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Environmental impacts of reject brine disposal from desalination plants

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ABSTRACT

The chemical composition and the impacts of reject brine disposal from desalination plants on soils of the west of Rio Grande do Norte, Brazil, were evaluated. Soil samples in the 0.0–0.2 and 0.2–0.4 m profiles were collected at three points of reject brine influences (0, 0.8 and 1.6 m of reject brine site) and a point in the native forest (without the influence of reject brine) for chemical characterization. The analysis showed that 25% of the native forest soils have problems of salinity and/or sodicity, suggesting that salt-affected soils already existed in some communities even without the disposal of brine. The variability between the results on analysis of soil chemical properties from study lands suggests an individual assessment of potential risk of soil salinization due to the disposal of reject brine from desalination plants.

Keywords: Salinity and sodicity; Soil saline; Desalination; Brine discharge; Reverse osmosis

1. Introduction

In rural communities in the Brazilian Northeast, the use of groundwater from wells is an alternative to water supply. However, there is a great limitation in the use of these sources to cope with the water scarcity, because many of them present high content of dissolved salts [1–5], causing harm to people and the environment. Thus, the need arises for the use of technologies that allow alleviating the precarious conditions of the water supply existing in the majority of the northeastern communities.

Reverse osmosis has been widely used for the treatment of brackish water, with successful experiences in most of the locations where desalination plants have been installed [6]. As a disadvantage, this technology generates, in addition to drinking water, a reject brine of potential pollutant power of 40%–70% of the total water withdrawal from wells, depending on the efficiency of the equipment and the water quality of well [7,8]. According to Porto et al. [9], much of this waste does not receive any treatment or exploitation, and even so, it is dumped in soil or in water bodies.

Inadequate disposal of reject brine has negative effects on environment as soil salinization and, salt movement into waterway and underground system [6]. Thus, the major challenge of using the reverse osmosis water treatment system is the disposal or reuse of wastewater in order to

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avoid negative impacts on the environment, since they are commonly spilled into watercourses and soil without any evaluation [4].

In view of the above, this study aimed to evaluate the chemical composition and the environmental impacts of reject brine disposal from desalination plants on soils of the western part from Rio Grande do Norte, semi-arid region of Brazil.

2. Materials and methods

2.1. Study area

The research was carried out in the rural area of the municipality of Mossoró, Rio Grande do Norte, Brazil, located at the geographical coordinates of latitude: 5° 11′ 15″ South and Longitude: 37° 20′ 39″ West of Greenwich. The climate of the municipality is the Tropical of Equatorial Zone with three subclimates (mild semiarid, average semiarid and strong semiarid) Diniz and Pereira [10], with annual mean of 673.9 mm, with a dry season, which generally comprises the period from June to January and a rainy season, between February and May, with the mean temperature being 27°C and relative humidity of 68.9% [11].

2.2. Methods

The areas of disposal of reject brine from 10 desalination plants operated by reverse osmosis were investigated; being 6 of which were Settlement Projects (S.P.) (Boa Fé - 5°37′44″S and 37°20′22.50″O, Cabelo de Negro - –5.243357°S and –37.561299°O, Oziel Alves - 4°56′32.74″S and 37°24′14.04″O, Santa Elza - 5°06′50.29″S and 37°31′9.86″O, Maracanaú - 5°20′38.52″S; 37°11′21.15″O and, Fazenda Nova - –5.335492°S and 37.500034°O) and 4 Rural Communities (Serra Mossoró - –5.118095°; –37.434993°, Espinheirinho - 5°27′22.17″S; 37° 09′42.84″O, Passagem do Rio - –5.312942°; –37.408762° and, Santana - –5.335492°; –37.303545°; Fig. 1).

In each area four soil samples were collected, at depths of 0.0–0.2 and 0.2–0.4 m. Collection point 1 (P_1) was in the reject brine disposal area while points 2 (P_2) and 3 (P_3) at 0.8 and 1.6 m distance from the disposal area, respectively. Point 4 (P_4) is the control, where the samples were collected in the native forest. After collection the samples were sent to the laboratory, air dried and sieved in 2 mm mesh sieves to remove impurities and gravel. In soil, the following parameters were determined: pH, electrical conductivity (EC), exchangeable sodium percentage (ESP), contents of Na^+, $Ca^{2+} + Mg^{2+}$, Al^{3+}, exchangeable acidity (H + Al), exchangeable and bases (EB), cation exchange capacity (CEC) and base saturation (V), according to methodology proposed by Embrapa Informação Tecnólogica [12].

2.3. Data analysis

The data were analyzed by means of descriptive statistics, with the aid of the statistical software SPSS®.

The reject brines were classified and interpreted for the salinity and sodicity risks, according to the parameters of the US Salinity Laboratory USSL [13]. Also, we have considered

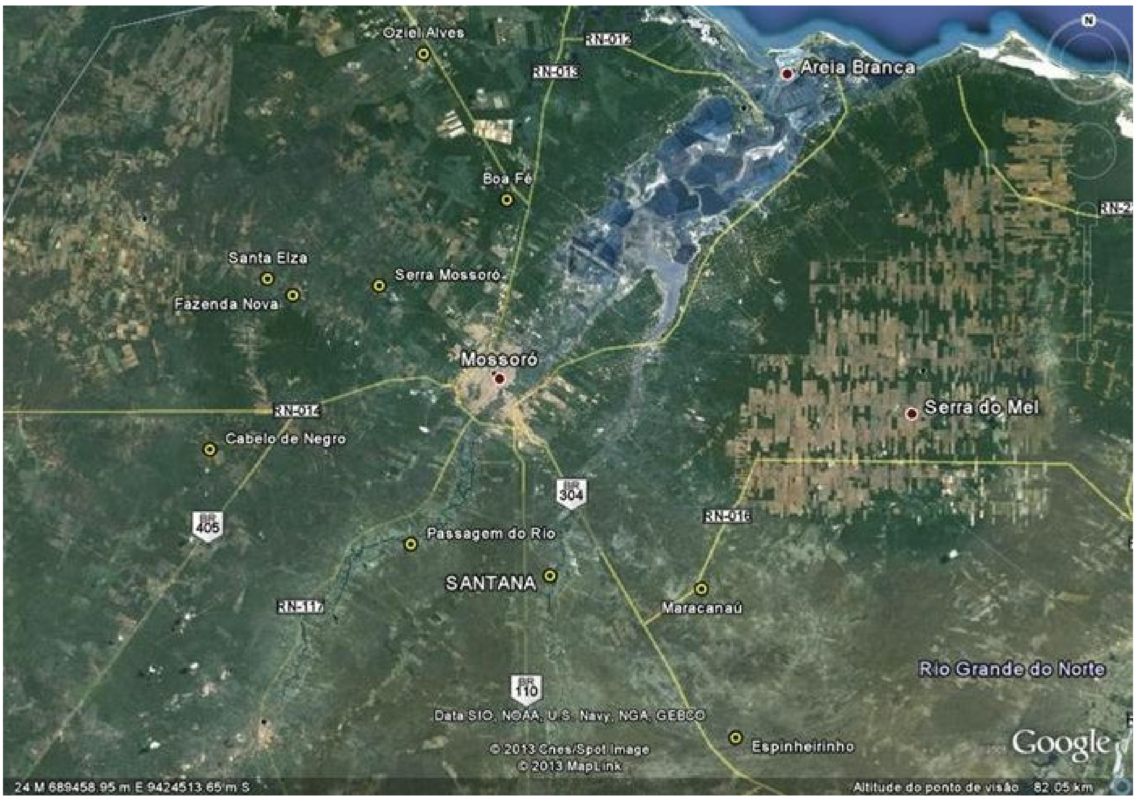

Fig. 1. Satellite image with location of settlement projects and rural communities, Mossoró, RN.

the FAO guidelines for the assessment of water quality for irrigation [14].

3. Results

3.1. Analysis of soil in the discharge point of reject brine

In the soil samples collected in the 0.0–0.2 m profile in the reject brine area, pH ranged from 6.9 to 8.9, with a mean of 8.1. In the 0.2–0.4 m profile, the pH ranged from 7.5 to 8.4, with a mean of 8.04, indicating that the soil is more alkaline in the deeper layers (Table 1).

In the analysis of EC_{se} and sodium saturation in the soil, it was verified that 45% of the samples had saline character and 25% salic character at the point of discharge of the reject brine. Sodium was 30% solodic and 10% sodic in the community of S.P. Boa Fé, which had sodium saline character in the collection of the two soil profiles located at the point of the discharge of reject brine. The Santa Elza community presented a salic character in the two depths sampled, and the Maracanaú, Santana and Espinheirinho communities presented this character in at least one analyzed depth (Fig. 2).

Still in relation to Fig. 2, only in S.P. Fazenda Nova, the soil was considered within the normal parameters for salinity and sodicity, in both sampling profiles. The Serra Mossoró community and S.P. Cabelo de Nego were within the normal parameters for salinity and sodicity only in the profile 0.0–0.2 m.

3.2. Analysis of soil at 0.8 m away from of the brine discharge point

Regarding to the soil chemical analysis, collected in the layers of 0.0–0.2 and 0.2–0.4 to 0.8 m of the discharge point of reject brine from desalination plants (Table 2), it was found that, in all collected samples at depths of 0.0–0.2 m, the pH presented a variation of 5.6 to 9.0, with a mean of 7.9, whereas that in the samples depths 0.2–0.4 m, pH ranged from 4.5 to 9.0, with a mean of 7.8, indicating a predominance of alkaline soils in the two soil layers evaluated. The samples of S.P. Boa Fé presented, at both depths, pH with acid reaction, totally atypical to the other collection sites. In other communities, pH is considered high for the practice of agriculture.

In regard to the classification of the samples for salinity and sodium saturation, it was observed that in relation to salinity, 30% of the soils presented saline character and 40% salic character. As for sodicity, it was observed that 20% had a solodic character and 5% with a sodium character, represented by S.P. Boa Fé, which had a saline sodium character in the depth of 0.2–0.4 m. The Santa Elza, Santana and Espinheirinho communities presented a salic character in the two depths verified, and the communities Maracanaú

Table 1
Results of the chemical analysis of soil samples collected at the brine discharge point for the profile of 0.0–0.2 and 0.2–0.4 m

Communities	Depth	pH	EC_{se}	ESP	Na^+	Ca^{2+} + Mg^{2+}	Al^{3+}	(H + Al)	EB	CEC	V
	m	H_2O	(dS m^{-1})	%	mg dm^{-3}			cmolc dm^{-3}			%
Oziel Alves	0.0–0.2	8.1	1.7	8.0	52.3	1.9	0.0	0.8	2.1	2.1	80.9
Boa Fé	0.0–0.2	7.3	6.8	15.8	198.6	2.7	0.0	0.8	4.7	4.7	84.6
Serra Mossoró	0.0–0.2	8.3	3.6	3.5	242.8	27.9	0.0	0.3	29.6	29.6	98.9
Santa Elza	0.0–0.2	8.5	7.7	8.3	675.8	30.2	0.0	0.0	35.5	35.5	100.0
Fazenda Nova	0.0–0.2	8.9	1.4	4.6	55.9	5.5	0.0	0.0	5.8	5.8	100.0
Maracanaú	0.0–0.2	8.2	11.6	0.1	7.3	30.4	0.0	0.1	30.4	30.4	99.7
Santana	0.0–0.2	8.2	5.0	0.1	3.1	18.0	0.0	1.2	18.2	18.2	94.0
Espinheirinho	0.0–0.2	7.9	6.9	0.1	3.2	26.3	0.0	0.6	26.4	26.4	97.9
Passagem do Rio	0.0–0.2	8.4	5.9	11.4	338.6	10.9	0.0	0.2	12.6	12.6	98.2
Cabelo de Nego	0.0–0.2	6.9	0.8	0.6	19.5	10.7	0.0	2.7	11.4	11.4	81.0
Oziel Alves	0.2–0.4	8.1	1.5	9.0	52.3	1.3	0.0	0.9	1.6	1.6	68.1
Boa Fé	0.2–0.4	7.5	6.4	21.2	199.9	2.4	0.0	0.9	3.3	3.3	81.3
Serra Mossoró	0.2–0.4	7.8	4.5	3.4	253.0	30.6	0.0	0.3	32.3	32.3	99.0
Santa Elza	0.2–0.4	8.4	8.1	7.0	713.3	37.8	0.0	0.0	43.1	43.1	100.0
Fazenda Nova	0.2–0.4	8.4	1.3	4.3	40.8	3.8	0.0	0.1	4.0	4.0	98.0
Maracanaú	0.2–0.4	8.4	5.8	0.1	4.3	28.8	0.0	0.2	28.9	28.9	99.4
Santana	0.2–0.4	8.1	9.6	0.1	6.2	31.2	0.0	0.5	31.3	31.3	98.4
Espinheirinho	0.2–0.4	7.7	12.3	0.1	3.9	29.0	0.0	0.9	29.0	29.0	97.0
Passagem do Rio	0.2–0.4	8.3	5.8	8.0	351.5	16.9	0.0	0.6	18.6	18.6	97.2
Cabelo de Nego	0.2–0.4	7.7	4.0	3.6	154.8	16.0	0.0	0.2	18.5	18.5	99.1

*pH H_2O: potential of hydrogen; EC_{se}: electrical conductivity of a saturated soil extract; ESP: exchangeable sodium percentage; Na^+: sodium; Ca^{2+}: calcium; Mg^{2+}: magnesium; Al^{3+}: aluminum; (H + Al): exchangeable acidity; EB: exchangeable bases; CEC: cation exchange capacity; V: base saturation.

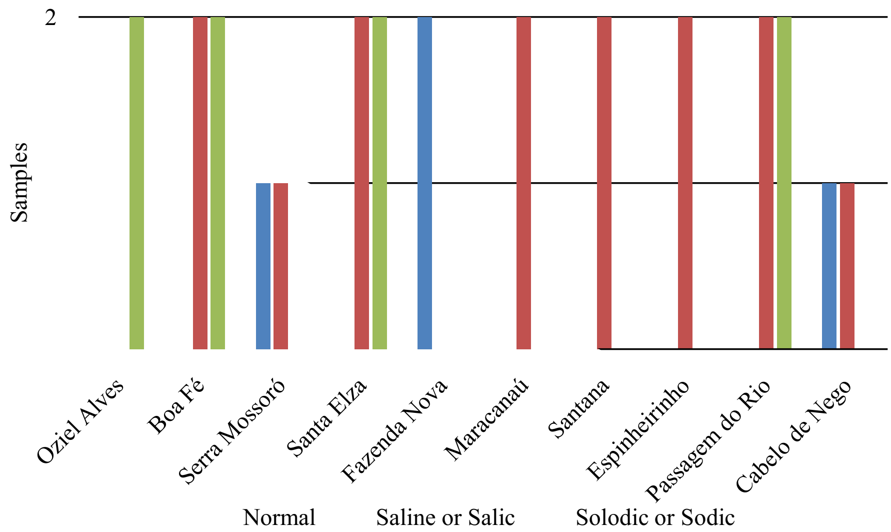

Fig. 2. Classification of soil samples for salinity and sodium saturation at the brine discharge point.

Table 2
Results of the chemical analysis of soil samples collected at 0.8 m from the brine discharge point for the profile of 0.0–0.2 and 0.2–0.4 m

Communities	Depth	pH	EC_{se}	ESP	Na^+	$Ca^{2+} + Mg^{2+}$	Al^{3+}	(H + Al)	EB	CEC	V
	M	H_2O	(dS m^{-1})	%	mg dm^{-3}		cmolc dm^{-3}				%
Oziel Alves	0.0–0.2	8.3	1.6	7.4	61.5	2.5	0.0	0.8	2.8	2.8	81.1
Boa Fé	0.0–0.2	5.6	0.0	3.4	21.2	0.9	0.0	1.8	1.0	1.1	37.2
Serra Mossoró	0.0–0.2	8.0	9.3	5.4	399.5	29.3	0.0	0.0	32.2	32.2	100.0
Santa Elza	0.0–0.2	8.3	10.7	4.1	300.4	28.1	0.0	0.1	30.3	30.3	99.7
Fazenda Nova	0.0–0.2	9.0	1.0	4.0	30.7	3.2	0.0	0.0	3.4	3.4	100.0
Maracanaú	0.0–0.2	8.2	12.5	0.1	7.5	30.3	0.0	0.2	30.3	30.3	99.5
Santana	0.0–0.2	8.1	21.6	0.2	7.0	13.6	0.0	0.2	13.7	13.7	98.2
Espinheirinho	0.0–0.2	7.6	12.3	0.0	2.7	28.1	0.0	1.3	28.2	28.2	95.5
Passagem do Rio	0.0–0.2	8.5	4.6	8.8	219.7	9.0	0.0	0.6	10.2	10.2	94.8
Cabelo de Nego	0.0–0.2	7.5	0.6	0.3	14.8	16.2	0.0	1.3	17.3	17.3	92.9
Oziel Alves	0.2–0.4	8.2	2.4	8.0	63.7	2.1	0.0	0.9	2.4	2.4	75.2
Boa Fé	0.2–0.4	4.5	5.6	19.1	163.2	1.2	0.0	1.7	2.0	2.1	54.4
Serra Mossoró	0.2–0.4	8.3	4.9	5.2	337.5	26.2	0.0	0.0	28.5	28.5	100.0
Santa Elza	0.2–0.4	8.2	10.6	4.0	354.5	35.1	0.0	0.0	37.0	37.0	100.0
Fazenda Nova	0.2–0.4	9.0	1.1	3.7	24.7	3.0	0.0	0.0	3.1	3.1	100.0
Maracanaú	0.2–0.4	8.2	6.7	0.1	7.3	38.0	0.0	0.0	38.0	38.0	100.0
Santana	0.2–0.4	7.9	22.6	0.1	8.2	26.8	0.0	0.3	26.9	26.9	98.8
Espinheirinho	0.2–0.4	7.8	9.3	0.0	2.4	30.8	0.0	3.6	30.8	30.8	89.5
Passagem do Rio	0.2–0.4	8.4	5.6	7.4	322.9	16.6	0.0	0.6	18.2	18.2	97.2
Cabelo de Nego	0.2–0.4	7.6	4.2	4.3	178.3	15.4	0.0	0.7	17.3	17.3	96.3

*pH H_2O: potential of hydrogen; EC_{se}: electrical conductivity of a saturated soil extract; ESP: exchangeable sodium percentage; Na^+: sodium; Ca^{2+}: calcium; Mg^{2+}: magnesium; Al^{3+}: aluminum; (H + Al): exchangeable acidity; EB: exchangeable bases; CEC: cation exchange capacity; V: base saturation.

and Serra Mossoró, presented this character in depth of 0.0–0.2 m. Only S.P. Fazenda Nova had analyzed soil considered within the normal parameters for salinity and sodicity in the two depths. The Boa Fé and Cabelo de Nego communities presented within the normal parameters for salinity and sodicity in the depth of 0.0–0.2 m (Fig. 3).

3.3. Analysis of soil at 1.6 m away from the brine discharge point

Amid the soil chemical analysis (Table 3), collected from a 0.0–0.2 and 0.2–0.4 m depth at a mean distance of 1.6 m, it was verified that in all the samples collected at depths of 0.0–0.2 m, the pH presented a variation of 5.0–8.9, with a mean

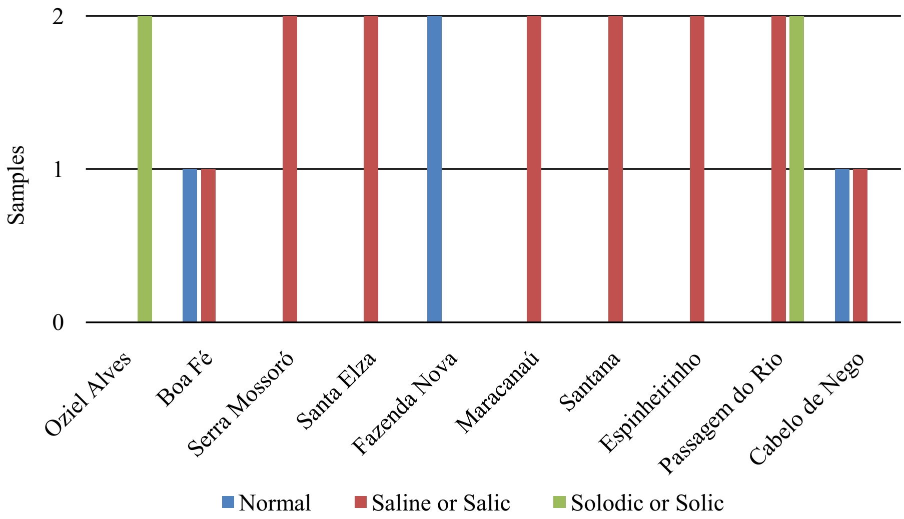

Fig. 3. Classification of the samples for salinity and sodium saturation at 0.8 m from the dumping point of reject brine.

Table 3
Results of the chemical analysis of soil samples collected at 1.6 m away from the brine discharge point for the profile of 0.0–0.2 and 0.2–0.4 m

Communities	Depth	pH	EC_{se}	ESP	Na^+	$Ca^{2+} + Mg^{2+}$	Al^{3+}	(H + Al)	EB	CEC	V
	m	H_2O	(dS m^{-1})	%	mg dm^{-3}			cmolc dm^{-3}			%
Oziel Alves	0.0–0.2	8.2	1.2	6.1	51.7	2.5	0.0	1.0	2.7	2.7	76.8
Boa Fé	0.0–0.2	5.0	1.5	2.7	16.0	0.6	0.1	1.9	0.8	0.8	29.6
Serra Mossoró	0.0–0.2	7.5	1.9	0.6	36.2	22.5	0.0	1.2	24.6	24.6	95.6
Santa Elza	0.0–0.2	7.7	21.1	6.9	582.8	32.3	0.0	0.1	36.5	36.5	99.8
Fazenda Nova	0.0–0.2	8.9	1.8	8.3	62.0	2.8	0.0	0.0	3.3	3.3	100.0
Maracanaú	0.0–0.2	8.2	19.3	0.1	9.1	41.9	0.0	0.2	42.0	42.0	99.6
Santana	0.0–0.2	8.7	5.6	0.1	4.2	12.2	0.0	1.0	12.2	12.2	92.5
Espinheirinho	0.0–0.2	7.8	3.2	0.1	4.2	26.7	0.0	1.3	26.8	26.8	95.3
Passagem do Rio	0.0–0.2	8.6	2.6	4.6	124.7	10.3	0.0	0.7	11.2	11.2	94.7
Cabelo de Nego	0.0–0.2	8.1	4.3	3.4	151.8	16.8	0.0	0.1	19.1	19.1	99.6
Oziel Alves	0.2–0.4	8.4	1.9	13.0	79.5	1.7	0.0	0.9	2.0	2.0	74.5
Boa Fé	0.2–0.4	4.2	4.0	12.6	93.0	0.8	0.1	2.1	1.3	1.4	38.7
Serra Mossoró	0.2–0.4	7.6	2.3	0.5	29.1	25.4	0.0	1.0	26.3	26.3	96.4
Santa Elza	0.2–0.4	7.8	15.4	2.3	247.4	40.7	0.0	0.1	42.4	42.4	99.8
Fazenda Nova	0.2–0.4	8.9	1.9	8.0	70.1	3.4	0.0	0.1	3.8	3.8	97.9
Maracanaú	0.2–0.4	8.1	14.4	0.1	6.1	33.1	0.0	0.2	33.1	33.1	99.5
Santana	0.2–0.4	8.4	12.5	0.2	10.4	24.1	0.0	0.5	24.2	24.2	98.0
Espinheirinho	0.2–0.4	8.0	3.4	0.0	1.2	28.3	0.0	1.6	28.4	28.4	94.8
Passagem do Rio	0.2–0.4	8.2	6.5	5.6	272.9	18.8	0.0	0.8	20.2	20.2	96.2
Cabelo de Nego	0.2–0.4	7.7	2.8	3.0	117.4	15.1	0.0	0.3	16.6	16.6	98.0

*pH H_2O: potential of hydrogen; EC_{se}: electrical conductivity of a saturated soil extract; ESP: exchangeable sodium percentage; Na^+: sodium; Ca^{2+}: calcium; Mg^{2+}: magnesium; Al^{3+}: aluminum; (H + Al): exchangeable acidity; EB: exchangeable bases; CEC: cation exchange capacity; V: base saturation.

of 7.9, while at the depths 0.2–0.4 m, pH ranged from 4.2 to 8.9, with a mean of 7.7, indicating a predominance of alkaline soils in the two soil layers evaluated. It was observed that these results are close to those of the distance of 0.8 m. Only the samples of S.P. Boa Fé presented, at both depths, pH with acid reaction.

Classifying the samples for salinity and sodium saturation at 1.6 m, from the dumping point of reject brine, it was observed that 35% of the soils presented saline character and 30% salic character. Regarding sodicity, it was observed that 35% of the soils present a solodic character. The Santa Elza, Santana and Maracanaú communities presented salic features in both analyzed depths. The Serra Mossoró and Espinheirinho communities have soils within the normal parameters for salinity and sodicity, in the two depths. The soils of the Boa Fé and Passagem do Rio communities were within the normal parameters, for salinity and sodicity, in the depth of 0.0–0.2 m. The soil of S.P. Cabelo de Nego did not show excess salinity or exchangeable sodium in the depth of 0.2–0.4 m (Fig. 4).

3.4. Analysis of soil in the area without the influence of reject brine

Table 4 presents the values of soil chemical analysis (control samples), collected at 0.0–0.2 and 0.2–0.4 m depth, in areas without the influence of the discharge of reject brine from desalination plants. Considering these data, it was observed that in the samples collected, at depths of 0.0–0.2 m, the pH presented a variation of 4.8–8.5, with a mean of 7.2 and at depths 0, 2–0.4 m, pH ranged from 4.0 to 8.4, with a mean of 7.1, indicating a predominance of neutral soils in the two soil layers evaluated. It was found that the pH values were slightly lower than those found in the other collection points.

Samples of Boa Fé and S.P. Oziel Alves presented pH values with acidic reaction in the two pH depths, with values below 5. The S.P. also presented a very low base saturation value (V), characterizing a dystrophic soil with Al toxic, which needs correction to obtain crops with good productivity. S.P. Boa Fé, on the other hand, also presented dystrophic character and a very acidic pH in the depth of 0.2–0.4 m; already in the depth of 0.0 to 0.2 m showed a low acid pH, close to 6, which would be considered a very good value for the availability of the nutrients for the plants.

In S.P. Fazenda Nova, pH values between 5.9 and 6.2 were observed, which is an ideal range for most cultivated crops. In the other communities, the lowest pH value was 7.0, which shows that in the soils of these 10 communities, the observed pH values have a natural tendency for the neutral to alkaline reaction of the soil.

Fig. 5 shows the classification of the samples for salinity and for sodium saturation collected without the influence of the discharge of reject brine. In the midst of this, it was verified that, as regards salinity, 20% of the soils presented saline character and 5% salic character. Regarding sodicity in the analyzed soils, 5% is solodic.

At the depth of 0.2 to 0.4 m, S.P. Boa Fé presented saline and solodic character. The community of Santana showed a salic character in the depth of 0.0–0.2 m and saline in the depth of 0.2–0.4 m. The Oziel Alves Communities, Fazenda Nova, Santa Elza, Maracanaú, Passagem do Rio, and S.P. Cabelo de Nego, representing 60% of the collected samples, presented soils within the normal parameters for salinity and sodicity at different depths. The PA Boa Fé, at depth of 0.0–0.2 m, Serra Mossoró and PA Espinheirinho, at depth of 0.2–0.4 m, corresponding to 15% of the samples, did not present excess salinity or exchangeable sodium.

3.5. Descriptive statistics for the analysis of soils in collect points

Table 5 shows the analysis of the descriptive statistics for the analysis of soils sampled at the discharge point of reject brine, at 0.8, 1.6 m, and without saline influence (control), in the 10 studied rural communities. Considering these data, it was observed that the analyzed parameters of the waters and the results of the soil analysis had a very high coefficient of variation (CV) for most of the variables, with the exception of pH and Al. The base saturation value, presented a low CV for the dumping point of reject brine and was increasing as the collected samples moved away from this point, reaching the highest CV value for the control samples, which indicates that the reject brine tends to increase the saturation of soils, reaching close to the maximum value (mean of 90% for distance 0). This greater variation was mainly due to the soil that presented dystrophic character in the witness points without influence of the discharge of reject brine, in the case of S.P. Oziel Alves and in S.P. Boa Fé.

The other analyzed soils presented eutrophic character and base saturation value high in all distances analyzed.

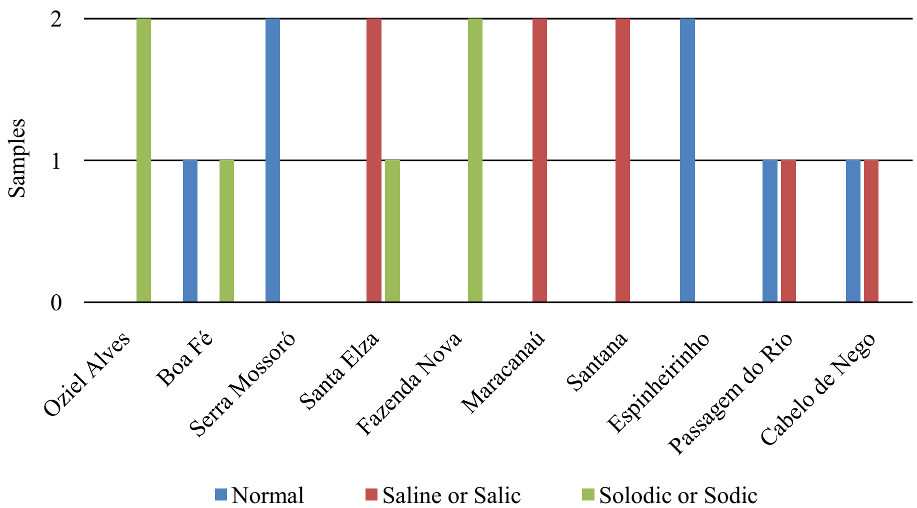

Fig. 4. Classification of samples for salinity and sodium saturation at 1.6 m from the dumping point of reject brine.

Table 4
Results of soil chemical analysis of the native forest (control), collected at 0.0–0.2 and 0.2–0.4 m

Communities	Depth	pH	EC_{se}	ESP	Na^+	$Ca^{2+} + Mg^{2+}$	Al^{3+}	(H + Al)	EB	CEC	V
	M	H_2O	(dS m^{-1})	%	mg dm^{-3}			cmolc dm^{-3}			%
Oziel Alves	0.0–0.2	4.8	0.0	3.0	25.1	0.7	0.3	2.9	0.8	1.1	22.0
Boa Fé	0.0–0.2	5.7	1.8	2.3	19.6	1.0	0.1	2.7	1.1	1.2	30.5
Serra Mossoró	0.0–0.2	8.1	5.2	2.2	150.4	29.1	0.0	0.0	30.0	30.0	100.0
Santa Elza	0.0–0.2	8.5	2.8	3.5	396.2	45.8	0.0	0.0	48.3	48.3	100.0
Fazenda Nova	0.0–0.2	6.0	1.1	0.5	5.0	3.3	0.0	0.7	3.5	3.5	82.6
Maracanaú	0.0–0.2	8.1	3.3	0.0	1.2	33.5	0.0	0.9	33.5	33.5	97.4
Santana	0.0–0.2	7.8	13.2	0.2	9.4	21.4	0.0	1.1	21.5	21.5	95.3
Espinheirinho	0.0–0.2	7.9	5.4	0.2	7.9	16.2	0.0	0.8	16.3	16.3	95.2
Passagem do Rio	0.0–0.2	7.1	2.9	0.8	30.9	12.6	0.0	1.8	14.0	14.0	89.1
Cabelo de Nego	0.0–0.2	8.0	3.7	4.5	197.7	15.1	0.0	0.9	18.0	18.0	95.2
Oziel Alves	0.2–0.4	4.0	1.2	3.4	33.5	0.6	0.5	3.3	0.8	1.3	19.0
Boa Fé	0.2–0.4	4.8	4.3	8.6	82.4	1.0	0.1	2.8	1.4	1.5	34.4
Serra Mossoró	0.2–0.4	8.2	3.9	1.5	111.1	31.4	0.0	0.0	32.2	32.2	100.0
Santa Elza	0.2–0.4	8.4	3.8	3.9	412.0	44.4	0.0	0.0	46.5	46.5	100.0
Fazenda Nova	0.2–0.4	6.2	0.7	0.1	0.7	1.8	0.0	1.0	1.9	1.9	66.9
Maracanaú	0.2–0.4	8.1	3.2	0.0	1.2	41.1	0.0	1.1	41.1	41.1	97.5
Santana	0.2–0.4	8.1	4.7	0.2	6.7	22.1	0.0	0.7	22.2	22.2	96.8
Espinheirinho	0.2–0.4	8.2	2.7	0.2	8.0	19.1	0.0	0.7	19.2	19.2	96.7
Passagem do Rio	0.2–0.4	7.4	2.2	1.2	37.0	10.4	0.0	1.7	12.0	12.0	88.1
Cabelo de Nego	0.2–0.4	8.0	3.3	4.4	205.8	16.9	0.0	0.5	19.9	19.9	97.6

*pH H_2O: Potential of hydrogen; EC_{se}: electrical conductivity of a saturated soil extract; ESP: exchangeable sodium percentage; Na^+: sodium; Ca^{2+}: calcium; Mg^{2+}: magnesium; Al^{3+}: aluminum; (H + Al): exchangeable acidity; EB: exchangeable bases; CEC: cation exchange capacity; V: base saturation.

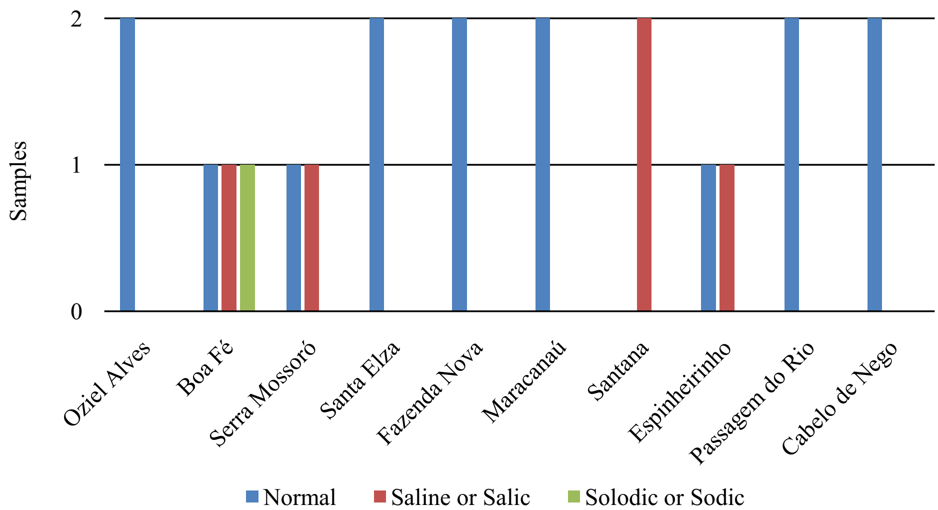

Fig. 5. Classification of the collected samples for salinity and for sodium saturation without influence of the brine discharge.

S.P. Boa Fé only showed eutrophic character at the point of discharge of reject brine; already S.P. Oziel Alves presented a eutrophic character in all distances studied. The base saturation was increased mainly by the Ca and Mg content, contributing to an improvement in soil fertility. The presence of a high content of sodium in the exchangeable bases to the fertility may compromise the quality of the soil due to the possibility of the increase of the sodium saturation, which can be observed in the soils of PA Oziel Alves that presented solodic character at the distances of 1.6 m, of 0.8 m and at the point of discharge in the two depths sampled. The S.P. Boa Fé not only showed a saline sodium character at the

Table 5
Descriptive statistics referring to the soil analysis

Source of Variation	Distance 0 m			Distance 0.8 m		
	M	Σ	CV	μ	Σ	CV
pH	8.0	0.47	5.79	7.8	1.07	13.59
EC_{se} (dS m^{-1})	5.5	3.33	60.35	7.3	6.40	87.29
ESP	5.5	5.78	105.75	4.3	4.58	107.03
Na^+ (cmolc dm^{-3})	168.8	214.06	126.78	126.4	143.49	113.54
Ca^{2+} + Mg^{2+} (cmolc dm^{-3})	18.1	12.39	68.44	17.8	12.79	71.83
Al^{3+} (cmolc dm^{-3})	0.0	0.0	0.0	0.0	0.01	326.24
H + Al (cmolc dm^{-3})	0.6	0.62	109.71	0.7	0.90	127.86
EB	19.4	13.00	67.19	18.7	13.07	70.00
CEC	19.4	13.00	67.19	18.7	13.07	69.96
V (%)	93.6	9.16	9.78	90.5	16.90	18.67
Source of variation	Distance 1.6 m			Control		
	M	Σ	CV	M	σ	CV
pH	7.8	1.18	15.24	7.1	1.39	19.46
EC_{se} (dS m^{-1})	6.4	6.37	100.14	3.5	2.72	78.73
ESP	3.9	4.14	106.04	2.0	2.21	109.14
Na^+ (cmolc dm^{-3})	98.5	138.19	140.30	87.1	126.26	144.99
Ca^{2+} + Mg^{2+} (cmolc dm^{-3})	18.0	13.52	75.14	18.4	15.11	82.30
Al^{3+} (cmolc dm^{-3})	0.0	0.0	337.7	0.0	0.12	280.55
H + Al (cmolc dm^{-3})	0.7	0.64	85.88	1.2	1.03	87.15
EB (cmolc dm^{-3})	18.9	13.82	73.23	19.2	15.44	80.37
CEC (cmolc dm^{-3})	18.9	13.81	73.13	19.3	15.39	79.92
V (%)	88.9	20.02	22.53	80.2	28.76	35.86

*pH H_2O: potential of hydrogen; EC_{se}: electrical conductivity of saturation extract; ESP: exchangeable sodium percentage; Na^+: sodium; Ca^{2+}: calcium; Mg^{2+}: magnesium; Al^{3+}: aluminum; (H + Al): exchangeable acidity; EB: exchangeable bases; CEC: cation exchange capacity; V: base saturation; CV: coefficient of variation.

discharge point and at 0.8 m from the discharge point at the 0 to 0.4 m depth but also presented a solodic character at a depth of 0.2–0.4 m, at distance of 1.6 m from the dumping point of reject brine and at the control point in the depth of 0.2 to 0.4 m.

In general, it can be observed that there was a tendency to increase the exchangeable sodium percentage (ESP) in the sub-surface samples. There was also a tendency for the electrical conductivity of the saturated soil extract. As for pH, the variation was minimal (Fig. 6).

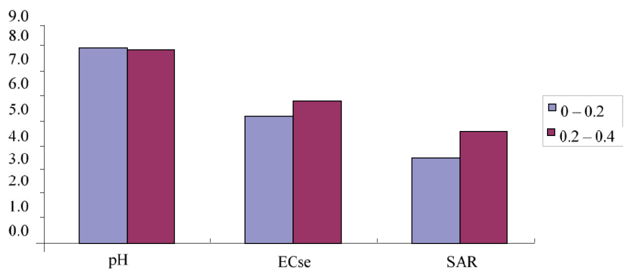

Fig. 6. Analysis of the pH and EC_{se} variation of the soils analyzed by the depth of the sample.

4. Discussions

A major concern regarding the reject brine generated in the desalination process is the lack of knowledge on the part of the beneficiary communities with the impacts that can be generated in the long term when adopting this technology. A study by Neves et al. in rural communities of Pentecoste, in the Ceará state, showed that a part of the waste generated in that municipality is used for animal feed, and the vast majority of the population, regardless of locality, is not aware if the waste causes any harm to human health or environment [5].

The results of the analysis showed that, in the majority of samples of soils under the influence of reject brine, regardless of the depths and effluent discharge distances studied in this study, the pH of the soil was above 8.0. According to Bernet et al. [15], these values are considered high for the development of plants, as it can cause immobilization of phosphorus, precipitation of calcium and magnesium carbonates and formation of calcium phosphate, as well as a decrease in the availability of micronutrients such as iron, copper, manganese, and zinc, thus leading to the risk of desertification. The area without the influence of reject brine (control) in some communities also presented pH above 8.0, which shows the tendency of the existence of alkaline pH in the studied region, being this problem aggravated by the disposal of reject brine.

Moura et al. [6] claim that the high salinity of the effluent rejected from desalination with high levels of chloride and sodium can reduce the productivity of the plants and increase the risk of salinity concentration of the soil. A possible solution for the use of this waste for agricultural purposes, avoiding its disposal in the soil, would be the adoption of hydroponic cultivation. Several authors have shown that in the hydroponics, the salinity tolerated by the crops is greater than in the conventional cultivation in saline soils, due to the greater and constant availability of water in the different types of hydroponic systems in relation to the soil cultivation, and the few or nonexistent contribution of the total potential of the water, which results in a greater absorption of water and nutrients by the plants for the same amount of salts [1,5,16–21].

In the present study, EC_{se} values ranging from 0.0 to 22.6 dS m^{-1} were observed in the sample collection points. The variability of the results of the soil analysis among the studied localities is probably due to the variation of the water quality from wells used in the desalination process. In addition, the accumulation of salts in soils depends on the initial salinity of the area without influence of reject brine and the physical properties and EC of the brackish water rejected in the desalination process. This hypothesis is reinforced by Oliveira et al. [4] in stating that despite the importance of studying the quality of water, it should be emphasized that it is only one of the factors and that it is not reasonable to generalize a single water classification system that can be used in all situations.

In addition to the effects on the soil, the disposal of reject brine generated in the desalination plants can cause a great degradation of water resources. A case study in India indicated that infiltration of saline tailings in the soil caused the contamination of groundwater from wells and resulted in an increase in groundwater hardness [22].

Despite the possible negative environmental impacts to the environment, the desalination waste may have a suitable destination. According to Neves et al. [5] there are successful experiments that show of the desalination plants being used for the development of some activity (production of shrimps and red tilapia, washing of clothes and vehicles, etc.), but these are isolated experiences motivated by the absolute lack of good quality water. According to the authors, what predominates is the drainage of the tailings for land near the system and watercourses, which is a more practical and low-cost way to discard them.

5. Conclusions

Disposal of reject brine increased pH, base saturation and electrical conductivity of the soils from Settlement Projects and Rural Communities.

Disposal of reject brine from desalination plants affects the soil physical-chemical properties to all study lands increasing potential risk of soil salinization.

Percentage of 25% of the native forest soils have problems of salinity and/or sodicity, suggesting that salt-affected soils already existed in some communities even without the disposal of reject brine.

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