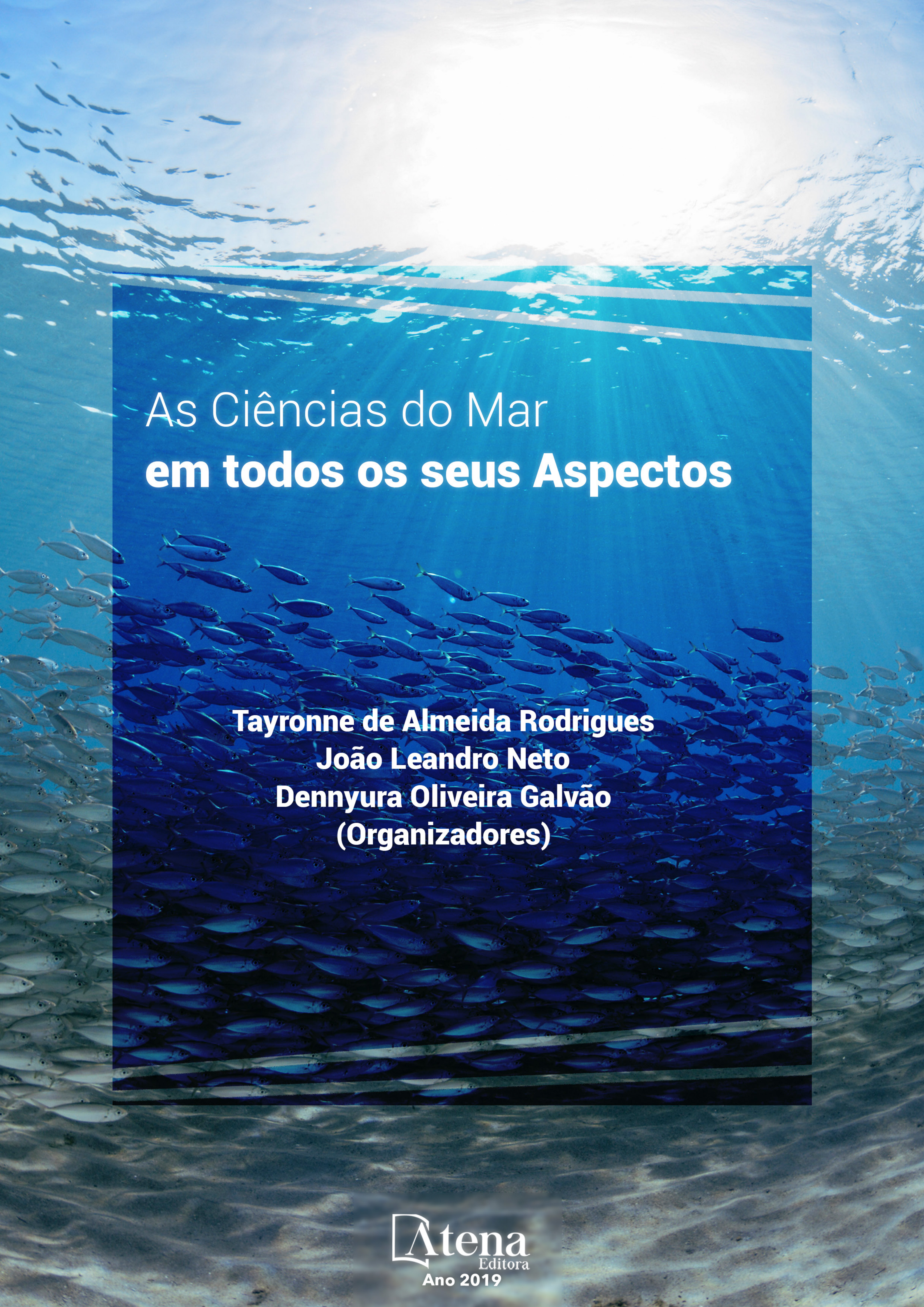

As Ciências do Mar
em todos os seus Aspectos

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João Leandro Neto
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(Organizadores)

Atena Editora
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Atena Editora
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APRESENTAÇÃO

O mar representa para o Homem desde as mais antigas datas uma fonte de mistérios, um universo repleto de criaturas com formas fantásticas e inimagináveis e essa forma de pensar tornava mais restrita a exploração marinha e o aprofundamento de pesquisas. Em 380 A.C., o filósofo grego Aristóteles foi o primeiro a estudar os oceanos com um cunho mais científico.

As ciências do mar lidam diretamente com região costeira e a região oceânica, pois trabalha em seus diferentes aspectos, com a cultura, a função dinâmica dos sistemas e também a interação do homem com esses princípios, considerando os aspectos biológicos, físicos e químicos. A oceanografia se divide em cinco áreas: oceanografia física, oceanografia química, oceanografia biológica, oceanografia geológica e oceanografia social. Possui também subáreas: paleoceanografia, a biogeoquímica marinha, a ecotoxicologia marinha, podendo existir outras.

Esta obra é de grande relevância, pois apresenta estudos pertinentes para a comunidade acadêmica que busca ampliar seus conhecimentos nos estudos sobre as Ciências do Mar. Apresentamos este volume em onze capítulos com abordagem em pesquisas científicas sobre os macroinvertebrados, biodiversidade algal, mudanças climáticas, moluscos marinhos, medicina popular, variabilidade genética, modelagem oceânica, oceanografia operacional e etnofarmacologia. Que estas contribuições possam refletir em futuros estudos para o crescimento das ciências do mar e todos os seus aspectos.

Tayronne de Almeida Rodrigues

João Leandro Neto

Dennyura Oliveira Galvão

SUMÁRIO

CAPÍTULO 9

ANALYSIS OF THE CORRELATION BETWEEN SALINITY AND ENVIRONMENTAL VARIABLES IN THE ESTUARY OF THE PARAÍBA DO SUL RIVER - BRAZIL

Glenda Camila Barroso
Leonardo Bernado Campaneli da Silva
Vicente de Paulo Santos de Oliveira

ABSTRACT: Limnological variables were studied in the estuary of Paraíba do Sul River (PSR), between July 2014 and December 2015, to understand the hydrodynamics of salinity variation up to 10 km upstream of its mouth. Sampling was performed at nine points, previously defined, and in the sampled period the river presented a historical series of low flow when critical values were reached 298 times. The measurement was performed in the locality with the use of a multiparametric probe to obtain estimated values for pH, dissolved oxygen (mg/L), salinity and water temperature (°C). Additional data on the air temperature, wind velocity, wind direction and barometric pressure were obtained from the meteorological station of Farol de São Tomé in the municipality of Campos dos Goytacazes of IMNET (2016). Principal Component Analysis (PCA) and linear regression were performed among the limnological variables to verify the influence on salinity in the estuary. The results show that salinity was the limnological variable most sensitive to the dynamics of the sea interaction and the PCA analysis indicates that the limnological parameters, water temperature, pH and dissolved oxygen, had an inverse salinity behavior. The influence of the semidiurnal cycle of the tide on the limnological characteristics in condition of low fluvial flow was evidenced as already pointed out in other works. The analysis of multiple linear regression shows that there was a significant difference between salinity and flow ($p = 0.024223$), showing that flow is the main determinant of salinity in the estuary of PSR.

KEYWORDS: Paraíba do Sul River (PSR); salinization; PCA of environmental variables; salinization-flow correlation

1 I INTRODUCTION

An estuary is characterized as a transitional water body between the river and the sea whose salinity varies temporally and spatially within it, being this salinity typically lower than the natural salinity of the sea (Potter, *et al.*, 2010). Limnological studies in estuaries around the world have shown that salinity, as well as other limnological parameters, respond directly to the seasonal variations of the flow (Yu, *et al.*, 2014; Song & Woo, 2015; Ylöstalo *et al.*, 2016) and these changes in flow observed in long term are influenced by the global climatic effect of El Niño / La Niña (Déry, Wood, 2005, Camiloni & Barros, 2006, Munoz, Dee, 2016). Both the decrease in river flow and the mean sea level increase lead to increased salinity of the estuaries that affect the fertility of the coastal zone soils as well as the fish assemblage composition of these areas (Nilsen, *et al.*, 2003; Liu & Liu, 2014; Vargas, *et al.*, 2017).

The estuary of Paraíba do Sul river (PSR) is strongly governed by flow pulses (Nicolite *et al.*, 2009; Cotovicz Jr. *et al.*, 2013, Ovalle *et al.*, 2013) and it can be classified as coastal wetland separated from the sea with fluctuating water level (Junk *et al.*, 2014). This river is 1,155 km long and drains an area of 55400 km² (Coelho, 2012), and its estuary has a surface area of 21.5 km², an average depth of 2 m, a 43.1 × 106 m³ volume and a hydraulic residence time of 0.75 days (Sterza, Fernandes, 2006; Cotovicz Jr., *et al.*, 2013). The morphosedimentary design of the RSP estuary is dominated by waves (Oliveira, 2015), and this estuary is located in a humid tropical climate and subject to a semidiurnal micro-tidal regime (Nicolite, 2009; Bernardes *et al.*, 2012, Alvares, *et al.*, 2013). According to Cotovicz Jr. *et al.* (2013), approximately 46.1% of the RSP estuary area is composed of fresh water, 33.2% of brackish water and 20.7% of saline water, but these values can be changed between dry and rainy season. These same authors analyze that, when the present flow conditions (450 m³/s in the dry season, 1000 m³/s in the rainy season) are maintained, the water quality of this river is good and tends to improve in the future. However, in recent years, the literature (Marengo & Alves, 2005; Ovalle, *et al.*, 2013; Oliveira, 2015) has shown that there has been a significant downward trend in PSR flow since 1934, especially in its final stretch. These publications have associated this drop in flow with the anthropic uses (mainly bus systems and water abstractions) that are done in this river as well as the La Niña phenomenon. Ovalle and collaborators (2013) also point out that the scenario of decreasing PSR flow and shortening the La Niña recurrence periods tend to worsen the water quality and the trophic level of the final portion of this river.

Computational models have endeavored to predict future scenarios of low river flow (Vargas, *et al.*, 2017), but they all lack real data of predicted conditions to test the accuracy of these models. In Brazil, the computational model of future scenarios for saline intrusion in estuaries, SisBaHiA version 8.5, (COOPETEC, 2013) was developed and it predicted that, in the critical flow of 247 m³/s, the mixing zone of the Paraíba do Sul river in the high tide of syzygy would enter up to 10 km in the channel of this river. According to this model, the tide and wind have less influence on the salt wedge intrusion and the flow would be the environmental component with more influence on the concentration of salt in the estuary. However, this model was not tested in real low-flow situations.

The aim of the present study is to identify the maximum range limit of the salt wedge intrusion in the estuary of PSR in low flow condition as well as to understand the hydrodynamics of the water mix in this estuary under this condition, proposing as hypothesis that, under flow conditions lower than 247 m³/s, the mixing zone of this estuary reaches 10 km of extension with the flow of the river as the main environmental factor to determine the concentration of salt in the estuary. Elucidating these aspects is fundamental in order to provide subsidies for better management of the water uses of this estuary by public authorities as well as to point out solutions to avoid the increase of salinity and the worsening of the water quality of this estuary.

2 I MATERIALS AND METHODS

2.1 Sampling strategy

As already known in the literature on the subject (Nicolite, *et al.*, 2009), the estuary of the PSR presents the highest tide levels in the period between 1 day before and 2 days after the night of full moon and the night of new moon. Thus, the measurements of this work were always made in this time interval at the time of the high tide and the low tide. Sampling was performed on 21 dates between July 2014 and December 2015. This time interval was chosen for being a continuous historical series of low PSR flow (Figure 1). In this time interval, the critical flow was reached 298 times, which allows to reliably verify other projections of the model built by the program SisBaHiA version 8.5.

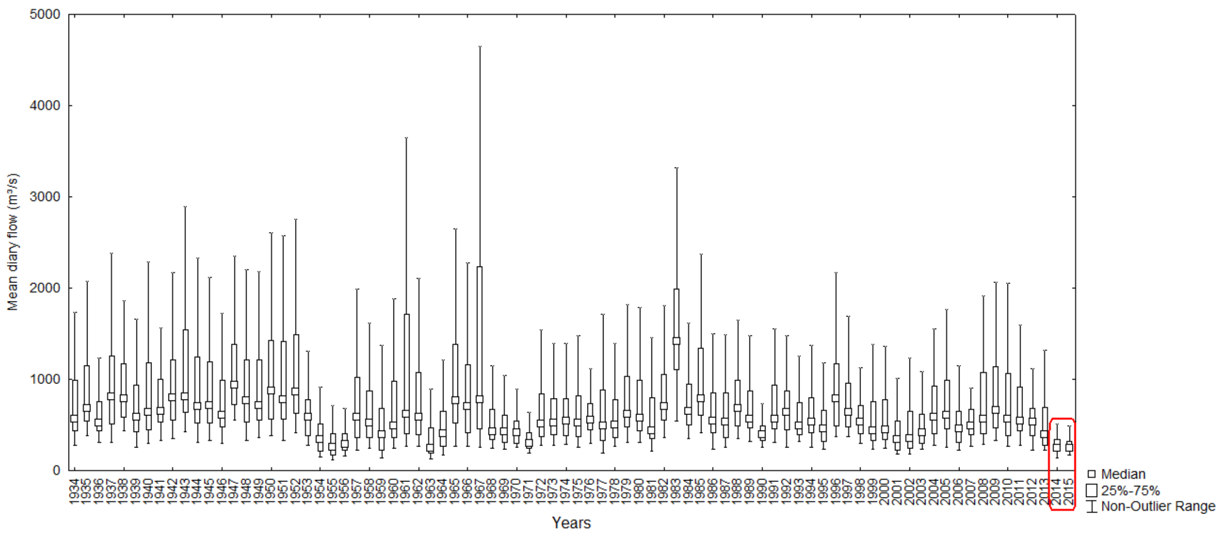

Figure 1: Graph showing the flow variations of the Paraíba do Sul river over the years. The red box highlights the variation of PSR flow in the years in which the samplings of this study occurred.

In the field, the limnological variables - pH, dissolved oxygen (mg/L), salinity and water temperature (°C) - were measured wth the use of a multiparameter probe (model 6820 V2, manufacturer YSI). The readings were made at 9 fixed points with the reading of the surface and the bottom always being made. (5 cm below the surface and 5m above the sediment of the river). The readings were made with the aid of a boat that ran through the points 1 to 9 always in the downstream-upstream direction (Table 1). All the points sampled were equidistant between the river banks, that is, they were centralized in the river channel (Figure 2). The sample design of the observations has as predictor variables the days of sampling (21 in total), the sampling points (9 in total), the sampling depth (surface and bottom) and the time of the tide sampled (high tide and low tide). Due to some navigation difficulties because of the formation of sandbars in the estuary of the RSP, in some occasions, it was not possible to sample some points.

Additional data of non-field-tested environmental variables (air temperature, wind speed, wind direction and barometric pressure) were obtained from the records of the meteorological station of Farol de São Tomé, municipality of Campos dos Goytacazes, (43 km away from the study area) (Imnet, 2016). This weather station was chosen because it is located about 100 m away from the sea, in the same coastal region of the estuary of the PSR.

The PSR flow was obtained from the website of the National Water Agency (2017), which monitors the flow of all major Brazilian rivers through automatic stations. Data were extracted from hydroweb (http://www.snirh.gov.br/hidroweb/) at the Campos dos Goytacazes station (fluviometric code 58974000).

	Coordenates (m)		Distance from the sea (m)
Points	E	N	
1	291323	7608092	609
2	290516	7608058	1422
3	289654	7608046	2283
4	288829	7607902	3118
5	288231	7607331	3945
6	287798	7606624	4775
7	287684	7605958	5450
8	286736	7605235	6718
9	285318	7604999	8287

Table1: Sampling points with their coordinates and distance between the point and the sea through the PSR channel. Coordenates in the UTM projection, Sirgas2000, Datum, zone 24K

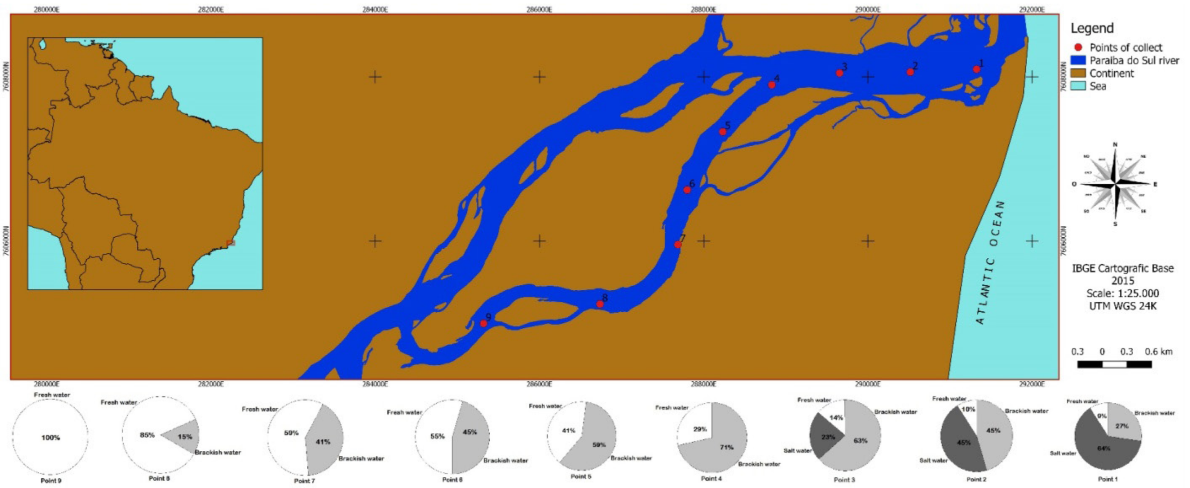

Figure 2: Map showing the location of sampling points in the estuary of Paraiba do Sul River and pie charts showing the percentage of times the water at these points was saline (salinity> 30), brackish (salinity between 30 and 0, 5) and fresh (salinity ≤ 0.5).

2.2 Statistical analysis

The Principal Components Analysis (PCA) was performed using the limnological variables pH, dissolved oxygen, salinity and water temperature in order to group the observations into classes according to similarity and to help to formulate new hypotheses (Kendall, 1980). The Guttman-Kaiser criterion (Yeomans & Golders, 1982) was adopted to retain from PCA components that have eigenvalues greater than 1 in order to plot the dispersion of the PCA points on a graph. By this criterion, component 1 (CP1) and component 2 (CP2) (eigenvalues of 1.61 and 1.39, respectively) were retained. A linear regression (Montgomery, Peck and Vining, 2015) was used to verify if the predictor variables influenced Comp1, and the possible interactions among the variables were also tested according to the groupings observed in the PCA. The CP1 data did not present residues normality by the Jarque Bera test (Jarque & Bera, 1980), did not present homoscedasticity by the Breusch-Pagan test (Breusch & Pagan, 1979), there being autocorrelation of residues by the Wooldridge test (Wooldridge, 2002). In order to circumvent these problems and enable the execution of valid inferences for the fitted models, as well as to guarantee the robustness of the models, the Heteroskedasticity and Autocorrelation Consistent (HAC) estimator was used for the covariance matrix of the estimated coefficients in order to test the significant differences among groups (Andrews, 1991).

Finally, a multiple linear regression was performed among the environmental variables - air temperature, wind velocity, wind direction, atmospheric pressure and PSR flow - in order to verify which of them most influenced the PSR estuary salinity (Montgomery, Peck *et al.* Vining, 2015). For this analysis, the mean value of these parameters obtained at the 21 sampling dates was used.

All statistical analysis were done through the use of R program (version 3.4.1).

3 I RESULTS AND DISCUSSION

3.1 Descriptive Analysis Of Limnological Parameters

The PSR, as already predicted in modeling works (Marengo & Alves, 2005; Ovalle, *et al.*, 2013, Oliveira 2015), tends to reduce its flow over the years, and in the years 2014 and 2015 it presented its lowest flows in a historical series of 81 years (Figure 2). This river follows a worldwide trend of increased freshwater catchment for anthropic uses, which may generate future problems of water quality loss and salinization of the coastal zone (Foley, *et al.*, 2005; Vargas, *et al.*, 2017). In this low-flow condition, the salinity was the parameter that showed the greatest variation of its values, indicating that this limnological variable is more sensitive to the dynamics originated from the sea-river interaction (Table 2).

		Water			Salinity			pH			Dissolved oxigen		
Sampl	N	mea	σ	cv	mea	σ	cv	mea	σ	cv	mea	σ	cv
1	7	20.5	2.4	11.8	23.2	16.2	69.89	6.64	0.9	14.9	7.74	0.5	7.11
2	7	20.7	2.4	11.6	18.1	15.0	82.89	6.89	0.9	13.8	7.83	0.6	8.37
3	7	20.8	2.4	11.8	13.7	14.3	104.8	7.03	0.9	12.8	7.88	0.7	10.0
4	7	21.1	2.5	12.1	5.30	8.71	164.3	7.18	0.8	11.8	8.30	0.8	9.93
5	7	21.2	2.6	12.4	2.27	4.88	215.1	7.20	0.8	11.4	8.44	0.8	10.0
6	7	21.2	2.6	12.4	1.24	3.15	255.1	7.21	0.8	12.3	8.51	0.8	9.95
7	7	21.1	2.5	12.1	3.17	7.92	250.1	7.15	0.7	10.7	8.40	1.2	14.3
8	7	21.4	2.7	12.9	0.20	0.39	193.3	7.29	0.7	9.80	8.83	1.0	11.3
9	7	21.6	2.7	12.6	0.05	0.01	17.78	7.36	0.7	10.7	9.01	1.0	11.7

Table 2: Summary of the limnological variables measured in the field, at the surface and on bottom of 9 monitoring points, in 21 field incursions carried out between 07/14/2014 and 12/11/2015. N = number of samples, σ = standard deviation, cv = coefficiente of variation

Although they did not study the PSR estuary throughout its length, other authors also found this greater variation in salinity values compared to other parameters measured (Gonçalves, 2003; Sterza & Fernades, 2006). From Figure 1, it is noticiable that the brackish waters have reached, at most, the sampling point 8, which is about 6.7 km from the sea. From Table 3 it can be seen that this event occurs in only three samplings (on 11/06/2014, 06/02/2015 and 10/27/2015). In these days, mean PSR flows at the time of sampling were all lower than the critical value of 247 m³/s predicted by the SisBaHiA version 8.5 software model (Coopetec, 2013). However, on 6 other occasions, the flow rate was below this critical value although without the salinity of point 8 being higher than 0.5. It is also worth noting that, in only 2 occasions, the average salinity of the estuary was lower than 0.5, with the river flow exceeding 500 m³/s in these two cases (Table 3). These results show that the water mixing zone of the river with sea water does not reach 10 km as predicted and suggest that 247 m³/s is not the critical value to determine the salt wedge intrusion since the mean salinity was higher than 0.5. in all cases of flow rate lower than 500 m³/s.

Date	Mean salinity of	Salinity in point 8	PSR mean flow (m³/s)	Wind mean velocity	Direction of wind in degrees	Mean of atmospheric temperature	Mean of atmospheric pressure
07/14/2014	6.73	0.26	250.17	4.24	130	23.3	1026
07/28/2014	14.0	0.05	309.55	8.16	220	21.4	1026
08/11/2014	2.72	0.05	308.73	5.50	168	24.1	1021
08/26/2014	2.87	0.04	278.42	9.16	162	27.2	1014
09/09/2014	9.76	0.21	275.74	9.44	63	26.1	1023
10/08/2014	5.55	0.08	210.16	9.15	45	25.7	1020
10/24/2014	9.58	0.98	207.9	8.35	83	27.2	1016
11/06/2014	8.06	0.12	207.64	4.94	190	29.1	1017
12/09/2014	0.06	0.04	530.35	10.23	65	28.1	1012
01/22/2015	7.84	0.21	218.44	6.90	70	33.9	1013
02/05/2015	2.29	0.04	278.24	6.94	30	27.7	1008
03/05/2015	11.1	0.04	269.18	8.33	80	30.8	1014
04/06/2015	7.68	0.04	387.01	3.36	300	23.3	1004
05/18/2015	14.4	0.05	267.18	3.93	80	27.5	1021
06/02/2015	19.7	1.42	240.96	4.10	158	24.8	1021
07/31/2015	11.3	0.08	244.15	7.25	40	27.1	1022
08/14/2015	15.7	0.14	209.98	7.35	47	25.3	1024
09/28/2015	15.5	0.28	221.29	6.40	180	31.1	1010
10/27/2015	10.9	1.17	237.57	9.47	57	31.0	1014
11/27/2015	2.90	0.05	469.34	6.30	97	26.3	1015
12/11/2015	0.05	0.05	878.58	7.05	112	31.2	1013

Table 3: Summary of the limnological variables measured in the field at the surface and bottom of 9 monitoring points, in 21 field incursions carried out between 07/14/2014 and 11/12/2015.

3.2 Pca Analysis And Statistical Test

The PCA analysis (Figure 3) showed that limnological parameters - water temperature, pH and dissolved oxygen - had an inverse behavior to salinity, that is, the water of the sea is more saline, has lower pH, lower temperature and lower dissolved oxygen concentration than the water of the river. This same tendency was found by other authors (Sterza & Fernades, 2006; Gonçalves, 2003). The variable with the highest value in CP1 was salinity (-0.564) while in CP2 it was dissolved oxygen (-0.789).

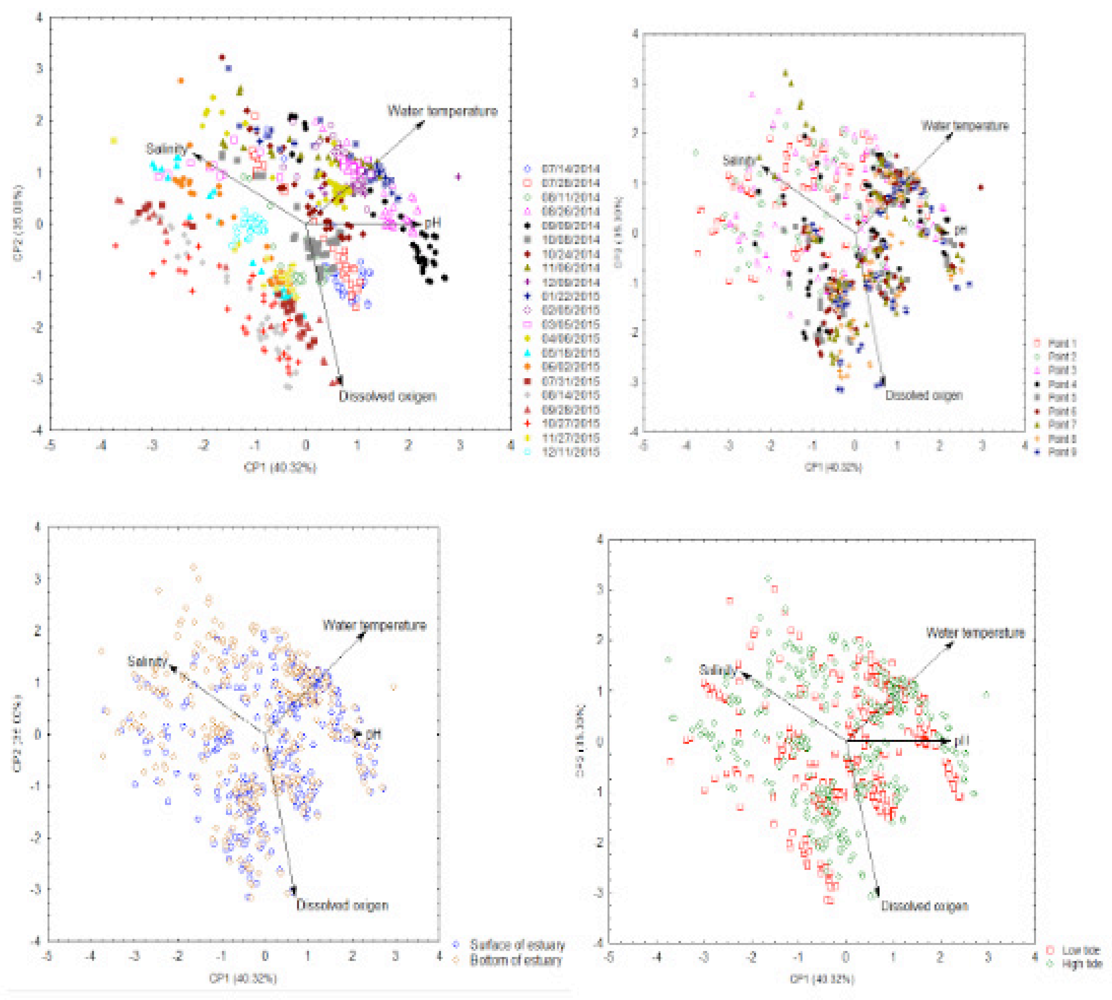

Figure 3: Graph showing data distribution of Components 1 and 2 of a PCA grouped according to predictor variables. (a) Grouped by sampling date. (b) grouped by sampling point. (c) grouped by sampling depth. (d) grouped at the time of the tide cycle when sampling was performed.

Figure 3 shows that groupings by sampling date and by point are clearer than groupings by depth and by high tide / low tide. Comparing the results shown in Tables 2 and 3 with Figure 3, it can be observed that there is a trend of greater dispersion of the graph points at the dates when the river flow was smaller and a larger grouping at the dates when the river flow was larger. Points 1, 8 and 9 tend to be more grouped than points 2, 3, 4, 5, 6 and 7, indicating that the middle of the estuary is where the largest mixture of river water and sea water occurs, whereas the extreme points, further downstream and further upstream, are basically dominated by sea water and river water respectively.

The result of the HAC estimator test applied to the CP1 components revealed that the following interactions are significant: point x depth (p = 0.000), days x depth (p = 0.005), days X point (p = 0.000), point x moment of the tide (p = 0.000). All the other interactions were not significant. The interaction point x depth showed a significant difference between surface and bottom at points 2, 3, 4, 5 and 7, with CP1 values being always lower at the bottom than at the surface. There was no difference between the depths sampled in points 1, 6, 8, 9. These results reveal that the sea water enters the estuary from the bottom due to the difference in density in relation to the river water, which causes a stratification between fresh and salt water. Research work conducted in this estuary had already pointed to this possibility (Sterza & Gonçalves, 2003; Fernandes, 2006) and a similar effect has already been reported for other estuaries around the world (Huges & Rettray Jr., 1980; Rosón, *et al*., 1997; Ralston, *et al*., 2010). It is noticeable that point 7 has this stratification while points 6 and 8 do not have it. At the sampling times, it was observed that there was a water treatment plant opposite sampling point 7 which dumped its waste into the river. The waste from this plant is basically composed of suspended particulate material which is separated from the water by the addition of aluminum sulfate salt. Perhaps this salt is responsible for the vertical gradient observed in point 7, but additional studies should be done to prove this possibility.

The interaction days x depth showed that there is difference between surface and bottom on the dates 08/11/2014, 03/05/2015, 04/06/2015, 05/18/2015 and 06/02/2015. Comparing this result with Table 3, it can be observed that it is not possible to derive a standard from these dates based on the variables in this table. Thus, it appears that another variable that has not been measured is responsible for determining if there is difference between surface and bottom in each sampling event. Souza and Knoppers (2003) showed that the PSR is one of the rivers with the greatest sediment transport capacity of the Brazilian east coast, with a significant seasonal difference between the rainy season (large volume of transported sediments) and the dry season (lower sediment volume transported). That, combining with the fact that the coast where the PSR is located has its morphosedimentary designer sculpted by waves (Oliveira, 2015), results in a favorable combination to suppose an intense sedimentation dynamic in this estuary. Paggioli *et al.* (2015) showed that the depth and slope of the bottom of an estuary are determinant in the mixture and vertical gradient formation in the water column. Thus, it is possible that the depth variation of this estuary is responsible for the similarities and differences between surface and bottom over the time period studied. It is important to point out that, although our work did not measure the depth of the estuary during sampling events, on some dates we were able to navigate very easily on the estuary while, on other dates, we had many navigational difficulties due to the fact that the boat constantly ran aground on sandbanks that were formed.

Regarding the interaction days x points, significant differences between points 1, 2 and points 8, 9 were found on the following dates: 07/14/2014, 09/09/2014, 10/08/2014, 10/24/2014, 06/11/2015, 01/22/2015, 05/18/2015, 06/02/2015, 08/014/2015, 09/28/2015 and 10/27/2015. Analyzing Table 3, it can be observed that the average flow of the estuary on these dates is among the lowest flows measured, showing that the significant difference between the points is due to the loss of capacity of dilution of the PSR, increasing the influence of the sea downstream of the estuary. This result was expected since several research works done on this river, as well on others, point to this problem (Ovalle *et al*., 2013, Yu, *et al.,* 2014, Song & Woo, 2015, Ylöstalo *et al*., 2016).

The statistical analysis applied to the interaction between point x time of the tide showed that the significant differences among the points change between high tide and low tide. At high tide, points 1 and 2 differ from points 4, 5, 6, 7, 8, 9, whereas point 3 differs from points 5, 6, 7, 8, 9; in contrast, at low tide, point 1 differs from points 4, 5, 6, 7, 8, 9 and point 2 differs only from points 8, and 9. These results show that at high tide there is actually a greater input of marine water into the estuary which increases the differences between the points further downstream and further upstream of the estuary.

On the other hand, at low tide the marine influence declines and, due to that, the differences between the points also decrease. However, it should be noted that even at low tide there are still differences between the waters of points 1 and 2 in relation to the waters of further upstream points, which emphasizes that the sea has significant influence in this estuary during the low flow condition of the river. These results highlight the influence of the tidal semidurnal cycle on the limnological characteristics in a low fluvial flow condition, as already pointed out in other studies (Gonçalves, 2003; Sterza & Fernandes, 2006; Nicolite, *et al.*, 2009) and they warn us that if these low flow conditions are maintained, the river could no longer have a water exchange regime in its estuary per flow pulse and could be having a water exchange regime per tidal cycle. Figure 4 synthesizes the horizontal gradient formation dynamic between the river and the sea water in this estuary.

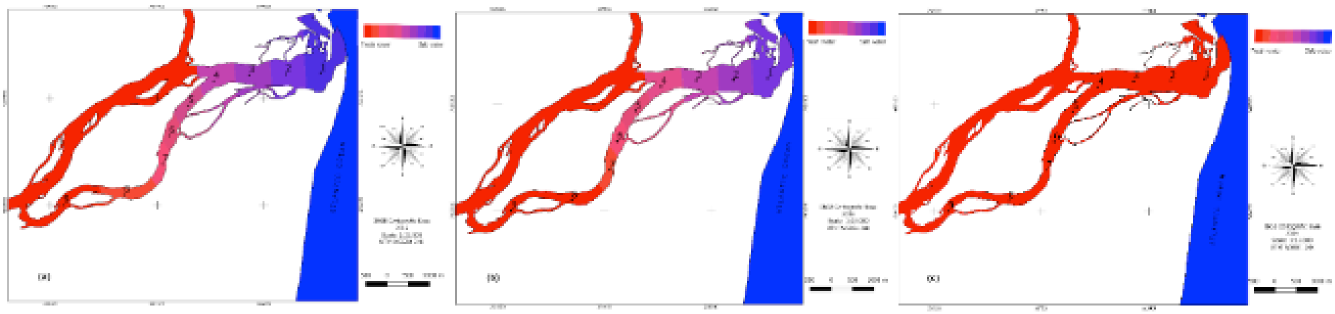

Figure 4: Maps showing the fluctuations between fresh water and salt water mixtures in the estuary of Paraíba do Sul River. (a) Horizontal gradient between fresh and saline water in the RSP estuary under low flow conditions (<500 m³/s) at the time of high tide. (b) Horizontal gradient between fresh and saline water in the estuary of the PSR in a low flow condition (<500 m³/s) at the time of the low tide. (c) PSR estuary in high flow condition (> 500 m³/s).

3.3 Regression Analysis

As previously discussed, salinity proved to be the parameter sensitive to the changes in the RSP estuary. Because of this sensitivity to environmental changes, salinity was the variable chosen to establish multiple linear regression with the environmental variables: air temperature, wind velocity, wind direction, atmospheric pressure and PSR flow.

The multiple regression among salinity, flow, wind, air temperature and atmospheric pressure showed $R^2 = 0.4729$ and $F(5.15) = 2.6911$. There was no significance for wind velocity and direction ($p = 0.4539$ and $p = 0.3554$ respectively) or for air temperature and atmospheric pressure ($p = 0.2744$ and $p = 0.1108$ respectively), but there was only significance for flow ($p = 0.024223$). Having established the existence of a causal effect between flow and salinity, the best function to explain the relationship between these fluvial characteristics was then searched for. As shown in Figure 5, the exponential equation is the one that best describes this function, presenting R^2 of 0.735. By the equation that describes this function it is possible to calculate that the minimum PSR flow to maintain an average salinity of the estuary around 0.5 is approximately 567.45 m^3/s. This result shows that the entrance of the saline water in the mouth of the PSR is not affected by atmospheric factors but by the flow, that is, the greater the flow, the lower the influence of the marine water and, consequently, the lower the salt content in this estuary. This result is consistent with what has already been demonstrated in the literature. Nicolite *et al.* (2009) concluded that, in periods of high flow, the tidal amplitude is reduced drastically even in the syzygy, with the estuary being dominated by the river. Ovalle *et al.* (2013) showed in a long-term historical series study that conductivity and the concentration of several ions (Ca^{+2}, K^{+}, Mg^{+2}, Cl^{-}, Na^{+}) are inversely proportional to the flow of the river.

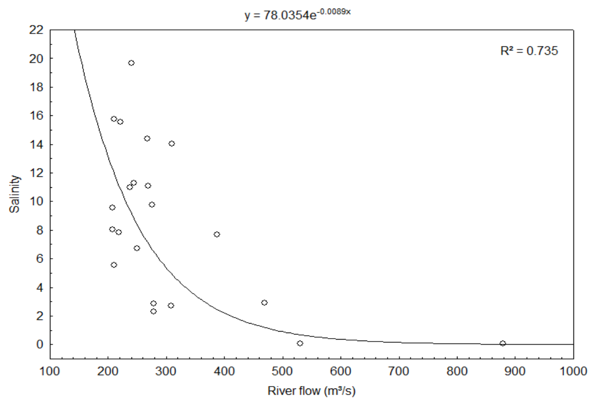

Figure 5: Graphical representation of the equation that best adjusts the model of the relation between PSR flow and salinity.

Wind was expected to be an important agent in the mixture of the sea and river water, since in several works done in Brazilian coastal lagoons, this environmental component interfered significantly both in the entrance of sea water into these environments and in the homogenization of the water column (ALVES, 2003; CRUZ, 2010; GOMES; 2009). However, as pointed out by these same authors, the larger the surface of the water surface, the greater the influence of the wind. In this aspect, the PSR estuary is far behind the lagoon complexes studied in those works: based on the delimitation of the mixing zone that we could map with our data (Figure 4), the PSR has 8.11 km^2 of water surface in its estuary, while the water surface of the lagoons mentioned vary from 35.2 km² to 220 km². Therefore, the explanation given is that the PSR estuary does not have sufficient water surface areas for the action of the kinetic energy of the wind to have any effect on the change of salinity in its interior.

4 I CONCLUSION

Based on the above, it can be concluded that the mixing zone of the PSR reaches approximately 6.7 km upstream from coastal line and its estuary has 8.11 km² of water surface. Salinity forms a decreasing gradient from the sea up to the upstream limit of the mixing zone.

There is significant difference among the limnological characteristics of the estuary comparing the upstream portion with the downstream portion (the upstream portion is dominated by fresh water and the downstream portion is dominated by marine water) with this difference being conditioned to the low flow of the river, since in times of high river flow, the river dominates the entire region of the estuary. The high tide moment is when the differences among the points of the river monitored in this work are greater because it is, at this moment, that the entrance of salt water into the estuary is more intense. However, even in the low tide, under low river flow conditions, the influence of the sea in the last 1400 m (between the coastline and point 2) of this estuary is still perceptible.

There is difference in the limnological characteristics of the RSP between surface and bottom, and this difference is affected primarily by the entry of marine water through the bottom of the PSR delta, and the vertical stratification is perceptible in the central region of the estuary and not perceptible in the further upstream and downstream portions. Stratification is also conditioned by low river flows, since high river flows tend to homogenize the water column.

River flow is the main determinant of the PSR salinity, with no significant regression with climatic factors. Therefore, maintaining the ecological flow (567.45 m³/s) is fundamental for the balance of this ecosystem and for the possibility of multiple sustainable uses of water for present and future generations.

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