Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2020.25889

195 (2020) 213–221
August

Disposal of waste brine from desalination in Eutrophic Red Argisol and Fluvic Neosol in the western Potiguar region, Brazil

André Moreira de Oliveira[a], Nildo da Silva Dias[a], Cleyton dos Santos Fernandes[a], Gabriela Cemirames Gurgel[b], Neyton de Oliveira Miranda[a], Jair José Rabelo de Freitas[a], Hozano de Souza Lemos Neto[a,*], Claudio Ricardo da Silva[a], Moisés Medeiros dos Santos[a], Marcia Regina Farias da Silva[b], Francisco Vanies de Sousa Sá[a], Jucirema Ferreira da Silva[a]

[a]*Universidade Federal Rural do Semi-Árido, Mossoró, Brazil, emails: hozanoneto@hotmail.com (H. de Souza Lemos Neto), andremoreira@ufersa.edu.br (A. Moreira de Oliveira), nildo@ufersa.edu.br (N. da Silva Dias), cleyton1959@hotmail.com (C. dos Santos Fernandes), neyton.miranda@ufersa.edu.br (N. de Oliveira Miranda), jair_palmeiras@hotmail.com (J.J. Rabelo de Freitas), claudio.ricardo@ufu.br (C. Ricardo da Silva), moisesmede@hotmail.com (M. Medeiros dos Santos), vanies_agronomia@hotmail.com (F. Vanies de Sousa Sá), jucirema.ferreira@gmail.com (J. Ferreira da Silva)*
[b]*Universidade do Estado do Rio Grande do Norte, Mossoró, Brazil, emails: gabrielacemirames@gmail.com (G.C. Gurgel), marciaregina@uern.br (M.R. Farias da Silva)*

Received 11 December 2019; Accepted 22 March 2020

ABSTRACT

Our objective was to evaluate the physicochemical parameters of waste brine from reverse osmosis desalination plants and to evaluate the physicochemical parameters of soils where it is discharged in rural communities in the western Potiguar region of the state of Rio Grande do Norte, Brazil. Soil samples of two types (Eutrophic Red Argisol and Fluvic Neosol) were collected in the dry and rainy seasons in two communities at two distances from the discharge point (1 and 2 m) and at the point itself, in two layers for each point (0–20 and 20–40 cm). In addition, samples of waste brine were taken from the desalination plants for the evaluation of the physicochemical quality and contamination risks. All brine samples were classified as C_3 or C_4, which is, extremely high risk of salinization, needing special practices for salinity control. The two soils that received the brine presented significant alterations of their attributes and quality throughout the periods. This was more pronounced in the dry season and the layers of soils with a greater amount of clay, which resulted in the soil receiving different classifications, which were influenced directly by the brine.

Keywords: Soil salinization; Reverse osmosis; Wastewater

1. Introduction

Access to water by diffuse rural people who need it for drinking and agriculture is still an important problem, despite the significant reduction in population due to migration to urban centers. In this regard, several public policies have been tried in the Brazilian semiarid zone, such as small reservoirs, wells with desalinators, and cisterns [1].

Desalination plants have existed in the world since the nineteenth century, but only in the last years has this become a reality for the semiarid zone of the Brazilian Northeast. This happened because domestic companies mastered the

* Corresponding author.

1944-3994/1944-3986

technology and started to produce desalination equipment on a large scale to replace that previously imported from other countries.

Desalination by reverse osmosis has been widely used to reduce salt content in water. It has been successful in most locations where implemented, thus allowing the use of water for human consumption.

There are several desalination plants in the western region of Rio Grande do Norte, Brazil. According to the operators, the amount of waste brine produced in some communities averages 8 $m^3\,d^{-1}$. Considering the existence of 62 desalinators installed in the region, according to [2], 440 $m^3\,d^{-1}$ of brine is released daily into the environment without any treatment, with harmful consequences for cultivated plants and soil [3]. Too much salt can harm plants as a result of the physiological drought and toxicity of Cl^- and Na^+ ions. In turn, the soil suffers damage to its structure when the Na^+ content is relatively high. This is due to clay expansion and consequently problems of compaction, causing reduced water infiltration, oxygen uptake, and root development.

Regardless of membrane efficiency, reverse osmosis plants will always produce both drinking water and brine (wastewater), whose amount is estimated at 60% of the feedwater. Moreover, the brine has a higher salinity than the feedwater [4]. In this context, a major challenge of treating water by reverse osmosis is to dispose of or reuse the wastewater so as to avoid negative impacts on the environment, like the careless release of the brine in watercourses and/or soil.

Most of the soils in the western region of Rio Grande do Norte are of sedimentary origin. They are composed of limestone, sandstone, sediments from the "Barreiras" group, and alluvial sediments. Therefore, they present great variation in chemical, physical, and mineralogical properties. Common soils in the region are Ultisols, Entisols, Inceptisols, Mollisols, Vertisols, and Oxisols, which have been little studied in relation to the influence of the successive disposal of saline tailings.

The importance of researching the chemical composition of the waste brine from desalination plants and the impact of its disposal on the soil is due to the need to determine possible damage from desalination and the precautions needed to prevent it. Unfortunately, large resources are invested in this technology without considering the environmental impact of waste disposal in the soil.

Our objective was to evaluate the chemical composition of drinking water, well water (feedwater), and discarded brine from desalination plants, and also the impact of discharging brine in the soil of two rural communities in western Rio Grande do Norte, Brazil.

2. Material and methods

The study was carried out in the western region of the state of Rio Grande do Norte, Brazil, where the prevailing climate is the BSW'H', according to the Köppen classification. It is very hot and semi-arid, with the rainy season lasting from summer to autumn, with two distinct seasons: a dry season during eight months, and a rainy season, which usually extends from February to May, with the strongest precipitation occurring in March and April. The average annual temperature is around 27°C–29°C and the average annual rainfall is around 550–750 mm.

Water and soil samples were obtained in two communities: Alagoinha (5°03′03.7″ S, 37°20′12.8″ W) and Juazeiro (5°43′29.6″ S, 37°44′53.8″ W). These sites were identified by means of the Survey of Rural Communities carried out by the Water Resources Secretariat of the Rio Grande do Norte (SEMARH).

Two communities with contrasting soil were selected considering the convenience for monitoring, because of the constant use and adequate maintenance of desalinators (Fig. 1), and disposal of the brine in the ground.

The description of the soil profiles according to the Brazilian System of Soil Classification [5] was performed in soil trenches opened near the sites where the waste brine was released. The two soils were classified as Argissolo

Fig. 1. (a) Desalinator plant and (b) reverse osmosis equipment installed at the communities Alagoinha and Juazeiro in the state of Rio Grande do Norte, Brazil.

Vermelho-Amarelo Eutrófico in Alagoinha and Neossolo Flúvico in Juazeiro (Fig. 2).

The sampling of soil and water in each area was carried out in four periods at regular intervals of three months, so as to include all seasons and to verify alterations in the waste brine and its effect on the soil: P_1 = October–November (2013) – the dry season, almost without rain; P_2 = February–March (2014), the start of the rainy season; P_3 = June–July (2014), end of the rainy season, and P_4 = October–November (2014), closing the cycle of 12 months in the dry season.

Soil samples were taken in a cross-section at the point of brine disposal (point 0), at 1.0 m from point 0 (point 1), and at 2.0 m from point 0 (point 2). There was also one sampling at a point in native vegetation without the influence of brine (control). At each point, samples were collected in the 0–20 and 20–40 cm layers, chosen considering the effective rooting depth in the region and the possible occurrence of shallow soils.

For soil chemical analysis, the samples were taken from each point and layer by means of a Dutch Auger and put in plastic bags identified with the name of the community, distance from the point of brine disposal and soil layer. The samples were dried, ground and passed through a 2 mm sieve to obtain air-dried soil for further analysis.

The potential of hydrogen (pH) and electric conductivity (EC_{se}) of the soil were determined in a 1:2.5 soil: deionized water suspension and then corrected as a function of the saturation moisture. In addition, contents of P, K^+, Na^+, Ca^{2+}, Mg^{2+} and Al^{3+} and potential acidity were determined. Soil parameters calculated were cation exchange capacity, the sum of bases (SB), saturation of bases (V%), and the exchangeable sodium percentage (ESP).

Soils were classified according to the effect of salts using the table proposed by Bohn et al. [6]. For that, the parameters EC_{se}, pH and ESP were considered.

Soil samples were also taken at each point for physical analysis (sand, silt and clay) according to the procedures described by Teixeira et al. [7] for a better comprehension of the influence of the brine on soil quality. These samples were obtained with a shovel and hoe in the two layers (0–20 and 20–40 cm).

The waste brine samples were taken after 5 min of operation of the desalination system and were put in 500 mL opaque plastic bottles, hermetically sealed and stored in ice chests to avoid microbiological activity.

The physicochemical parameters of soil and water were determined according to the methods of Teixeira et al. [7] and Richards [8]. In the samples of water for irrigation purposes, the following parameters were determined: electrical conductivity (EC – dS m^{-1}), pH, and contents of Na^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, CO_3^{2-}, and HCO_3^-, according to methods proposed by Richards [8]. The sodium absorption ratio (SAR) was also calculated to classify water samples according to the risk of water infiltration problems caused by high content of sodium.

The risks of water infiltration problems were classified according to Ayers and Westcot [9], which resulted in three classes of sodicity, obtained from information about SAR and EC of irrigation water.

The classification of water regarding its risk of toxicity was done according to the contents of sodium and chloride, as proposed by Ayers and Westcot [9], considering two ways of application and three classes.

To enable the discussion of the effects of salt leaching, meteorological data referring to rainfall in both municipalities during the period studied were collected by the Agricultural Research Company of the State of Rio Grande do Norte – EMPARN (Fig. 3).

The waste brine was classified in relation to the risk of salinity and sodicity according to the parameters proposed by Richards [8]. For this purpose, a diagram developed in Excel® was used for each type of water analyzed, namely brackish water from the wells, purified water, and the waste brine.

The guidelines of FAO [11] were used to evaluate the quality of irrigation water, mainly the risks of specific ion toxicity of water samples regarding suitability for agricultural use and adequate irrigation management.

Fig. 2. Sites of discharge of waste brine at the communities (a) Alagoinha and (b) Juazeiro in the state of Rio Grande do Norte, Brazil.

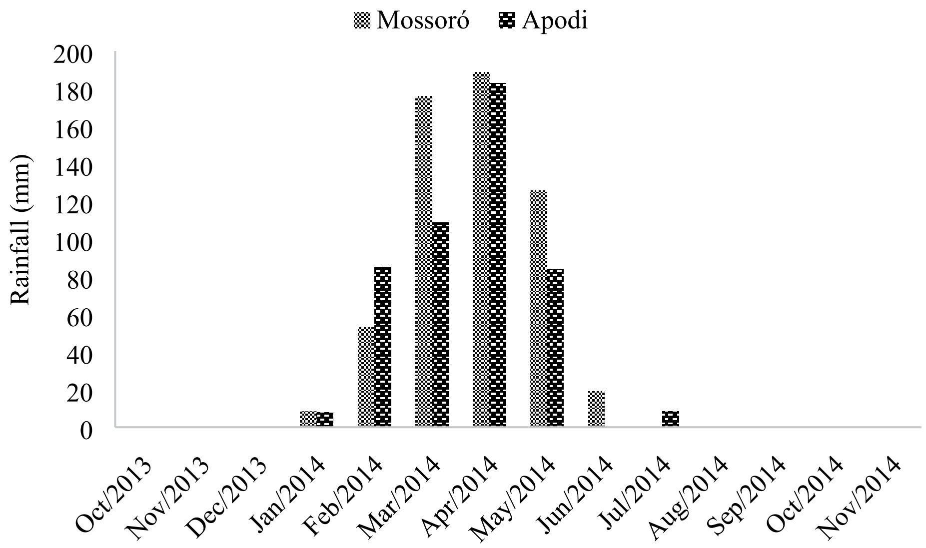

Fig. 3. Amounts of rainfall (mm) in the periods of sampling in the municipalities where the rural communities Alagoinha (Mossoró) and Juazeiro (Apodi) are located. *Source*: adapted from [10].

The data were interpreted by means analysis of variance and the *F*-test. The factors studied were the sampling periods, distances from the disposal point, and soil layers. For comparison of means, the Scott–Knott test was used ($p < 0.05$). The analyses were performed with the R® statistical package and Excel®.

3. Results and discussion

3.1. Evaluation of waste brine quality

Regarding the classification of waste brine for irrigation, samples from Alagoinha were rated high (C3) for salinity risks, low (S1) for risks of water infiltration problems, and high and moderate risk of toxicity (T_3 and T_2) (Table 2).

It can be inferred that in Alagoinha the brine poses a high risk of salt accumulation in the root zone, and if used in irrigation, requires the use of plants tolerant to salinity effects and also moderate leaching (leaching fraction of 10%–15%), to prevent salt accumulation [3]. However, considering the soil textural class as sandy clay loam in the 0–20 and 20–40 cm layers (Table 1), the saline tailings have no restrictions on use regarding the risks of problems with water infiltration. This is true also for the P3 period, especially due to low SAR of 4.88 $(\text{mmol}_c\ \text{L}^{-1})^{0.5}$ and EC (1.50 dS m^{-1}) of the brine, which maintains the soil flocculated. On the other hand, brine has severe restrictions regarding the toxicity of Na^+ and Cl^- ions, and its use is recommended only in drip irrigation systems with high leaching fractions associated with tolerant plants (Table 2).

Regarding the potential risks of brine in Juazeiro, in all periods except P3 there was a high risk of salinity (C3 and C4), with EC ranging from 1.95 to 3.20 dS m^{-1}, but no risk of water infiltration problems (Class S1) (Table 2), even in the loamy fine sand layer in the study area (Table 1). In addition, brine samples had severe use restrictions regarding the toxicity of Cl^- and Na^+ ions. The use of this waste brine in irrigation significantly impairs the development and production of most cultivated plants, as a result of physiological drought (reduced water absorption by plants) and toxicity caused by the osmotic effects of high EC and excess Na^+ and Cl^-.

Brine with high EC (above 7.0 dS m^{-1}) can only be used for the irrigation of halophytes, such as the forage species saltgrass (Atriplex nummularia) [12]. These authors found average dry matter mass values of this species above 5,000 kg ha^{-1} y^{-1} and crude protein content higher than 14% when irrigated with saline tailings with EC of 9.35 dS m^{-1}.

Considering only the period P2 (February–March), in both communities, our estimates showed that about 4.0 g of salts per liter of brine is discharged in the soil. Discharging brine without any control or management to mitigate its effects can cause desertification of the receiving soils of these communities due to the evolution of the salinization process.

High (C3) and very high (C4) risks of salinity were also observed in 40% and 60%, respectively, of the samples analyzed by Anders et al. [13] when classifying brine samples from 10 desalination plants operated in rural communities and settlements in the western Potiguar region. Considering the high rate of recovery of the saline and brackish water treatment system by reverse osmosis, the high salinity of the waste brine is due to the high EC of the desalination system feedwater, which in the present study came from tubular wells that generally have a high concentration of salts. This fact is confirmed in the study of Cosme et al. [14], who found irrigation water classes between C3 and C4 in more than 80% of samples from wells in rural communities in the municipality of Mossoró.

Brine from both communities showed significant changes in physicochemical parameters throughout the collection periods. This variation was due to the rainfall that occurred, and consequently to the dilution of salts. The rainfall events in the period between October 2013 and October 2014 were below the annual averages of municipalities in the region, influencing the water quality parameters.

Table 1
Granulometric fractions and textural classification of soils from the communities of Alagoinha and Juazeiro

Community (Municipality)	Granulometry (g kg^{-1}) Layer (cm)	Sand	Silt	Clay	Textural class
Alagoinha (Mossoró)	0–20	737.4	47.2	215.4	Sandy clay loam
	20–40	616.4	55.6	328.0	Sandy clay loam
Juazeiro (Apodi)	0–20	861.0	82.5	56.5	Loamy fine sand
	20–40	822.5	98.7	78.8	Loamy fine sand

Table 2
Chemical analysis of the water from the saline reject from the communities Alagoinha and Juazeiro in four periods of sampling

Locality	Period	pH	EC[a]	Na$^+$	Cl$^-$	RAS[b]	USSL[c]	S[d]	T[e]
			dS m^{-1}	mmol$_c$ L^{-1}					
Alagoinha	P_1	7.38	1.54	4.51	8.80	1.90	C3S1	S[1]	T[2]
	P_2	7.76	2.00	3.64	10.20	1.40	C3S1	S[1]	T[3]
	P_3	7.60	1.50	12.99	9.40	4.88	C3S1	S[1]	T[3]
	P_4	7.26	1.51	10.27	9.60	3.71	C3S1	S[1]	T[3]
Juazeiro	P_1	7.28	2.97	6.96	27.00	2.10	C4S1	S[1]	T[3]
	P_2	7.06	3.20	9.09	27.60	2.70	C4S1	S[1]	T[3]
	P_3	7.50	1.95	15.20	19.40	5.30	C3S1	S[1]	T[3]
	P_4	7.03	2.70	15.89	37.00	4.07	C4S1	S[1]	T[3]

[a]Electric conductivity
[b]Sodium absorption ratio
[c]Diagram for classification of water for irrigation by USSL [8].
[d]Permeability (Affects infiltration rate into soil [9].
[e]Affects sensitive crops [9].

The pH of all samples from the two communities in the four sampling periods presented values above 7.00. The lowest pH (7.03) was observed in Juazeiro and the highest (7.76) in Alagoinha. Waste brine usually has higher pH values than the feedwater (from wells) and the desalinated water. This is due to the increase in carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-) contained in the water from the Jandaíra aquifer, which is of limestone origin. Most of the wells of rural communities supplied by this aquifer contain these ions, which concentrate on the waste brine when removed from the feedwater.

The assessment of the risk of salinization in an irrigated area must not only consider the water quality, since the effects depend on the physicochemical characteristics of the soil, salt tolerance of the crops grown, local climate conditions, and irrigation and drainage management [3]. Therefore, the importance of studying water quality should not be overlooked, but it is not possible to adopt a single water classification system for use in all situations.

3.2. Chemical attributes of soils under the influence of the waste brine disposal

The salinity and sodicity classifications of the receiving soils confirmed that the disposal of brine in the soils of Alagoinha (Table 3) and Juazeiro (Table 4) promoted changes in the pH, EC_{es} and ESP attributes at different collection points and layers of the soil profile compared to the respective controls (native forest soil).

Soil samples at the brine discharge point in Alagoinha, and at 1 m from that point, presented higher salt accumulation in the soil profile in relation to the control in all collection periods. The highest salt accumulation was recorded at the beginning of the dry season (P1). On the other hand, there was an increase of salts in the soil samples collected 2 m from the discharge site, but the process of salinization and/or sodification was not noted. In both layers, the EC_{es} increased until P3 and then there was a reduction in the EC_{es}, but without changing the soil classification as saline or normal (Table 3).

In Alagoinha, of the 24 samples collected only in places where brine was discharged in all periods, 87.5% were classified as normal according to the classification of soils affected by salts [6]. That is, in practically all periods the soils were classified as normal from the standpoint of soil quality. The exceptions were two samples in P1 and one in P3, which were classified as saline, although this does not seriously compromise the soil structure.

Despite the influence of the brine on the changes of physicochemical attributes of the soils of Alagoinha, all the EC_{es} values observed were lower than the EC of saline tailings (Table 3). Salt accumulation in the soil depends not only on the EC of the discarded brine, but also on the soil

Table 3
Classification of salt-affected soils from Alagoinha (Mossoró) in four sampling periods

Period	Point	Layer (cm)	pH	EC_{se} (dS m^{-1})	ESP (%)	Soil classification[a]
Dry season in 2013	0	0–20	8.30	3.56	4.77	Saline
	0	20–40	8.20	4.79	5.63	Saline
	1	0–20	7.40	1.89	2.94	Normal
	1	20–40	7.47	1.99	3.64	Normal
	2	0–20	6.98	0.68	1.62	Normal
	2	20–40	6.88	0.27	1.59	Normal
	Control	0–20	6.60	1.06	1	Normal
	Control	20–40	6.20	0.54	0	Normal
Start of rainy season in 2014	0	0–20	8.27	2.04	6.47	Normal
	0	20–40	8.05	1.48	6.14	Normal
	1	0–20	8.49	1.43	5.53	Normal
	1	20–40	8.41	1.55	6.02	Normal
	2	0–20	8.51	1.43	4.75	Normal
	2	20–40	8.44	1.48	5.04	Normal
	Control	0–20	7.75	1.36	1	Normal
	Control	20–40	7.57	1.21	0	Normal
End of rainy season in 2014	0	0–20	7.80	1.51	4.27	Normal
	0	20–40	7.90	1.82	5.26	Normal
	1	0–20	7.91	1.66	4.68	Normal
	1	20–40	7.84	2.22	5.30	Saline
	2	0–20	8.17	1.66	3.45	Normal
	2	20–40	8.00	1.95	4.42	Normal
	Control	0–20	6.72	0.75	1	Normal
	Control	20–40	6.43	0.74	1	Normal
Dry season in 2014	0	0–20	8.00	1.13	4.48	Normal
	0	20–40	8.27	1.62	5.26	Normal
	1	0–20	8.35	0.83	2.62	Normal
	1	20–40	8.29	0.87	3.31	Normal
	2	0–20	8.15	0.68	1.68	Normal
	2	20–40	8.22	0.54	1.98	Normal
	Control	0–20	7.13	1.43	2	Normal
	Control	20–40	7.21	0.47	1	Normal

[a]Classification of salt-affected soils [6].

texture, original CEs of the soil, and mainly the volume of brine discharged daily. However, for any variation factor studied, the EC_{es} were always significantly higher than the soil EC_{es} without the influence of brine.

In Juazeiro, several of the samples collected were classified as saline or saline-sodic in most of the collection periods, with EC_{es} between 0.78 and 31.25 dS m^{-1} being observed. This demonstrates that salinity advanced rapidly between the layers and distances from the brine discharge point (Table 4). In general, samples collected away from the saline disposal point were classified as saline-sodic, also indicating a rapid sodification process in relation to Alagoinha. This is due to the fact that sodification is a process subsequent to salinity [3].

Considering the two communities, a direct relationship was found between the brine EC and the soil profile EC_{es}, that is, the soil salinity was directly proportional to the brine salt concentration, regardless of the collection period.

Factors such as soil type and climatic condition (amount of rain) contribute to increase or decrease the EC_{se} of the soil, if the concentrations and volume of salt in the discharged brine are constant. In addition, due to the high volume of brine discharged on the soil surface, salinity increases below the surface and also away from the dumping point. In localized irrigation systems, the accumulation of salt in the soil is directly proportional to the salinity of the water used. In this system, there is a higher concentration of salts in the surface layer and a decrease with depth [15]. A similar trend was observed by us in Juazeiro.

In Alagoinha, the highest soil EC_{se} values were found in the P1 period, correlating with the high EC values of the waste brine in the period (Table 5). Even considering the distances and depths of the dumping point, the saline concentration was higher than the other periods in almost all collections. The soil of this community was classified as Eutrophic Red–Yellow Ultisol, with a predominant sand

Table 4
Classification of salt-affected soils of Juazeiro in four sampling periods

Period	Point	Layer (cm)	pH	EC_{se} (dS m^{-1})	ESP (%)	Classification of soil[a]
Dry season in 2013	0	0–20	7.40	4.86	9.03	Saline
	0	20–40	7.51	5.00	22.37	Saline-Sodic
	1	0–20	7.62	14.30	25.02	Saline-Sodic
	1	20–40	7.60	7.76	24.64	Saline-Sodic
	2	0–20	7.08	16.25	19.03	Saline-Sodic
	2	20–40	7.11	17.50	21.37	Saline-Sodic
	Control	0–20	7.30	2.36	1	Saline
	Control	20–40	7.40	1.31	1	Normal
Begin of rainy season in 2014	0	0–20	7.58	4.72	6.56	Saline
	0	20–40	7.65	4.34	9.08	Saline
	1	0–20	7.78	7.63	11.30	Saline
	1	20–40	7.76	7.10	12.96	Saline
	2	0–20	7.09	31.25	24.15	Saline-Sodic
	2	20–40	7.29	13.02	17.32	Saline-Sodic
	Control	0–20	6.96	0.83	1	Normal
	Control	20–40	6.96	0.65	1	Normal
End of rainy season in 2014	0	0–20	7.58	3.19	4.43	Saline
	0	20–40	7.35	4.73	7.06	Saline
	1	0–20	7.12	12.50	18.51	Saline-Sodic
	1	20–40	7.31	5.13	14.75	Saline-Sodic
	2	0–20	7.23	10.13	12.03	Saline
	2	20–40	7.22	7.63	11.68	Saline
	Control	0–20	6.73	0.83	0	Normal
	Control	20–40	6.17	0.75	0	Normal
Dry season in 2014	0	0–20	7.58	2.36	6.77	Saline
	0	20–40	7.56	2.89	6.63	Saline
	1	0–20	7.72	14.30	15.98	Saline-Sodic
	1	20–40	7.65	6.31	10.36	Saline
	2	0–20	7.64	13.33	19.71	Saline-Sodic
	2	20–40	7.46	5.78	12.26	Saline
	Control	0–20	7.02	0.83	1	Normal
	Control	20–40	6.71	0.78	1	Normal

[a]Classification of salt-affected soils [6].

fraction (73% and 61% sand in the 0–20 and 20–40 cm layers, respectively – Table 2), which favored the leaching of salts in the profile. The EC_{es} was practically equal to the EC values of the brine in the respective periods.

According to Dias et al. [3], the content and type of clay predominant in the soil can influence the concentration of ions in the solution, and consequently the electrical conductivity of the soil. The clay fraction acts as an ion accumulator by the process of adsorption and subsequent ionic desorption, with the main influence of temperature and ionic concentration in the soil solution. Thus, the higher the concentration of a specific ion, the greater its adsorption on the colloidal complex will tend to be.

In Alagoinha, the EC_{es} was statistically different between the periods P1 and P4, that is, there was salt accumulation with the time of waste disposal in the soil. A study carried out by Porto Filho et al. [16] reported that salinity increases with depth and also accumulates in the regions where the wetting front ends. This is perceived in our study at ground distances from point 0, considering the very sandy soil of the area, and affects the subsurface layers (vertical) more than points 1 and 2 (horizontal) (Table 6). No apparent behavior of the soil was observed in relation to the deposition of waste brine in Alagoinha. The soil of this community has poor drainage due to the presence of a compacted subsurface horizon, caused by the dispersed clay content, which causes easy flooding of the area.

However, when analyzing distances and depths separately, it was clear that the tendency for salinization in the soil of Juazeiro was greater at points 1 and 2 (Table 6). Probably severe and intense changes in the soil occurred due to the intensity and volume of brine produced by the desalinator and applied to the soil, besides the characteristics of the Fluvic Neosol, which has drainage restrictions in the subsurface horizon. The brine produced by the desalination plant of this community and its disposal caused a greater impact

Table 5
Summary of the comparison between means of collection periods for the electrical conductivity of the soil (dS m^{-1}) according to the Scott–Knott test at 5% significance

Point/layer (cm)	Alagoinha (Mossoró)			
	Period 1	Period 2	Period 3	Period 4
0 (0–20)	3.56 *a*	2.04 *b*	1.51 *c*	1.13 *d*
0 (20–40)	4.79 *a*	1.48 *d*	1.82 *d*	1.62 *c*
1 (0–20)	1.89 *a*	1.43 *c*	1.66 *b*	0.83 *d*
1 (20–40)	1.99 *b*	1.55 *c*	2.22 *a*	0.87 *d*
2 (0–20)	0.68 *c*	1.43 *b*	1.66 *a*	0.68 *c*
2 (20–40)	0.27 *d*	1.48 *b*	1.95 *a*	0.54 *c*
Mean	2.20 *a*	1.54 c	1.80 b	0.95 *d*
	Juazeiro (Apodi)			
0 (0–20)	4.86 *a*	4.72 *a*	3.19 *b*	2.36 *c*
0 (20–40)	5.00 *a*	4.34 *b*	4.73 *a*	2.89 *c*
1 (0–20)	14.30 *a*	7.63 *c*	12.50 *b*	14.30 *a*
1 (20–40)	7.76 *a*	7.10 *b*	5.13 *d*	6.31 *c*
2 (0–20)	16.25 *b*	31.25 *a*	10.13 *d*	13.33 *c*
2 (20–40)	17.50 *a*	13.02 *b*	7.63 *c*	5.78 *d*
Mean	10.94 *a*	11.34 *a*	7.21 *b*	7.49 *b*

Means followed by different letters in the same row are different by the Scott–Knott test ($p < 0.05$).

Table 6
Summary of the comparison between means for the interaction of layers and distances of the soil electrical conductivity (dS m^{-1}) according to the Scott–Knott test ($p < 0.05$)

	Communities	
Layer (cm)	Alagoinha (Mossoró)	Juazeiro (Apodi)
	Interaction of layers inside the distance 0	
0–20	2.06 *b*	3.78 *b*
20–40	2.42 *a*	4.24 *a*
	Interaction of layers inside the distance 1 m	
0–20	1.45 *b*	12.18 *a*
20–40	1.67 *a*	6.57 *b*
	Interaction of layers inside the distance 2 m	
0–20	1.11 *a*	17.74 *a*
20–40	1.06 *a*	10.98 *b*
	Interaction of layers in the control	
0–20	1.15 *a*	1.21 *a*
20–40	0.74 *b*	0.87 *b*
	Communities	
Point	Alagoinha (Mossoró)	Juazeiro (Apodi)
	Interaction of distances in the 0–20 layer	
0	2.06 *a*	3.78 *c*
1	1.45 *b*	12.18 *b*
2	1.11 *c*	17.64 *a*
Control	1.15 *c*	1.21 *d*
	Interaction of distances in the 20–40 layer	
0	2.42 *a*	4.24 *c*
1	1.67 *a*	6.57 *b*
2	1.06 *b*	10.98 *a*
Control	0.74 *c*	0.87 *d*

Means followed by different letters in the same row are different by the Scott–Knott test ($p < 0.05$).

on the receiving soils, notably reducing the vegetation in the moist spots.

4. Conclusion

Waste brine produced in the desalination plants of both communities had restrictions for irrigation use ranging from medium to severe in all evaluation periods.

The evolution of the salinization and sodification process in the studied soils depended on the salt concentration of the discharged brine, the initial salinity of the receiving soils, the climate conditions, and mainly the physical properties of the soils.

In both communities, the evolution of salinization occurred during the collection periods, between the soil profile layers and with the distance from the point of disposal of the waste brine, being more evident during dry periods.

References

[1] ANA, A questão da água no Nordeste, Agência Nacional de Águas, CGEE, Brasília, 2012. Available at: http://arquivos.ana.gov.br/institucional/sge/CEDOC/Catalogo/2012/aQuestaoDaAguaNoNordeste.pdf. Accessed 07 July 2019.

[2] SEMARH – Secretaria de Estado de Meio Ambiente e dos Recursos Hídricos, Plano Estadual de Recursos Hídricos (Relatório síntese), Natal, 2013. Available at: http://www.semarh. rn.gov.br/. Accessed 25 July 2018.

[3] N.S. Dias, F.F. Blanco, E.R. Souza, J.F.S. Ferreira, O.N. Sousa Neto, I.S.R. Queiroz, Efeitos dos sais no solo e na planta, H.R. Gheyi, N.S. Dias, C.F. Lacerda, E. Gomes-Filho, Eds., Manejo da salinidade na agricultura: Estudos básicos e aplicados, INCTSal, Fortaleza, 2016, pp. 130–140.

[4] A.M. Oliveira, N.S. Dias, J.J.R. Freitas, D.F.F. Martins, L.N. Rabelo, Avaliação físico-química das águas do processo de Dessalinização de poços salobros e salinos em comunidades rurais do oeste potiguar, Águas Subterrâneas, 31 (2016) 58–73.

[5] H.G. Santos, P.K.T. Jacomine, L.H.C. Anjos, V.A. Oliveira, J.F. Lumbreras, M.R. Coelho, J.A. Almeida, J.C. Araujo Filho, J.B. Oliveira, T.J.F. Cunha, Sistema Brasileiro de Classificação de Solos, 5th ed., Embrapa, Brasília, 2018.

[6] H.L. Bohn, B.L. Mcnell, G.A. O'Connor, Soil Chemistry, John Wiley & Sons, New York, 1985.

[7] P.C. Teixeira, G.K. Donagema, A. Fontana, W.G. Teixeira, Manual de métodos de análises de solo, Embrapa Solos, Rio de Janeiro, 2017.

[8] L.A. Richards, Diagnosis and Improvement of Saline and Alkali Soils, USDA, Washington, 1954.

[9] R.S. Ayers, D.W. Westcot, A qualidade da água na agricultura, UFPB, Campina Grande, 1999.

[10] EMPARN, Empresa de Pesquisa Agropecuária do Rio Grande do Norte, Monitoramento pluviométrico, 2014, Available at: http://www.emparn.rn.gov.br/, Accessed 20 Jan 2018.

[11] R. Vargas, E.I. Pankova, S.A. Balyuk, P.V. Krasilnikov, G.M. Khasankhanova, Handbook for saline soil management, FAO, Rome, 2018.

[12] E.S.R. Moura, C.R. Cosme, N.S. Dias, J.C. Portela, A.C.M. Souza, Yield and forage quality of saltbush irrigated with waste brine from desalination plant by reverse osmosis, Rev. Caatinga, 29 (2016) 1–10.
[13] C.R. Anders, M.R.S. Melo, N.S. Dias, A.C.M. Souza, J.C. Portela, F.S. Sousa Junior, Caracterização das águas de estações de tratamento na mesorregião do oeste potiguar, Brasil, Rev. Bras. Agric. Irri., 11 (2017) 1430–1437.
[14] C.R. Cosme, N.S. Dias, M.R.S. Melo, A.M.P. Oliveira, G.F. Silva, E.S.R. Moura, Avaliação da qualidade das águas de poços em comunidades e assentamentos rurais em Mossoró-RN, Acta Iguazu, 7 (2018) 97–108.
[15] N.S. Dias, S.N. Duarte, H.R. Gheyi, J.F. Medeiros, T.M. Soares, Manejo da fertirrigação e controle da salinidade do solo sob ambiente protegido, utilizando-se extratores de solução do solo, Rev. Bras. Eng. Agríc. Amb., 9 (2005) 496–504.
[16] F.Q. Porto Filho, J.F. Medeiros, H.J. Gheyi, N.S. Dias, P.S. Sousa, D.C. Dantas, Evolução da salinidade e pH de solo sob cultivo de melão irrigado com água salina, Rev. Bras. Eng. Agríc. Amb., 15 (2011) 1130–1137.