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Assessment of water and sediment quality variation due to organic and conventionally irrigated pre-germinated rice-field cultivation

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ABSTRACT

This study evaluated the water and sediment quality of samples collected from different points in organic (O1, O2, O3, and O4) and conventional (C1, C2, and C3) pre-germinated rice fields located in Viamão/RS. Quality indicators such as phosphorus, dissolved oxygen, manganese, iron, turbidity, and BOD_5 reduced water quality beyond Classes 3 and 4, as defined by CONAMA Resolution 357/2005. Based on the aluminum levels, the water samples collected from all the points were categorized as Class 4; furthermore, the IQA classified the quality of water samples from Points O4 and C1 as “bad.” The COD/BOD ratio was high, demonstrating that the biodegradable fraction was considerably low. The conductivity of water at points O4, C1, C2, and C3, exceeded 100 µS/cm, as defined by CETESB, indicating impacted environments. The levels of zinc in C1 and nickel in O2, C2, and C3 in the sediment exceeded the quality reference values established by the FEPAM Ordinance 85/2014. In general, the lowest water quality was observed in the samples collected from Points O2 and O4, and the lowest sediment quality was observed in the samples collected from all points in the conventional rice fields and from Point O2 in the organic rice field.

Keywords: CETESB, coliforms, CONAMA no 357/2005, FEPAM Ordinance no 85/2014, irrigated rice, physicochemical analysis.

Variação da qualidade da água e do solo de cultivo convencional e orgânico de arroz irrigado pré-germinado

RESUMO

Neste estudo, avaliou-se a qualidade da água e do sedimento de amostras coletadas em diferentes pontos de arrozais orgânicos (O1, O2, O3 e O4) e convencionais (C1, C2 e C3) pré-germinados em Viamão/RS. Indicadores de qualidade como fósforo, oxigênio dissolvido, manganês, ferro, turbidez e DBO_5 reduziram a qualidade da água além das classes 3 e 4, conforme definido pela Resolução CONAMA 357/2005. Com base nos níveis de alumínio, as amostras de água coletadas em todos os pontos foram categorizadas como classe 4; além disso, o IQA classificou a qualidade das amostras de água dos pontos O4 e C1 como "ruim". A relação

DQO/DBO foi alta, demonstrando que a fração biodegradável era consideravelmente baixa. A condutividade da água nos pontos O4, C1, C2 e C3, ultrapassou 100 µS/cm, conforme definido pela CETESB, indicativo de ambientes impactados. Os teores de zinco em C1 e níquel em O2, C2 e C3 no sedimento superaram os valores de referência de qualidade estabelecidos pela Portaria FEPAM 85/2014. De maneira geral, a mais baixa qualidade da água foi observada nas amostras coletadas nos pontos O2 e O4, e a mais baixa qualidade do sedimento foi observada nas amostras coletadas em todos os pontos nos arrozais convencionais e no ponto O2 nos arrozais orgânicos.

Palavras-chave: análises físico-químicas, arroz irrigado, CETESB, coliformes, CONAMA no 357/2005, Portaria FEPAM no 85/2014.

1. INTRODUCTION

The State of Rio Grande do Sul (RS) is the largest rice producer in Brazil, with a harvested area of 964,537 ha and a total production of 7,241,458 tons in 2018/2019 (IRGA, 2019). Although the cultivation of pre-germinated rice is uncommon, it is the cultivation technique adopted in the metropolitan region of Porto Alegre (RS). As a result, the watercourses in this region frequently receive effluents contaminated with agricultural inputs and pesticides, suspended solids, and organic residues carried by the drainage water of rice fields. Consequently, the supply of quality water to the population is impaired, leading to the suspension of the public water supply system.

Water management is essential for crop performance in flood-irrigated rice, as water, in addition to weed control, interferes with nutrient availability, and increases incidences of certain pests and diseases (Gomes *et al.*, 2008). The pre-germinated rice cultivation system uses large volumes of water that aid in the formation of mud during the initial soil preparation, thus providing favorable conditions for seeding. The lowering of the water layer level carried out 3–5 days after sowing releases effluents with a high polluting load into the watercourses. Thus, this cultivation system considerably affects the water quality of the Gravataí River Basin because of the release of effluents with high turbidity and high concentrations of suspended solids. In 2016, the release of drained water from rice fields, which was highly turbid, caused an interruption in the water collection, treatment, and distribution system for public supply, in the municipality of Gravataí.

The sustainable practice of rice farming in Brazil undergoes occasional conceptual changes, mainly to address environmental concerns, especially in terms of the quality of effluent water from farming (Mattos and Martins, 2009). Various efforts have been made to address this issue, such as the intensified search for technological alternatives for organic rice production systems, including but not limited to the discontinued use of pesticides prevalent in traditional farming. When not used according to technical recommendations, these pesticides can contaminate the environment and adversely affect the aquatic and soil organisms within production systems and in their surroundings. Similarly, fertilizers, especially nitrogen and phosphorus, can cause eutrophication of both surface and groundwater, leading to oxygen depletion and severe consequences on aquatic ecosystems (Mattos and Martins, 2009). According to the IRGA (2019), organic rice plantations/cultivation systems in RS occupied 6,000 ha in 2017/2018, with 4,600 ha in settlements of the “Sem Terra” Movement. The average productivity was observed to be 5,000 kg/ha, and the production cost was half that of traditional cultivation (IRGA, 2019).

The pre-germinated rice cultivation system is mainly characterized by the initial drainage of the crop, carried out a few days after sowing, to ensure the proper establishment of the crop. This type of water management, still used by many rice growers, causes detrimental effects on the environment, such as the loss of nutrients (nitrogen, phosphorus, potassium, calcium, and sodium) and total solids; furthermore, it aids the transport of pesticides adsorbed on soil particles into water sources. In addition, they cause an increase in water turbidity, re-infestation of the area by weeds, and imply additional use of water (Scivittaro *et al.*, 2010).

Therefore, in this study, we aimed to evaluate the quality of water and sediment in both conventional and organic cultivation systems of irrigated pre-germinated rice crops located in the municipality of Viamão (RS) through physicochemical and microbiological analyses.

2. MATERIAL AND METHODS

2.1. Collection of water and sediment samples

The water samples were collected on November 30, 2020 (beginning of cultivation period) and March 12, 2020 (end of cultivation period), in organic and conventional pre-germinated rice fields in Viamão (RS). The water samples were stored in sterilized glass bottles (500 mL), and their preservation was inherent to each analysis. Additionally, sediment samples (1 kg) were collected on November 11, 2019, and placed in sanitized plastic bags. Seven points were sampled for collection (Figure 1), four in the organic rice field (O1, O2, O3, and O4) and three in the conventional field (C1, C2, and C3). O1 was in the Águas Claras Dam (-30.070590 and -50.874573), which supplies water for irrigating the organic rice fields. The O2 and O3 were in the drainage channels of the organic rice fields (-30.063640 and -50.886690; -30.04350 and -50.884500). The O4 was also located in a drainage channel (-30.030999 and -50.867704), close to the border of the conventional rice field. Drain water from the cultivated areas of organic rice fields converged at O4. C1 and C2 were located in the drainage channels of the conventional rice fields (-30.021599 and -50.880455; -30.012875 and -50.895273). C3 was located in the Rio Gravataí adduction channel (-30.004383 and -50.923700), and is the main source of water for irrigating the conventional rice fields.

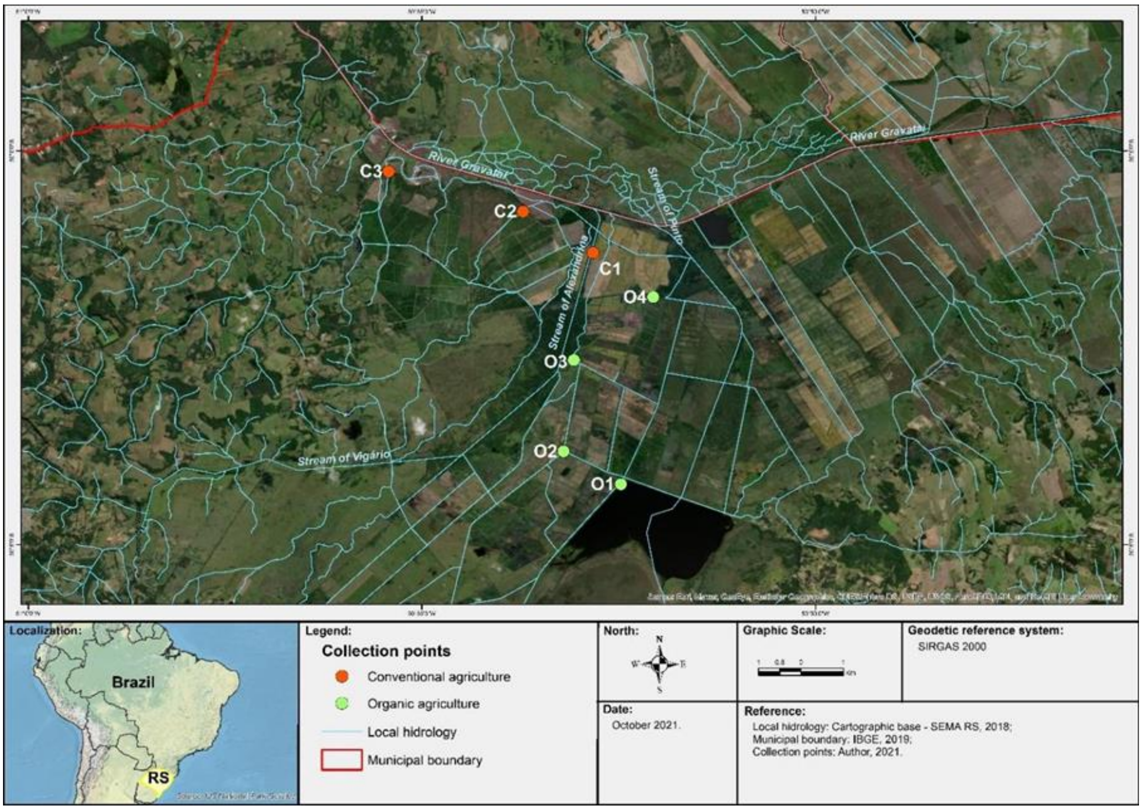

Figure 1. Location of the sampling points in organic and conventional rice cultivation areas in Viamão (RS).

2.2. Physicochemical and microbiological analysis

Electrical conductivity (EC), temperature, turbidity, and pH were measured in situ using HI 9829 (Hanna Instruments) and EXO1 (YSI) multiparameter probes. Physicochemical analyses of the water samples were carried out at the Environmental Analysis Laboratory/FEPAM: total dissolved solids (mg/L), total chloride (mg Cl/L), dissolved oxygen (DO) (mg O_2/ml), chemical oxygen demand (COD) (mg O_2/L), biochemical oxygen demand (BOD_5) (mg O_2/L), total phosphorus (mg P/L), ammonia nitrogen (mg N/L), aluminum (mg Al/L), cadmium (mg Cd/L), lead (mg Pb/L), copper (mg Cu/L), chromium (mg Cr/L), iron (mg Fe/L), manganese (mg Mn/L), nickel (mg Ni/L), and zinc (mg Zn/L) (APHA *et al.*, 2005). The samples obtained were classified according to CONAMA Resolution no 357 (CONAMA, 2005). The identification of the metals present in the sediment was carried out at the Soil Analysis Laboratory/UFRGS, using inductively coupled plasma optical emission spectrometry (ICP-OES, Perkin Elmer), which allowed the categorization of the samples according to CONAMA Resolution no. 420 (CONAMA, 2009) and FEPAM Ordinance no. 85 (FEPAM, 2014). Additional elements analyzed in the sediments were phosphorus (P%), potassium (K%), calcium (Ca%), magnesium (Mg%), sulfur (S%), sodium (mg Na/kg), arsenic (mg As/kg), selenium (mg Se/kg), barium (mg Ba/kg), vanadium (mg V/kg), and cobalt (mg Co/kg) (APHA *et al.*, 2005).

For the quantification of thermotolerant coliforms (TC), the most probable number (MPN) technique was used. The dilutions were inoculated on a chromogenic substrate (Colilert, Idexx) in five sets of five tubes and then incubated for 24 h at 35°C. The substrates that changed their color to yellow and emitted fluorescence were considered positive for thermotolerant coliforms.

For the integrated analysis of physicochemical and microbiological parameters, principal component analysis (PCA) was performed using Past 3.14 software.

2.3. Water Quality Index

The water quality index (WQI) was calculated according to CETESB (2016), based on which the water quality of a source was graded on a scale from very poor to very good (Table 1).

Table 1. WQI classification (CETESB, 2016).

Statement	WQI range
Very good	79 < WQI ≤ 100
Good	51 < WQI ≤ 79
Fair	36 < WQI ≤ 51
Poor	19 < WQI ≤ 36
Very poor	WQI ≤ 19

3. RESULTS

3.1. Microbiological and physicochemical analysis of water at sampled points

Based on the DO values, water from O2 (3.57 mg O_2/L) and C1 (2.57 mg O_2/L) were considered to belong to Class 4 (Table 2), and O1 and C2 were categorized as Class 3 and Class 2, respectively (Table 2). At O3 and O4, the DO values were much lower (0.48 and 0.96 mg O_2/L) than the detection limits established (CONAMA, 2005), making it impossible to classify them above Class 4. Based on turbidity levels, water from O4 and C1 were considered to belong to Class 2; furthermore, as C3 had the highest level of turbidity (151.4 NTU), it could not be categorized above Classes 3 and 4. On the basis of the levels of Fe, O1, O3, O4, C1, and C2 were categorized as Class 3 and O2 (10.9 mg Fe/L) and C3 (5.18 mg Fe/L) above the classes. Mn levels from O4 and C1 indicated that these samples belong to Class 3; furthermore, at O2 with a level of 1.25 mg Mn/L, the class was higher than 4. According to the Zn levels from C1, the water samples were classified as Class 3. Based on BOD_5, water from O2 and O3 were considered to belong to Class 3 (CONAMA, 2005). COD ranged from 47 mg O_2/L (for O3 and C2) to 80 mg O_2/L (for O1), and COD/BOD ratio was high (>3.5, Table 1). According to the total P levels, the samples were categorized above Classes 3 and 4. The pH of C3 was 6.22, which is within the range stipulated by legislation (6.0–9.0, CONAMA, 2005); however, at all the other points, the pH values were between 4.55 and 5.75. The highest EC levels were observed at C2 (117 µS cm^{-1}) for the samples collected on March 12, 2020 (Table 2). Based on total chloride, total dissolved solids, ammonia nitrogen, Cd, Cu, and Ni levels, the water from all points were categorized as Class 1. Water samples collected from O2 on March 12, 2020, had the lowest water quality primarily because their pH values and Fe, Mn, and P levels were above the stipulated class limit, and based on the DO level, the water was classified as Class 4 (Table 2).

The samples collected on November 30, 2020, from O2, O3, C1, and C2 were classified as Class 4 water, based on the DO levels, with values ranging between 2.14 and 3.88 mg O_2/L (Table 3). The DO from O4 (0.52 mg O_2/L) was substantially lower than the values established, and its classification was not possible (CONAMA, 2005). Based on turbidity values, water from C3 was considered to belong to Class 2. However, the turbidity values of water from O2, O3, O4, C1, and C2 (ranging from 263 to 1800 NTU) also exceeded the permissible limits stipulated by legislation (CONAMA, 2005). Furthermore, based on the Fe concentration, the water from O1 and C3 were categorized as Class 3; however, as samples from all other points exhibited high Fe concentration (from 8.38 to 55.7 mg Fe/L), they could not be placed in a class greater than 4. Based on the Mn levels, water from O2, O4, C1, C2, and C3 were considered Class 3. Moreover, based on the Zn concentrations, the samples from O4 were categorized as Class 3. According to the total Cr the samples from O4 were categorized as Class 4 (0.051 mg Cr/L). On the basis of the BOD_5 levels, O4 were classified as Class 2; furthermore, it was observed that the BOD_5 were higher in the water from O3 (14 mg O_2/L) than any of the classes. The COD ranged from 273 mg O_2/L in O4 to 33 mg O_2/L in C3. The COD/BOD ratio was high (Table 3) and was >3.5. High concentrations of Al were found at all samples, ranging from 0.247 in O1 to 281 mg Al/L in O4, making it impossible to categorize them into any of the classes. Total phosphorus showed similar results. The pH of the water from all the points in the conventional rice fields was within the range stipulated by legislation (6.0– 9.0) (CONAMA, 2005); however, the pH of points in the organic rice field varied between 4.94 and 5.81. The EC at O4, C1, C2, and C3, was greater than 100 µS/cm; this result is indicative of impacted environments (CETESB, 2016). For total dissolved solids, the value of 684 mg/L in C1 exceeded the framework limit of CONAMA Resolution no 357 (CONAMA, 2005). On the basis of total chloride, Cd, Pb, Cu, Ni, and ammonia nitrogen levels, the water from all points were classified as Class 1. Based on the parameters presented in Table 3, water samples collected from O3 and O4 on November 30, 2020, had the lowest water quality. Water from O3 was considered low quality primarily based on their pH, BOD_5, and turbidity values. The Al, Fe, and P levels were above the stipulated class limits, and according to the DO levels, the samples were categorized as Class 4. The pH, OD, and turbidity values, and Al, Fe, and P levels of water from O4 were above the stipulated class limit; furthermore, based on the total Cr levels, the samples were categorized as Class 4 (Table 3).

The highest values for TC were observed at O4 (240 MPN/100 mL) and C1 (3300 MPN/100 mL), on November 30, 2020, classifying these water samples as Class 2 and Class 3, respectively (Table 3), which is water suitable for the irrigation of cereals as well as other purposes, according to CONAMA Resolution no 357 (CONAMA, 2005).

Table 2. Classification of water samples collected in organic and conventionally irrigated rice fields based on the physicochemical parameters and proportion of thermotolerant coliforms of the samples as class 1 (green), class 2 (blue), class 3 (orange), class 4 (red) and with quality lower than class 3 or 4 (yellow) (Brasil, 2005). Parameters that are not highlighted were not included in the resolution. Sampling date: March 12, 2020. *NR: not in the resolution.

Parameters	Organic rice fields				Conventionally rice fields			Class 3 CONAMA no 357/2005
	O1	O2	O3	O4	C1	C2	C3	
Electric conductivity (µS/cm)	6	34.0	29.0	26,0	46,0	117,0	88.0	NR
Dissolved oxygen (mg/L)	4.36	3.57	0.48	0.96	2.57	5.22	6.79	4.0
pH	5.00	4.99	4.55	4.57	4.70	5.75	6.22	6.0-9.0
Water temperature (°C)	32.2	29.5	26.0	26.9	24.9	26.3	29.5	NR
Turbidity (NTU)	38.7	31.5	10.5	46.9	70.6	31.5	151.4	100
Cadmium (mg/L)	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006	0.01
Copper (mg/L)	<0.004	0.004	<0.004	<0.004	<0.004	<0.004	<0.004	0.013
Chrome (mg/L)	0.907	10.9	1.09	2.43	3.00	2.13	5.18	5.0
Manganese (mg/L)	0.031	1.25	0.059	0.129	0.106	0.056	0.100	0.5
Nickel (mg/L)	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	0.025
Zinc (mg/L)	0.064	<0.020	<0.005	0.008	0.306	0.015	0.014	5.0
Total chloride (mg/L)	8.7	20.6	10.9	10.1	11.4	22.2	16.6	250
BOD_5 (mg/L)	2	9	6	3	3	1	1	10.0
COD (mg/L)	80.0	62.0	47	78	65.0	47	61.0	NR
COD/BOD	40	6.9	7.8	26	21.7	47	61	NR
Total phosphorus (mg/L)	0.135	0.217	0.080	0.138	0.176	0.210	0.298	0.030
Ammoniacal nitrogen (mg/L)	<0.064	<0.064	<0.064	<0.064	0.088	<0.064	<0.064	13.3
Total dissolved solids (mg/L)	70	63	71	95	123	112	191	500
Thermotolerant coliforms (MPN/100mL)	4	13	50	4	6	17	8	4000

Table 3. Classification of water samples collected in organic and conventionally irrigated rice fields based on the physicochemical parameters of the samples as Class 1 (green), Class 2 (blue), Class 3 (orange), Class 4 (red) and with quality lower than Class 3 or 4 (yellow) (CONAMA, 2005). Parameters that are not highlighted were not included in the resolution. Sampling date: November 30, 2020. *NR: not in the resolution.

Parameters	Organic rice fields				Conventionally rice fields			Class 3 CONAMA no 357/2005
	O1	O2	O3	O4	C1	C2	C3	
Electric conductivity (µS/cm)	34.50	58.60	57.70	102,00	154,10	209.30	130.70	NR
Dissolved oxygen (mg O_2/L)	7.90	3.35	2.14	0.52	3.46	3.88	6.58	4.0
pH	4.94	5.77	5.62	5.81	6.42	6.63	6.82	6.0-9.0
Water temperature (°C)	25.7	25.3	25.5	25.4	25.9	25.3	26.6	NR
Turbidity (NTU)	13.80	263	345	1,800	1,600	760	81	100
Aluminum (mg Al/L)	0.247	21.1	27.4	281	196	84.2	4.81	0.2
Cadmium (mg Cd/L)	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.01
Lead (mg Pb/L)	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	0.033
Copper (mg Cu/L)	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.004	0.0013
Chrome (mg Cr/L)	<0.004	<0.007	0.008	0.051	0.037	0.017	<0.004	0.05
Iron (mg Fe/L)	0.413	8.38	9.53	55.7	47.3	21.5	4.57	5.0
Manganese (mg Mn/L)	0.027	0.162	0.060	0.447	0.477	0.301	0.151	0.5
Nickel (mg Ni/L)	<0.004	<0.004	<0.004	0.011	0.010	0.004	<0.004	0.025
Zinc (mg Zn/L)	0.003	0.018	0.062	0.467	0.125	0.047	0.018	5.0
Total chloride (mg Cl/L)	9.4	10.8	11.7	20.3	30.2	37.9	14.6	250
BOD_5 (mg O_2/L)	2.0	2	14	4	3	2	1	10
COD (mg O_2/L)	49	54	64	273	206	123	33	NR
COD/BOD	24.5	27	4.6	68.3	68.7	61.5	33	NR
Total phosphorus (mg P/L)	0.146	0.52	0.547	2.70	2.70	1.61	1.10	0.030
Ammoniacal nitrogen (mg N/L)	<0.064	<0.064	<0.064	<0.064	1.67	1.20	0.488	13.3
Total dissolved solids (mg/L)	22	96	67	488	684	173	30	500
Thermotolerant coliforms (MPN/100mL)	1	17	11	240	3300	21	7.8	4000

3.2. Water Quality Index

The water samples collected from O3, O4, and C1 on March 12, 2020, were classified as "fair," and those collected from O1, O2, C2, and C3 were classified as "good" (Table 4). However, the samples collected on November 30, 2020, had relatively lower WQI values. The water from O4 and C1 were classified as "poor," those from O3 and C2 were classified as "fair," and those from O1, O2, and C3 were classified as "good."

Table 4. WQI of the water samples collected from different organic and conventionally irrigated rice fields.

Sampling date	Organic rice fields				Conventionally rice fields		
	O1	O2	O3	O4	C1	C2	C3
March 12, 2020	66.85	57.18	40.68	43.81	50.87	72.80	69.99
WQI	Good	Good	Fair	Fair	Fair	Good	Good
November 30, 2020	77.40	51.30	40.50	28.38	34.18	39.46	72.33
WQI	Good	Good	Fair	Poor	Poor	Fair	Good

3.3. Principal component analysis of physicochemical and microbiological parameters of the water samples

During the collection on March 12, 2020 (Figure 2), Component 1 separated points O2, C2, and C3 from points C1, O1, O3, and O4. Furthermore, O2 and O3 were separated from the other points by Component 2, with O3 from organic rice fields being the least impacted. The air temperature was separated from the other attributes by Component 1, and Component 2 separated iron and chloride from the other variables. Turbidity was related to total phosphorus, conductivity, DO, and pH. During the collection on November 30, 2020 (Figure 3), Component 1 separated points O4, C1, and C2; Component 2 grouped points O1, O2, and O3 and separated these three points from C3, indicating that these points from the organic rice field are less impacted. DO was separated by Component 1, and Component 2 separated and grouped nickel, COD, aluminum, chromium, iron, turbidity, and total dissolved solids. Conductivity was more associated with pH and ammonia nitrogen; furthermore, phosphorus and manganese were closely associated.

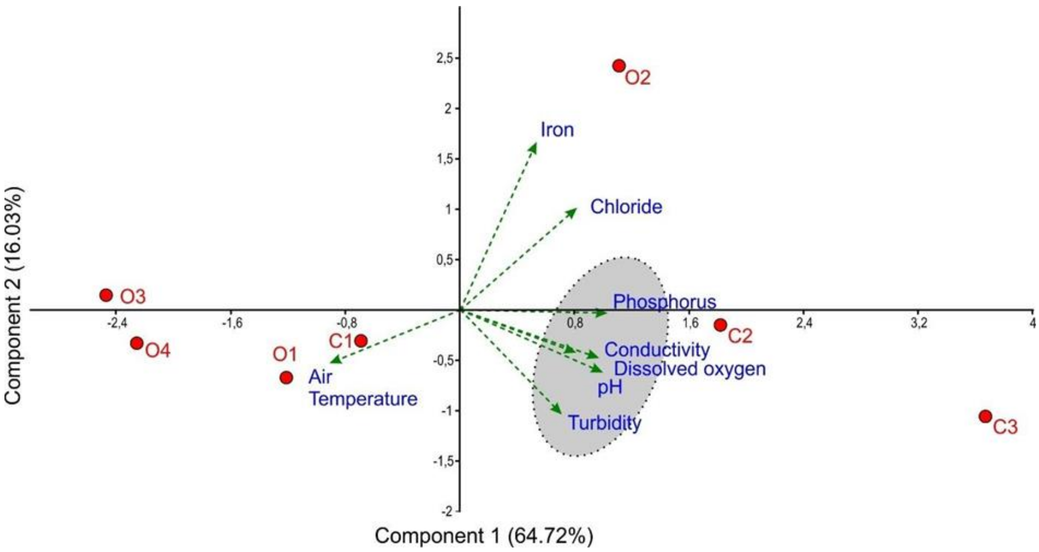

Figure 2. PCA of the physicochemical and microbiological parameters analyzed at different points in the organic and conventionally irrigated rice fields. Component 1, with 64.72% affinity, separates from Component 2 with 16.03% affinity. Sampling date: March 12, 2020.

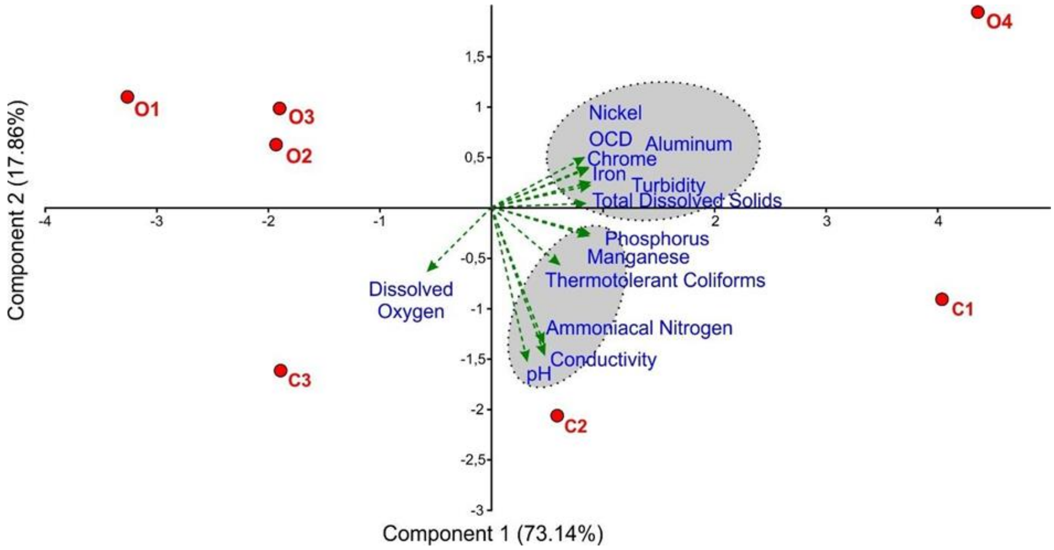

Figure 3. PCA of the physicochemical and microbiological parameters analyzed at different points in the organic and conventionally irrigated rice fields. Component 1, with 73.14% affinity, separates from Component 2 with 17.86% affinity. Sampling date: November 30, 2020.

3.4. Physicochemical analysis of the sediment at the sampled points

According to Table 5, sediment from C1 of the conventional tillage presented the highest levels of P, K, Cu, Zn, Na, Al, Co, and Ba. The samples collected from O2 (organic rice field) had the highest levels for Ca, Mg, S, Fe, Mn, and Va. However, C2 had the highest levels of Ni and P, and O3 had higher Cr levels. Based on the quality reference values (QRV, FEPAM, 2014) the QRV of Zn was 30 mg Zn/kg in C1; this was above the stipulated (29 mg Zn/kg). O2, C2, and C3, had Ni levels of 8, 12, and 8 mg Ni/kg, respectively, all of which were above the established (7 mg Ni/kg). The sediment from conventional tillage, along with that from the O2 from organic tillage, had the lowest quality among the sampled points (Table 5).

Table 5. Concentrations of chemical elements at the sediments sampled on November 11, 2019 in organic and conventionally irrigated rice fields compared with the levels allowed in CONAMA Resolution no 420 (CONAMA, 2009) and FEPAM Ordinance no 85 (FEPAM, 2014).

Parameters	Organic rice fields			Conventionally rice fields			CONAMA Resolution no 420/2009	FEPAM Ordinance no 85/2014
	O2	O3	O4	C1	C2	C3		
Phosphorus (P%)	0.03	0.01	0.01	0.04	0.02	0.02	NR	NR
Potassium (K%)	0.09	0.03	0.03	0.10	0.07	0.08	NR	NR
Calcium (Ca%)	0.24	0.05	0.05	0.21	0.08	0.10	NR	NR
Magnesium (Mg%)	0.18	0.03	0.02	0.09	0.06	0.06	NR	NR
Sulfur (S%)	0.06	0.03	0	0.06	0.03	0.02	NR	NR
Copper (mg/kg)	3	0	1	4	2	2	200	11
Zinc (mg/kg)	22	9	11	30	22	20	450	29
Iron (Fe%)	1.7	0.29	0.28	1.1	0.84	0.73	NR	NR

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Manganese (mg Mn/kg)	442	53	27	179	52	115	NR	NR
Sodium (mg Na/kg)	131	76	93	166	122	145	NR	NR
Cadmium (mg Cd/kg)	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	3	0.42
Chromium (mg Cr/kg)	11	17	7	11	15	13	150	21
Nickel (mg Ni/kg)	8	7	4	6	12	8	70	7.0
Lead (mg Pb/kg)	7	2	2	8	9	7	180	16
Aluminum (Al%)	1.9	0.59	0.99	3.2	2.2	2.1	NR	NR
Arsenic (mg As/kg)	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	35	NR
Selenium (mg Se/kg)	<4	<4	<4	<4.	<4	<4	NR	NR
Cobalt (mg Co/kg)	6	2	2	7	6	5	35	7.0
Barium (mg Ba/kg)	75	23	30	95	51	65	300	NR
Vanadium (mg V/kg)	36	7	8	35	30	27	NR	76

*NR: not in the resolution.

As shown in Figure 4, PCA Component 1 separated C1, C3, and O2 from C2, O3, and O4. O2, O3, and O4 were separated from the other points by Component 2. Furthermore, Component 2 separated P, K, N, and organic carbon from pH, Mg, Mn, Fe, and Ca.

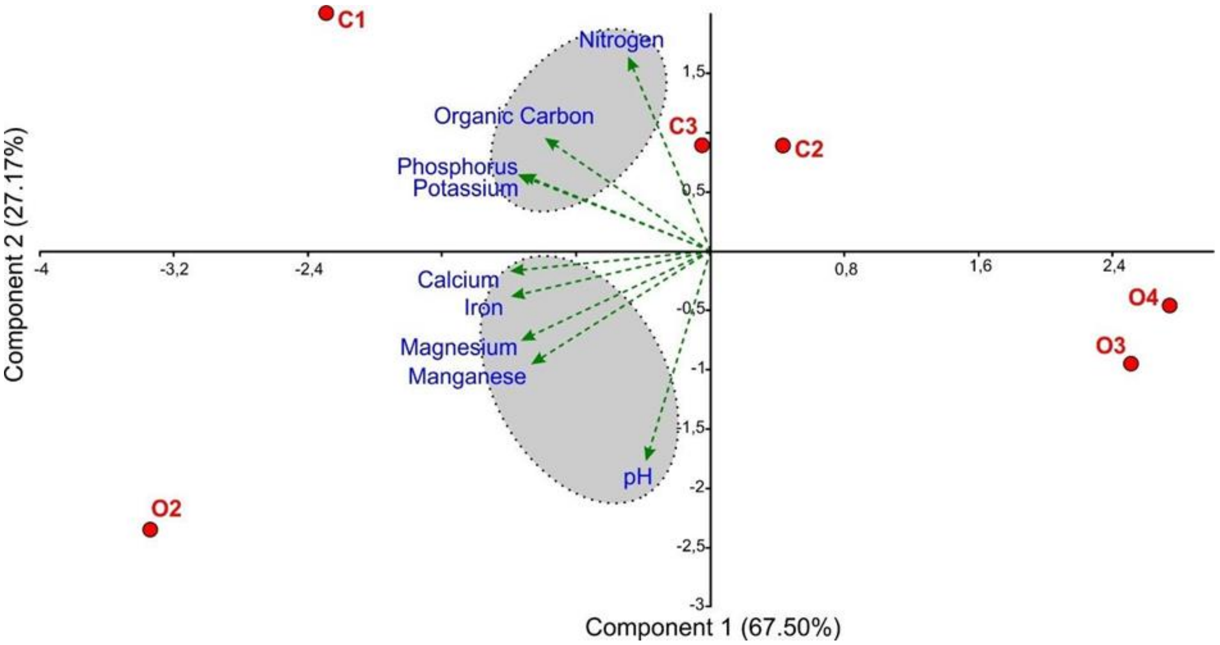

Figure 4. PCA of the physicochemical and microbiological elements analyzed at different points in the organic and conventionally irrigated rice fields. Component 1, with 67.50% affinity, separates from Component 2 with 27.17% affinity. Sampling date: November 11, 2019.

4. DISCUSSION

In this study, the quality of water and sediment was evaluated in two pre-germinated irrigated rice fields (organic and conventional). Both the cultivation areas were located in the Gravataí River Basin (Viamão/RS), in the stretch identified as Middle Gravataí classified as Class 3 (Bourscheid, 2012) based on CONAMA Resolution no 357 (CONAMA, 2005). The water sampled from Points O1 and C3 is used for irrigation and comes from the Águas Claras Dam and the Gravataí River, respectively. The water from Points O3, O4, C1, and C2, is used for drainage and is reused for irrigating organic and conventional rice fields via pumping. According to Mondstock (2015), rice crops can have a great impact on water quality, especially when taking into consideration the runoff from cultivated land. Furthermore, during periods of intense rainfall, when the soil is unable to absorb the entire volume of accumulated water, drainage channels help in restoring flow.

CONAMA Resolution no 357 (CONAMA, 2005) classifies Class 3 fresh waters as those that can be used for irrigation of arboreal, cereal and forage crops as well as other purposes. The results of the physicochemical analysis of the water samples in this study indicated high concentrations of P, turbidity, DO, BOD_5, Mn, and Fe beyond the permissible limits established for Classes 3 and 4 (CONAMA, 2005). At all points sampled, including O1 (Águas Claras dam) and C3 (adduction channel connected to the Gravataí River), P levels exceeded the permitted limits of 0.05 mg P/L indicating high eutrophication. The P from agricultural areas is relevant as it is an indicator of water quality; other indicators such as suspended solids and turbidity are associated with P transport (Scivitaro *et al.*, 2010). In a study conducted by Scivitaro *et al.* (2010) in Capão do Leão (RS), the P levels found in the waters during the drainage period of pre-germinated rice cultivation ranged from 9 to 27 mg P/L, exceeding the maximum value defined for Class 3 (CONAMA, 2005). The previous flooding of the soil in this type of cultivation promotes physical, chemical, and biological changes in relation to the original condition. Among these changes, the increase in the P availability in solution is significant; this increase, in addition to the partial dissolution of the phosphate fertilizer applied during pre-sowing, explains the high P levels in drainage water (Scivitaro *et al.*, 2010). Furthermore, P and turbidity levels (>100 NTU) were high for Class 3 (CONAMA, 2005), with the highest turbidity levels observed at O4 (1800 NTU). This high value coincides with the period of crop cultivation (November 30, 2020), soil preparation, sowing, water depth reduction, and drainage. Drainage causes the loss of total solids, which causes an increase in turbidity in the water, as well as the loss of nutrients and other materials, such as pesticides that are adsorbed on suspended soil particles and can be transported to water sources (Mattos *et al.*, 2012).

DO is also one of the primary parameters affecting the environment, with natural water bodies having high levels of DO, essential for the maintenance of aquatic life (Britto *et al.*, 2016; Silva and Pereira Filho, 2010). According to CONAMA Resolution no 357 (CONAMA, 2005), the limit for DO in Class 4 is >2 mg O_2/L. Water samples collected from O1 (7.90 mg O_2/L, Águas Claras Dam) and C3 (6.79 mg O_2/L, the Gravataí River adduction channel) had the highest DO levels. Based on these values, the water samples were categorized as Class 1, that is, water that can be used: a) for human consumption, after simplified treatment; b) the protection of aquatic communities; c) primary contact recreation, such as swimming, water skiing, and diving; d) the irrigation of vegetables that are consumed raw, fruits that grow close to the ground, and the ones that are eaten raw without removing the skin; and e) the protection of aquatic communities in indigenous lands (CONAMA, 2005). The lowest DO value was observed in the water samples collected from O4, < 2.0 mg O_2/L, which is the minimum value for classification in Class 4, that is, waters utilized for navigation and landscape harmony (CONAMA, 2005). Britto *et al.* (2016) attributed DO values <1.0 mg O_2/L to the presence of agricultural production residues in the water body. In the study conducted in the Itajaí hydrographic basin (SC), to assess the quality of water used in irrigated rice farming, relatively low concentrations of DO were observed in the drainages, with an average of 3.7 mg O_2/L, while in the abstractions, the average was 6.6 mg O_2/L. This variation reflects the negative influence of rice farming on water quality (Silva and Pereira Filho, 2010).

According to CETESB (2016), organic discharges result in the greatest increase in BOD in a water body, which completely depletes oxygen in the water, consequently leading to the disappearance of aquatic life. The greater the BOD, the greater is the degree of water pollution (CETESB, 2016). In this study, high levels of BOD were found at all sampling points in the organic rice fields, with the highest value in O3 (14 mg O_2/L) at the time of crop cultivation, surpassing the limit of Class 3 (<10 mg O_2/L) (CONAMA, 2005). Silva and Pereira Filho (2010) analyzed the quality of irrigation water used in rice farming and showed that the average levels of BOD were 3.2 mg O_2/L and 4.8 mg O_2/L in abstraction and drainage, respectively. In this study, BOD values were higher in practically all samples collected from drainages, thus indicating a greater amount of organic matter in returning waters to the Gravataí River after passing through rice fields. Associating BOD with ammoniacal nitrogen and DO reinforces this idea, as BOD was higher in returning water, indicating increased ammonia concentration and decreased DO.

COD is an extremely useful parameter when used in conjunction with BOD to observe the biodegradability of dumps (Britto *et al.*, 2016). However, no reference for COD exists in the CONAMA Resolution no 357 (CONAMA, 2005). Molozzi *et al.* (2006) reported that during the rice maturation stage, COD values were higher in drainage water than that in irrigation water. It was only after the harvest that irrigation water had a higher COD than that of drainage water. In this study, the COD values ranged from 47 mg O_2/L (in O3 and C2), during the rice maturation and harvest phases, to 273 mg O_2/L (O4) during the soil preparation and rice sowing phases. In general, the COD was higher in the conventional rice field than that in the organic rice field; this value can be attributed to the application of chemical fertilizers and pesticides (Molozzi *et al.*, 2006). In this study, the COD/BOD ratio was high, demonstrating that the biodegradable fraction was very low, which suggests the need for physicochemical treatment of these waters (Von Sperling, 1996).

High levels of the metals Fe, Mn, Zn, and Ni were found in samples collected for the present study. The highest Fe concentrations were found during the cultivation period of the crop and at O4 (55.7 mg Fe/L). Fe concentrations >5 mg Fe L^{-1}, which is the maximum value for this parameter for Class 3 (CONAMA, 2005), were found at some points, mainly at the end of cultivation and harvest. Fe is toxic to vegetables at concentrations >5 mg Fe L^{-1}, when it makes P and Mo unavailable, causing nutritional deficiency (Almeida, 2010). Moreover, the red yellow alic argis soil of this region contains iron, hematite, and goethite with a high propensity for erosion (EMBRAPA, 2018), which may also contribute to these high levels. Santos and Hernandez (2013) also found high Fe concentrations at all sampled points of the agricultural basin of the Ipê Stream in Ilha Solteira (SP). The Mn level in O2 was 1.25 Mn mg/L, which is higher than the maximum value allowed for inclusion in the classes (0.50 mg Mn/L, CONAMA, 2005). According to Quinatto *et al.* (2019), Mn rarely reaches concentrations of 1.0 mg Mn/L in natural surface waters and is usually present in amounts of <0.2 mg Mn/L. The concentration of Zn in the sediment collected from C1 (30 mg Zn/kg) exceeded the QRV (29.0 mg Zn/kg, FEPAM, 2014); this increase can be attributed to the application of fertilizer in the conventional field. In the study by Lavnitcki *et al.* (2020) in the Ponte Grande River Basin (Lages/SC), Zn concentration in the sediments ranged from 57.86 to 210.90 mg Zn/kg between the sampled points, being found in springs, junctions and mainly in urbanized areas due to the release of domestic effluents and rainwater. Sanches Filho *et al.* (2015) conducted a study on the São Lourenço River (RS) and found high Zn concentrations (between 27.9 and 83.6 mg Zn/kg) for most of the sampling points; however, the high concentrations were attributed to the geology of the region. In this study, the highest Ni concentration in the sediment was 12.0 mg Ni/kg at C2, which is a drainage channel in the conventional rice field. O2, O3, C2 and C3 also presented high concentrations of Ni above the QRV of 7.0 mg Ni/kg (FEPAM 2014). Sanches *et al.* (2014) reported that the Ni concentration at sediment sampling Point 3 (20 mg Ni/kg) was high enough to present a possible risk to aquatic life in the São Lourenço Stream.

The water quality index (WQI) was classified as "poor" and indicated a decrease in the water quality of samples collected from O4 (organic farming) and C1 (conventional farming) on November 30, 2020. The samples collected from other points were either "fair" or "good" water. Lopes *et al.* (2008), based on the isolated analysis of the variables that comprise the WQI, reported that the isolated value of this index is not sufficient for an accurate analysis of water quality. According to the authors, the fluctuations of the WQI variables compensate each other, keeping the index relatively stable at a level; however, this relative "stability" masks important fluctuations in the environment and must be monitored and analyzed with greater care. An environment can fall into the "optimal" range of the WQI even if some substances are at concentrations that are toxic to the biota and WQI does not include important potential contaminants, such as pesticides (Cunha *et al.*, 2013).

Although the electrical conductivity (EC) is not determined in CONAMA Resolution no 357 (CONAMA, 2005), CETESB (2016) considers values >100 µS cm^{-1} indicative of impacted environments. The EC of samples collected from C2 on March 12, 2020, and those collected from O4, C1, C2, and C3 on November 30, 2020, exceeded 100 µS/cm, indicative of impacted environments. In a study by Scivitaro *et al.* (2010), the EC indices of the post-sowing drainage water of pre-germinated rice remained >150 µS cm^{-1}, indicating the changes in water composition, especially in the concentration of minerals, owing to the dissolution of salts of the applied fertilizers. In conventional farming, EC values are higher than those in organic rice farming because of the application of fertilizers. EC is one of the most important criteria regarding the quality of irrigation water, as high values imply a risk of salinization of the soil and corrosive characteristics of the water. Although EC is a good indication of changes in the mineral composition of water, it does not indicate the relative amounts of the various components (Scivitaro *et al.*, 2010).

5. CONCLUSION

Based on different parameters, the lowest water quality was observed in Points O2 and O4 (organic rice field). However, for the sediment, the lowest quality was observed in the conventional rice fields along with Point O2 in the organic rice field. Although high levels of metals and other parameters provide essential and beneficial micronutrients to crops, they introduce toxic and potentially carcinogenic heavy metals to the production chain, which through cumulative soil contamination, can reach the food chain and cause various health problems in humans (Nava *et al.*, 2011). The techniques used in organic agriculture, when carried out correctly, improve soil fertility, increase the capacity to retain water and nutrients, reduce erosion and leaching, consequently, the loss of quality of this resource (Kamiyama *et al.*, 2011). This is possible by applying the key concepts of organic agriculture and soil conservation, such as the maintenance of soil cover, crop rotation, increase in organic matter content, and favorable biological activities occurring in the soil. In addition, the soil in an organic production system has a greater capacity to retain potential contaminants, thus reducing the chances of their percolation (Morgera *et al.*, 2012).

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