

Evaluation of freshwater benthic communities: a case study in an urban source in the Northeast of Brazil

Avaliação da comunidade meiobentônica de água doce: estudo de caso em um manancial urbano no Nordeste brasileiro

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ABSTRACT

The environmental damage suffered by urban water bodies and the need for public water supply result in a greater interest in techniques that enable water treatment in an efficient and ecological way, such as River Bank Filtration (RBF). This technique uses the soil as a filtering medium, as well as the biological activities of organisms that dwell in the Hyporheic Zone (HZ), the zone of interaction between the surface water body and its underlying aquifer. Knowledge of sediments and hyporheic organisms is indispensable to study RBF. The present paper aimed to characterize the HZ of the middle section of Beberibe river (Pernambuco State, Brazil) in its sedimentological and biological aspects, with sampling during the rainy and dry seasons, in two distinct sampling sites, one in a conserved area and the other in a highly urbanized area. Biological characterization was performed at the level of large taxonomic groups of meiofauna, accounting for 982 individuals, with the three most abundant taxa being Nematoda, Annelida, and Rotifera. Permutational Analysis of Variance (PERMANOVA) statistical tests were performed, showing significant differences for the season and point factors ($p < 0.05$) in relation to abundance. The highest concentration of individuals and total organic matter were seen in the rainy season, especially at the point located in the urbanized area. With sedimentological characterization by grain size tests of the hyporheic sediments, the predominance of silt was observed during the rainy season, and sandy during the dry season. It

RESUMO

Os danos ambientais sofridos pelos corpos hídricos urbanos e a necessidade de suprir o abastecimento público das cidades resultam em um maior interesse por técnicas que possibilitem o tratamento de água de maneira eficiente e ecológica, como a Filtração em Margem (FM). Essa técnica utiliza o próprio solo como meio filtrante, além das atividades biológicas dos organismos que ocupam a Zona Hiporreica (ZH), zona de interação entre o manancial superficial e o aquífero subjacente. É indispensável o conhecimento acerca dos sedimentos e dos organismos hiporreicos para o estudo da FM. Este artigo objetivou caracterizar a ZH do trecho médio do rio Beberibe (Pernambuco, Brasil) em seus aspectos sedimentológicos e biológicos, com coletas nos períodos chuvoso e seco, em dois pontos distintos, um em uma área conservada, e o outro em área altamente urbanizada. A caracterização biológica foi realizada em nível de grandes grupos taxonômicos da meiofauna, contabilizando-se 982 indivíduos, sendo os três *táxons* mais abundantes o Nematoda, a Annelida e a Rotifera. Realizaram-se testes estatísticos de Análise Permutacional de Variância (PERMANOVA), constatando-se diferenças significativas para os fatores período e ponto ($p < 0,05$) em relação à abundância. A maior concentração de indivíduos e de matéria orgânica total ocorreu no período chuvoso, sobretudo no ponto localizado na área urbanizada. Por meio da caracterização por ensaios granulométricos dos sedimentos hiporreicos, observou-se a predominância arenosa no período seco, e de silte durante o período chuvoso. Concluiu-se que o

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was concluded that the main factor that influenced the structure of the meiofauna community was the release of domestic effluents. The information obtained by the present work helps to understand some features of the HZ, which is essential for RBF or other techniques that use the interstitial matrix.

Keywords: meiofauna; riverbank filtration; Beberibe river; hyporheic zone; sedimentology.

principal fator que influenciou na estrutura da comunidade da meiofauna foi o lançamento de efluentes domésticos. As informações obtidas com o presente trabalho auxiliam a compreensão de algumas características da ZH, a qual é essencial para a FM ou outras técnicas ambientais que utilizem a matriz intersticial.

Palavras-chave: meiofauna; filtração em margem; Rio Beberibe; zona hiporreica; sedimentologia.

Introduction

A problem currently observed in Brazilian urban centers is the pollution of their water sources, mainly due to irregular urban occupation and lack of basic sanitation (GUGLIELMELI; SILVA; STRAUCH, 2018), contributing to the degradation of water resources and making water supply more expensive (SILVA; FIGUEIREDO; MORAES, 2015).

In this context, alternative water treatment techniques, such as Bank Filtration (BF), are being increasingly studied and applied in developing countries to obtain water efficiently at a reduced cost, even from degraded urban sources (PHOLKERN *et al.*, 2015; HU *et al.*, 2016; FREITAS *et al.*, 2018).

BF consists of the indirect abstraction of water from a surface source with pumping wells close to the river (or lake), causing an increase in the difference of hydraulic head between the source and the water table, which induces the passage of water through the porous medium to the well (RAY, 2002). In this technique, physical, chemical, and biological processes occur (FREITAS *et al.*, 2018), mainly during the passage of water through the Hyporheic Zone (HZ), which is the transition zone

between the surface environment and the underground environment (VERAS *et al.*, 2017). The HZ plays a fundamental role in the river-aquifer interaction, acting as a regulator in the water flow and as a natural filter (MUGNAI; MESSANA; DI LORENZO, 2015). The water percolating through the hyporheic sediments undergoes several biogeochemical processes (LIU *et al.*, 2017) and reaches the well installed on the bank with better quality water than water collected directly from the superficial source (RAY, 2002). Figure 1 illustrates the relation between a BF system and the HZ.

Thus, knowledge of the hyporheic zone is important for BF understanding. Similarly, the analysis of their physical and biological characteristics, with textural and grain-size analysis of hyporheic sediments, the content of sedimentary organic matter, and the evaluation of hyporheic fauna are fundamental to characterize the HZ. In addition, these biotic and abiotic parameters analysis are also important for assessing the vulnerability of underground and surface water bodies, commonly used in environmental studies (BORN; OLIVEIRA; CUBAS, 2014; JUNQUEIRA *et al.*, 2018).

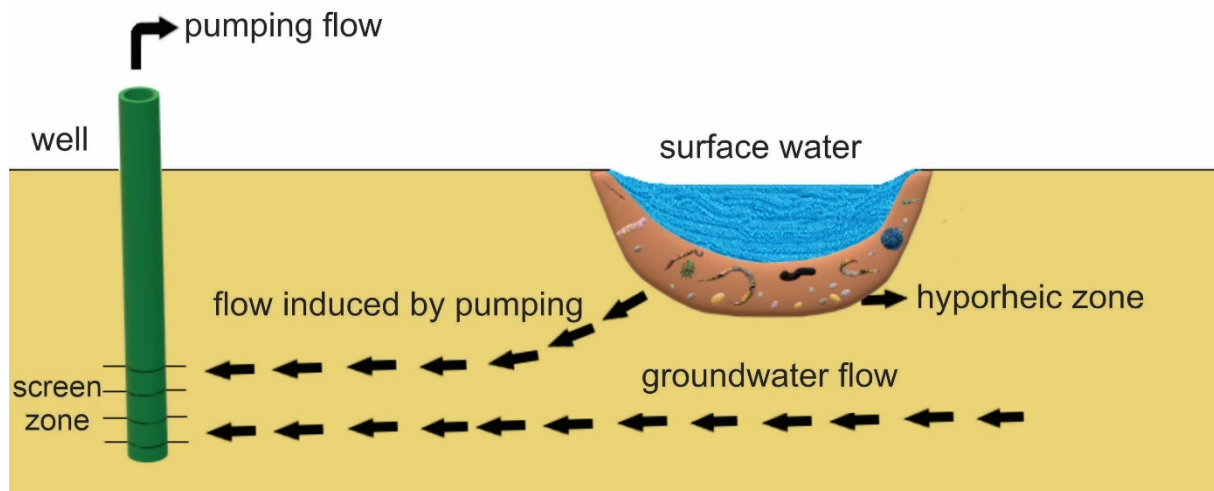


Figure 1 – Scheme of a bank filtration system and the hyporheic zone of the surface water source.

Among the organisms belonging to the hyporheic fauna, meiofauna organisms (or meiobenthos) stand out, which are small benthic organisms capable of interacting with different types of substrates and are distinguished by the opening of the mesh in which they are retained: between 500 and 42 μm (MARE, 1942).

These organisms have representatives that occupy aquatic and terrestrial ecosystems, which can inhabit the substrate of streams, trunks, and roots, in addition to coral reefs and several sedimentary matrices (GIERE, 2009). Meiobenthos have a short life cycle, facilitating observations in environmental studies (JUNQUEIRA *et al.*, 2018; VERAS *et al.*, 2018), act on nutrient cycling (ZEPILLI *et al.*, 2015) and favor the formation of biofilms (LIU *et al.*, 2017). They play an important role in the river-aquifer interaction (FREITAS *et al.*, 2019), with highlights for studies with meiofauna in recent years. Despite the increase in the number of research on meiofauna, most of them have been developed in marine and estuarine environments (MARIA *et al.*, 2016). Thus, focusing on the study of meiofauna in freshwater environments is needed, which requires a greater number of studies. The use of organisms as biotic indexes of water quality is not largely widespread in Brazil, even though there are some adaptations for macrozoobenthos, for example (JUNQUEIRA *et al.*, 2018).

Sedimentological characteristics of the HZ are important for directly determining the spatial and structural conditions and indirectly

determining the physical and chemical environment of the sediment (MUGNAI; MESSANA; DI LORENZO, 2015). In addition, meiofauna is important to influence the spatio-temporal distribution of the hyporheic meiofauna (VERAS *et al.*, 2017).

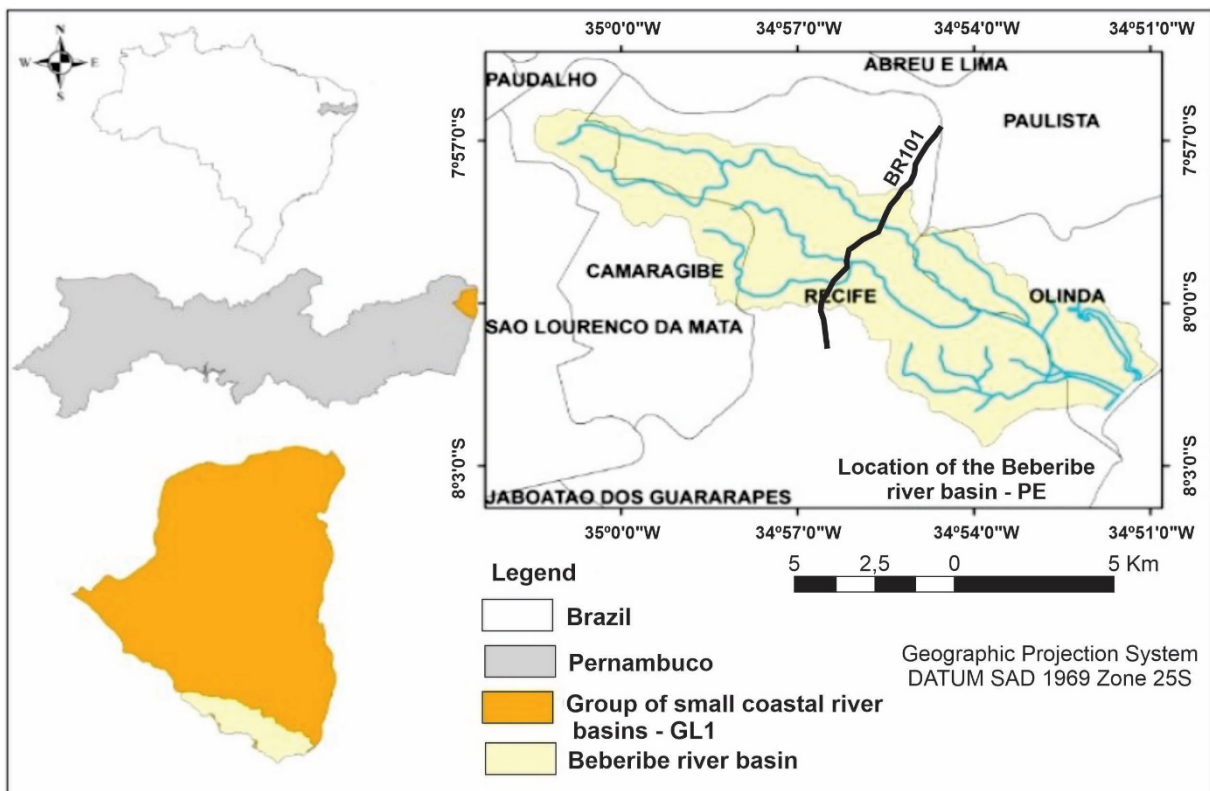
In this context, knowing the sedimentological and meiofaunal compositions of the HZ is relevant, since these factors interact and provide a basis for an effective analysis of the river-aquifer interaction. Thus, the present paper aims to evaluate the HZ, in terms of its sedimentological characteristics (grain-size and total sedimentary organic matter content) and biological (abundance of meiofauna organisms and their interaction with several factors), aiming to contribute to the understanding of the processes that occur in BF.

Materials and Methods

Study area

Hyporheic Zone (HZ) was studied on Beberibe river, located in Recife Metropolitan Region (RMR), Pernambuco State (Figure 2). Beberibe river has its source in Camaragibe municipality, its hydrographic basin is 81 km^2 , and it includes portions of the municipalities of Recife, Olinda, and Camaragibe (SIRH, 2019).

It is one of the most polluted rivers in Pernambuco State, because there is a high population density along its length, especially defined by



Source: Silva and Barbosa Neto (2016).

Figure 2 – Location of Beberibe river's basin (PE).

their low income and no adequate basic sanitation, besides the industrial activities in its basin (CAMPOS, 2003; SIRH, 2019).

In terms of land use and occupation, Beberibe river's basin is divided into two distinct sectors by the BR-101 highway, one to the west of this highway, a sparsely urbanized area with preserved fragments of Atlantic forest, and the other to the east of the highway, with a high rate of urbanization (CAMPOS, 2003).

Beberibe river's basin is represented by areas of slopes with exposed soil, characterized by sandy-clayey sediments from Barreiras Formation. These areas are subject to water erosion during rainfall periods (CAMPOS, 2003).

With a hot and humid climate, Beberibe river's basin is part of the Humid Tropical Climate (AS'), with a great amount of rainfall during the autumn-winter period, according to the Köppen classification (1948). Given that the annual thermal variability is very low, there are two distinct seasons related to rainfall levels: the rainy season (winter), and the dry season (summer).

Rainfall data from the last ten years (2007 to 2017) were obtained from Pernambuco Water and Climate Agency (*Agência Pernambucana de Águas e Clima* — APAC) from Olinda 199 rain station near the study area. Figure 3 shows that the rainfall in the study area was higher in May, June, and July; and lower in October, November, and December (APAC, 2019).

The research samples were obtained with different samplings, which were carried out in the middle section of Beberibe river in RMR, on the border between the cities of Recife and Olinda.

Two different sampling sites were selected (Figure 4): Sampling Site 1 (SS1) and Sampling Site 2 (SS2). SS1 is located close to BR-101 in Gu-

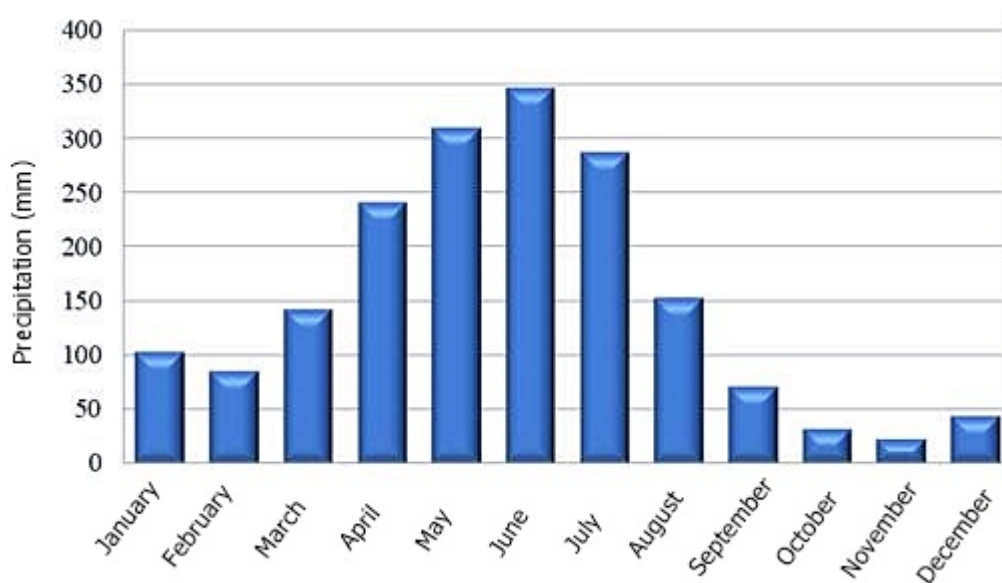
abiraba neighborhood, in Recife, in an area with traces of the remaining Atlantic forest vegetation and without upstream urbanization. SS2 is located 3.5 km downstream of SS1, in a section where an experimental Bank Filtration (BF) station is located, in an area highly urbanized by low-income settlements and with a large supply of domestic sewage.

Field methodology

All samples presented in this paper were extracted from the Hyporheic Zone (HZ) of Beberibe river at Site 1 (SS1) and Site 2 (SS2) on July 27th, 2018 (rainy season) and December 21st, 2018 (dry season).

For the analysis of meiofauna, the number of samples collected during the summer season was carried out in three replicates for SS1 and three replicates in SS2. During winter, the number of replicates remained three for SS1 and three for SS2. After being collected, each replicate was stored in a plastic pot, later preserved in formaldehyde 4%, so that it could later be transported for screening in the laboratory. Recent authors also use formaldehyde 4% in their work (COSTA; VALENÇA; SANTOS, 2016; SARMENTO *et al.*, 2017).

For the grain-size analysis, a sediment sample (from 0 to 10 cm deep) was collected in SS1, and another sample from SS2 during summer, repeating the sampling in the winter. The granulometric samples were packed in plastic bags and transported in styrofoam until they were stored in a freezer for later analysis. The sediments collected for both granulometry and meiofauna were obtained with a corer (cylindrical sampler of smooth and transparent acrylic) with a cross-sectional area of 11.33 cm². The corer was marked with different depth stratifications: 0-5 cm and 5-10 cm, as illustrated in Figure 5. The depth stratification was present for both meiofauna and granulometry.



Source: APAC (2019).

Figure 3 – Average monthly rainfall (mm) at Olinda 199 station in the last ten years (2007-2017).

Laboratory methodology

Particle size and total organic matter analysis

The grain-size analyses were performed at Universidade Federal de Pernambuco (UFPE), in the Oceanography Department (DOCEAN), Laboratory of Geological Oceanography (LABOGEO). These grain-size analyses were made using the sieving and pipetting technique described by Suguio (1973). Besides that, the contents of total organic matter (TOM) were also obtained, using the methodology described by Muller (1967).

The sediments were removed and placed in Becker for drying in the oven for 24 hours at 60°C. After that, the TOM analysis was performed with a 30 g aliquot of the post-drying sediments, in which a 10% H₂O₂ solution was used for the oxidation of organic matter. Subsequently, the TOM contents were acquired from the difference in weight before and after the oxidation process after determining the TOM. The fine and coarse particles were separated with wet sieving to remove the fines with the aid of distilled water. The finer particles, which are difficult to quantify by sieving, were subjected to the pipetting process.

The weighing results were placed in the SYSGRAN 3.0 software to identify the granulometry and plot the data of the granulometric fractions, using parameters such as average diameter, classification and degree of selection, according to the equations by Folk and Ward (1957).

Meiofauna

The characterization of meiofauna organisms was carried out with a quantitative survey and identification of large taxonomic groups. The samples were subjected to elutriation and wet sieving (washed in running water and filtered), in sequence, with the aid of geological sieves nested with 500, 200, 100, and 45 µm mesh openings. This methodology was chosen because the Flotation method is not highly recommended for this work, considering that the solution of NaCl or sucrose (most commonly used) has a very high osmotic potential, for example, thus damaging part of the fauna and spoiling the data. Therefore, it is more appropriate to use the nested sieve separation method. Thus, in the sieves of greater opening, the thicker sediments and some other material of larger size are retained: pieces of leaves, small stones, among others. This avoids clogging the mesh opening sieve (45 µm) and possible damage to the retained fauna (SOMERFIELD; WARWICK; MOENS, 2005).

The material retained in the 45 µm sieve was placed in a plastic pot and stained with Rose Bengal. The main taxonomic groups of meiofauna were counted with the aid of a stereomicroscope. Authors, such as Castro (2003) and Veras (2015), also used similar methodologies for meiofauna quantification in an estuary area and in a river, respectively.

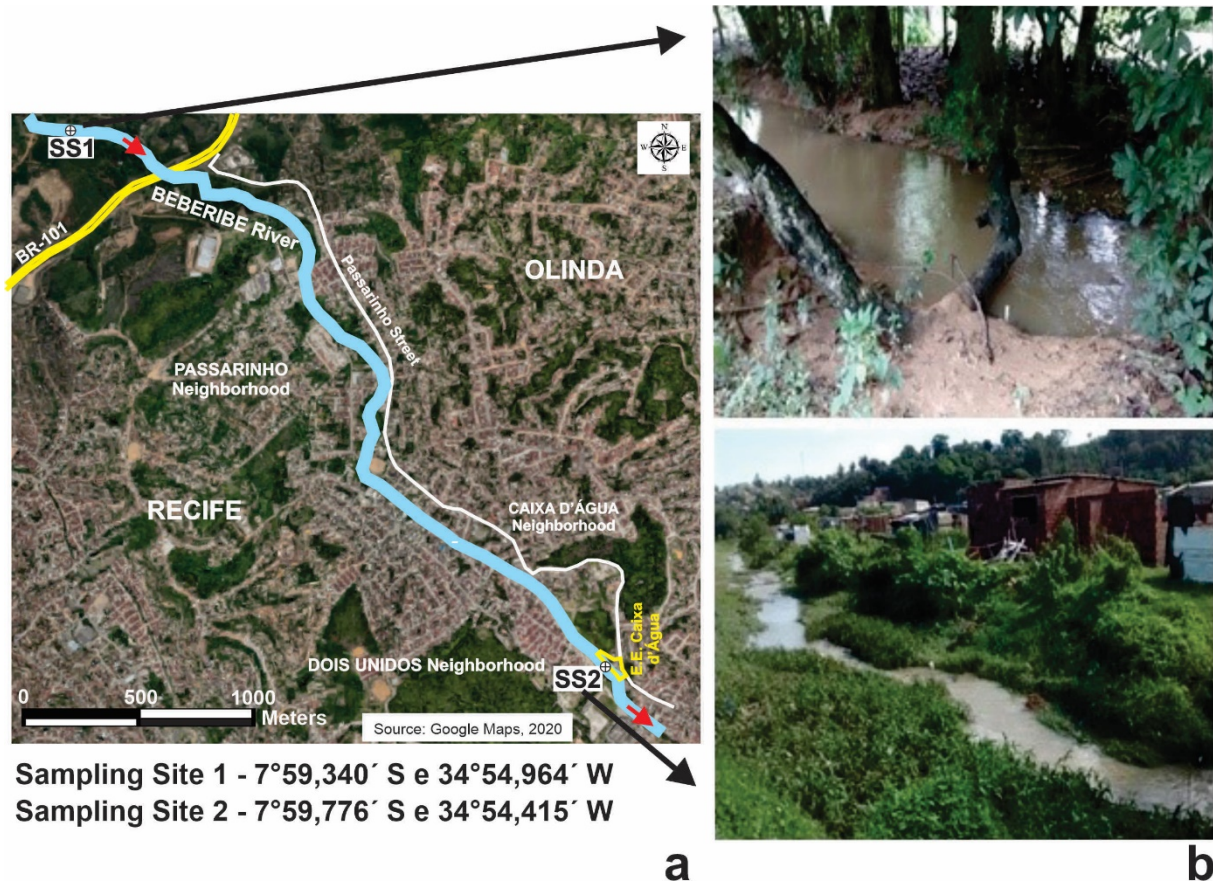


Figure 4 – Location of study sampling sites (SS1 and SS2) in the middle section of Beberibe river (PE).

The density of meiofauna is calculated by the cross-sectional area of the corer used (11.33 cm^2). Then, the density was standardized to values corresponding to individuals/ 10 cm^2 from Equation 1:

$$D = (N / V) \times 10 \quad (1)$$

In which:

D: the density;

N: the total number of organisms present in the samples;

V: the sample volume (cm^3).

Based on the similarity matrix of Bray Curtis, the analysis of the meiofauna community structure was performed with the representation on a multidimensional scale (MDS), in which it is used to graphically express the similarities (groupings) between replicates and factors (CLARKE; WARWICK, 2001). Significance between clusters was tested using Permutational Analysis of Variance (PERMANOVA) (ANDERSON, 2005); in case of significance, Tukey's posterior test was applied to the pairs of levels of each factor.

Three factors were adopted for data analysis: Period (winter and summer), Space (P1 and P2), and Depth (0-5 and 5-10 cm). All analyzes were performed using the software Primer[®] v.6 + PERMANOVA (Plymouth Routines in Multivariate Ecological Research).

Results and Discussion

Hyporheic sediments

Table 1 describes the data found with granulometric analyses and Total Organic Matter (MOT) in summer and winter periods. All samples presented in this paper were extracted from Beberibe river Hyporheic Zone (HZ) at Sampling Site 1 (SS1) and Sampling Site 2 (SS2) on July 27th, 2018 (rainy season) and December 21st, 2018 (dry season).

According to Xavier *et al.* (2016), a greater number of fines may be linked to organic manure of anthropic origin. This can be seen in SS2, which is the most urbanized and probably receives a greater discharge of domestic waste.

The MOT values did not show relevant differences between the two depths studied. During summer, the MOT contents were 1.67 and 1.56% in SS1, 4.53 and 5.08% in SS2, respectively for depths 0-5 cm and 5-10 cm. During winter, these values were 11.44 and 11.70% in SS1, 9.95 and 9.03% in SS2. Furthermore, there was no clear distinction between the MOT levels between SS1 and SS2. According to Junqueira *et al.* (2018), the domestic effluent can cause the excess of organic matter in waters, consisting of an important fact for evaluation and the use of improvement techniques capable of identifying the integrity of rivers.

On the other hand, SS2 obtained contents of fine sediments (silt and clay) considerably higher than SS1, in which the vegetation cover in its surroundings contributes to a smaller contribution of fines. These results differ from the observation made by Barcellos *et al.* (2016), who stated that fine particles are associated to a larger surface area of the sediment, which allows a greater accumulation of organic matter, because it is adsorbed by finer sediments. However, it must be considered that the entry of MOT in the system may have occurred by natural processes, especially in the rainy season (winter) due to the carrying of organic matter from the vegetation in SS1.

When comparing the rainfall seasons, an increase in clay contents in winter was seen when compared to summer in all respective sampling sites and their depths. The most expressive values of clay in winter possibly occurred due to the period's rainfall, causing a greater runoff and carrying fine particles to the riverbed.

This result is similar to those obtained by Resende, Craveiro and Pereira (2016) in sediments from stretches of the river Capibaribe, where the predominance of fine particles was observed, and the authors related this fact to the influence of the rainy season.

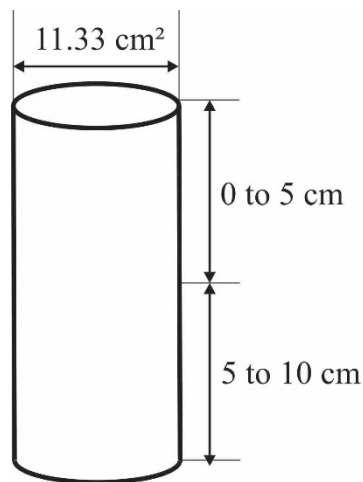


Figure 5 – Corer sampler used in sampling of meiofauna and sediment.

Regarding the selection degree of samples, this degree is a statistical parameter of dispersion classified from the standard deviation (σ) (FOLK; WARD, 1957). Given the above, the smaller the standard deviation the better the sediment that will be selected, that is, the grains will have sizes with less dispersion. Only one sample was classified as poorly selected, with all the others being very poorly selected. Samples

predominantly indicated dispersion of their granulometric values, with the size of their grains varying expressively, with very large and very small grains distributed throughout the sedimentary matrix. This fact contributes to a lower hydraulic conductivity in the bed, considering that the empty spaces between the larger grains are filled by grains of smaller diameters.

Table 1 – Granulometric analyses of sediments collected in Beberibe river (PE) during summer (December 21st, 2018) and winter (July 27th, 2018) periods in SS1 (7°59,340 'S 34°54,964'W) and SS2 (7°59,776 'S 34°54,415'W).

Point and Depth	Parameters in summer period						
	% Gravel	% Sand	% Silt	% Clay	% TOM	Selection degree	Classification
SS1 0-5 cm	2.03	81.13	9.14	7.70	1.67	VPS	Thin sand
SS1 5-10 cm	3.8	79.40	4.04	12.77	1.56	VPS	Thin sand
SS2 0-5 cm	3.08	53.55	11.88	31.49	4.53	VPS	Thick silt
SS2 5-10 cm	3.31	71.72	12.14	12.83	5.08	VPS	Very thin sand
Point and Depth	Parameters in winter period						
	% Gravel	% Sand	% Silt	% Clay	% TOM	Selection degree	Classification
SS1 0-5 cm	1.87	35.97	38.36	23.81	11.44	VPS	Medium silt
SS1 5-10 cm	3.58	41.26	34.86	20.30	11.70	VPS	Thick silt
SS2 0-5 cm	0.09	17.29	25.40	57.22	9.95	VPS	Thin silt
SS2 5-10 cm	0.03	14.86	45.09	40.02	9.03	PS	Thin silt

TOM: total organic matter; VPS: very poorly selected; PS: poorly selected.

Table 2 – Total abundance of meiofauna collected in Beberibe river (PE) during summer (December 21st, 2018) and winter (July 27th, 2018) periods in SS1 (7°59,340 'S 34°54,964'W) and SS2 (7°59,776 'S 34°54,415'W).

		Summer	Winter	Total
Sampling Site 1	Nematoda	68	108	176
	Annelida	83	58	141
	Rotifera	8	19	27
	Others	2	3	5
	Subtotal	161	188	349
Sampling Site 2	Nematoda	142	200	342
	Annelida	120	125	245
	Rotifera	0	31	31
	Others	4	11	15
	Subtotal	266	367	633
	Total	427	555	982

Hyporheic meiofauna

In total, 982 individuals were counted: 427 during summer and 555 during winter. The highest percentage of individuals was from group Nematoda (53%), followed by Annelida (39%), Rotifera (6%), and others (2%). Thus, taxonomic diversity was very low, in which 92% of the total abundance was concentrated in just two taxa. The other organisms found were mostly insects and amphipod larvae. Table 2 shows a summary of the abundance of phyla found.

Table 3 shows the difference in organism abundance between periods (summer and winter) compared to different depths (0-5 and 5-10 cm, respectively).

The results of PERMANOVA showed that there were significant differences between the sampling site factor (Pseudo-F = 13.547; $p < 0.05$) and the period factor (Pseudo-F = 13.547; $p < 0.05$). However, no significant difference was detected for the depth factor (Pseudo-F = 10.161; $p > 0.05$). In addition, significant differences were also observed in the interaction between the point and period factors (Pseudo-F = 7.255; $p < 0.05$).

Figures 6 and 7 show the MDS graphical representations for better visualization of the clusters with greater similarity. The figures present the MDS for the factors that had a significant difference: analyzed points and time periods.

These MDS representations presented two distinct clusters in Figures 6 and 7, respectively for sites SS1 and SS2 and for the summer and winter periods, validating the significant differences previously found with PERMANOVA. Variations in the values of parameters such as rainfall, sediment content, organic matter, and hydrodynamics were important for these differences.

The abundance in SS2 was higher than SS1, even though it is a totally degraded site in relation to the organic supply, greater abundance was observed when compared to the other less impacted site. Chemical pollution, due to domestic waste, can cause eutrophication of the surface water source, contributing to the resistance of several individuals to this pollution, although the taxonomic diversity is less.

In view of this, the organic enrichment caused by the greater potential sanitation deficit in the SS2 area is likely to also increase the density of meiofauna organisms. However, if the organic enrichment continues, the density of the organisms may decrease gradually or until the group disappears completely, a fact known as the “enrichment paradox” (TOWNSEND; BEGON; HARPER, 2009; RANA *et al.*, 2013), caused by a subsequent decrease in oxygen dissolved in water (FOTI *et al.*, 2014).

During the winter period, rainfall enriches the environment, and, according to Dalto and Albuquerque (2000), organic matter increases the temporal variability of meiofauna with this enrichment. The same occurred in the present study, in which a greater abundance and quantity of MOT was obtained in the rainy season.

Probably, the greater abundance of meiofauna in winter was due to the contribution of total organic matter (MOT), which, as shown in Table 1, presented the highest levels in this period. Organic matter can be obtained with different forms and anthropogenic sources (BUENO *et al.*, 2018), and even changes in sediments as a deposition environment can increase the contribution of MOT (OLIVEIRA *et al.*, 2014; XAVIER *et al.*, 2016). The seasonal rainfall variation influences the distribution of meiofauna organisms: rainfall can enrich the benthic environment with its organic contribution, increasing the availability of food (DALTO; ALBUQUERQUE, 2000; GHOSH; MANDAL; CHATTERJEE, 2018), including driving diffuse pollutants present in effluent networks and rainwater drainage to water bodies (CAMELO, 2019).

Thus, the statistical differences observed between a more degraded site and another site in a preserved area, and the influence of the rainy season with processes of sedimentation and organic matter input by washing urban drainage devices show that domestic effluent is the main source of organic matter in Beberibe river, which can lead to different behaviors in the meiofaunistic community in such river.

This great influence of domestic effluents was also observed in studies of meiofauna in the most diverse habitats, such as in estuaries

Table 3 – Abundance of meiofaunistic organisms collected by stratification at Sampling Site 1 and Sampling Site 2 during summer and winter.

		Summer	Winter	Total
SS1	0–5 cm	117	82	199
	5–10 cm	64	106	170
	Subtotal	181	188	369
SS2	0–5 cm	141	145	286
	5–10 cm	105	222	327
	Subtotal	246	367	613
	Total	427	555	982

(VANAVERBEKE *et al.*, 2003; FRASCHETTI *et al.*, 2006) and in rivers (HEWITT; MUDGE, 2004; VERAS *et al.*, 2018).

Despite not indicating significant differences for the depth factor alone, PERMANOVA indicated that there were significant differences in the interaction between the period and depth factors (Pseudo-F = 7.255; $p < 0.05$). The Pair-wise a posteriori test helped to better understand these differences and, gathering the information generated from the representation in MDS and relating them to Table 3, the abundance was more concentrated in the superficial layers (0-5 cm) with few organisms in the 5-10 cm layers during summer. This result is convergent with the vertical distribution found in other studies on meiofauna (DALTO; ALBUQUERQUE, 2000; HUANG *et al.*, 2014; FREITAS *et al.*, 2019).

On the other hand, during winter, this vertical distribution occurred so that the organisms were more distributed in the 5-10 cm layer, with great dispersion and few organisms in the superficial layers. This fact is possibly related to the rains in the winter period, which, as previously seen, can redistribute the organisms in the sedimentary matrix and the water column.

From this calculation of meiofaunistic density (D), SS1 obtained an average density of 87.82 ind./10 cm² in the 0-5 cm layer, whereas the average density was of 75.02 ind./10 cm² in the 5-10 cm layer.

Authors such as Kotwicki *et al.* (2005) and Giere (2009) identified the decrease in meiofaunistic density according to depth and, in the case of limnic environments, Albuquerque (2015) and Freitas (2018) also observed this distribution of organisms by stratification, that is, the decrease of these with depth. For SS2, the average density obtained was 126.20 ind./10 cm² in the most superficial layer studied, and 144.33 ind./10 cm² in the deepest layer.

As for the fact of a lower density of organisms on the surface during winter, this may have occurred because of a higher flow in the rainy season, as it is known that hydrodynamics can influence the structure of different benthic communities (FREITAS *et al.*, 2019). The rainiest period may have caused the meiofaunistic redistribution of the most superficial layers due to sedimentation. The increase in hydrodynamics in the rainy season can be a determining factor in the concentration of organisms in the most superficial sedimentary layer, which may lead to a decrease in them, as was the case in the present study and other studies previously carried out in hyporheic environments (VERAS *et al.*, 2018; FREITAS *et al.*, 2019).

Thus, the migration of organisms from more superficial layers of the sediment to deeper layers (5-10 cm) may have occurred by resus-

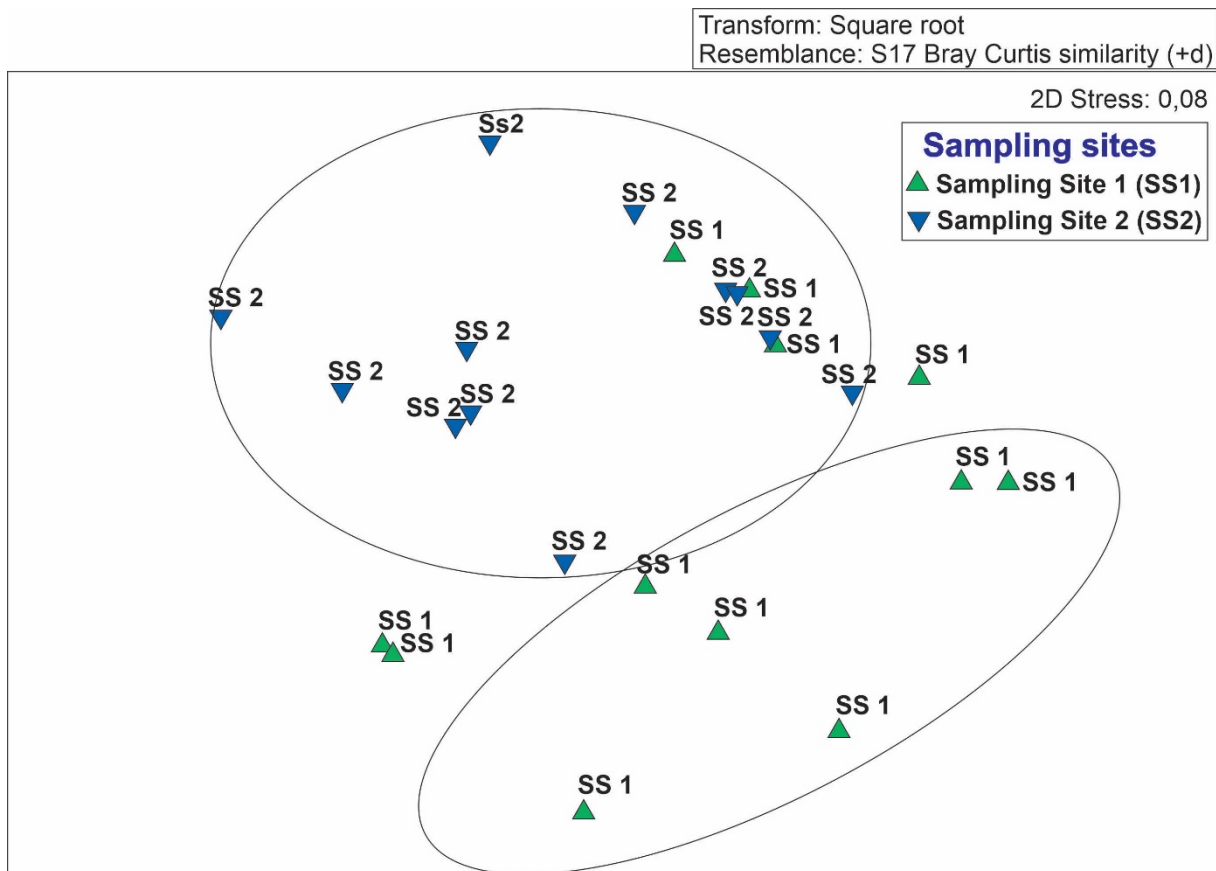


Figure 6 – Representation in MDS of the meiofaunistic structure related to the Sampling Site Factor (SS1 and SS2) during the seasons (winter and summer).

pending them to the water column, due to the hydrodynamics of the system being greater in the rainy season.

This influence was observed not only in the present study in a hyporheic environment, but also in studies carried out in estuarine environments in Brazil, such as in Porto de Galinhas City, Pernambuco State, by Maranhão (2003), and in the Biological Reserve of Lago Piratuba, Amapá State, by Venekey, Melo and Rosa Filho (2019), in which factors such as resuspension and hydrodynamics affected the pattern of the vertical distribution of the studied organisms.

Conclusions

This study encompassed several fields of knowledge. In addition to the middlebentology, data related to sedimentology (granulometry and sedimentary organic matter), rainfall and biostatistics were collected. This interdisciplinary approach is essential for the study of hyporheic meiofauna.

A low taxonomic diversity was found, in which 92% of the organisms found to belong to only two taxa: Nematoda and Annelida. With statistical analysis using PERMANOVA, there were significant differences in the structure of the meiofauna community regarding the

factors sampling site (location) and period (time). Meiofaunistic abundance was greater in the most qualitatively degraded site, located in a densely urbanized area. From the low diversity found, the higher content of organic matter obtained at this site and the local socio-environmental characteristics, it was concluded that the main responsible factor for the characterization of community is the organic contribution through domestic effluents.

In addition, the statistical differences between summer and winter periods also have rainfall as an explanatory variable. Rainfalls act in the washing of the urban drainage systems, which in low-income communities in Brazil commonly function as mixed systems, thus transporting domestic effluents. This explains the increase in the organic supply in spring during the rainy season and its consequent influence on the meiofauna community.

However, it is important to infer that the increase in organic matter input can cause the increase in the density of certain taxonomic groups. Oxygen may not be enough for all organisms after this initial populational growth, later causing a dramatical reduction in population. This process is called the “enrichment paradox” (CRANFORD; BRAGER; WONG, 2017).

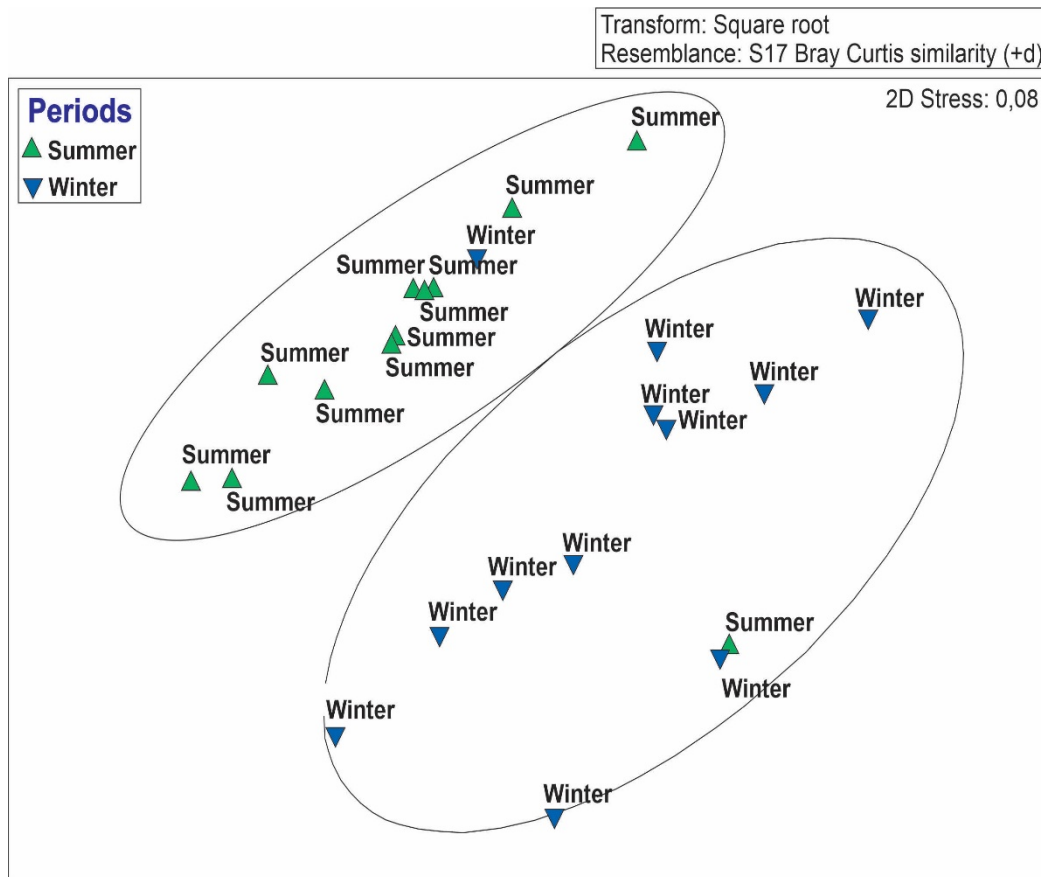


Figure 7 – Representation in MDS of the meiofaunistic structure for sampling sites (SS1 and SS2) relating to the Period Factor (winter and summer).

As to granulometry, the relation between a larger amount of fine sediments and the abundance of meiofauna was verified, since these sediments are more likely to adsorb organic matter.

The summer period had more abundance of meiofauna in the upper layer (0-5cm), which was convergent with several studies, since the more superficial layer has a higher level of dissolved oxygen. On the other hand, the opposite occurred in winter. This can be explained by the greater hydrodynamics that occurs during the rainy season, which causes a disturbance in the superficial layers, causing some of these organisms to be resuspended to the water column, and others to seek refuge in the deeper layers (migration between layers).

Therefore, the characterization of meiofauna in its interdisciplinary aspects in Beberibe river is needed for a better understanding of this environment, including for the understanding of the biogeochemical

processes that occur in the hyporheic zone. However, this study should be continued, and expand further studies in freshwater environments within an urban and tropical context are encouraged, in view of the complexity of the relationships between environmental conditions in the hyporheic zone.

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Contribution of authors:

Santos, S.N.: Formal analysis, Conceptualization, Methodology, Data curation, Software. Freitas, J.B.A.: Formal analysis, Conceptualization, Methodology, Writing – First Redaction. Cabral, J.J.S.P.: Formal analysis, Conceptualization, Methodology, Review & editing, Obtaining Financing. Paiva, A.L.R.: Formal analysis, Conceptualization, Methodology, Writing – First Redaction. Clemente, C.C.C.: Formal analysis, Conceptualization, Methodology, Data curation, Software.

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