J. Braz. Chem. Soc., Vol. 13, No. 1, 71-77, 2002.
Printed in Brazil - ©2002 Sociedade Brasileira de Química
0103 - 5053 $6.00+0.00

Article

Evaluation of the Siltation of River Taquari, Pantanal, Brazil, through ^{210}Pb Geochronology of Floodplain Lake Sediments

José M. Godoy[a,b], Carlos R. Padovani[c], Jean R. D. Guimarães[d], José C. A. Pereira[a], Luis M. Vieira[c], Zenildo L. Carvalho[a] and Sergio Galdino[c]*

[a] *Instituto de Radioproteção e Dosimetria, Comissão Nacional de Energia Nuclear, CP 37750, 22780-190, Rio de Janeiro - RJ, Brazil*

[b] *Departamento de Química, Pontifícia Universidade do Rio de Janeiro, 22453-900, Rio de Janeiro - RJ, Brazil*

[c] *Centro de Pesquisas Agropecuárias do Pantanal, EMBRAPA, 79320-900, Corumbá - MS, Brazil*

[d] *Instituto de Biofísica, Universidade Federal do Rio de Janeiro, Ilha do Fundão, 21949-900, Rio de Janeiro- RJ, Brazil*

O trabalho apresenta a geocronologia, obtida através do ^{210}Pb, de sete testemunhos de sedimentos de fundo, coletados em três lagoas de inundação localizadas na região do médio rio Taquari, Pantanal, Brasil. Em cinco deles, foi observado um significativo aumento na taxa de assoreamento, refletindo um aumento da carga de material em suspensão para o Pantanal. Adicionalmente, de modo a validar os resultados de ^{210}Pb, o teor de mercúrio foi determinado em dois dos testemunhos. Os resultados mostraram que, a despeito de uma concentração constante ao longo dos testemunhos, houve um acréscimo no fluxo de mercúrio devido ao aumento na taxa de assoreamento. Este fato foi atribuído à expansão das atividades agrícolas no alto rio Taquari durante os últimos 25 anos.

This work presents the ^{210}Pb geochronology of seven bottom sediment cores, collected in three floodplain lakes located in the area of the middle Taquari River, Pantanal, Brazil. In five of them, a significant increase in the sediment mass deposition rate was observed, reflecting an increase of the sediment input to the Pantanal. Additionally, in order to validate the ^{210}Pb results, the mercury content was determined for two sediment cores, showing that despite a constant concentration, the flux of Hg has increased due to an increase in the mass sedimentation rate. This increase can be attributed to the expansion of agricultural activity in the upper Taquari River during the last 25 years.

Keywords: sediment dating, ^{210}Pb, Brazil, Hg, erosion

Introduction

The Taquari River basin (TRB) drains an area of 28,000 km^2 in the plateau adjacent to the so-called Pantanal, a large floodplain area in midwest Brazil. It is characterized by sedimentary soils, primarily sandy soils, with areas of accentuated declivities and high erosive potential. These characteristics of TRB, associated with its intensive use and the mishandling of the soil by agricultural activities during the last 25 years have intensified erosion processes. This is evidenced by the presence of recent gullies and by the siltation of rivers of the TRB. The intensification of these processes causes the instability of the riverbed, and consequent flooding of large areas, leading to environmental, social and economic problems. These processes have already been reported by several authors.[1-9]

Direct estimates of sediment production related to agricultural activity are difficult to obtain for such a large and diversified area as the TRB, and no data are available at present. Historical records of suspended sediment loads for the Taquari River are scarce, although attempts have been made to compare such information.[8] The lack of former studies for the characterization of this environment, prior to the expansion of agricultural activities in the plateau of the upper Taquari River region, makes it difficult to evaluate and compare past and present environmental impacts. Such evaluation can however be undertaken using

* e-mail jmgodoy@rdc.puc-rio.br

a methodology that provides information on past sedimentation rates.

Usually, ^{210}Pb sediment dating is validated using data on ^{137}Cs in fallout from atomic tests or from accidents such as Chernobyl. However, both contribute very little to the pool of ^{137}Cs in the Southern Hemisphere, thereby limiting the use of this type of data for dating purposes.[10] In addition to ^{137}Cs, other indicators such as pollen or heavy metals can be applied.[10-11] In the Amazon and Pantanal regions, the sedimentary records of Hg offer potential opportunity for recent sediment dating, due to the gold rush that took place in Brazil and other neighboring countries in the 1980's.[12] Small scale primary gold mining, using Hg amalgamation for gold recovery, is a practice that started as early as the 18th century, in areas such as Poconé, on the border of the Pantanal and the surrounding lateritic soil plateaus.[13] However, as in other gold mining areas, the link between Hg emissions to the environment from gold mining and Hg in fish could not be demonstrated, and the latter were extremely low even in piscivorous fish species sampled near Poconé.[14] In contrast, high natural Hg levels have been found in most tropical soils and soil erosion was shown to be the main Hg source to aquatic systems in different drainage basins in the Amazon. Roulet *et al*[15] and. Lechler *at al*[16] have shown that while lateritic and other forest soils along the Madeira River were enriched in Hg, recent floodplain soils along the Jamari River were only slightly enriched in Hg and the channel bed sediments were very low in Hg.

Hylander *et al*[13] have carried out a survey of total Hg in surface sediments from floodplain lakes covering the north of the Pantanal, near Cáceres and Barão de Melgaço, and, at the South, in the region near the confluence of the Cuiabá and Paraguay rivers. They have found a mean value of 33.2 ng g^{-1} (first quartile 18.4 and third quartile 46.8 ng g^{-1}). The Hg content of fine bottom sediments from water courses in the immediate vicinity of present or former gold mining sites was higher than in the lake sediments. The results reported by them, for both lakes and river sediments, were lower than those previously reported[17-20] for surface sediments. Leady and Gottgens[21] observed similar values for Hg in lake sediments from a non-contaminated reference area in Northern Pantanal (29.1±0.7 ng g^{-1}).

The lakes included in the present study are situated in the middle Taquari drainage basin area. Gold mining areas are absent in the upper and middle Taquari drainage basin, but the middle Taquari is considered a deposition region for the lateritic soil eroded from the upper basin, a process enhanced by the agricultural development in the Taquari river highlands. The upper land is considered a natural source of Hg to the Pantanal area[13] and therefore if an increase in the mass sedimentation rates has occurred in recent decades, due to an increase in soil erosion at the upper TRB, an increase in the Hg flux to the sediment column must have ocurred . This Hg flux should correlate more closely with the mass sedimentation rate than with the Hg concentration in sediment layers of floodplain lakes from the middle Taquari region. On the other hand, these Hg concentrations in sediments should be relatively constant.

Experimental

The lakes studied in this work are located close to the city of Coxim, at coordinates 18^0 24' 10'' S and 54^0 58' 46'' W (Lake 1), 18^0 21' 57'' S and 54^0 59' 38'' W (Lake 2) and 18^0 21' 57'' S and 55^0 00' 22'' W (Lake 3), Figure 1.

These lakes are oxbow lakes, formed by abandoned river meanders. They are presently separated from the river and receive river water mainly during the flood season, when large amounts of sediment in suspension are transported by the river. The lakes were selected using aerial photographs from 1966, at the 1:60,000 scale and Landsat-TM satellite images (bands 3, 4 and 5 composition), at the 1:100,000 scale, from 1995. Since the aerial photographs from 1966 were taken during the drought period of 1958-1972, the chosen lakes were those older than 30 years and with a probability of receiving water even during that dry period.

A 20kg gravity corer with PVC tubes of 100 cm length and 5.0 cm internal diameter was used to collect sediment cores from study lakes. A first sampling campaign was carried out during October 96, and another one year later. Three cores were collected from Lake 1, three from Lake 2 and one from Lake 3. The cores were sectioned into 2cm slices, and the central part of each slice was reserved for mercury determination. Each slice was dried at 105°C, ground, a 5 gram aliquot taken and the excess ^{210}Pb content was determined by HBr leaching as described by Godoy *et al*[22]. A low-background proportional counter (EG&G Prof. Berthold LB 750) was used and the detection limit for 5 g dry material and 24,000 s counting time was 3 mBq g^{-1}. The results were evaluated according to Appleby and Oldfield.[23]

For the total Hg determination, sediment were dried at 50°C to constant weight and samples of up to 2 g were digested for 5 min in a hot bath at 60°C, in 5 mL of *Milli*-Q water and 5 mL of $HCl:HNO_3$ (3:1). After addition of 50 mL of *Milli*-Q water and 15 mL of 5 % $KMnO_4$, samples were further digested for 30 min at 60°C and left overnight at room temperature. A few drops of 12 % NH_4OCl were added, the extracts were filtered through Whatman 42 paper

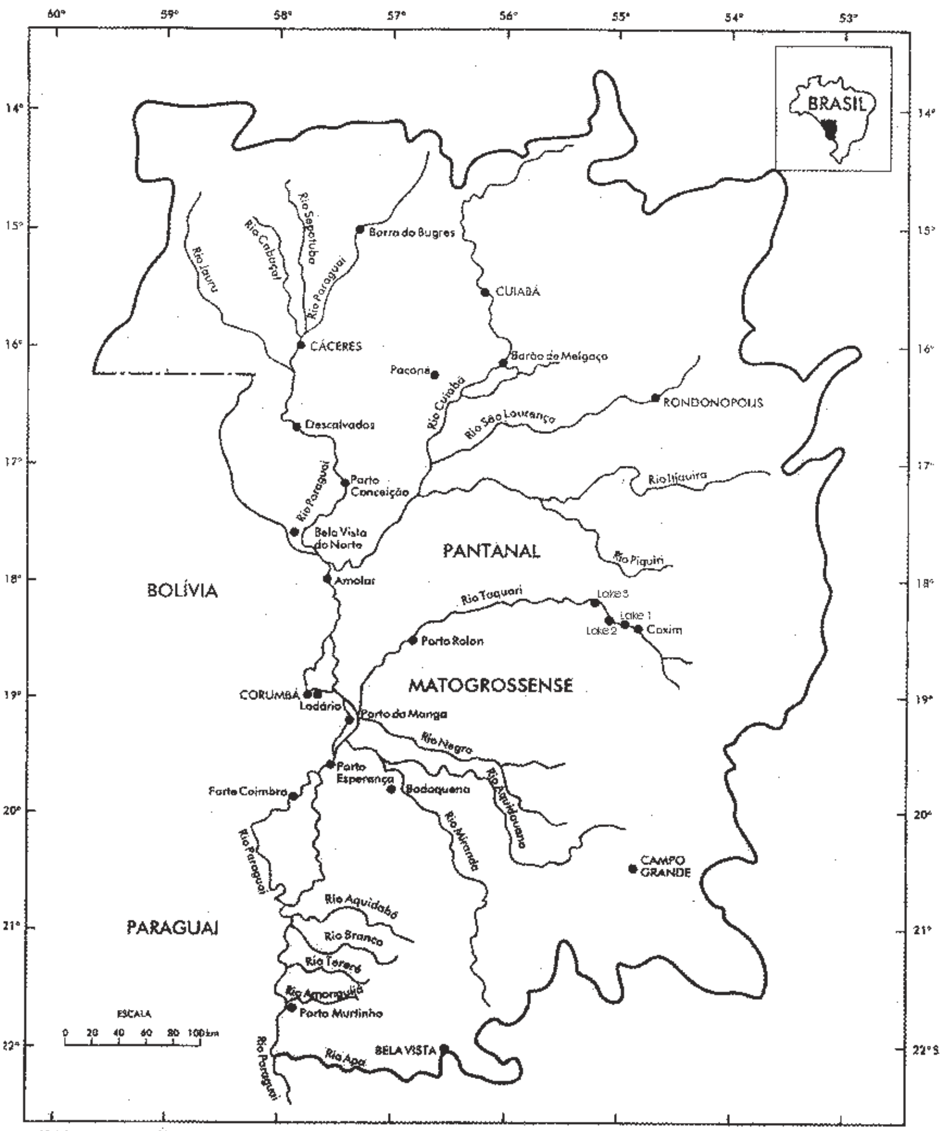


Figure 1. Localization of the studied lakes, with the Brazilian Pantanal area enhanced.

and analyzed by CVAAS. Analytical accuracy was verified by frequent interlaboratorial comparisons and regular analysis of NIES Pond sediment certified reference material.

Results and Discussion

Figures 2a-2c show the changes on the mass sedimentation rates (mg cm^{-2} year^{-1}) found in Lake 1. Sampling point 1 was located closer to the river than the sampling point 2, and point 2 was sampled again during the 1997 sampling campaign (Figure 2c). All the profiles show a similar picture, with a peak during the 1970s to 1980s coinciding with the end of the dry period of 1958-1972. Preliminary evaluation of the existing rainfall data for the plateau area indicated that the rainfall erosivity was larger during the period from 1974 to 1994 than that from 1965 to 1973.[8] In the 1970s, agricultural activities on the plateau underwent a marked expansion, intensifying the erosion processes, over the last 25 years. The values of the mass sedimentation rate corresponding to the present decade also show a period of higher sedimentation rates at present. For all the three cores, the mean mass sedimentation rates for the 1990s are significantly higher ($p<0.001$) than those for the 1920-1950 period: (395±44) and (141±44) mg cm^{-2} year^{-1} for the sampling point 1, (261±54) and (125±17) mg cm^{-2} year^{-1} and (458±85) and (143±27) mg cm^{-2} year^{-1} for the first and second cores of sampling point 2. A comparison between the results of these cores is shown in Figure 3,

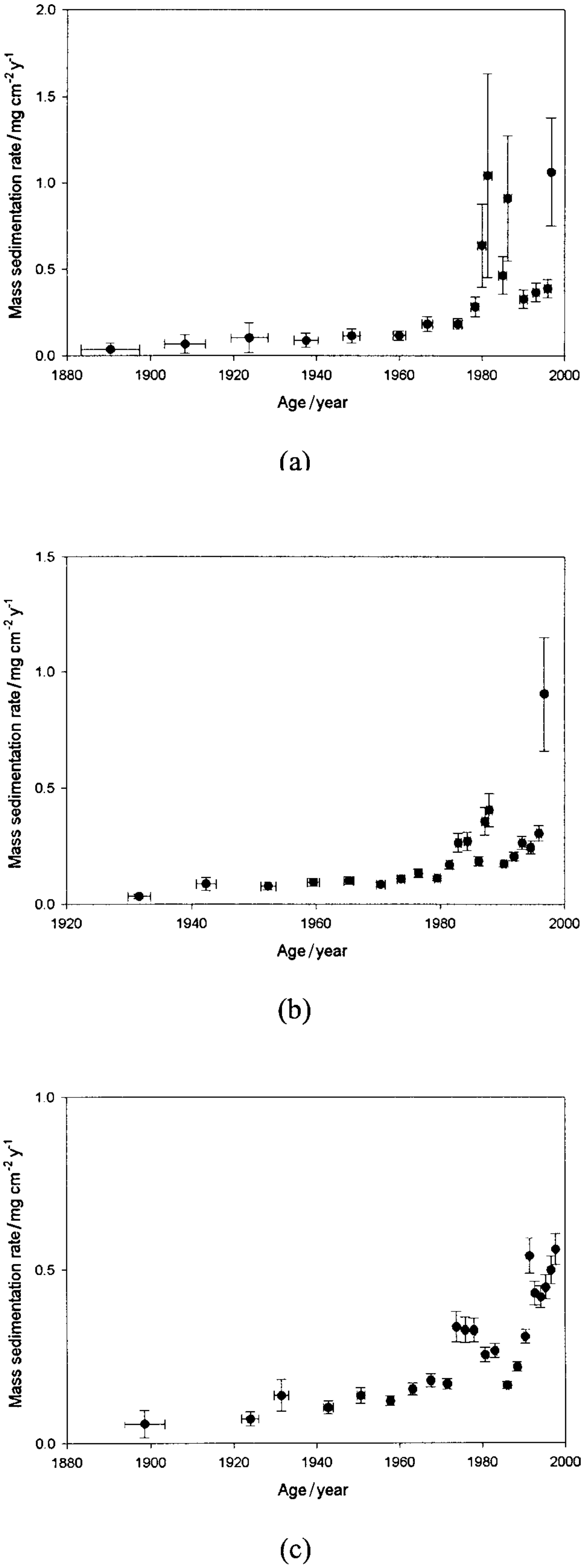


Figure 2. Mass sedimentation rate profiles: (a) Sampling point 1, Lake 1, October 1996; (b) Sampling point 2, Lake 1, October 1996; (c) Sampling point 2, Lake 1, October 1997.

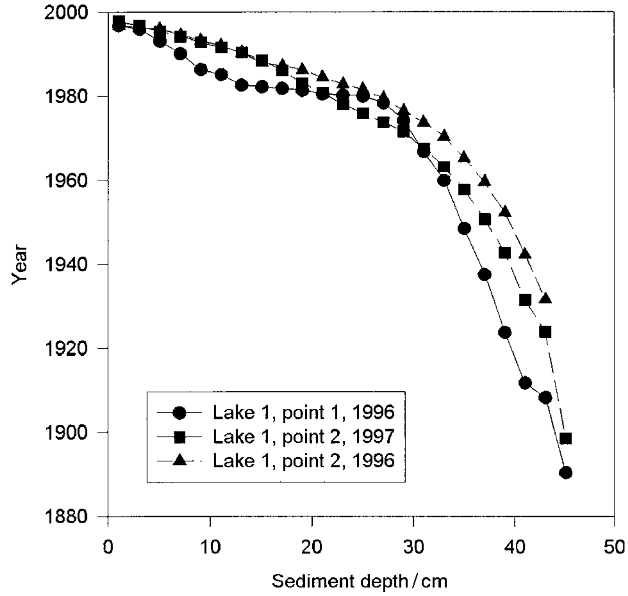


Figure 3. Comparison between the results obtained for the different cores taken from Lake 1.

illustrating the similarity of the two cores taken at point 2, one during 1996 and the other during 1997.

Similar results were observed in Lake 2 for the sampling points 1 and 2 (Figures 4a and 4b). Both points are located in the inlet channel of the lake, one at its left and the other at its right side, almost one in front of the other. The increase in mass sedimentation rates, observed since the late 1970s, was confirmed and the recent rates are substantially greater than those for the 1920-1950 period: (511±76) and (105±21) mg cm^{-2} year^{-1} and (525±81) and (93±18) mg cm^{-2} year^{-1} for the sampling points 1 and 2, respectively. The close concordance between the results of both sampling points is illustrated in Figure 4c.

Forsberg *et al*[24] have reported an analogous case to lakes 1 and 2 situation in floodplain lakes near the Samuel hydro-electrical power station, Rondonia state, Northern Brazil A close correlation was observed between mass sedimentation rate and land denudation and cassiterite artisanal mining activities. The mass sedimentation rate has increased from original values around 50 mg cm^{-2} year^{-1} up to 800 mg cm^{-2} year^{-1} during the seventies.

A third point was sampled during the first campaign. It was located at the end of the lake. There were several curves and straight channels between the lake entrance and this sampling point, as a consequence, the obtained results showed a characteristic pattern of a location with constant sedimentation rates (Figure 5a), and a much lower mass sedimentation rate was observed (63 mg cm^{-2} year^{-1}).

Lake 3 is a small lake, located downstream the two others. Between the lake and the river, there was a buffer

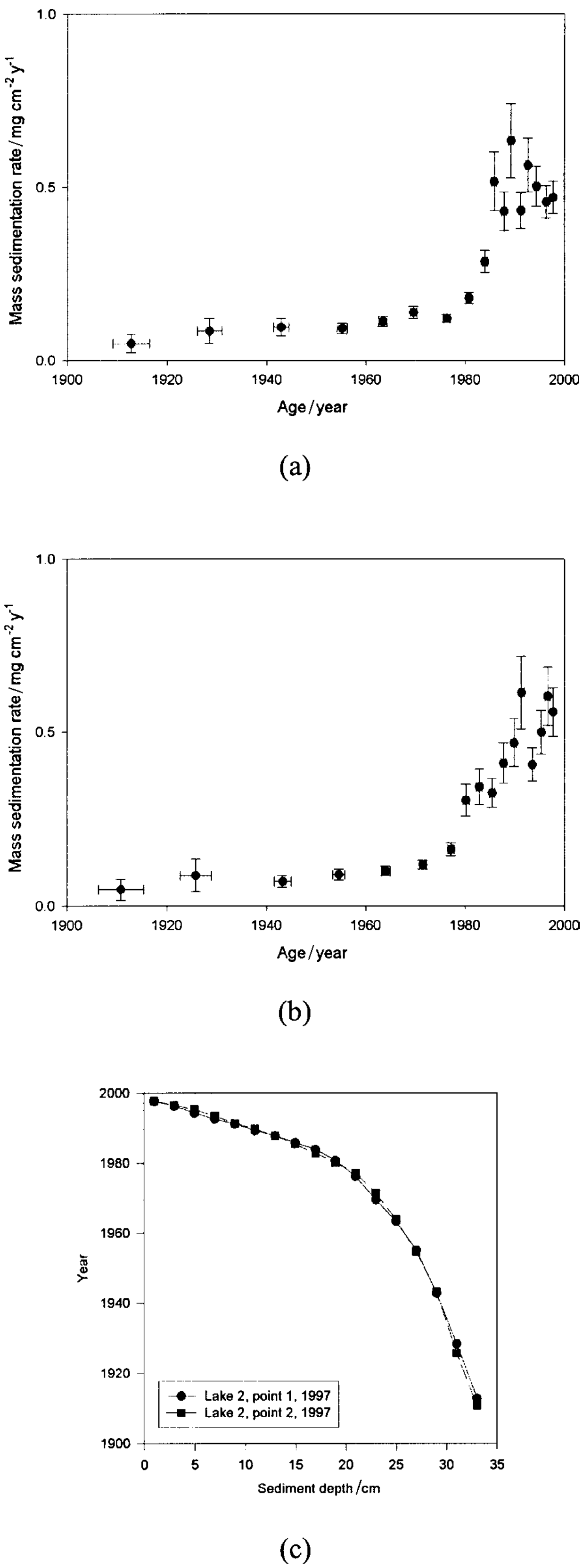


Figure 4. Mass sedimentation rate profiles, (a) Sampling point 1, Lake 2, October 1997 and (b) Sampling point 2, Lake 2, October 1997, and comparison between both profiles (c).

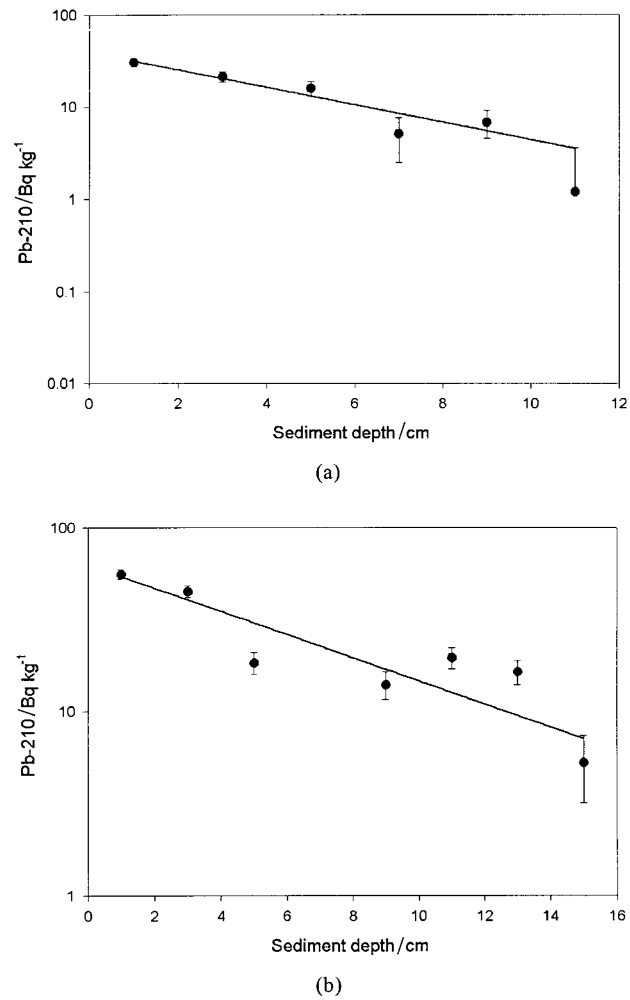
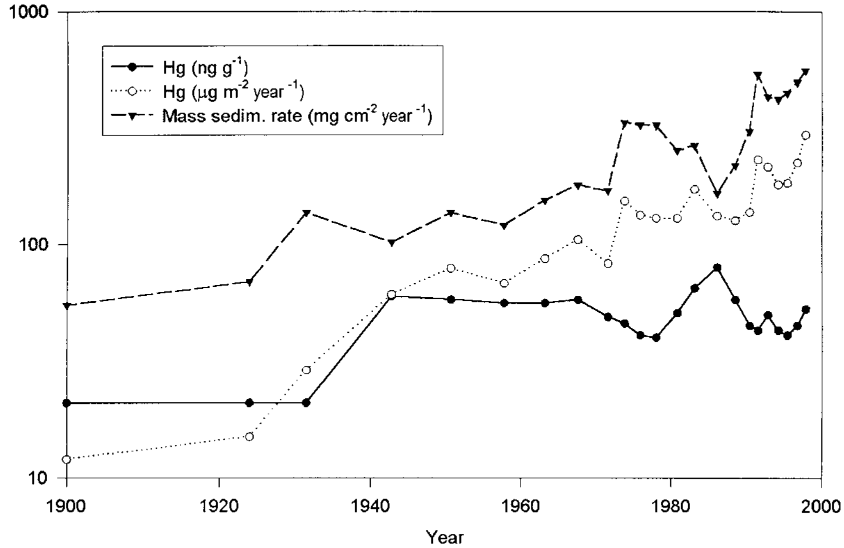


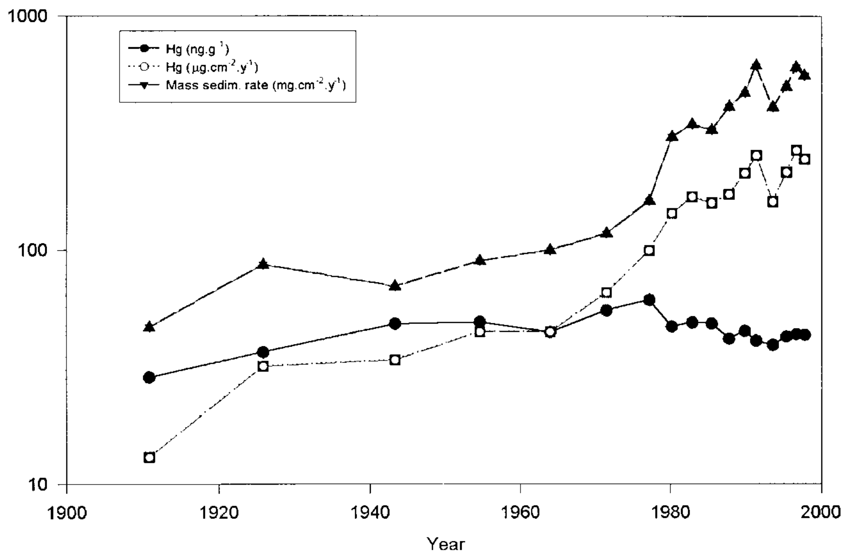
Figure 5. Pb-210 activity concentration variation with the sediment layer depth obtained for: (a) Sampling point 3, Lake 2, October 1996 and (b) Sampling point 1, Lake 3, October 1996.

zone, wider than 100 m, with a dense aquatic vegetation mat. This promotes deposition of the suspended material before the lake itself, leading to the observed constant sedimentation rates (Figure 5b), and also to a low mass sedimentation rate (52 mg cm^{-2} year^{-1}).

Based on satellite images, Oliveira *et al*[25] have shown that the area of the upper Taquari River drainage basin covered with native vegetation has decreased from 96.2% in 1977, to 57.0% in 1984 and 42.5% in 1991, the deforested area being used for both annual crops and cattle raising. Using the mass sedimentation rates observed for sampling points 1 and 2 in Lake 2, the mean value has increased from 142 mg cm^{-2} year^{-1} in 1977 to 306 mg cm^{-2} year^{-1} in 1984 and 523 mg cm^{-2} year^{-1} in 1991. As the mass sedimentation rate observed for the period prior to 1950 was about 100 mg cm^{-2} year^{-1}, it becomes clear that the land denudation occurring on the upper drainage basin area of the Taquari River had a significant impact on sedimentation rates.



(a)



(b)

Figure 6. Mercury concentration and annual flux and mass sedimentation rate time profile for: (a) Sampling point 2, Lake 1, October 1997 and (b) Sampling point 2, Lake 2, October 1997.

Mercury levels were determined in a core from Lake 1 (sampling point 2/1997) and Lake 2 (sampling point 2/1997). The results obtained are shown in Figures 6a and 6b. As expected, the total Hg concentration, despite some fluctuations, are, after the 40's, quite constant and similar for both lakes (Lake 1: 52±10 ng g^{-1}, N=20, and Lake 2: 47.0±5.7 ng g^{-1}, N=15). These values are in the same range of that reported by Hylander *et al*[13] for surface sediments from other lake in the Pantanal region. The mean value of the Hg content before 1940 is also similar for both lakes (21 ng g^{-1} and 23 ng g^{-1}, for lakes 1 and 2 respectively) and coherent with values reported by Lacerda *et al*[17] and Leady and Gottgens[21] for mercury in lacustrine sediments in remote areas of the Pantanal wetlands (20 ng g^{-1} and 29 ng g^{-1}, respectively).

In contrast, the Hg flux has steadily increased dominated by the mass sedimentation, showing the same pattern in both lakes. These findings show that an increase on the soil erosion at the upper TRB has occurred and that the eroded material has reached the middle Taquari river region. The Hg fluxes at the bottom of both cores (12-15 mg cm^{-2} $year^{-1}$) are comparable to those of remote areas between 10°N and 10°S[26] and with values observed around the turn of the century in similar environments as the Everglades, Florida.[27] These fluxes, due to the increase of the mass sedimentation rates, are now 20 times higher than in the past.

Additionally to the ^{210}Pb dating, ^{137}Cs dating was also tried. The same samples were submitted to a gamma spectrometry, applying an intrinsic germanium detector CAMBERRA GL2020R and a counting time of 100,000 s. No ^{137}Cs was found above the actual detection limit of 3 Bq kg^{-1}.

Conclusions

The reported results, based on five out of seven sediment cores taken on floodplain lakes close to the Taquari River, have shown a contemporary mass sedimentation rate much higher than that existing before the expansion of the agricultural activities on the highland adjacent to the river. As a consequence, it is possible to corroborate the previous studies that have pointed the expansion of the agricultural activities in the upper TRB as a cause for the accelerated siltation in the river.

Acknowledgements

The authors are grateful to Professor Peter Appleby (University of Liverpool) for comments on the first version of the manuscript as well as for reviewing the mass sedimentation rates calculations. They also wish to thank Ms. Rosane Amaral and Lilian Belem for the English revision of the final version.

References

1. Adámoli, J.M.*; Diagnóstico do Pantanal: Características Ecológicas e Problemas Ambientais*. Brasília: Programa Nacional do Meio Ambiente, 1985.
2. BRASIL, Ministério do Interior, Departamento Nacional de Obras de Saneamento; *Estudos Hidrológicos da Bacia do Alto Paraguai: Relatório Técnico*, Rio de Janeiro, v. **1**, 1974.
3. BRASIL, Ministério das Minas e Energia; *Projeto RADAMBRASIL - Campo Grande: Geologia, Geomorfologia, Pedologia, Vegetação, Uso Potencial da Terra*, Rio de Janeiro, Folha SE. 21, 1982, p. 412.
4. Braun, H.H.G.; *Revista Brasileira de Geografia* **1977,** *39*, 164.
5. MATO GROSSO DO SUL, Secretaria de Meio Ambiente; *Relatório Técnico: sub-bacia do Taquari*, 1992.
6. MATO GROSSO DO SUL; *Proposta de Enquadramento dos Corpos de Água das Sub-bacias dos Rios Miranda, Taquari e Imbiruçu*. Campo Grande, MS, 1995.
7. Santos, A. T.; Crepani, E.; *Anais do Simpósio Brasileiro de Sensoriamento Remoto*, Curitiba, Brazil. 1993.
8. EMBRAPA, Centro de Pesquisa Agropecuária do Pantanal; *Relatório Anual do Subprojeto: Impactos Ambientais e Sócio-econômicos na Bacia do Rio Taquari*. Corumbá, MS, 1997.
9. Tucci, C.E.; Risso, A.; Borges, A.; Semmelman, F.; Leão, M.I.; Lopes, M.S.; Marques, D.M.; In BRASIL. Ministério do Meio Ambiente, dos Recursos Hídricos e da Amazônia Legal. Plano de Conservação da Bacia do Alto Paraguai (Pantanal) - PCBAP. *Hidrosedimentologia do Alto Paraguai*. Brasília, v.2, t.2 - B, 1997, p. 659.
10. Godoy, J.M.; Moreira, I.; Bragança, M.J.; Wanderley, C.,; Mendes, L.B.; *J. Radioanal. Nucl. Chem.* **1998**, *228*, 157.
11. Appleby, P.G.; Oldfield, F.; In *Uranium–series Disequilibrium: Applications to Earth, Marine and Environmental Sciences*, Ivanovich, M. ; Harmon, R. J., ed., Claredon Press, Oxford, 1992.
12. Lacerda, L.D.; *Quim. Nova,* **1997**, *20*, 196.
13. Hylander, L.D.; Meili, M.; Oliveira, L.J.; Castro e Silva, E.; Guimarães, J.R.D.; Araújo, D.M.; Neves, R.P.; Stachiw, R.; Barros, A.J.P.; Silva, G.D.; *The Science of the Total Environ.* **2000**, *260*, 97.
14. Guimarães, J.R.D.; Malm, O; Meili, M.; *Proceedings of the 5th International Conference on Hg as a Global Pollutant*, Rio de Janeiro, Brazil, 1999.
15. Roulet, M.; Lucotte, M.; Farella, N.; Serique, G.; Coelho, H.; Souza Passos, C.J.; de Jesus da Silva, E.; Scavone de Andrade, P.; Mergler, D.; Guimarães, J.R.D.; Amorim, M.; *Water, Air, Soil Pollut.* **1999,** *112*, 297.
16. Lechler, P.J.; Miller, J.R.; Lacerda, L.D.; Vinson, D.; Bonzongo, J.C., Lyons; W.B.; Warwick, J.J.; *The Science of the Total Environ.* **2000**, *260*, 87.
17. Lacerda, L.D.; Salomons, W.; Pfeiffer, W.C.; *Biogeochemistry* **1991**, *14*, 91.
18. Rodrigues Fº, S.; Maddock, J.E.L.; *J. Geochem. Explor.* **1997**, *58*, 231.
19. Hylander, L.D.; Siva, E.C.; Oliveira, L.J.; Silva, S.A.; Kuntze, E.K.; Silva D.X.; *Ambio* **1994**, *23*, 478.
20. von Tümpling Jr., W.; Wilken, R.D.; Einax, J.; *J. Geochem. Explor.* **1995**, *52*, 127.
21. Leady, B.S.; Gottgens, J.F.; *Wetlands Ecology and Management*, in the press.
22. Godoy, J.M.; Moreira, I.; Wanderley, C.; Simões Filho, F.F.L.; Mozeto, A. A.; *Radiation Protection and Dosimetry* **1998** *75*, 111.
23. Appleby, P.G.; Oldfield, F.; *Hydrobiologia* **1983** *103*, 29.
24. Forsberg, B.; Godoy, J.M.; Victoria, R.; Martinelli, L.A.; *Geo Journal* **1989,** *19*, 399.
25. Oliveira, H.; Oliveira, F.D.A.; Adámoli, J.M.; *26º Congresso Brasileiro de Ciência do Solo*, Rio de Janeiro, Brazil, 1997.
26. Manson, R.P.; Fitzgerald, W.F.; Morel, F.M.M.; *Geochim. Cosmochim. Acta* **1994**, *58*, 3191.
27. Rood, B.E.; Gottgens, J.F.; Delfino, J.J.; Earle, C.D.; Crisman, T.L.; *Water, Air, Soil Pollut.* **1995**, *80*, 981.

Received: March 19, 2001
Published on the web: November 8, 2001