modelling impacts of precision irrigation on crop yield and in-field water management. *Precision Agriculture*, 19(3), 497–512. https://doi: org/10.1007/s11119-017-9535-4

Pimenta, F. M., Speroto, A. T., Costa, M. H., & Dionizio, E. A. (2021). Historical changes in land use and suitability for future agriculture expansion in Western Bahia, Brazil. *Remote Sensing*, 13(6), 1–31. https://doi:org/10.3390/rs13061088

Queiroz, J. G., Alves, L. S. F., & Silva, J. B. (2021). Processos de degradação socioambiental: os impactos das atividades produtivas desenvolvidas no perímetro irrigado de São Gonçalo - Paraíba/Brasil. *Novos Cadernos NAEA*, 23(3), 121–143. https://doi:org/10.5801/ncn.v23i3.7737

Rodrigues, L. N., & Domingues, A. F.. (2017). *Agricultura Irrigada: Desafios e Oportunidades para o Desenvolvimento Sustentável*. Brasília, DF: Inovagri.

Rodrigues, G. S., & Irias, L. J. M. (2004). *Considerações sobre os impactos ambientais da agricultura*. Jaguariúna, SP: Empresa Brasileira de Pesquisa Agropecuária.

Rodrigues, J. B., Silva, D. D. S., Freitas, S. J. N., Cabral, A. C. L. C., Pfeiff, G.K., & Amorim, I. L. de, S. (2020). Qualidade da água utilizada na irrigação de produtos orgânicos: o caso de um polo agrícola em Paço Lumiar/MA. *Nature and Conservation,* 13(1), 16–21. https://doi:org/10.6008/cbpc2318-2881.2020.001.0003

Sales, J. M. J., Aguiar Netto, A. O., Monteiro, A. S. C., & Carvalho, C. M. (2020). Variabilidade espaço-temporal da qualidade da água em área de agricultura irrigada. *Revista Brasileira de Agricultura Irrigada*, 14(3), 4071–40854. https://doi:org/10.7127/rbai.v14n101167

Santi, G. M., Furtado, C. M., Menezes, R. S., & Keppeler, E. C. (2012). Spatial variability of parameters and water quality indicators in the Igarapé sub-basin São Francisco, Rio Branco. *Ecología Aplicada*, 11(1–2), 23. https://doi:org/10.21704/rea.v11i1-2.422

Scarpare, F. V., Hernandes, T. A. D., Ruiz-Corrêa, S. T., Picoli, M. C. A., Scanlon, B. R., Chagas, M. F., Duft, D. G., & Cardoso, T. de F. (2016). Sugarcane land use and water resources assessment in the expansion area in Brazil. *Journal of Cleaner Production*, 133, 1318–1327. https://doi:org/10.1016/j.jclepro.2016.06.074

Souza, A. O, Carvalho, C. M., Gomes Filho, R. R., Garcia, C. A. B., Cerqueira, E. S. A., Valnir Júnior, M., Carvalho, L. L. S., Saraiva, K. R., & Silva, A. F. (2021). Temporal and spatial analysis of the waters of the irrigated perimeter Cotinguiba/Pindoba in the hydrographic region of the lower São Francisco Sergipano. *Agrarian and Biological Sciences*, 10(2), 1–18. https://doi:10.33448/rsdv10i2.12403.

Ucker, F. E., Lima, P. B. S., O., Camargo, M. F., Pena, D. S., Cardoso, C. F., & Evangelista, A. W. P. (2013). Elementos interferentes na qualidade da água para irrigação. *Revista Eletrônica em Gestão, Educação e Tecnologia Ambiental*, 10(10),2102–2111. https://doi:org/10.5902/223611707540

Veldkamp, T. I. E., Wada, Y., Aerts, J. C. J. H., Döll, P., Gosling, S. N., Liu, J., Masaki, Y., Oki, T., Ostberg, S., Pokhrel, Y., Satoh, Y., Kim, H., & Ward, P. J. (2017). Water scarcity hotspots travel downstream due to human interventions in the 20th and 21st century. *Nature Communications,* 8. https://doi.org/10.1038/ncomms15697

Vieira, E. O., Sandoval-Solis, S., Pedrosa, V. A., & Ortiz-Partida, J. P. (2020). *Integrated Water Resource Management.* Cham. Switzerland: Springer International Publishing.

Winsemius, H. C., Aerts, J. C. J. H., Beek, L. P. H., Bierkens, M. F. P., Bouwman, A., Jongman, B., Kwadijk, J. C. J., Ligtvoet, W., Lucas, P. L., Vuuren, D. P., & Ward, P. J. (2016). Global drivers of future river flood risk. *Nature Climate Change*, 6(4), 381–385. https://doi.org/10.1038/nclimate2893

Zandalinas, S. I., Fritschi, F. B., & Mittler, R. (2021). Global Warming, Climate Change, and Environmental Pollution: Recipe for a Multifactorial Stress Combination Disaster. *Trends in Plant Science*, 20(20), 1–12. https://doi:org/10.1016/j.tplants.2021.02.011