Remote Sensing and ^{210}PB Geochronology in sediment profiles of the Mãe d'Água Dam for evaluation of areas impacted by urbanization

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Abstract — A primary outcome of water basin urbanization is the set of changes of the natural environment into an anthropic environment, favoring the formation of residential and industrial conglomerates. Such changes lead to increases in water demand, causing higher production and release of effluents from anthropic actions, in addition to originating diffuse sources of pollution. These changes can drastically deteriorate the physicochemical characteristics of the local water resources. Due to the absence of urban planning during the last forty years, the water basin of the Mãe d'Água dam has brought to the top some environmental liabilities, such as organic and/or inorganic contaminants. In this context, the present study sought to evaluate the isotopic composition using lead 210 (^{210}Pb) in the different sedimentary layers produced in the water basin that composes the Mãe d'Água dam. With this, it is possible to characterize and identify the urbanization process on the water basin, applying the geochronology technique. Samples were collected in June 2014, where two sediment samplings were taken both at the entrance and near the lake margin of the dam (T1 coordinates: 488716.3334; 6672912.682, and T4 coordinates: 488729.6452; 6672984.7221). A "Piston core" sediment sampler was used to extract the samples. The geochronology studies (^{210}Pb), that date the years in which sediment deposition occurred, allowed to make an outlook of the evolutionary process of environmental degradation that the basin has been suffering from over the last four decades. This was achieved by means of multiple remote sensing devices that allowed confronting and displaying the evolution of urbanization in the studied water basin. Thus, identification of the layer's deposition period, by combining techniques such as ^{210}Pb geochronology and remote sensing, enables to find possible causes of sediment contribution to the reservoir , such as urban expansion, industrialization, erosion, agricultural practices. Therefore, the present study describes the impacts caused by urbanization on the Mãe d'Água water basin.

Keywords— Sediment, ^{210}Pb radium isotope, Geochronology, Remote sensing, Mãe d'Água dam.

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I. Introduction

One of the primary current causes of natural resource degradation is the expansion of water basins due to residential and industrial constructions without the adequate planning. This activity, generates damages not only due to hydrological changes, but also to the load of pollutants that are leached or carried along with the sediments, For example, heavy metals, (Pb, Zn, Ni, Fe, Al,...). In urban water basins, pollutants are produced and found more frequently, occurring by natural and/or anthropogenic causes. These elements, although often associated with toxicity, should be treated differently, since some are essential to both plants and animals. Anthropic modifications in urban areas may also imply several environmental/hydrological liabilities, where the quality of water, whether superficial or underground, will be subject to degradation. [1] pointed out the discharge of effluents, whether domestic, industrial or from agricultural activities, their deposition in the water bodies in the liquid and solid forms, or even the infiltrate

Ion of effluents through the soil as the main implications of urbanization in the loss of quality of water resources. Measuring the impacts of urbanization on the evolutionary process of contaminant enrichment among ranges of the sampled lake sediments (deposited layers, CORE) is of paramount importance in the field of hydro-sedimentology. This techniques show several advantages, such as the relatively low cost in real systems. Assuming that the pollution generated in urban-rural water basins is added to the deposited sediments, regarding the methods available for the study of sediment transport, the proposal of this research was to elaborate an evolutionary mapping of the Mãe d'Água basin, using the lead 210 (^{210}Pb) geochronology method, which allows the visualization of the period of sediment deposition, comparing and finding the link of urbanization to annual sedimentation rate, (via Geographic Information System - GIS).

A. ^{210}Pb Geochronological Studies

The presence of radioactivity in the sediments is a result of the decay of these elements, originally present in the sediments, as well as those that are removed from the atmosphere by precipitation with rain and deposited through processes of sedimentation [2]. The ^{210}Pb is an intermediate element that occurs naturally as one of the radioisotopes of the ^{238}U series of the chain of radioactive decay. Following the deterioration sequence, ^{210}Pb is generated after the formation of radon gas (^{222}Rn) and is present in the atmosphere as a result of ^{222}Rn release from the soil. In aquatic ecosystems, the presence of ^{210}Pb is mainly caused by atmospheric precipitation, as well as by the decay of ^{226}Ra, present in the water. According to [2], the ^{210}Pb deposited on the surfaces of lakes and oceans is adsorbed by the solid matter in suspension, adding it to the sediments by the flow of sedimentation, or partly dragged along with soil. Therefore it can be considered as the ideal radionuclide to date back recently aged sediments. The dating technique using 210Pb has been diffused among several studies about water resources management. Satisfactory results of high relevance have been obtained in the establishment of environmental history, with respect to the geochronology of sediments of up to approximately 150 years. These results gain even greater relevance when applied in areas of intense anthropic activity, since sediments of estuaries and lakes keep a valuable historical record of environmental changes due to industrial activity [3]. Currently, most of the studies that aim to evaluate geochronology (history of sediment deposition) and sedimentation rates use the 210Pb method, primarily in lentic environments, such as natural and artificial lakes (reservoir) [4] [5] [6] [7]. Sediments are of fundamental importance to acquire a historical view of the evolution undergone by natural systems over time, because a significant amount of information on the phenomena that may have occurred is engraved in the different layers of these compounds. It is in the uppermost layers of the sediment that information related to the influence of the vast increase in human and industrial activity over the last century is observed [8] [9] [10]. The knowledge of the accumulation rate of radionuclides in lacustrine and marine environments during the last hundred years is of fundamental importance in understanding sedimentary and aquatic geochemical processes. In general, the interpretation of chemical profiles of surface sediments is limited by the lack of knowledge with respect to sedimentation rates [11] [12] [13] [14].

D. Characterization of the advance of urbanization using geotechnologies

With the increase of geochronology studies, the use of geotechnologies emerged as a multidisciplinary tool, concerning spatial, temporal and environmental management dynamics, and providing the necessary support for research with the aim of correlating urban expansion, accumulation of sediments in active sources of leached anthropogenic contamination and the water resources present in the water basin. Regarding this, the integrated use of geographic information systems and satellite images of high spatial resolution allows public authorities and researchers to verify the feasibility of local development projects, compliance of environmental legislation and analysis of the occurrence of inappropriate land use [15]. Among the advantages in the use of automated approaches for such processes, reliability and reproducibility of results stand out, and may be organized and easily accessed in digital databases [16]. In planning and urban management activities, it is necessary to use technologies that allow the systematization of a large amount of distinctive information, which is required to analyze urban areas. Given such complexity, GIS are useful and potent instruments in the elaboration of diagnostics and scenarios regarding the built environment, which allow, based on spatial analysis, to substantiate better proposals and interventions regarding the management and use of urban areas. Also, with GIS it is possible to recognize several features and enable preservation through the establishment of compatible practices [17]. Remote sensing is defined as the collection of data regarding an object or phenomenon without physical contact between it and the collector. Data results from the interaction with electromagnetic radiation, reflected or emitted by the studied object. The sensor systems, which are the primary instruments of remote sensing, are responsible for capturing the radiation and converting it into an analyzable and interpretable form [18]. The images are a product of the record of spectral responses from objects captured by the sensor systems. Recently, in Brazil, authors have applied the dating methodology, correlating with the sedimentation rate and contamination by metals, but GIS techniques are seldom used. The aim of this study was to relate urban growth and the production of contaminants by anthropogenic activities in the Mãe d'Água Dam water basin..

II. MATERIAL AND METHODS

C. *Choice and location of sediment CORE sampling*

The location chosen for the case study and sediment collection follows [19]. The sampled area is located in the State of Rio Grande do Sul (Brazil), in the metropolitan region of Porto Alegre, municipality of Viamão. The Mãe d`Água dam is a tributary of the Arroio Dilúvio, an important water course that extends to the city of Porto Alegre, cutting it in East-West orientation.

The Mãe d'Água dam is a four river exutory, corresponding to an area of 353 ha and is located in the Vale Campus of the Federal University of Rio Grande do Sul. Figure 1 represents the dam's water basin, characterizing the studied location and area.

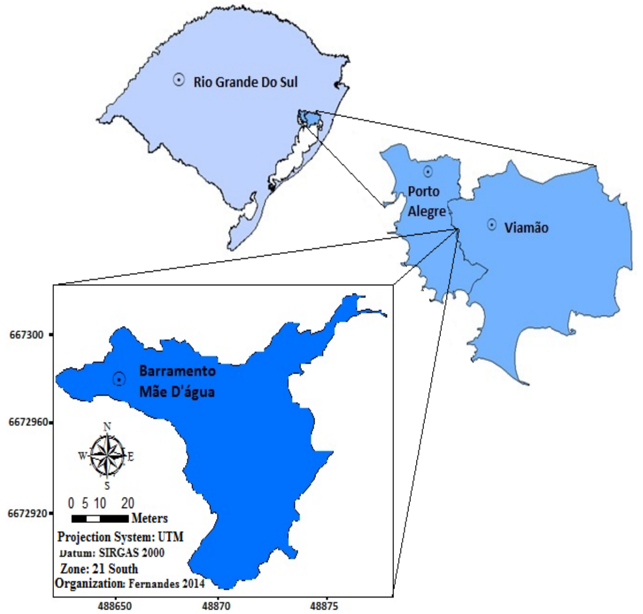

Figure 1 *– Location and representation of the studied* reservoir *in the Metropolitan Area of Porto Alegre – RS (Brazil).*

D. Collection of sediments

According to [19], the samples were collected on 06/09/2014. The collection points of the samples were planned, aiming to obtain optimal spatial distribution in the lake and respecting the local hydrodynamics. The reports were sampled and the data, such as the geographical coordinates of the points, water depths, and the length of the sedimentary profile was registered tabulated(Table 1).

Table 1 *– Collected sediment core information.*

Sample (Core Sampling)	UTM coordinates (m) (Ellipsoid WGS-84)		Water depth (m)	Core sampling length (m)
	X	Y		
T1	488716,34	6672912,68	0,40	0,60
T4	488729,65	6672984,72	0,40	0,57

The employed technique was “Core Sampling”, composed by a set of detachable parts, consisting in the introduction of a rigid cylindrical PVC tube, with 75 millimeters of diameter, to sample bottom sediments. During sample collection, a boat was used which provided safety for the development of the activity and assured the necessary stability of the crew and sample removal, in accordance with the studies carried out by [2], [19] and [20] .

E. Laboratory Analyses

^{210}Pb chronological analysis

Opening and digestion of the sediment samples was carried out using the EPA-3052 total digestion method, according to the standard methodologies and procedures of the Nuclear Energy Research Institute at the University of São Paulo (IPEN-USP), recommended by [21], which is considered suitable for applications that require the total digestion of samples. The protocol was designed by the Environment Protection Agency (USEPA).

The methodology used at the IPEN-USP is based on the sequential radiochemical separation of ^{226}Ra and ^{228}Ra by co-precipitation with barium sulfate and radium sulfate, and of ^{210}Pb by co-precipitation with lead chromate, followed by total alpha and beta counts. The selected technique is suitable for environmental measurements when the concentrations of ^{210}Pb activity are very low and when the aliquots containing masses of available sediment are too small for the analysis. Lastly, determination of the age of the sediment was performed using the C.R.S. method (Constant Rate of Supply).

The applied mathematical formula, described in Equation 1, integrates the values of the activities to be carried out, taking into account the depth of the extracted sediment sample and the depth where the activity becomes insignificant [22], [23], and [24].

$$\mathbf{B_z = B_\infty \cdot} e^{-\lambda} \quad \mathbf{(1)}$$

Where:

- B_z represents the integrated activity of “non-produced” ^{210}Pb, from the base of the sedimentary column until depth z;
- B_∞ stands for the integrated activity along the entire sediment column;
- λ is the ^{210}Pb radioactive decay constant (0.0311 year^{-1}).

The sediment age at depth z is calculated using Equation 2.

$$\mathbf{t = (1/\lambda)\cdot \ln[B_\infty / B_z]} \quad \mathbf{(2)}$$

Where:

- t represents the age of the sediment sample;
- λ is the ^{210}Pb radioactive decay constant (0.0311 year^{-1});
- B_∞ stands for the integrated activity along the entire sediment column;
- B_z is the integrated activity of “non-produced” ^{210}Pb, from the base of the sedimentary column until depth z.

III. RESULTS

F. ^{210}Pb geochronology

Records 1 and 4 of the sediments from the Mãe d'Água reservoir displayed optimal linearity, constituting a suitable environment for chronological analyses.

Figure 2 shows the ^{210}Pb chronology in the sedimentary layers deposited over the decades, regarding depth in the T4 sediment profile (only the 10 to 30 cm range did not exhibit adequate linearity, without interfering with the results of the study, with R² for T1 of 0.92 and for T4 of 0.93).

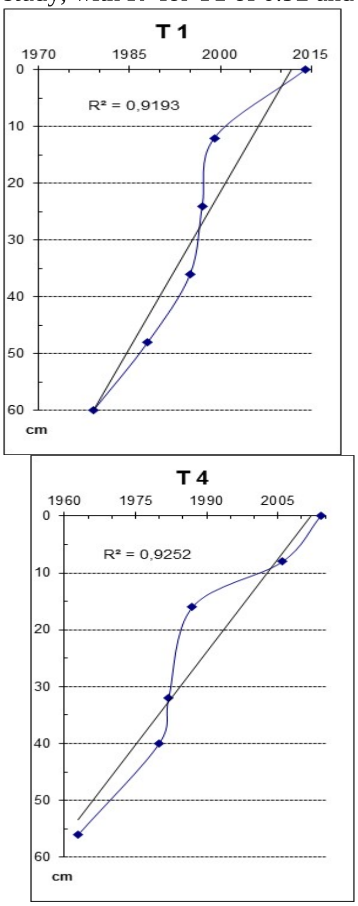

Figure 2 *- Geochronology of the sediment profiles sampled in the Mãe d'Água reservoir.*

The sediment profiles collected at T1 and T4 correspond to a period of approximately 45 years of accumulation, with the deepest layer reaching the years 1970 and 1960, respectively. The mean sedimentation rate at T1 was 1.77 cm/year, which was higher than the average recorded at T4, of 1.14 cm/year. This increased deposition rate at T1 may explain the fact that higher concentrations have been reported as being connected to depth due to their location near the margin, where velocities are lower, thus favoring sedimentation, and T4 is located at the entrance of the channel, under the talweg.

The research conducted by [20] obtained satisfactory geochronology results, with sampling of sediment cores in the Rio Grande reservoir, responsible for the water supply of four cities (São Bernardo do Campo, São Caetano do Sul, Santo André, and Diadema). This water basin has been severely affected by urban expansion in the metropolitan area of São Paulo, due to chaotic urbanization land use.

[25] carried out studies on geochronology using ^{210}Pb in cores sampled in the Amazon River, and when the data was analyzed, good similarity between each other, thus demonstrating that these elements exhibit conservative behavior, confirming their great utility as environmental tracers. Therefore, over the past few decades, there has been an increase in research based on the use of these natural radionuclides in the environment, especially in research involving sediments.

The study of sediments is recent and relevant in tracing man's activities in the environment, mainly determining the impact caused over the past 150 years (the reliable limit for 210Pb geochronology). This interval may vary regarding the local area and sediment characteristics.

G. Urbanization

In order to assess the evolution of urbanization in the study area, two types of remote sensing data were used: aerial photographs and satellite images; which were integrated into a geographic database using the 9.2 version of the ArcView® application package, in accordance with studies conducted by [26]. The aerial photographs consisted of two photographs, dated in 1972 and 1991. In turn, the QUICKBIRD satellite images date back to 2003 and 2008, reproducing an optimal space-time for the analysis of the present research, regarding geochronology.

Data related with the urbanization processes were arranged in tables, displaying hectare unit values and percentage (all values shown in Tables 2, 3, 4 and 5 are in accordance with the recommended by [26].

According to [27], the Mãe d'Água Dam was inaugurated in 1962 by the National Department of Works and Sanitation and acts as an outlet to all the water drained by the basin. The majority of the drainage area is located in the municipality of Viamão and is therefore included in the urban formation and development context of the Metropolitan Region of Porto Alegre. Based on historical records from residents and technicians involved in the construction of the reservoir , [27], in possession of several photographs, was able to reconstruct the environmental scenario before the construction of the reservoir , retaining preserved river banks, abundant fauna and small basins of accumulation built by the residents themselves. It was also verified that the first subdivisions approved by the city, regarding the basin area, were from the 1950s. The construction and implementation of the Vale Campus of the UFRGS began in the 1970s, along with the improvement of urban and road infrastructure.

Table 2 shows the data regarding the areas where visual interpretation of the 1972 aerial photographs was carried out. Anthropogenic activity was identified in 267 ha of the area, corresponding to 76% of the basin, consisting of allotments, road openings, and civil constructions in general that characterize urbanization.

Table 2 – Land use in 1972.

Category	Area (ha)	%
Anthropic	267	76
Natural	80	23
Reservoir	5	1

Source: [26].

Table 3 shows data concerning the areas in which visual interpretation of the aerial photographs of the year 1991 was carried out. An increase of the area of anthropic use and a reduction in natural areas can be observed, due to the process of urbanization of the basin. As a result, this process generated products such as sediments, which silt the reservoirs, explaining the reduction of the reservoir area from 5 to 4 hectares.

Table 1 – Land use interpretation results in 1991.

Category	Area (ha)	%
Anthropic	290	82
Natural	58	17
Reservoir	4	1

Source: [26].

As of 2003, the study relied on panchromatic images with 4 m of spatial resolution from the QUICKBIRD satellite, were used to find the basin land use in the early 2000s. Unlike the aerial photographs used in the analysis of the previous period, the mentioned satellite operates with the use of colored imaging, which for visual interpretation is of significant assistance [26]. Table 4 displays the evolution of the basin with regard to this period.

Table 2 – Land use interpretation results in 2003.

Category	Area (ha)	%
Anthropic	297	84
Natural	53	15
Reservoir	3	1

Source: [26].

A noticeable decrease in vegetation areas can be observed in Table 4, justified by an increase in the use and occupation of soil where native vegetation was removed. The growth of the families residing in the area and the lack of alternatives for the low-income population, led to the development of small family settlements, characterized by precarious conditions and the agglomeration of several housings on the same land plots.

Table 5 shows the data regarding the period of 2008. The numbers are similar to those observed in 2003, although it is possible to see that the urbanization process kept growing. The area corresponding to the anthropic occupation was 299 ha, increasing to 85% in the area of the urbanized basin, representing a growth in 2% over a 5-year period. A significant decrease in the natural areas of the basin stands out, which reduced from 80 to 51 hectares, resulting in 64% deforestation from 1972 to 2008.

Table 3 - Land use interpretation results in 2008.

Category	Area (ha)	%
Anthropic	299	85
Natural	51	14
Reservoir	2	1

Source: [26].

The occupation of riparian areas constitutes an imminent risk to the residents, in addition to being prohibited by law. However, it is one of the few alternatives for families that have been excluded in the process of "regular" urban land occupation [28].

The evolution of land use occupation related to the population increase and the different forms of intervention in the water basin provided the transformation of its characteristics over the years. Figure 3 shows the data obtained from the years 1972, 1991, 2003 and 2008. The growth of urbanization, due to the anthropogenic use of basin areas, resulted in the reduction of natural areas and the reservoir lake in the 2008 period.

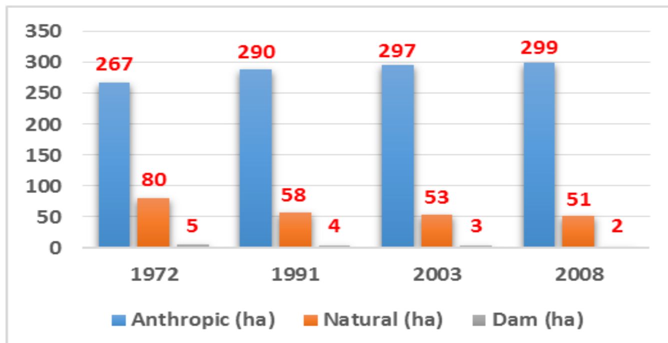

Figure 3 – Evolution of the Mãe d'Água Basin from 1972 to 2008.

Source: Adapted from [26].

Currently, the study area is predominantly characterized by diffuse residential occupation, which has generated environmental liabilities with organic and inorganic pollutants such as increased load of organic compounds and heavy metals. Also, urbanization has led to an increase in areas with uncovered soil, which fosters erosion, and increased sediment production, resulting in sediment transport and sedimentation of water resources present in the basin, as well as contamination of the ecosystem.

IV. CONCLUSION

Observing and crossing the data obtained in the present study, involving 210Pb geochronology, sedimentation rate, and geotechnology (GIS), it is shown that the increase in anthropogenic areas reflects the growth of urbanization of the water basin and, consequently, the reduction of the natural areas and of the reservoir. Urbanization leads to high production of particulate materials that are carried by the water resources in the basin. These materials, with an origin in the uncovered soils lacking vegetation, lead to silting, as evidenced by the sedimentation rate and the reduction in the reservoir area.

In addition, and as a consequence, the degradation of the ecosystem occurs because of an increase in environmental liabilities, due to diffuse pollution sources present in the basin, such as heavy metals, organic matter, erosion, urban waste, industrial construction and the reduction of green or natural areas.

Therefore, in order to increase knowledge of the dynamics of urbanization and its impacts on sediments and, consequently, the degradation of downstream water bodies, it is necessary to seek out studies that carry out integrated research on sediment geochronology and geotechnologies such as GIS, in order to estimate sedimentation rates, sediment profile geochronology and area urbanization over the decades in order to support the correlation between these varibles.

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