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E-mail: ambi.agua@gmail.com

Sanitary quality of reused water for irrigation in agriculture in Brazil

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Natasha Berendonk Handam[1*]; Ana Beatriz Loureiro Gonçalves da Silva[2]; Rodrigo Bezerra da Silva[3]; Priscila Gonçalves Moura[1]; Elvira Carvajal[4]; Adriana Sotero-Martins[5]; José Augusto Albuquerque dos Santos[6]

[1]Programa de Doutorado em Saúde Pública e Meio Ambiente. Escola Nacional de Saúde Pública Sérgio Arouca. Fundação Oswaldo Cruz (FIOCRUZ), Rua Leopoldo Bulhões, n° 1480, CEP: 21031-210, Rio de Janeiro, RJ, Brazil. E-mail: priscila.moura.gema@gmail.com
[2]Graduação em Engenharia Química. Centro de Tecnologia da Indústria Química e Têxtil (SENAI CETIQT), Rua Leopoldo Bulhões, n° 1480, CEP: 21041-210, Rio de Janeiro, RJ, Brazil. E-mail: beatrizloreiro@hotmail.com
[3]Graduação em Biologia. Universidade do Estado do Rio de Janeiro (UERJ), Rua Leopoldo Bulhões, n° 1480, CEP: 21041-210, Rio de Janeiro, RJ, Brazil. E-mail: rodrigobezera2@gmail.com
[4]Instituto de Biologia Roberto Alcantara Gomes. Departamento de Biologia Celular. Universidade do Estado do Rio de Janeiro (UERJ), Rua São Francisco Xavier, n° 524, CEP: 20550-900, Rio de Janeiro, RJ, Brazil. E-mail: elvira.dbiocel@gmail.com
[5]Departamento de Saneamento e Saúde Ambiental. Escola Nacional de Saúde Pública Sérgio Arouca. Fundação Oswaldo Cruz (FIOCRUZ), Rua Leopoldo Bulhões, n° 1480, CEP: 21041-210, Rio de Janeiro, RJ, Brazil. E-mail: adrianasotero@ensp.fiocruz.br
[6]Laboratório de Avaliação e Promoção da Saúde Ambiental. Instituto Oswaldo Cruz. Fundação Oswaldo Cruz (FIOCRUZ), Avenida Brasil, n° 4365, CEP: 21040-360, Rio de Janeiro, RJ, Brazil. E-mail: santosjaa@gmail.com
[*]Corresponding author. E-mail: natashabhandam@gmail.com

ABSTRACT

Reused water is produced from treated effluents, and can be an alternative source of water for agriculture. However, its quality must be assessed to avoid causing damage to human and environmental health. This study evaluated the sanitary quality (bacteriological and physicochemical) of reused water samples for agricultural irrigation, compared with those described in Brazilian and international regulations. Bacteriological analyses were performed, and the results were compared with the norm of the Brazilian Association of Technical Norms (ABNT) NBR nº 13.969/1997. Physical and chemical analyses of the reused water samples were carried out, and the results were compared with the standards described by regulations: Resolution of the State Council for the Environment of Ceará No. 2 of 2017; Resolution of the Bahia State Water Resources Council No. 75 of 2010; and "Guidelines for Water Reuse" from the U.S. Environmental Protection Agency - EPA. According to Brazilian regulations, bacteriological analyses showed that the "chlorinated" and "polished" samples were suitable for agriculture. However, the "biological" sample was unsuitable for use, and showed a high level of thermotolerant coliforms (25.800 CFU / mL). According to bacteriological and physical-chemical analyses, the "polished" sample was only proper for agriculture irrigation. Therefore, the work suggests the creation of federal law regarding agricultural reuse to control the sanitary quality of water for human and environmental health.

Keywords: agricultural reuse, agriculture, bacteriological and physicochemical evaluation, norms for reuse in agriculture.

Qualidade sanitária de águas de reúso para irrigação na agricultura no Brasil

RESUMO

A água de reúso é um recurso proveniente de efluentes tratados e pode ser uma fonte alternativa de água para agricultura. No entanto, é importante a avaliação da sua qualidade para não causar agravos a saúde ambiental e humana. O objetivo foi avaliar a qualidade sanitária (bacteriológica, físicas e químicas) de amostras de água de reúso para irrigação da agricultura, de acordo com padrões estabelecidos em normativas brasileiras e internacional. Foram realizadas análises bacteriológicas, sendo os resultados comparados com a norma da Associação Brasileira de Normas Técnicas NBR nº 13.969/1997. E foram feitas análises físicas e químicas das amostras de água de reúso, sendo os resultados comparados com os padrões das normativas: Resolução do Conselho Estadual de Meio Ambiente do Ceará nº 2 de 2017; Resolução do Conselho Estadual de Recursos Hídricos da Bahia nº 75 de 2010; e "*Guidelines for Water Reuse" from the U.S. Environmental Protection Agency - EPA*. As análises bacteriológicas mostraram que as amostras "clorada" e "polida" estavam próprias para agricultura, de acordo com as normativas brasileiras. No entanto a amostra "biológica" estava imprópria para uso, apresentando nível elevado de coliformes termotolerantes (25,800 CFU/mL). Segundo as análises bacteriológicas e físico-químicas apenas a amostra de reúso "polida" estava própria para reúso agrícola. O estudo mostrou a importância da forma de tratamento de água de reúso para qualidade sanitária da água, e isso é fundamental a criação de lei federal de reúso agrícola, a fim de evitar danos à saúde humana e ambiental.

Palavras-chave: agricultura, avaliação bacteriológica e físico-química, normativas de reúso na agricultura, reúso agrícola.

1. INTRODUCTION

There are currently several examples of reusing water in agriculture in Brazil and worldwide (Fito and Van Hulle, 2021; Mancuso and Santos, 2013). Reused water is defined as the reuse of water from treated effluents (Morais *et al.*, 2016). It can be classified according to Moura *et al.* (2020), who conceptualized the origin of reuse water as follows:

"(i) Local or internal reuse, the water reuse obtained from greywater treatment from residential reuse (house or building) and reuse of new commercial or non-commercial ventures; (ii) External reuse, the water reuse obtained from black water (raw sewage) and sewage treatment plant and which subsequently pass through wastewater treatment plants (STP+WWTP)."

Agriculture is the economic activity that most consumes freshwater, reaching around 70% (Peng *et al.*, 2019). However, the scarcity of water sources for this activity in several regions makes reused water an alternative to face this problem (FAO, 2017).

The use of reused water in agriculture can bring benefits such as nutrients and water, favoring the growth of plants and reducing the use of artificial fertilizers (USEPA, 2012). Irrigation with reused water is a form of natural fertigation derived from nutrients such as nitrogen, potassium and phosphorus, which is essential for cultivation in poor soils (Lahlou *et al.*, 2020; Otenio, 2015). Furthermore, it represents an alternative to reduce the demand pressure on water sources and reduce the amount of sewage discarded (Lima *et al.*, 2021; Mancuso and Santos, 2013).

However, reused water must be well managed, or it can offer negative impacts such as posing risks to human and environmental health (WHO, 2006). Depending on the origin and treatment used to produce reused water, it may not be safe for human and environmental health

(Moura *et al.*, 2020). Disease transmission is also controlled by agronomic factors such as irrigation practices used as drip, culture and harvesting practices (Orlofsky *et al.*, 2016).

Countries have sought to expand the regulation and monitoring of pollutants and contaminants that were not the object of attention by legal provisions for wastewater reuse (Cui and Liang, 2019; USEPA, 2012). The United States is more advanced in the quality of water bodies; many states adopt guidelines for reused water, encouraging new uses, such as irrigation in agriculture.

In Brazil, there is still no federal legislation showing criteria and parameters for assessing the water reuse quality for agriculture (Handam *et al.*, 2021). The Brazilian Association of Technical Standards (ABNT) has only a technical standard, nº 13,969/97 (ABNT, 1997), but it is not specific, bringing few reused water quality parameters. There are specific laws in some Brazilian states that have quality parameters for the use of reused water in agriculture: Resolution of the State Council for the Environment (COEMA) of Ceará nº. 2 of February 2017 (CEARÁ, 2017) and the State Resolution of the State Water Resources Council (CONERH) of Bahia nº 75 of 2010 (BAHIA, 2010). According to FUNASA (2007), "For the agricultural use of effluents, the recommendations of the World Health Organization...and the recommendations of the United States Environmental Protection Agency (EPA)".

The study suggests measuring the sanitary quality (bacteriological and physicochemical) of reused water samples for agricultural irrigation, according to standards described in Brazilian and international regulations.

2. MATERIAL AND METHODS

Three samples of reused water from different sources were collected: "chlorinated" reused water obtained from treated sewage in a sewage treatment plant (STP), after which the effluent was chlorinated; "polished" reused water from sewage treated in STP and subsequently submitted to three treatments in wastewater treatment plants (WWTP), which were filtration, ultrafiltration and reverse osmosis; and "biological" reused water, from gray water that has been treated by a physical and biological filter system. The physical and biological filter system was according to Poblete (2010) (Figure 1).

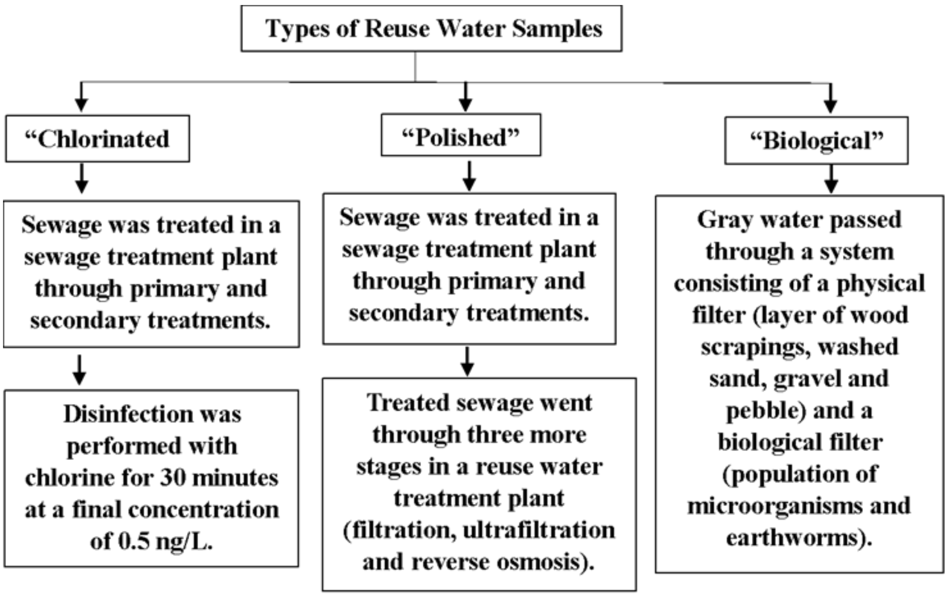

Figure 1. Flowchart on the treatment systems for the production of each reused water sample used in the research: "Chlorinated, Polished, Biological".

Bacteriological analyses (thermotolerant coliforms) were performed within 24 hours after collections according to the Standard Methods for the Examination of Water and Wastewater (APHA *et al.*, 2017). Serial dilutions were carried out as described by Sotero-Martins (2017), using the membrane filter method with the chromogenic culture medium indicator Chromocult® Coliform Agar (Cat. No. 1,10426,0100/500 Merck) and quantified in Colonies Forming Units of water (CFU/mL) (Sotero-Martins *et al.*, 2017).

Physicochemical analyses of total hardness, turbidity, fluoride, chlorine residual, nitrate, nitrite, sulfate, alkalinity, conductivity, apparent color, pH and free chlorine were done according to the methods based on Standard Methods for the Examination of the Water and Wastewater (APHA *et al.*, 2017). The bacteriological results found in the reuse water samples were compared with the Class 4 standard for agriculture, established in the Norm of the Brazilian Association of Technical Norms (ABNT) NBR nº 13,969/1997 (ABNT, 1997).

Compared to international laws, the limit values recommended by ABNT regulations (5,000 NMP/100 mL) and Ceará Resolution 2/2017 (1,000 NMP/100 mL) were converted to values in CFU/mL, considering that the quantification in NMP is 2.167 times greater than in CFU (Sotero-Martins *et al.*, 2017), according to statistical data observed in the work of Gronewold and Wolpert (2008). Thus, the standard for thermotolerant coliforms converted from the ABNT 13,969/97 standard was 23 CFU/mL, and from the Ceará Resolution 2/2017, it was 4.6 CFU/mL. The standards of EPA (2012) and Resolution nº 75 of 2010 of Bahia were converted to CFU/mL, that is, in EPA (2012), the standard was 2 CFU/mL, and the standard of Resolution 75 of 2010 was 100 CFU/ mL.

For physical-chemical parameters, the Brazilian regulations for agricultural reuse do not set quality standards for all parameters analyzed in this study, with standards being established only for electrical conductivity, chlorine residual, pH and fluoride. Thus, the results were compared with the norms: Resolution of the State Council for the Environment (COEMA) of Ceará nº 2 (COEMA, 2017); and the State Resolution of the State Water Resources Council (CONERH) of Bahia nº 75 (CONERH, 2010). The results of the physicochemical parameters turbidity, chlorine, nitrate and apparent color were compared with the Maximum Allowable Values (VMP) defined by the international standard “Guidelines for Water Reuse” from the U.S. Environmental Protection Agency - EPA (USEPA, 2012). The regulation was considered because it has physical-chemical and microbiological quality parameters for reused water for agriculture based on scientific studies. The other parameters analyzed were total hardness, alkalinity, nitrite and sulfate were compared with the quality standards established in Consolidation Potability Ordinance nº 5 of 2017 (Brasil, 2017) because they do not have quality standards for agricultural reuse in Brazilian and international standards.

3. RESULTS AND DISCUSSION

Bacteriological analyses showed that the “chlorinated” reuse water sample had 20 CFU/mL of thermotolerant coliforms and the “polished” sample had no thermotolerant coliforms. The quality of both samples was in accordance with the quality standard for agricultural reuse established by NBR nº 13,969/97 (ABNT, 1997).

Research indicates that reused water produced by sewage treatment plants together with chlorination and/or ultrafiltration treatment reduces the level of coliforms in the water and the risks associated with the presence of other microorganisms (Bakopoulou *et al.*, 2011; Youn-Joo *et al.*, 2007), which corroborates the low level of coliforms found in the chlorinated reuse water and the absence of coliforms in the “polished” reuse water.

However, the "biological" reuse water sample showed a high level of thermotolerant coliforms (25.800 CFU/mL). It was inadequate and above the recommended limit for agricultural application according to Standard NBR nº. 13,969/97 (Figure 2).

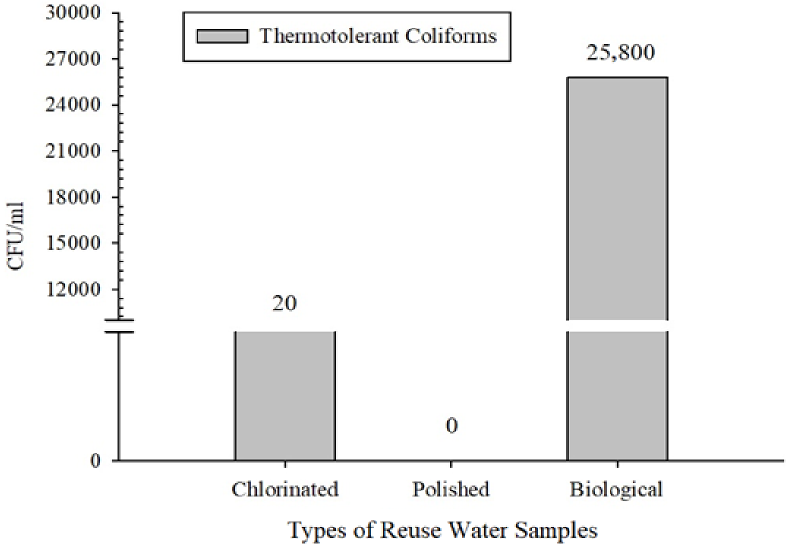

Figure 2. Thermotolerant coliform levels of contamination in water reuse samples from Brazil. Break interval: 5 – 10000. Water reuse samples from Brazil: "Chlorinated" - reused water from treated sewage (ETE) and then chlorinated; "Polished" from treated sewage (ETE) and reused water treatment (WWTP - filtration, ultrafiltration and reverse osmosis); "Biological" reused water from grey waters treated by the physical and biological filter.

The Resolution of the State Council for the Environment (COEMA) of Ceará nº 2/2017 (Ceará, 2017) determines parameters for water reuse for agricultural and forestry purposes. The "biological" sample showed a maximum of 4.6 CFU/mL of coliform thermotolerant. In addition, this law determines that there must be an absence of thermotolerant coliforms in cultures to be consumed raw whose consumed part has direct contact with the irrigation water. Bahia State Resolution nº 75/2010 (Bahia, 2010) has less restrictive bacteria levels than other regulations. The quality of the sample was also up to the established standard. This law determines a limit value for thermotolerant coliforms of 10 CFU/mL for Category A “Irrigation, including hydroponics, of any crop including food products consumed raw”, and of 100 CFU/mL for drip irrigation; and 100 CFU/mL of thermotolerant coliforms for Category B "Irrigation, including hydroponics, of uneaten raw food products, non-food products, forages, pastures, trees, crops used in revegetation and recovery of degraded areas" (Bahia, 2010).

The “biological” reuse water sample was characterized as unsuitable for irrigation of crops due to the level of bacteria, even with drip irrigation according to Resolution nº 75/2010 (Bahia, 2010). Drip irrigation is a strategy for watering water close to the ground, leaving the water available only to the plant's root system and reducing the risk of contamination (Mancuso and Santos, 2013).

Greywater is not effluent from toilets, so it does not have a direct faecal contribution, and it may have been contaminated with thermotolerant coliforms through hand washing, bathing, washing food and clothing and even diaper washing (Peters, 2006). In addition, there may have been a possible saturation of the biological filter due to a large amount of water, which may have caused the mortality of earthworms, which are part of the filtering system, impairing the treatment of gray water. The result may have been due to a specific improper condition;however, attention is recommended in the treatment of this effluent to ensure the quality of agricultural reuse, which may add another disinfection process. According to Bakopoulou *et al.* (2011), treatment with chlorination can contribute to eliminating coliforms, and it can be incorporated into the production of “biological” reuse water because it is not part of the system's treatment process. Another possible solution would be constructing another physical and biological filter parallel to the existing one to divide the treatment of a large amount of gray water to produce higher-quality reused water (Dombroski *et al.*, 2013). Dombroski *et al.* (2013) also introduced a similar study of reused water samples from a greywater treatment system and identified 692.82 CFU/mL of thermotolerant coliforms, which is up to the level allowed for agricultural reuse.

It is worth mentioning that from an epidemiological and immunological point of view, the presence of pathogenic microorganisms in water does not mean that people will acquire diseases (Mancuso and Santos, 2013). However, signaling care in the face of risks concerning certain types of reuse water with potential contaminants, which can be added to the soil, which affect human and animal life, are fundamental data for health actions. Workers, especially those who continuously deal with agriculture, can be exposed to soil contaminated with elements that can be carried through reused water, a vehicle for transmitting diseases. However, the risk can be reduced through good practices, using personal protective equipment (PPE) in agriculture (WHO, 2006), so it is essential to know the contaminants and pollutants that may be in the reuse water. In addition, the transmission of diseases becomes less or even controlled through irrigation, culture and harvesting practices used, for example, application of drip irrigation (Morais *et al.*, 2016; Mancuso and Santos, 2013; WHO, 2006).

Gatta *et al.* (2016) found that despite identifying microorganisms such as E. coli and Salmonella spp. in sewage samples by secondary and tertiary treatment, the artichoke crops irrigated with these samples were not contaminated. Moreover, the reduction of these bioindicators in the soil may be due to the drip irrigation system, which avoids contact of water with the plant, and/or the death of bacteria in the soil and the barrier through the roots of the plants. In addition, the production of crops irrigated with reused water increased from 33 to 55% compared to crops irrigated with freshwater (Gatta *et al.*, 2016).

The physicochemical results showed that in all samples, only the parameters free residual chlorine, conductivity, pH, fluoride were in accordance with the Maximum Allowable Values (VMP) established by Brazilian and international regulations: Resolution of the State Environmental Council (COEMA) of Ceará nº 2 of February 2017 (Ceará, 2017), State Resolution of the State Water Resources Council (CONERH) of Bahia nº 75 of 2010 (Bahia, 2010) and Guidelines for Water Reuse - EPA (2012) (Table 1).

Table 1. Physicochemical results of reused water samples and quality standards according to Brazilian regulations: State Resolution of the State Water Resources Council of Bahia nº 75 of 2010; Resolution of the State Environmental Council of Ceará nº 2 of February 2, 2017; Guidelines for water reuse 2012 - EPA - U.S. Environmental Protection Agency.

Parameters	Chlorinated	Polished	Biological	EPA (2012)	Ceará (2017)	Bahia (2010)
Chlorine mg/L	0.15	0.05	0	1	ND	ND
Total hardness mg/L	68.5	14	645	ND	ND	ND
Alkalinity $CaCO_3$ mg/L	31.8	715	698	ND	ND	ND
Conductivity µS/cm	554	284	1017	3.0	3000	3.0
pH	7.0	7.0	7.0	6.5 – 8.4	6.0 – 8.5	ND
Turbidity NTU	2.55	0.3	44	2	ND	ND
Apparent color Pt-Co units	44.2	19	340	150	ND	ND
Fluoride mg/L	0.61	0.42	0.77	1.0	ND	1.0
Chlorine residual mg/L	97.68	16.6	146.24	10	ND	100 – 350
Nitrate mg/L	60.20	1.35	14.34	30	ND	ND
Nitrite mg/L	0.71	0.06	0	ND	ND	ND
Sulfate mg/L	38.93	22.37	15.56	ND	ND	ND

ND: Maximum permitted values of the parameter are not described in the regulations on agricultural reuse.

The "biological" reused water sample presented non-standard physical-chemical parameters, such as turbidity apparent color, as it presented values up to the permitted level according to EPA (2012) regulations. Turbidity indicates the presence of suspended solids in the water, it hinders the disinfection process, and pathogenic microorganisms may also be present (APHA *et al.*, 2017). The apparent color parameter is indicative of particles dissolved in water (Von Sperling, 1996), and its non-compliance does not necessarily imply a health risk. However, it needs to be observed as a warning.

The conductivity parameter analyzed in the "biological" sample, despite being within the VMP according to the Ceará regulations (2017), establishes a limit of up to 3,000 µS/cm; the sample presented a high conductivity value with 1017 µS/cm. Bahia (2010) and EPA (2012) regulations show the limit standard for conductivity around 1,000 times slower than the Ceará standard (2017), with a limit of up to 3 µS/cm being established. According to Ayres and Westcot (1991), reused water with electrical conductivity ranges from 700 to 3,000 µS/cm are classified as having moderate salinity and requires a moderate restriction of use for irrigation. The moderate salinity classification indicates that there may be a moderate reduction in the rate of water infiltration into the soil. Therefore, these waters become more suitable for irrigation of soils with salt-tolerant crops. Conductivity is an important parameter for agriculture as an indirect measure of salinity. The greater the electrical conductivity, the greater the degree of salinity, which affects the water availability for crops (USEPA, 2012). The result found for electrical conductivity was similar to the value identified in a study by Rolim *et al.* (2016), who found 1,200 µS/cm. They also used conductivity as an indicator of salinity. The "chlorinated" reuse water sample was unsuitable for the nitrate-nitrogen parameter with a level of 60.2 mg/L. It is up to the standard value recommended by the normative Guidelines for Water Reuse (USEPA, 2012), which establishes a limit of up to 30 mg/L of nitrate.

The parameters nitrate and nitrite are essential macronutrients for soil fertility and crop productivity (Rolim *et al.*, 2016), but it can be a public health risk in large quantities, up to 30 mg/L, making it harmful to plant development. Above this level, plants can absorb nitrogen, which is very dangerous for some cultures, as it causes excessive vegetative growth (Ayres and Westcot, 1991). In the environment, especially in sandy soils, nitrogen can reach the water table more efficiently and is considered highly soluble in water (Mancuso and Santos, 2013). The result demonstrates that the treatment by ETE and chlorination did not show good efficiency in removing nutrients.

The “chlorinated” and “biological” reuse water samples were unsuitable in terms of turbidity level for agricultural purposes according to EPA (2012), as the quality standard is 2 NTU, the standard established in the Food Crops category "The use of reclaimed water for surface irrigation or a sprinkling of food crops intended for human consumption, consumed raw" presented in the EPA (2012). The “chlorinated” sample was 1.3 times larger than the standard recommended by the regulations. The "biological" sample was 22 times higher than allowed; it showed a high turbidity level. Results of reuse water analysis by Rolim *et al.* (2016) also showed unacceptable levels for the turbidity parameter with an average value of 32.4 NTU. They did not recommend unrestricted irrigation in agriculture, as they are not suitable for use in drip or sprinkler irrigation systems.

According to Bakopoulou *et al.* (2011), sand filtration treatment is recommended to reduce turbidity in reuse water, as it is considered an effective and essential method before the effluent disinfection process. With filtration, the treatment can better remove coliforms in the disinfection stage (Bakopoulou *et al.*, 2011). In view of this, the treatment for "biological" reuse water production needs to be improved because of the high turbidity level. The filter sand layers could be increased, thus favouring more significant coliform removal in the reused water.

The results of the physical-chemical parameters of the “polished” reused water sample showed that it is within the VMP according to EPA (2012) and Ceará (2017) regulations. Only the chlorine residual parameter presented a value of 16.6 mg/L, being below the range of 100 to 350 mg/L, standard established by Bahia Resolution nº 75/10. Furthermore, it was slightly above the limit recommended by EPA (2012), 10 mg/L. According to Ayres and Westcot (1991), chlorine residual at a level above 10 mg/L, as presented by the "polished" reused water sample, can be slightly toxic to the plants. Compared to other reuse water samples, "polished" was the lowest level of chlorine residual, which can be explained by the treatment method with ultrafiltration technology, which according to Rolim *et al.* (2016), is considered effective in further removing salts.

There is no standard for agricultural reuse of parameters such as total hardness, total alkalinity, nitrite and sulfate, but other norms and studies can indicate the level of quality of these parameters. In the reuse water samples, the nitrite and sulfate parameters were in accordance with the potability standard, Ministry of Health Consolidation Ordinance nº 5 of 2017 (Brasil, 2017). However, the “biological” sample was unsuitable for total hardness, with a value above the standard for potability, which establishes a maximum value of 500 mg/L (Brasil, 2017). Total hardness is defined as the sum of the concentrations of calcium and magnesium ions in water, expressed as calcium carbonate (FUNASA, 2013). Indirect contact with water levels above the potability standard can cause a laxative effect on humans (Von Sperling, 1996). According to Almeida (2010), it can also cause encrustations in the pipes. Thus, for drip irrigation systems, it can be detrimental. According to Almeida (2010), to reduce the hardness of the water, aeration can be done, as it induces calcium precipitation. However, it is recommended to use water with a higher degree of hardness in soils with high sodium. As for total alkalinity, the "polished" and "organic" reused water samples had high and similar levels compared to the "chlorinated" sample, with levels of 715 mg/L, 698 mg/L, 31.8 mg /L, respectively. This parameter is of great importance because it shows the capacity of water to neutralize acids present, which is measured by the total concentration of hydroxides, carbonates and bicarbonates. The presence of these substances neutralizes the effects of acidic substances, for example, due to acid rain (FUNASA, 2013). Moreover, in the soil, it is essential to check alkalinity, because when the soil is acidic, substances previously present in the mineral form are transformed into ions, some of which are toxic to plants, such as aluminium and cadmium ions (Carmo *et al.*, 2016; Silva, 2012).

4. CONCLUSIONS

According to the analysis carried out in the study, only "polished” reused water is suitable according to Brazilian and international regulations, and it can be considered for agricultural reuse. According to current regulations that determine standards for agricultural reuse, the other samples of reused water, "biological and chlorinated", were unsuitable.

The results showed that the production of reused water by physical and biological filters studied in this article cannot remove microorganisms effectively. This suggests a reassessment of the proposed treatment or the inclusion of a new treatment phase. Reused water with similar treatments should be used in agriculture if it undergoes a complementary treatment to reduce impacts on the soil and ensure a supply of nutrients to crops, reducing costs with artificial fertilizers, and not offering risks to public health and the environment.

Therefore, the study of the sanitary quality of three samples from different sources shows the importance of treating and producing reused water with good quality for safe use that does not adversely impact public and environmental health. For an assessment of quality that can guarantee the safety of reused water for use in agricultural irrigation, it is essential to create legislation at the national level for agricultural reuse, which codifies the origin of this water, sanitary quality standards and forms of treatment for production. Every state must comply with the law in order to avoid human and environmental health damage at the national level.

5. ACKNOWLEDGEMENTS

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