Limnological Characterization of Gravataí River, Rio Grande do Sul State, Brazil.

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ABSTRACT: Limnological Characterization of Gravataí River, Rio Grande do Sul State, Brazil. A limnological study of Gravataí River, RS, Brazil (29° 45' - 30° 12'S and 50° 27'- 51° 12'W) was carried out in order to characterize the spatial and temporal changes of physical, chemical, climatic and microbiological variables along its course attempting to explain its functioning as a lotic system, in terms of current theories. A set of meteorological, hydrological, physical, chemical and microbiological variables were monitored each month at six selected locations along the Gravataí River, between September 2000 and August 2002. The variables analyzed were: water temperature, pH, transparency, conductivity, OD, BOD-5, COD, total nitrogen, organic nitrogen, orthophosphate, total phosphorus, chloride and faecal coliforms. Air temperature, rainfall, and river discharge data were also recorded. The results showed that there is a continuum from the headwater to the middle course of the river, characterized by a gradual decrease in dissolved oxygen concentration and rising turbidity, nutrients, conductivity, chlorides, and biochemical oxygen demand. A discontinuity in the gradient, caused by the input of large amounts of organic matter was found, where many variables increased or decreased abruptly with changes of one order of magnitude or more, characterizing two distinct portions of Gravataí River: a better-preserved upper and middle portion conforming with the river continuum model, and the polluted lower portion, a discontinuity imposed by the heavy input of organic wastes. A comparison of the present limnological conditions in Gravataí River with information available from earlier years reveals that significant changes have occurred over the last decade, indicating an accelerated process of eutrophication.
Key- words: Gravataí River, river ecology, river pollution, eutrophication.

RESUMO: Caracterização Limnológica do Rio Gravataí, Rio Grande do Sul, Brasil. Variações espaciais e temporais das características físicas, químicas e microbiológicas no rio Gravataí, RS (29° 45' a 30° 12'S e l50° 27' a 51° 12'W), foram analisadas visando entender seu funcionamento, em decorrência das alterações ocorrentes em sua bacia. Variáveis climáticas, hidrológicas e características físicas e químicas da água foram avaliadas mensalmente, em seis estações de amostragem selecionadas ao longo do rio, da nascente à foz, no período de setembro de 2000 a agosto de 2002. As variáveis avaliadas foram: temperatura da água, pH, transparência, condutividade, OD, DBO_5, DQO, nitrogênio total, nitrogênio orgânico, ortofosfato, fósforo total, cloretos e coliformes fecais, temperatura do ar, precipitação e vazão. Os resultados evidenciaram que da nascente até o trecho médio do rio há um contínuo, caracterizado pelas diminuições graduais nas concentrações de OD, e aumento da turbidez, da condutividade, dos cloretos e da DBO. Evidencia-se, no entanto uma descontinuidade no gradiente, ocasionada por elevada entrada de material orgânico, em que os valores das diversas variáveis aumentam ou decrescem bruscamente com variações de uma ou mais ordens de magnitude. Foram caracterizadas duas porções distintas do rio Gravataí. A primeira, formada pelo trecho superior-médio do rio, mais preservada, e que segue o modelo do contínuo fluvial e a outra, no trecho inferior do rio formada por uma descontinuidade imposta pela entrada de despejos orgânicos de origem antropogênica. A comparação das características limnológicas atuais do rio Gravataí com

as informações existentes de anos anteriores, revela a ocorrência de grandes mudanças na última década que caracterizam um acelerado processo de eutrofização.

Palavras-chave: rio Gravataí, ecologia de rios, poluição de rios, eutrofização.

Introduction

Freshwaters have suffered great changes in its physical, chemical, and biological characteristics all over the world, as a result of antropic alterations in hydrographic basins. Some of these changes come from direct intervention, as in the case of dams, reservoirs, and canals, however the largest changes come from the inadequate land use, increasing the amounts of suspended matter in the water, both dissolved and particulate. Non-point sources as the agricultural runoff and point sources from industrial and domestic effluents considerably alter the water quality in most populated and industrialized regions.

Rivers are very individualized ecosystems, each with its own characteristics, mainly influenced by climatic, geomorphological and hydrological factors occurring and interacting within the hydrographic basin. Other factors vary temporally and between heterogeneous spaces differing from basin to basin, or from region to region, depending on anthropogenic interferences (Neves, 2002).

According to Neiff (1990), rivers behave like systems in permanent non-equilibrium, where spatial and temporal variation is a complex function of the energy and material entering and leaving distinct locations of the hydrographic basin, and also of interactions determining population abundances and distributions. After the introduction of the River Continuum Concept (RCC) by Vannote et al. (1980), there was a renewed interest in the study of rivers. Although interesting, the RCC does not apply to most tropical rivers, as pointed out by Junk et al. (1989), who found that flood pulses are more important to the functioning of low-land tropical rivers, as the Amazon and Paraná-Paraguai basins.

In the present study the longitudinal and seasonal changes of chemical, physical, and microbiological variables, along the course of the Gravataí River, were analyzed aiming to provide a limnological characterization of this important water resource in the Guaíba hydrographic basin.

Material and methods

The climatic data was provided by the Instituto de Pesquisas Agronômicas do Rio Grande do Sul (IPAGRO) (Rio Grande Do Sul Agricultural Research Institute), having been recorded at the nearest meteorological station to field site 4 (29º 57' 16"S and 51º 07'37" W), on the Gravataí River.

The physical, chemical, and microbiological data were obtained by the Fundação Estadual do Meio Ambiente do Estado do Rio Grande do Sul (FEPAM) (Rio Grande do Sul State Foundation for the Environment) and the Departamento Municipal de Água e Esgoto (DMAE) (Municipal Water and Sewage Department), which have been conducting monthly monitoring of the water quality in this river, as past of the Pró-Guaíba project. Data was collected, on a single day each month, between September 2000 and August 2002, at six sampling sites along the Gravataí River, marked in Fig. 1.

The water and air temperature, depth of water at sampling site, pH, transparency, dissolved oxygen (DO) and conductivity were measured in situ and water was collected and transferred immediately to glass and polyethylene flasks, for turbidity, biochemical oxygen demand (measured after 5 days incubation (BOD_5)); chemical oxygen demand (COD), total nitrogen, organic nitrogen, ammoniacal nitrogen, orthophosphate, total phosphate, chloride and faecal coliform counts. Samples were kept in ice, transported to the laboratory and analysed immediately on arrival. The techniques used in both sampling and analysis followed the procedures described in APHA (1992).

Data Analysis

Mean values of each variable in each season, between September 2000 and August 2002, were subjected to cluster analysis. The following environmental variables were analysed: water and air temperature, conductivity, turbidity, pH, dissolved oxygen (DO), biochemical oxygen demand measured after 5 days (BOD_5), chemical oxygen demand (COD), ammoniacal nitrogen, organic nitrogen, orthophosphate, total phosphate, chloride, and faecal coliforms.

Discriminant and Cluster Analysis were carried out on the transformed data with the program Pcord 4.0 using the similarity matrix of Euclidean distances. According to Digby & Kepton (1987), the Euclidean distance may be a poor measure of similarity when the values range over many decades, but this effect can be reduced by applying a logarithmic data transformation before the distance calculations, as performed here.

The results obtained in both analyses were represented graphically. Data for discriminant analysis were standardized using the squared Mahalanobis's distances between groups.

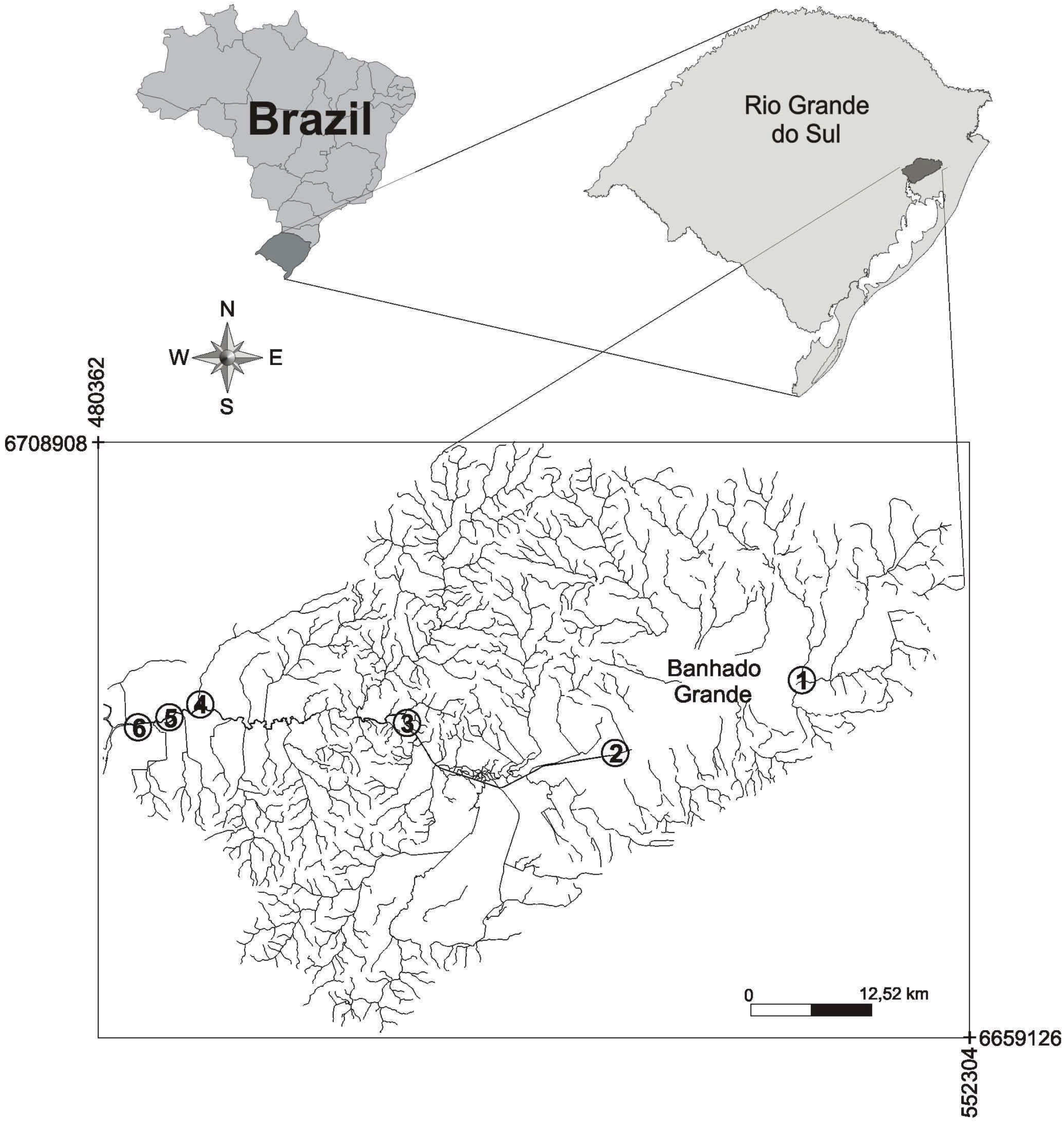


Figure 1: Location of the hydrographic Basin of the Gravataí River, in the state of Rio Grande do Sul, Brazil, and the six sampling stations along the Gravataí River. 1 = Chico Lomã Stream, District of Santo Antônio da Patrulha; 2 = Juca Barcelos' Farm, District of Glorinha; 3 = Passo dos Negros bathing pool, of Gravataí town; 4 = Pumping station, city of Porto Alegre/Canoas; 5 = Areia Stream, city of Porto Alegre/Canoas; 6 = Gravataí River mouth, city of Porto Alegre.

Results

Climatic Variables

Monthly rainfall between January 2000 and October 2002 is represented in Fig. 2. The precipitation registered in January 2001 (298.9 mm) represents a large inflow of water into the system.

During the winter precipitation was low, averaging 88.5 mm, and the highest reported value was 146.2 mm, in July. Annual precipitation was 1,323.2 mm in the year 2000; 1,536.3 mm in 2001 and 1,496.8 mm in 2002.

Minimum and maximum monthly temperatures (°C) variation between January 2000 and October 2002 are presented in Fig. 3. The highest mean maximum temperature registered was 33.6 °C in March 2002 and the lowest was 5.1 °C in July 2000.

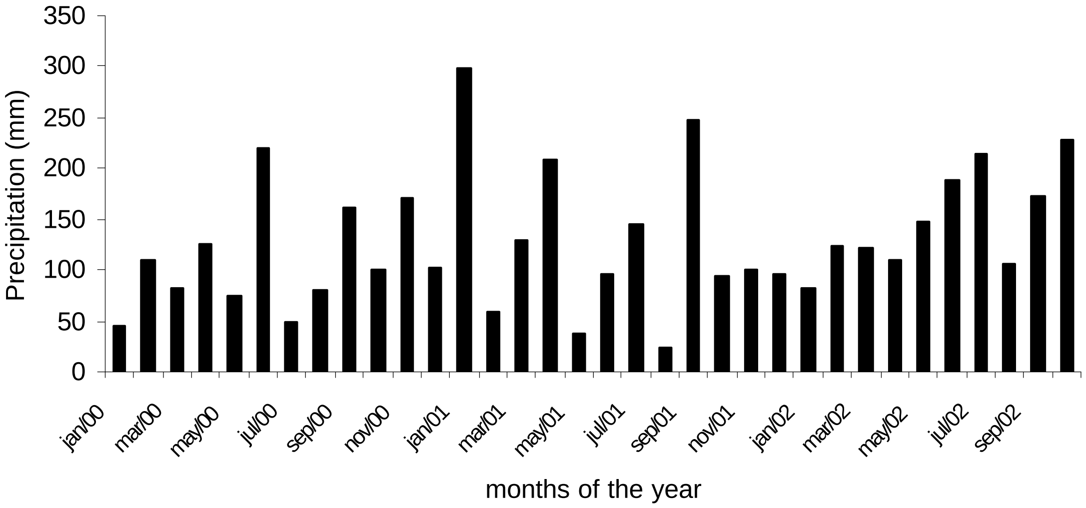


Figure 2: The monthly variation of precipitation (mm) during the period January 2000 - October 2002. Source: Instituto de Pesquisas Agronômicas do Rio Grande do Sul (IPAGRO – the Rio Grande do Sul Agricultural Research Institute), located in Gravataí River basin, Porto Alegre, RS.

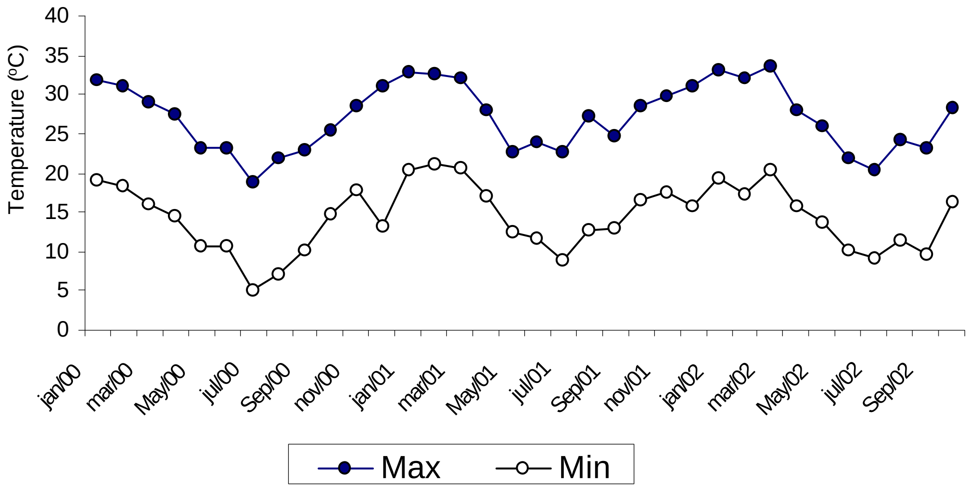


Figure 3: Monthly maximum and minimum temperatures (°C) from January 2000 to October 2002. Source: Instituto de Pesquisas Agronômicas do Rio Grande do Sul (IPAGRO) (The Rio Grande do Sul Agricultural Research Institute) station located in Gravataí River basin, Porto Alegre, RS.

Environmental Variables

Spatial and seasonal changes of physical, chemical and microbiological variables in the water along the course of the river are presented in Figures 4 to 8. Water temperatures varied from 27.5 ± 0.52°C during the summer of 2002 and the summer of 2002 16.7 ± 0.65°C) in the winter of 2002, both in the lower stretch of the river (Figs.4A and 4B). Water turbidity was variable and generally high in both portions of the river. There is a seasonal pattern of variation with higher turbidities in the spring and summer and a lower levels during fall and winter, in both analysed years (Figs 4C and 4D).

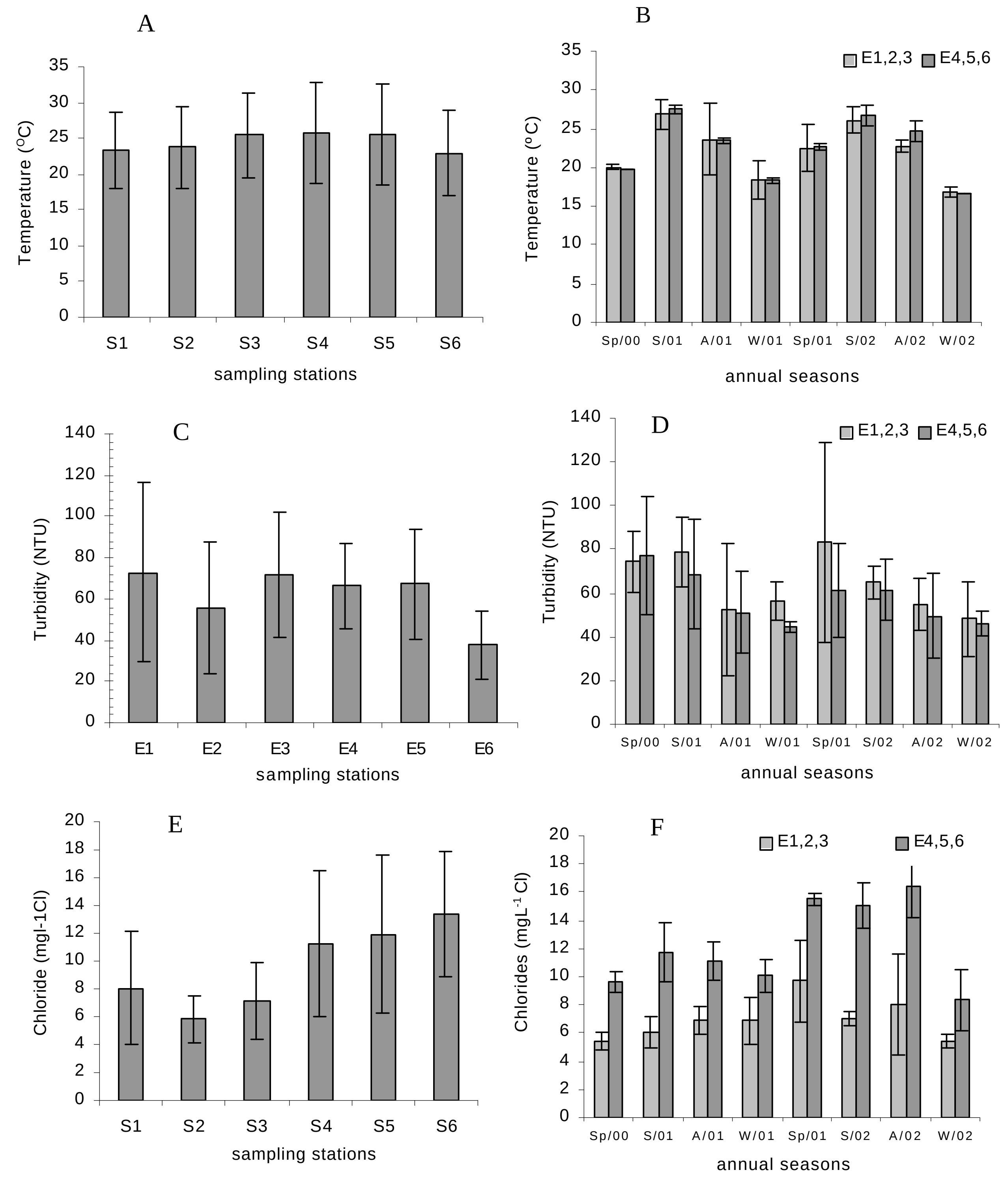


Figure 4: Values (mean ± standard deviation (SD)) of the measured physical and chemical variables of temperature (°C), turbidity (NTU) and chloride (mg L^{-1} Cl), at each sampling station (S1=station 1, S2= station2, S3=station3, S4=station 4, S5=station 5, S6= station 6) and the seasons (S1,2,3 = mean of stations 1,2,3; S4,5,6= mean of stations 4,5,6; Sp=spring, S=summer, A=autumn, W=winter; 00=year 2000, 01=2001, 02=2002) in the period of September 2000 to August 2002, for six sampling stations along the Gravataí River, State of Rio Grande do Sul, Brazil.

Rising concentration gradients were observed from riverhead to the mouth for chloride (Fig. 4E), conductivity (Fig. 5C), BOD (Fig. 6C) and all nutrients (Figs.7 A, 7C, 7E; 8A and 8C). For all the quantified nutrients, the concentrations in the lower river stretch were from three to five times higher than those reported in the upper-middle river stretch.

As for the seasonal variation, in general, all the nutrient concentrations during the spring and winter were lower than those of in summer and fall (Figs 4F; 5D; 6D; 7B, 7D, 7F; 8B and 8D).

A large degree of homogeneity was observed throughout the Gravataí River regarding the chemical oxygen demand (COD), (Fig. 6E).

The density of faecal coliforms was quantified as a biological indicator of water quality from the sanitary point of view. The spatial analysis reveals that the highest mean faecal coliform values were found at station 6, 175,120 ± 186,047.5 MPN/100mL, while the lowest values were reported at station 2, 270 ± 206.9 MPN/100mL (Fig. 8).

During the two years sampled, the highest mean faecal coliform counts were registered in the lower river, while the lowest counts were seen in the upper stretch during the summer of 2002. Two distinct groups were formed by the application of cluster analysis to all the values from the set of analyzed variables. The groups denote a disruption in the gradient: the first part representing the upper-middle stretch of the river, and the other of corresponding to the lower river stretch (Fig.9). All seasons were represented in each group, with no indication of seasonality effect.

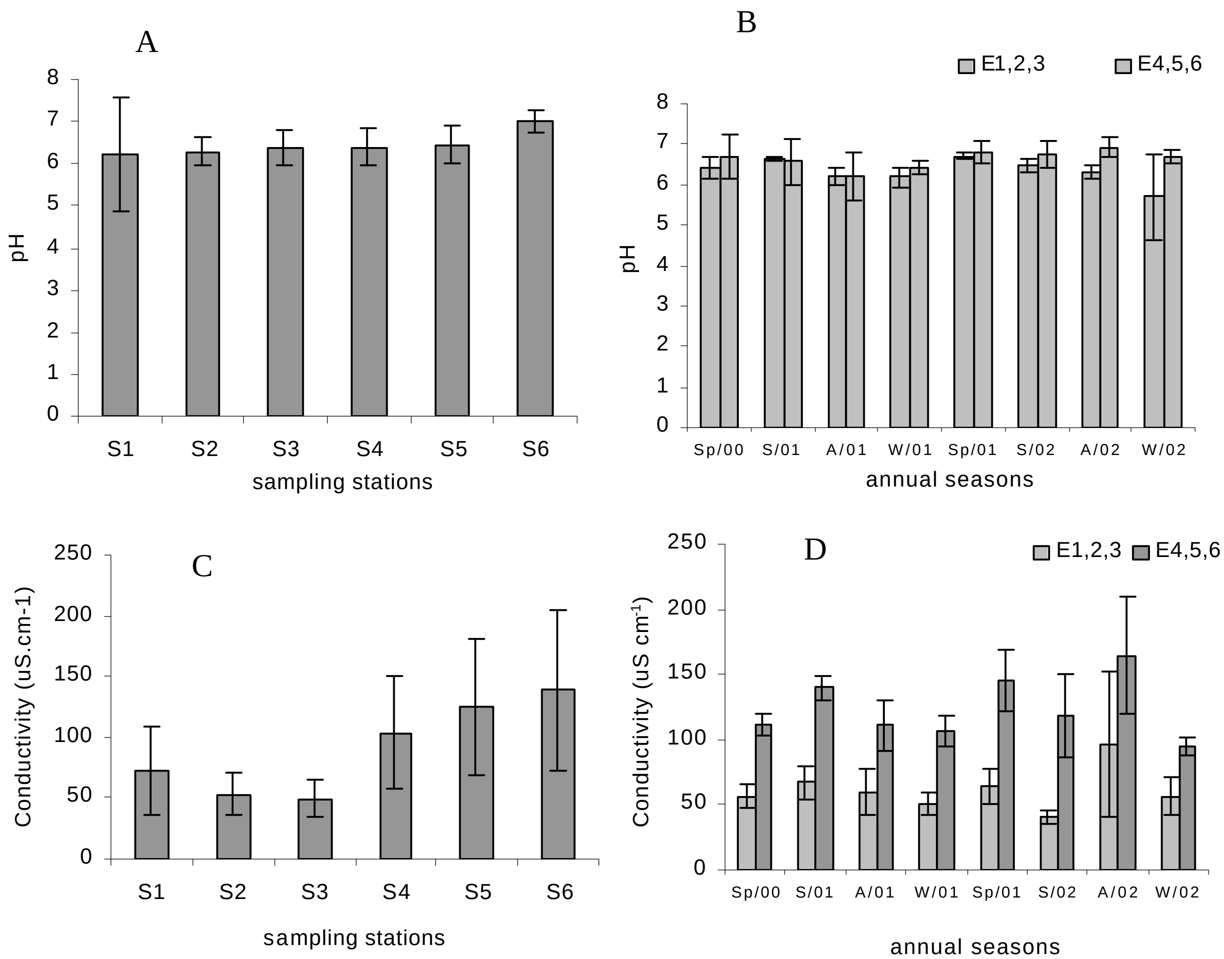


Figure 5: Values (mean ± standard deviation (SD)) of the measured pH and conductivity (mS cm^{-1}) at each sampling station (S1=station 1, S2= station2, S3=station3, S4=station 4, S5=station 5, S6= station 6) and the seasons (S1,2,3 = mean of stations 1,2,3; S4,5,6= mean of stations 4,5,6; Sp=spring, S=summer, A=autumn, W=winter; 00=year 2000, 01=2001, 02=2002) in the period of September 2000 to August 2002, for six sampling stations along the Gravataí River, State of Rio Grande do Sul, Brazil.

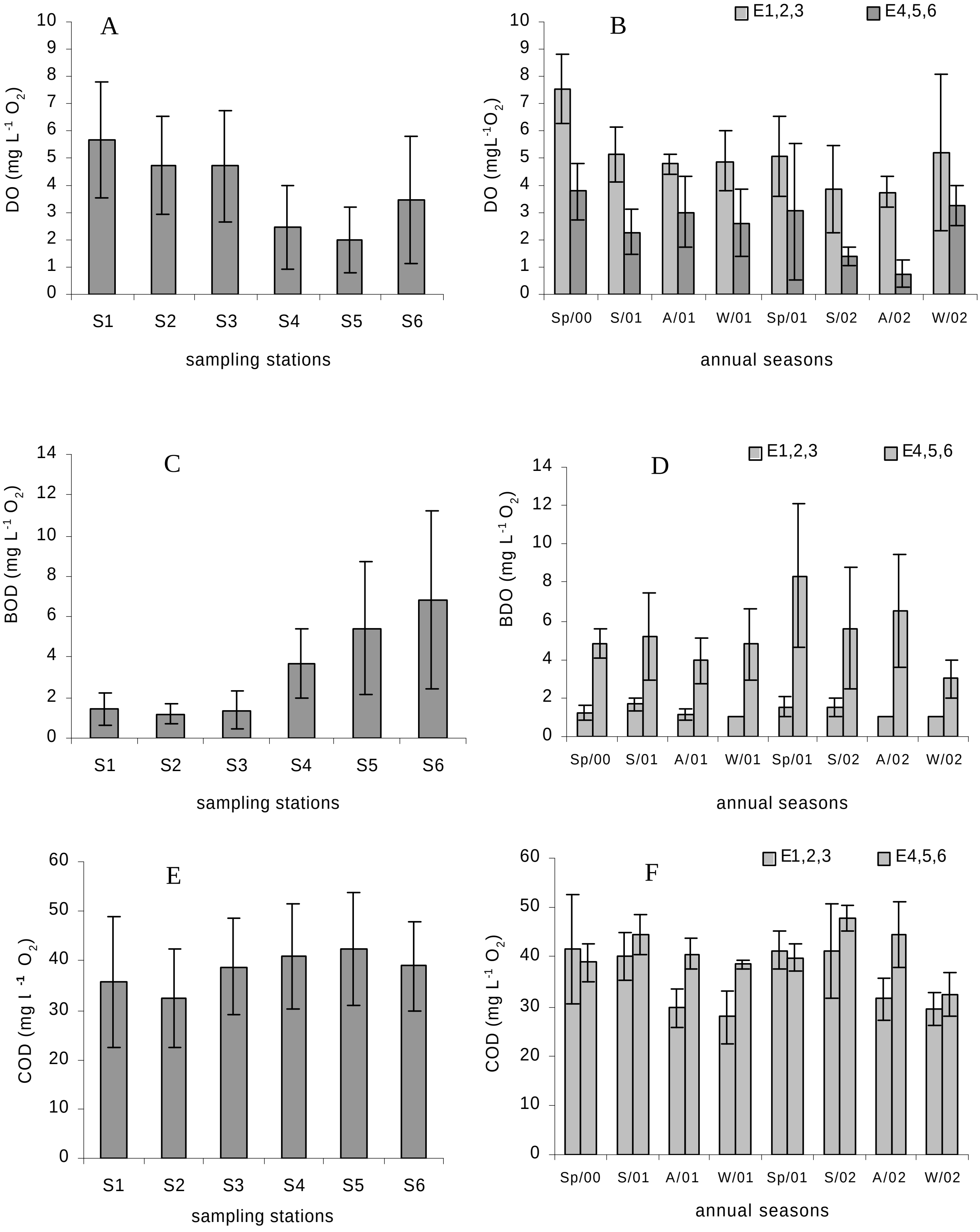


Figure 6: Values (mean ± standard deviation (SD)) of the measured chemical variables of DO, BOD, COD (mg L $^{-1}$ O_2), at each sampling station (S1=station 1, S2= station2, S3=station3, S4=station 4, S5=station 5, S6= station 6) and the seasons (S1,2,3 = mean of stations 1,2,3; S4,5,6= mean of stations 4,5,6; Sp=spring, S=summer, A=autumn, W=winter; 00=year 2000, 01=2001, 02=2002) in the period of September 2000 to August 2002, for six sampling stations along the Gravataí River, State of Rio Grande do Sul, Brazil.

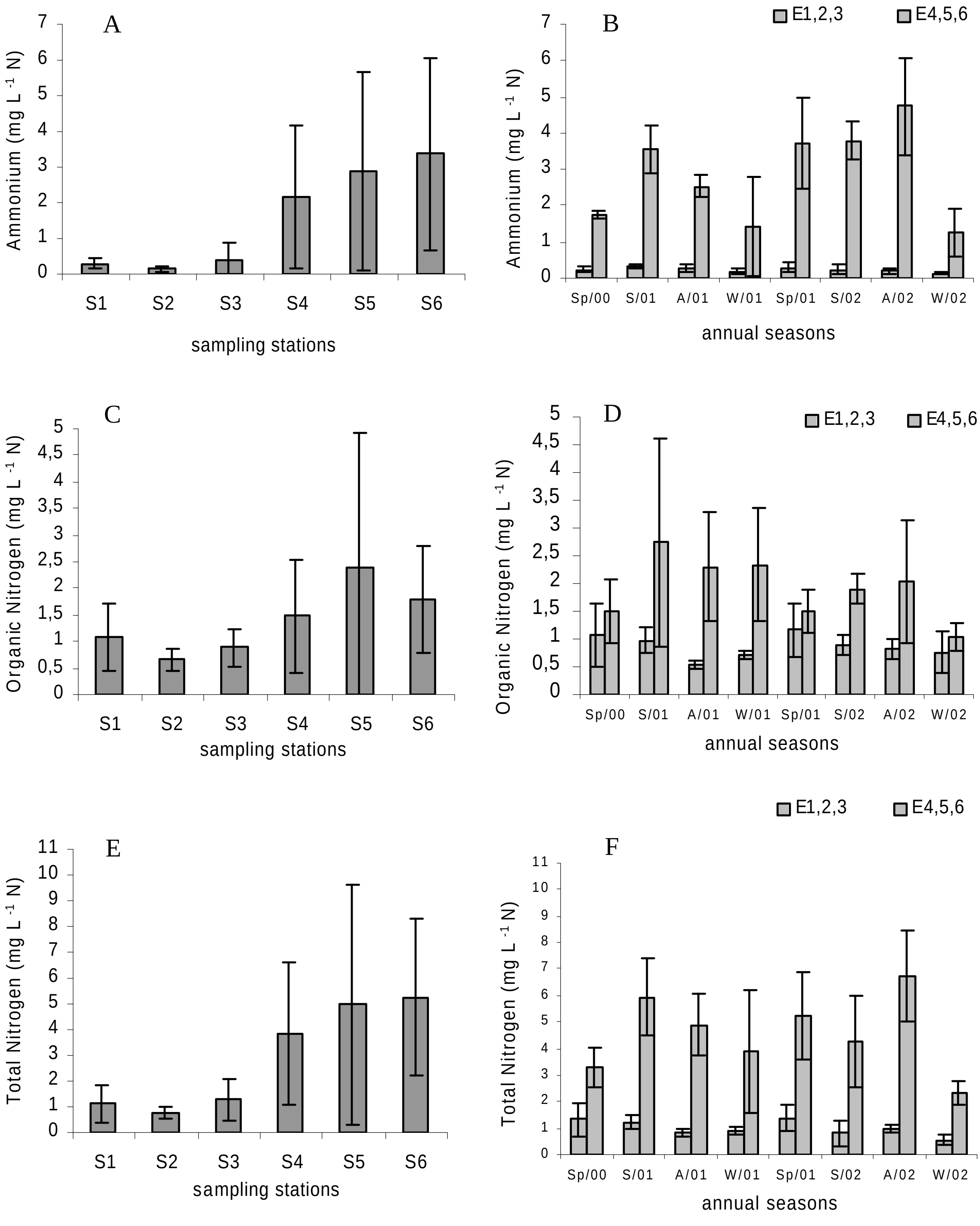


Figure 7: Values (mean ± standard deviation (SD)) of the measured chemical variables of ammonium, organic nitrogen and total nitrogen (mgL^{-1} N), at each sampling station (S1=station 1, S2= station2, S3=station3, S4=station 4, S5=station 5, S6= station 6) and the seasons (S1,2,3 = mean of stations 1,2,3; S4,5,6= mean of stations 4,5,6; Sp=spring, S=summer, A=autumn, W=winter; 00=year 2000, 01=2001, 02=2002) in the period of September 2000 to August 2002, for six sampling stations along the Gravataí River, State of Rio Grande do Sul, Brazil.

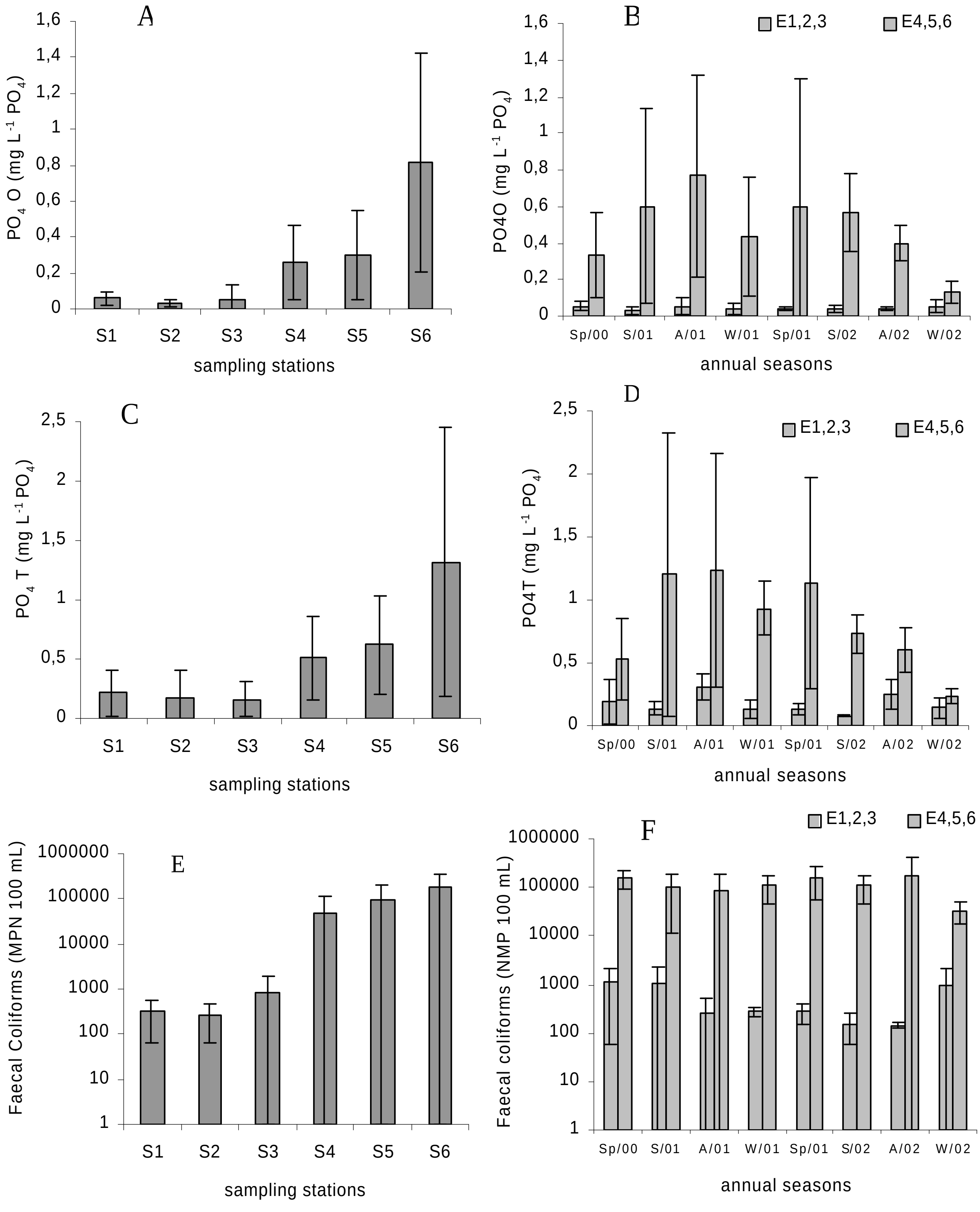


Figure 8: Values (mean ± standard deviation (SD)) of the measured chemical variables PO_4O and PO_4T (mg L^{-1} PO_4) and number of faecal coliforms (MPN 100 mL) at each sampling station (S1=station 1, S2= station2, S3=station3, S4=station 4, S5=station 5, S6= station 6) and the seasons (S1,2,3 = mean of stations 1,2,3; S4,5,6= mean of stations 4,5,6; Sp=spring, S=summer, A=autumn, W=winter; 00=year 2000, 01=2001, 02=2002) in the period of September 2000 to August 2002, for six sampling stations along the Gravataí River, State of Rio Grande do Sul, Brazil.

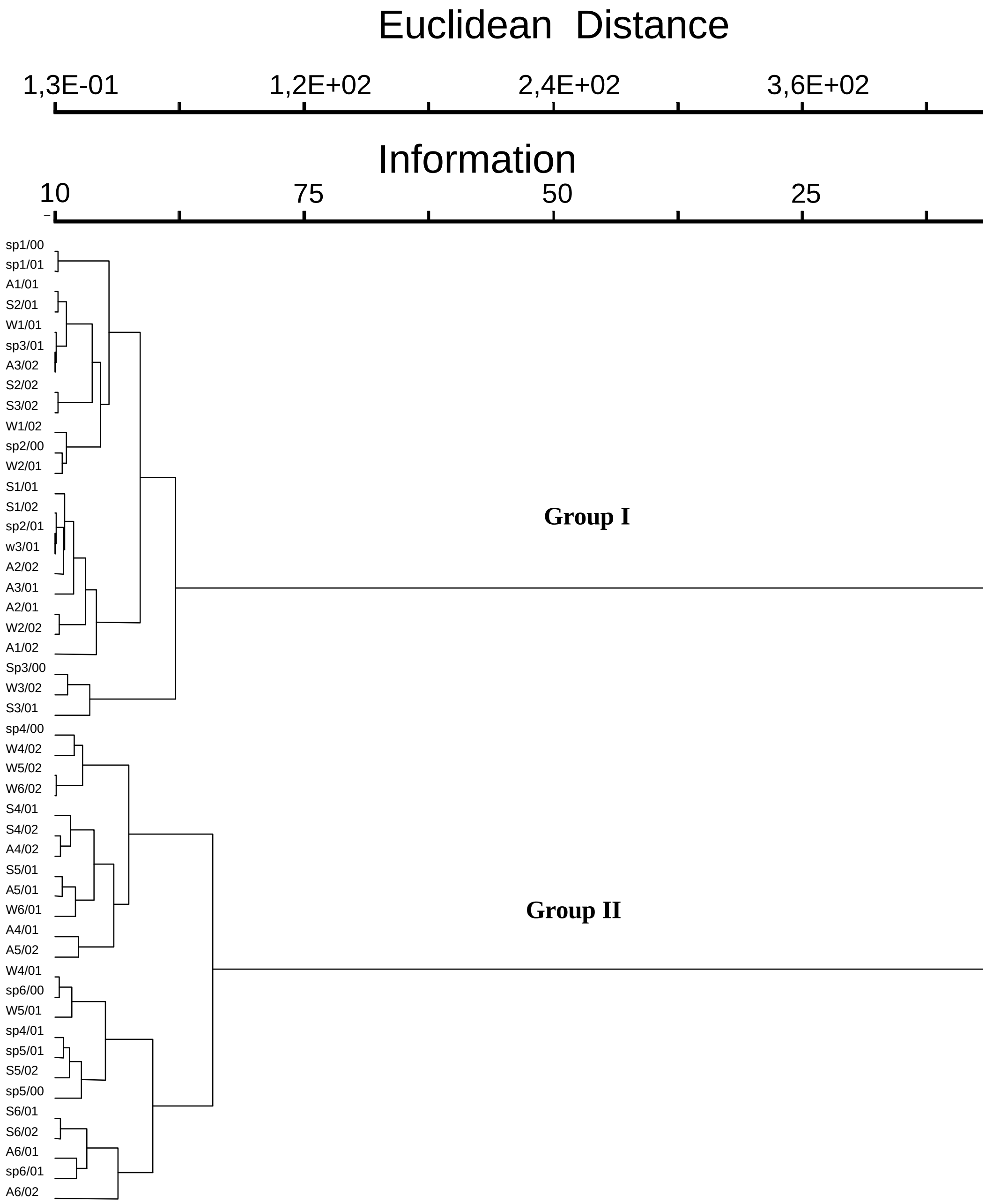
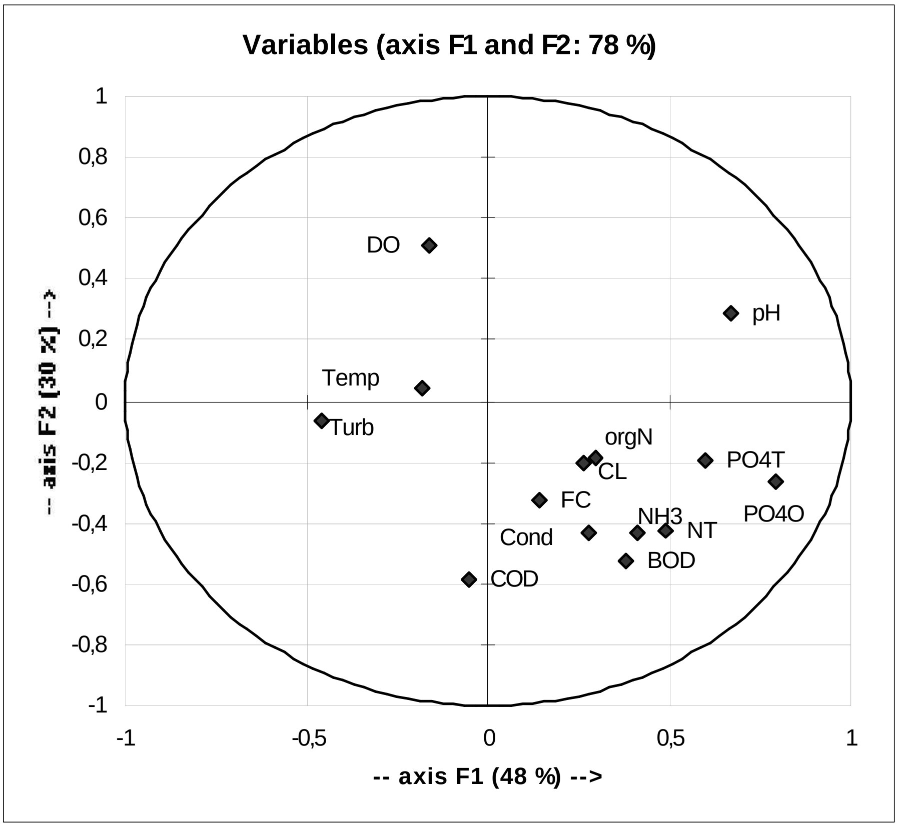


Figure 9: Dendrogram (Euclidean distances) resulting from cluster analysis based on similarities among the physical, chemical, and biological characteristics of six sampled locations along Gravataí River, in the period of September 2000 to August 2002, sampled in eight seasonal periods (sp=Spring, S=Summer, A= autumn, and W=Winter). Numbers 1 to 6 correspond to the sampling stations, ordered from the head to the mouth, and 00, 01 and 02 correspond to the years 2000, 2001, and 2002.

The result of the ordination of all environmental variables by discriminant analysis is presented in Figure 10. Axis 1, explaining 48% of the variability contain the most important vectors on the positive side as evidenced by their eingenvalues (in parenthesis): PO4 (0.79), pH (0.67), total phosphate (0.59), total nitrogen (0.48) and organic nitrogen (0.29) (Fig.2a), representing the increase in organic pollution and eutrophication at the stations 4, 5, and 6 (Fig.2b). Axis 2, explaining 30% of the variability, was positively connected with stations 1, 2 and 3, which were correlated with the high concentrations of dissolved oxygen (0.51). A comparison of data from the present study and those from an earlier period is reported in Table I.

A



B

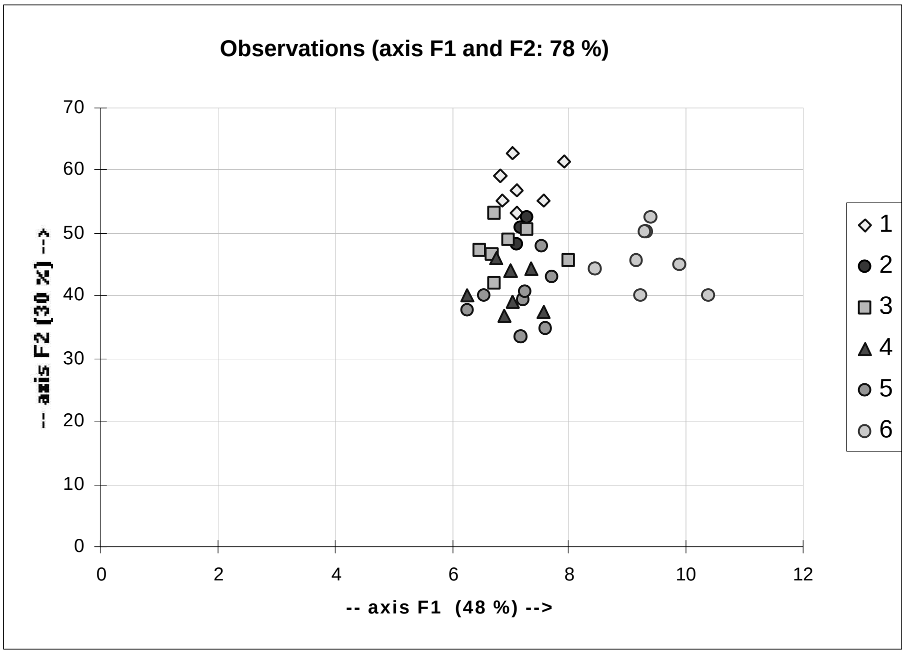


Figure 10: Ordination by Discriminant Analysis of environmental variables (A) and ordination of the sampling stations (S1,S2,S3,S4,S5,S6) according to the environmental variables (B), during the period of September 2000 to August 2002, on the Gravataí River, RS, Brazil.

Table I: Mean value (± standard deviation (sd)) and range of the measured physical, chemical and microbiological variables monitored in the sampling stations (S1, S3, S4 and S6) along the Gravataí River, Rio Grande do Sul State, Brazil, in the period 1992 to 2002. Source: Fundação Estadual de Proteção Ambiental do Rio Grande do Sul. (FEPAM/RS).

Períods	DO mgL-1O2	BOD mgL-1O2	TN mgL-1 N	PO4T mgL-1 PO4	Conductivity mS cm-1	Faecal coliforms MPN/ 100 mL
S1 1992 - 1994	7.22 ± 1.81 4-11	1.89 ± 0.84 1-4	0.95 ± 0.34 0.44-1.62	0.10 ± 0.11 0.0097-0.55	60.61 ± 23.11 34-150	14.863 ± 4398.85 50-5000
1995 - 1998	5.13 ± 1.94 2-9	1.75 ± 0.92 1-5	1.18 ± 0.58 0.65-2.96	0.11 ± 08 0.019-0.44	74.99 ± 39.35 10-250	1023.26 ± 2506.3 40-16000
1999 - 2002	5.80 ± 2.53 1-11	1.74 ± 2.10 1-6	1.29 ± 0.71 0.18-3.0	0.18 ± 0.16 0.025-0.86	91.70 ± 55.92 21-340	606.16 ± 715.93 74-2500
S3 1992 -1994	7.66 ± 1.43 5-11	1.78 ± 1.13 1-5	1.21 ± 1.07 0.49-4,86	0.06 ± 0.05 0.0125 – 0.247	46.90 ± 15.0 30-100	401.81 ± 587.84 23-2200
1995 - 1998	6.30 ± 1.61 2 – 10	1.44 ± 0.91 1 – 6	1.02 ± 0.42 0.22 – 2.71	0.07 ± 0.04 0.0100 – 0.229	57.91 ± 24.31 10 – 160	581.00 ± 1424.23 23 - 9000
1999 - 2002	5.39 ± 2.14 1.9 –10	1.33 ± 0.76 1 – 5	1.20 ± 0.64 0.48 – 4.68	0.13 ± 0.11 0.028 – 0.208	56.12 ± 17.71 12.4 – 94.3	6359.75 ± 36083.09 20 –9700
S4 1992 -1994	5.44 ± 2.49 0.60 – 13.07	3.78 ± 3.81 1-21	3.37 ± 4.55 0.51 – 17.8	0.25 ± 0.17 0.017 – 0.69	91.0 ± 52.23 34 - 200	27912.90 ± 37957.28 1300 - 160000
1995 - 1998	3.878 ± 3.544 0.10 – 20	6.24 ± 10.58 1-19	4.77 ± 4.167 0.93 – 17.8	0.377 ± 0.281 0.077 – 0.916	124.59 ± 92.59 25 – 311	171626.410 ± 374008.4 1300 – 900000
1999 - 2002	2.65 ± 2.30 0.10 – 10.3	5.19 ± 4.26 2 – 18	5.59 ± 5.39 1.07 – 21.6	0.65 ± 0.52 0.160 – 2.32	158.24 ± 124.8 32.2 - 560	151809.76 ± 203507.85 1600 - 860000
S6 1992 -1994	4.59 ± 2.91 0.38 – 11.10	5.59 ± 4.00 2.0 -17	4.78 ± 5.76 0.50 – 19.6	0.43 ± 0.32 0.11 – 1.53	119.06 ± 74.68 45 – 400	66233.33 ± 60856.92 3000 - 170000
1995 - 1998	2.42 ± 2.285 0.0 – 6.90	8.38 ± 7.40 2.00 – 31.0	5.34 ± 3.26 1.32 – 14.8	0.538 ± 0.356 0.14 – 1.42	149.88 ± 87.49 29 - 460	176290.323 ± 220520.021 5000 - 900000
1999 - 2002	3.33 ± 2.32 0.2 – 8.8	6.94 ± 4.42 1.9 - 19	5.42 ± 2.98 1.68 – 11.72	1.36 ± 1.14 0.18 – 4.69	141.28 ± 66.70 94 -297	1880000 ± 188407.51 1900 - 660000

Discussion

The interpretation of the influence of hydrological and climatic variations on limnological characteristics of rivers is rather complex, involving the superposition of spatial and temporal factors. Changes over different time-scales, such as seasonal and inter-annual fluctuations, are superimposed, making the identification of recurrent patterns difficult, except in long-term studies. The data obtained for Gravataí River basin have showed for example, great inter-annual changes regarding the total rainfall between the years of 2000 and 2002, and also changes in the monthly rain distribution. Some months had higher rainfall, like January, April, and September.

In several countries, rivers located near dense human agglomerations or in highly industrialized areas do suffer large alterations in their physical and chemical characteristics, jeopardizing the water quality and representing a significant risk to human health (Sabater et al. 1996; Agatz et al. 1999; Sonnemann et al. 2001).

A comparison of the data in the present study and those reported for an earlier period (Leite et al., 1992/1994) shows that over the last decade there have been significant changes, revealing an accelerated eutrophication of the Gravataí River water in recent times.

One of the most striking limnological changes observed refers to the dissolved oxygen concentration in the water, which suffers a marked decrease in the upper and middle stretch due to oxidative degradation of organic matter. Other very apparent changes were the rise in the concentrations of ions (electrical conductivity) and phosphorus, particularly in the middle and lower stretches, except at the mouth. The almost anaerobic conditions in the site nearest to the disturbance and gradual recovery follow the pattern usually found for many rivers submitted to heavy organic pollution (Margalef, 1983) and well described by Mirande et al. (1999) in the Gastona River, Argentina.

The continuum concept model foresees a gradual rise in conductivity and turbidity from the source to the mouth of a river, due to the gradual loading of fine ionic and particulate material contributed by effluents and surrounding terrestrial ecosystems. The present limnological study shows that Gravataí River thus not conform to the usual river model. The headwater region has a semi-lentic character and a higher nutrient concentration than subsequent stretch, although still somewhat preserved and presenting oligotrophic characteristics.

The statistical analysis confirmed the existence of two distinct portions in the river: The first, comprising the upper and middle stretches, from the headwater until Passo dos Negros where the expected increase in the mineral content and ionic concentrations occurs along the river. The second part comprising the inferior stretch of the river has hypereutrophic characteristics, only comparable with those of highly polluted rivers.

The absence of seasonal variation was striking for some variables like temperature, conductivity and the concentration of nutrients. It appears that the effect of eutrophication is so strong that it masks the seasonal changes. A similar situation was found for the higher portion of Tietê River by Tundisi & Matsumura-Tundisi (1990) due to heavy inputs of domestic and industrial wastes from São Paulo city discharged into the river. Moretto & Nogueira (2003), have also shown striking differences between Lavapés and Capivara Rivers in the Paranapanema River basin related to the land uses and human impacts in the watershed.

At the middle of Gravataí River, between Passo de Negros and Air-base Pumping Station, there is a great change in the water quality caused by discharge of domestic and industrial sewage from the north part of Porto Alegre city. There is noticeable increase in labile organic material, characteristic of residual water dumped in natura, that is also reflected in the BOD values and in faecal coliform numbers which increased by 3 to 50 times. Near the river-mouth, nutrient concentrations and coliform densities become even greater, increasing by about 10 and 100 times, respectively.

Gravataí River is a typical plain river, with a sinuous course, low flow-rate and mean of 5.14 m^3/s (IPH, 2002) resulting in reduced re-aeration and pollutant dilution capacity. The impact of organic pollution by the city of Porto Alegre promotes a severe water quality deterioration, characterizing the so-called serial discontinuity. Chemical and physical parameters and the density of faecal coliforms indicate that the lower part of the river can be classified as eutrophic and polysaprobic with low sanitary quality. Multiple uses of the Gravataí River water are jeopardized in its lower portion and strong remedial action are urgently necessary in order to revert this condition.

Acknowledgements

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