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URBANIZATION, ENVIRONMENTAL AND SOCIOECONOMIC TRENDS IN A COASTAL ZONE UNDER AN ANTHROPOCENE APPROACH: 1940 – 2020 (GUANABARA BAY HYDROGRAPHIC BASIN, RIO DE JANEIRO, BRAZIL)

URBANIZAÇÃO, TENDÊNCIAS AMBIENTAIS E SOCIOECONÔMICAS EM UMA ZONA COSTEIRA SOB O ENFOQUE DO ANTROPOCENO: 1940-2020 (BACIA HIDROGRÁFICA DA BAÍA DE GUANABARA, RIO DE JANEIRO, BRASIL)

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Abstract

This study aims to reconstruct the urbanization of the Guanabara Bay Hydrographic Basin (GBHB) region during the period between 1940 and 2020, and its environmental and socioeconomic corollaries. To achieve this, remote sensing data, sustainable development indicators, and geoprocessing techniques were employed. The lack of remote sensing data from 1940 to 1960 and of official statistics for 2020 were projected using mathematical and statistical approaches. Results demonstrate that, from 1940 to 2020, urban areas increased by 5.3% per year, direct interference of urban areas on selected freshwater resources increased by 6.1% per year and the urban population increased at about 4.6% per year. The results also demonstrate that the GBHB has a lack of sanitation facilities, with less than 50% of the households having access to sewage facilities, which explains the high concentrations of organic matter in the freshwaters, 11.2 $mg.l^{-1}$. Income inequality and poverty are evident in the region. The Minimum Wage and Gross Domestic Product *per capita* ratio was estimated at about 0.2 (mean value estimative for 1940 - 2020). The study concludes that unplanned urbanization and inefficient public policies deplete the environment and the human condition in growing trend, making the GBHB an interesting local case to verify elements of Anthropocene theory.

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Keywords: Geotechnologies. Land use changes. Social degradation. Environment degradation. Socioeconomic well-being.

Resumo

Este estudo tem como objetivo reconstruir a urbanização da região da Bacia Hidrográfica da Baía de Guanabara (BHB) no período entre 1940 e 2020, e seus corolários ambientais e socioeconômicos. Para tanto, foram empregados dados de sensoriamento remoto, indicadores de desenvolvimento sustentável e técnicas de geoprocessamento. A falta de dados de sensoriamento remoto de 1940 a 1960 e de estatísticas oficiais para 2020 foram projetadas usando abordagens matemáticas e estatísticas. Os resultados demonstram que, de 1940 a 2020, as áreas urbanas aumentaram 5,3% ao ano, a interferência direta das áreas urbanas nos recursos de água doce selecionados aumentou 6,1% ao ano e a população urbana aumentou cerca de 4,6% ao ano. Os resultados também demonstram que o GBHB carece de instalações de saneamento, com menos de 50% dos domicílios com acesso a esgoto, o que explica as altas concentrações de matéria orgânica nas águas doces, 11,2 mg.l-1. A desigualdade de renda e a pobreza são evidentes na região. A relação entre o Salário Mínimo e o Produto Interno Bruto per capita foi estimada em cerca de 0,2 (estimativa do valor médio para 1940-2020). O estudo conclui que a urbanização não planejada e políticas públicas ineficientes empobrecem o meio ambiente e a condição humana em tendência crescente, tornando o GBHB um caso local interessante para verificar elementos da teoria do Antropoceno.

Palavras-chave: Geotecnologias. Mudanças no uso da terra. Degradação social. Degradação do meio ambiente. Bem-estar socioeconômico.

Introduction

Coastal zones are, probably, the main portion of Earth's surface to identify the anthropogenic factors which induce environmental and socioeconomic modifications over time. About half of the world's population lives in coastal zones (GFDDR, 2016). Such anthropogenic drivers directly impact the physiography of the coastal areas, mainly the land use changes, which generates some threats to the stability of ecosystems (LOICZ, 2006). The intensive and continuous process of environmental resource depletion and human condition degradation, mainly in the less developed countries, could lead to the total dissociation between humanity and the environment – the metabolic rupture (FOSTER; CLARK; YORK, 2010). These elements integrate the notion of the Anthropocene (ALEXIADES, 2018). The Anthropocene and its evidences are identified in sedimentary records and could be understood as an imprint of intensive and fast acceleration of the Holocene, which leads the Earth System to a 'non-analogue state' (STEFFEN et al., 2015). Discussions on the definition of the new geologic epoch are occurring, and there is a recommendation presented to the International Union of Geological Sciences (IUGS) to adopt the year 1945 as the beginning of the Anthropocene (CARRINGTON, 2016). The elements of the 'Anthropocene Crisis' are not only observable on a global scale. In complex systems, such as Earth's System, the possibilities of local anthropogenic processes are widespread, interaction and magnitude exist, and the effects and unpredictable consequences could reach regional and global scales (BIGGS et al., 2011).

Intense urbanization is one of the main processes which implies great modifications of coastal zones. In Brazil, the land use changes in coastal zones began with the colonization and the modus operandi adopted for the foundation of coastal cities, and the continuous occupation of the coastal hinterland, since the 16th century. The economic cycles of the Brazilian economy, such as sugar cane, mining, and coffee, were the drivers for the intense urbanization of coastal zones. By the 20th century, Brazil had five municipalities with more than 100 thousand inhabitants - Belém, Recife, Salvador, Rio de Janeiro and São Paulo (SANTOS, 1993). By the 1960s, the metropolitan urbanization could be observed in municipalities of São Paulo and Rio de Janeiro, with more than 1 million inhabitants (SANTOS, 1993). The metropolitan regions in Brazil have been increasing constantly in terms of urban population, being an important drive for land use changes, deforestation, and unplanned occupation. Brazilian metropolitan regions are characterized by peripheral expansion, environmental degradation, a lack of public services, and an increase in poverty and inequality (SANTOS, 1993; MARICATO, 2000; ROLNIK; KLINK, 2011).

In Brazil, about 35% of the population lives in a coastal zone (65 million inhabitants) and the GDP of coastal zones and adjacent metropolitan regions represents 70% of the Brazilian total GDP (IBGE, 2019). Although the Brazilian economy is one of the ten largest in the world (WORLD BANK, 2020) and the GDP of coastal zones has an important role on the Brazilian prosperity, the environmental and socioeconomic contradictions are evident, such as the high rates of deforestation of the Atlantic Forest - about 75% (MMA, 2015), income inequality as measured by the Gini index of 0.536 (IBGE, 2010) and the lack of sanitation facilities – sewarage (about 40% of Brazilian municipalities) (MDR, 2020). The Metropolitan Region of Rio de Janeiro can be understood as representative of the Brazilian coastal zone, since it has about 20% of the total GDP of the Metropolitan Regions (IBGE, 2016), a massive urban population accounting for 99.5% of the inhabitants (IBGE, 2010), 7% of the population living under the poverty line of US$ 60 in terms of *per capita* income, 2% are extremely poor with less than US$ 20 *per capita* income (UNDP, 2020) and a global income inequality of 0.50, as measured by the Gini Index (IBGE, 2010).

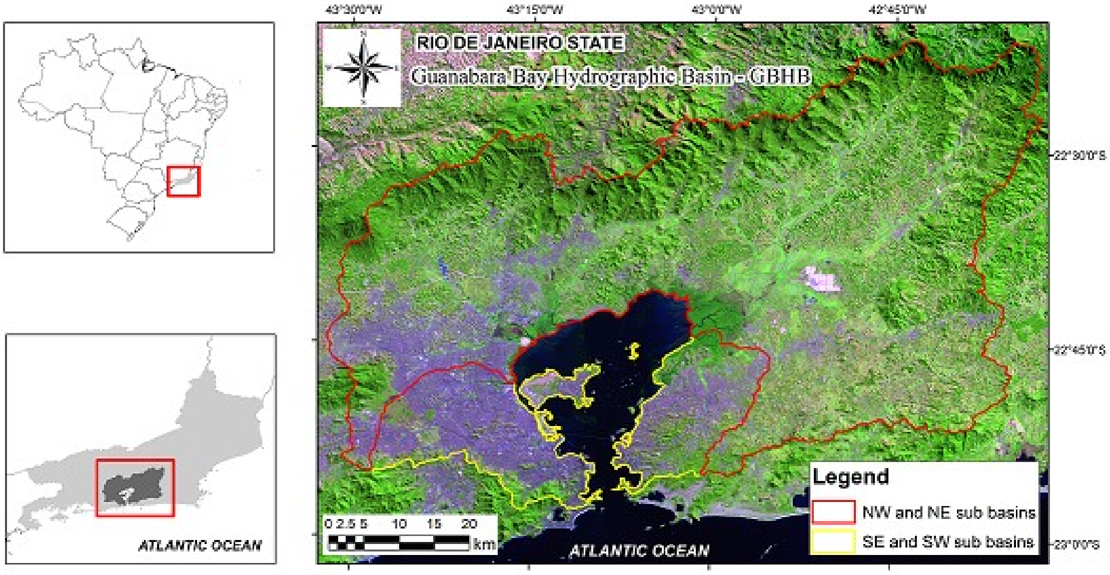
The Guanabara Bay Hydrographic Basin (GBHB) integrates the Metropolitan Region of Rio de Janeiro. The historical development of the GBHB was based on an agricultural economy from the 16th century until the 19th century. By the end of 19th century and the first half of 20th century, industrialization became intense and the region was, at that moment, one of the two most important industrial areas of the country. With the industrialization and the greater employment opportunities, large areas once occupied by agricultural activities were converted into urban areas. Transportation infrastructure, such as railways and highways, were the drivers for the integration of the new urban areas with the central areas of Rio de Janeiro (GEIGHER; SANTOS, 1954; SOARES, 1962; AMADOR, 1997). The region experimented a great expansion of the urban areas, without planning nor public policies of land use regulation or public services (ABREU, 1997). The vulnerability of the GBHB concerning environmental and socioeconomic aspects play a key role in the investigation of the anthropogenic modifications due to the intense urbanization phenomena.

Presented here is an interesting case of historical land use changes with direct impacts on the environment and society in an important metropolitan area of the Brazilian coastal zone over the last five centuries. Moreover, its environmental and socioeconomic consequences can be observed in other metropolitan regions of the world. This study aims to reconstruct the urbanization of the GBHB region during the period between 1940 and 2020 and its environmental and socioeconomic corollaries. To reach this main objective, we propose a methodology with the employment of geotechnologies to the following specific objectives: 1. Estimation of urban areas; 2. Estimation interference of urban areas on freshwater resources – rivers and channels; and 3. Integration of geographic data with official environmental, social and economic indicators.

Study area

The GBHB is located in the southeast of Brazil, in Rio de Janeiro State, an Atlantic Ocean coastal zone delimited by the coordinates 43°30’ W, 22°30’ S and 42°30’ W, 22°50’ S. In general aspects the GBHB has about 4,080 km² and climatic conditions characterized by high temperature and humidity. The mean annual rainfall is estimated at 1,140 mm and the mean temperature is about 24°C (COPPETEC, 2014). About 29% of the total GBHB consists of protected areas for biodiversity conservation with restricted use directives (MMA, 2020). The GBHB has about 55 rivers draining into Guanabara Bay, with a discharge of 220.6 m³. s-1 (JICA, 1994; SILVEIRA et al., 2017). This study focuses on the northwestern (NW) and northeastern (NE) sub-basins, which correspond to 83% of the total GBHB area. The other 17% corresponds to southwestern (SW) and southeastern (SE) sub-basins. Figure 1 presents the location of the study area.

Figure 1: Study area localization



Notes: Image Landsat 5 TM RGB composition. Available from United States Geological Service – USGS.

The GBHB is part of a large group of coastal embayments with common physiographic aspects, observed along the Brazilian southern to southeastern coastline. The geomorphology is characterized by a fast transition from high altimetric elevations (Serra do Mar) to a large coastal plain. Vegetation is composed of Atlantic Forest species mainly at Serra do Mar, some agricultural areas on the transition to coastal plain. The geomorphology and the land use changes of the GBHB are determinants of the main rivers' water quality, varying from pristine to highly polluted freshwaters. These freshwaters are discharged into Guanabara Bay (GB), being one of the determinants for its water quality and sediments. The other component is the tidal fluctuations, with marine contribution (BIDONE et al., 1999). In 2019, values of biochemical oxygen demand were higher than the recommended values in 55% of the monitored data – 5.0 mg. l-1 (CONAMA, 2005; INEA, 2019). The environmental issues related to water quality can be explained by the sanitation indicators. Inequality in access to the sanitation services is a fact, and its due to the absence of consistent public policies (MARQUES, 1996; QUINTSRL; BRITO, 2014; QUINTSRL, 2018). About 40% of the population did not have sewage facilities, 10% had no piped water supply and 2% lacked waste collecting services (MDR, 2020).

In socioeconomic terms, the Gini Index of the 12 municipalities that comprise the hydrographic basin varies from 0.46 to 0.64. 33% of the total population did not have any income, and 41% had at least two times the Minimum Wage - the equivalent of US$ 570 in 2010 (IBGE, 2010). The *per capita* income varies from US$ 240 to US$ 1,140 and, in contrast, the Human Development Index (HDI) was estimated at between 0.65 and 0.84, considered as respectively mean and high HDI values (UNDP, 2020). Like other large Latin American metropolitan regions, urban areas of the GBHB have a complex occupational pattern. This is a result of the associations between the public and private sectors, and its characterization by gentrification and residential segregation (CORRÊA, 2016). The expansion of urban areas in metropolitan regions can be understood as the main driver of the effects on natural resources, especially forests and rivers.

Materials and methods

Estimation of urban areas

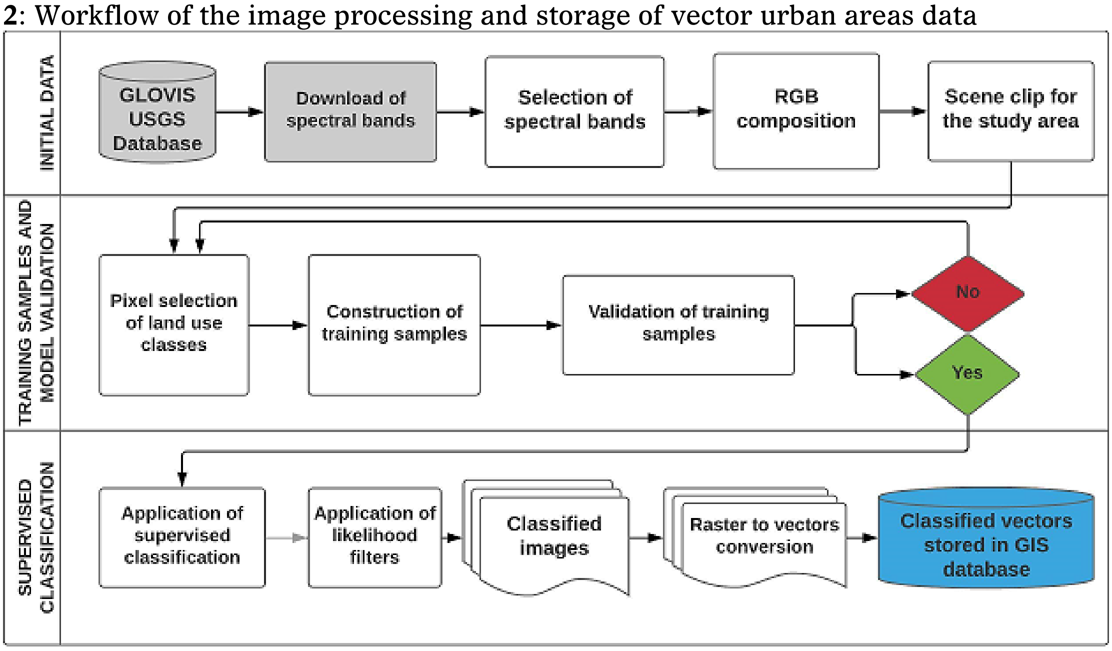
The main source to produce the estimation of urban areas was remote sensing data. A total of five Landsat scenes were selected from the Global Visualization Viewer (GloVis) open access archives catalog, from 1970 to 2010. The GloVis project is managed by the United States Geological Service (USGS). After the selection of the scenes with less cloud cover for each decade, the spectral bands were downloaded from the GloVis catalog and the RGB composition images were obtained with application of geotechnologies in a Geographic Information System (GIS) – ESRI ArcMap 10.3, using specific spectral bands to emphasizes the urban areas. The Landsat scenes here employed provides a spatial resolution varying from 60 to 30 meters. The attributes of Landsat scenes and the spectral bands of each RGB composition image are presented in Table 1.

Table 1: Attributes of Landsat scenes and the spectral bands of each RGB composition image. The spectral bands used from Landsat 2 MSS are: Band 5 - Visible red, Band 6 - Near-Infrared and Band 4 – Visible green. The spectral bands utilized from Landsat 5 TM are: Band 5 - Near-Infrared, Band 4 - Near-Infrared and Band 3 – Visible red

Year of scene	Landsat sensor	Path/Row	Spatial resolution (m)	Scene acquired date (YYYY-MM-DD)	Spectral bands of RGB composition
1975	Landsat 2 MSS	233/76	60	1975-07-09	5-6-4
1981	Landsat 2 MSS	233/76	60	1981-02-01	5-6-4
1991	Landsat 5 TM	217/76	30	1991-08-06	5-4-3
2000	Landsat 5 TM	217/76	30	2000-08-14	5-4-3
2010	Landsat 5 TM	217/76	30	2010-08-26	5-4-3

The RGB composition images were submitted to the supervised classification images processing. This processing needs training samples obtained by the image data analyst. As a consequence, the results of this image process in part depend on the experience of the image data analyst but mainly on the area's physiography and human man-made structures. Polygons referred to the land use classes identified on each image and are the components of the training samples. Each polygon of the training samples has the range of pixel value according to each RGB composition image. Each RGB composition has its own training samples (NOVO, 2008). Before the supervised classification image processing, training samples must be validated. ESRI ArcMap 10.3 supervised classification tool has an auto validating visual method using the comparison of the distribution of two mapped land use classes in a two-dimensional scatterplot. A satisfactory classification requires minimal overlay of identified classes. If this condition is satisfied, the supervised classification tool can be run. After classification, the resultant raster files were filtered to eliminate possible errors of classification and converted to vectors. The vectors referred to consolidated urban areas and unconsolidated urban areas were normalized with official urban areas according to 2010 demographic census vector data (IBGE, 2010). Figure 2 presents the workflow of the image processing and storage of urban area vector data.

Figure 2: Workflow of the image processing and storage of vector urban areas data



Although urban areas from 1970 to 2010 could be obtained from remote sensing data, the urban areas from 1940 to 1960 and the urban areas for 2020 could not. For the period of 1940 to 1960, there is a lack of remote sensing data and to obtain vector data from analogically mapped information is extremely hard and the results are extremely poor in terms of quality in comparison to remote sensing image data, even when it does not have a high resolution. For 2020, there is a lack of official statistical data to define urban areas. This specific lack of data represents a limitation for the estimation of the urban areas for these periods. For 1940 to 1960, the solution adopted was to estimate the urban areas proportionally to the household data according to the demographic census and the historical evolution of the core urban localities (IBGE, 1951; GEIGHER; SANTOS, 1954; IBGE, 1955; SOARES, 1962; IBGE, 1968; AMADOR, 1997). For 2020, urban areas were estimated by the linear regression of the annual growth rates of urban areas from 1970 to 2010.

Estimation of direct interference of urban areas on freshwater resources – rivers and channels

The estimation of the direct interference of urban areas on freshwater resources was obtained by geoprocessing techniques. In this study, we consider freshwater resources from some selected rivers and channels of the GBHB, which corresponds to about 70% of the total discharge of the hydrographic basin. The layers of the urban areas estimated for each decade by remote sensing data processing were set as the clip features of the official vectors of hydrographic data (IBGE, 2018). This process was applied to the estimation of freshwater with direct interference of urban areas from 1970 to 2010. For the period from 1940 to 1960, the freshwater with direct interference from the urban areas was estimated proportionally to the estimate of the urban areas for these periods. The results are compatible with a cartographic scale of 1:25,000 (i.e., 25 meters of spatial resolution).

Integration of geographic data with official environmental, social, and economic indicators

The official statistics were converted when necessary and defined as indicators referring to environmental, social, and economic dimensions according to the United Nations Commission on Sustainable Development’s framework for sustainable development indicators (UNCDS, 2007). The institutional dimension of sustainable development can be observed in all of the three other ones, and it represents the governmental purposes and public policies of environmental protection and socioeconomic well-being. The selected indicators were for environmental dimension: biochemical oxygen demand – concentration (cBOD), and households connected to sanitation facilities - sewage system; social dimension: total urban population; economic dimension: total Gross Domestic Product of the municipalities (GDP-M), and minimum wage. These indicators were obtained from water quality monitoring data, census data, and economic statistics data (IBGE, 1951; IBGE, 1955; IBGE, 1968; IBGE, 1975; SANERJ, 1975; IBGE, 1983; FEEMA, 1987; IBGE, 1994; FEEMA, 2000; IBGE, 2000; IBGE. 2010; INEA, 2018; INEA, 2019; IPEA, 2020).

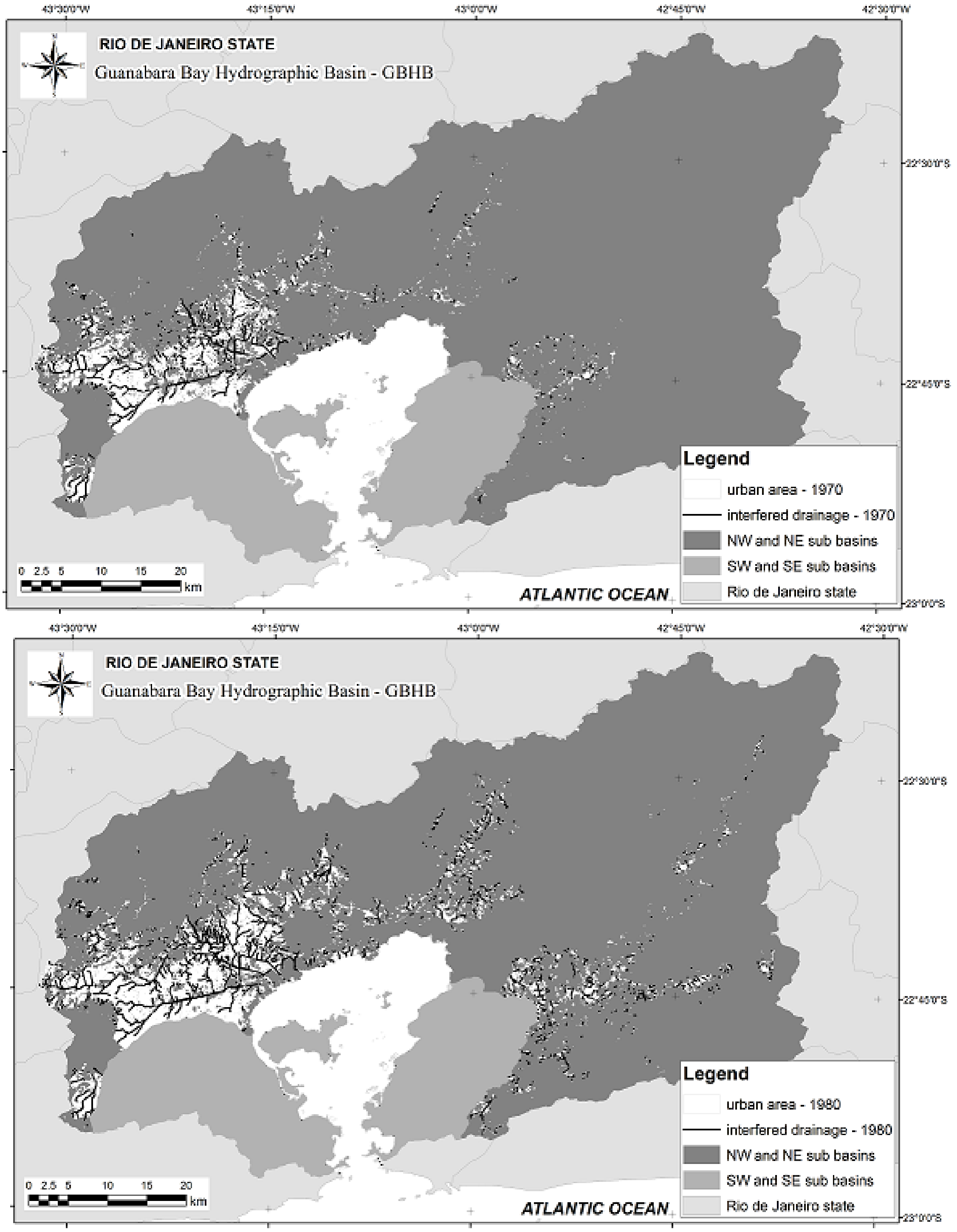
The integration of geographic data (urban areas and interfered drainage) with the indicators was done by a process of table matching on GIS, only for the indicators whose territorial reference is known (cBOD, households connected to sanitation facilities, urban population and GDP-M). The cBOD refers to rivers and was converted to mean values for all selected rivers. Minimum wage is the minimum value of labor remuneration, and it is determined annually by the Brazilian government. All indicators, except the cBOD mean values, refer to the decades between 1940 and 2010. The cBOD refers to the period from 1970 to 2010. To fill the blanks on indicators, data were estimated using data from mathematical methods (logistic growth, linear regression, proportionalities) or data from years close to each selected time sample were used. The results of this proposed integration permits the analysis of urbanization and its environmental and socioeconomic corollaries.

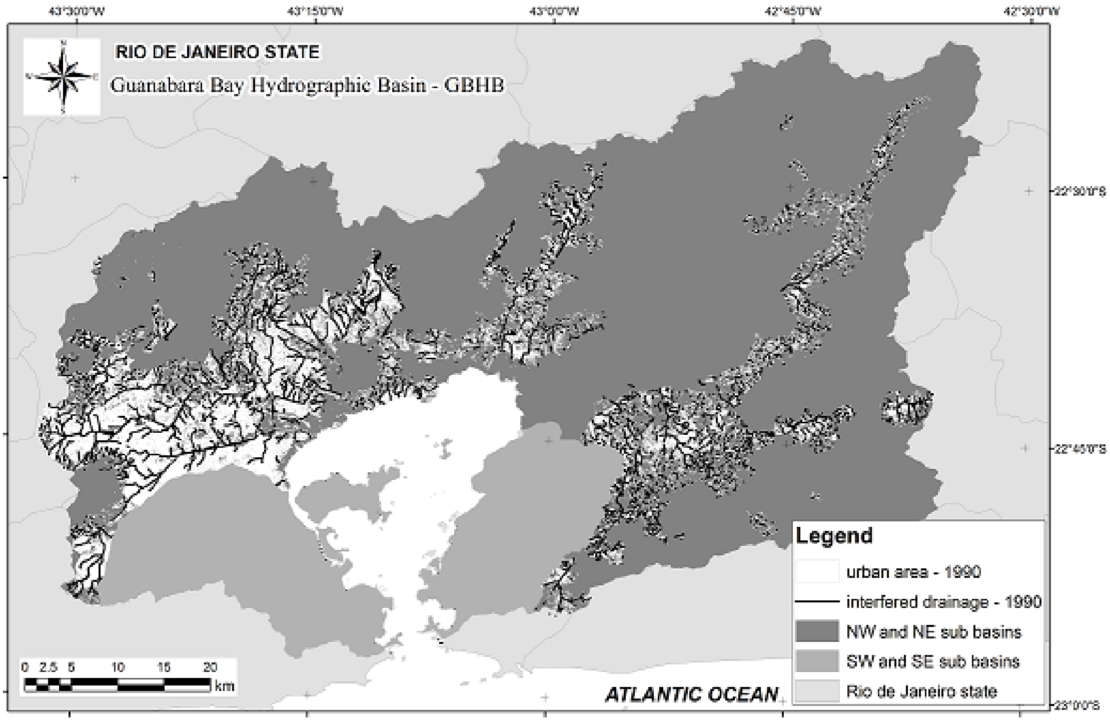
Results and discussion

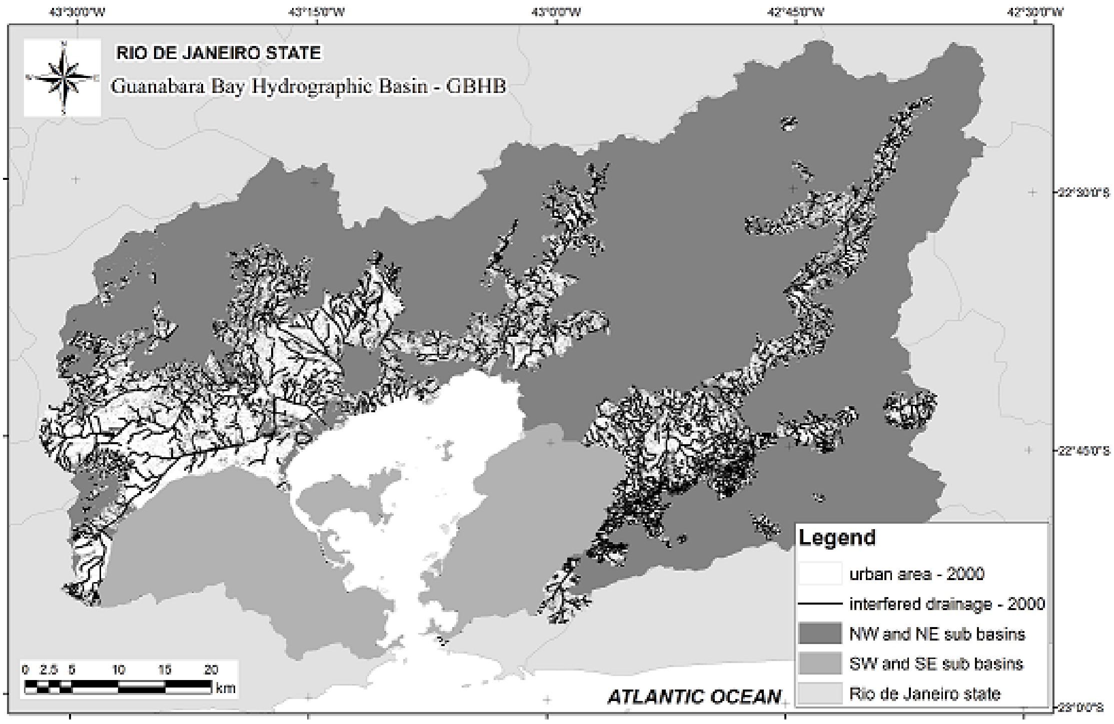
Estimation of urban areas

The different mapped urban areas from 1970 to 2010 are presented in Figure 2. The main pattern of urban expansion that could be identified is the areal increase from plane areas towards high altimetric elevations. The integration of sparse urban locations as well as the massive urban areas of central sites became intense during the course of the period. The latter are integrated by highways, the main vector of land use changes of the GBHB region since the second half of the 20th century (ABREU, 1997). By 1990, urban areas reached the high altimetric elevations, towards the boundaries of the GBHB, and Guanabara Bay became almost surrounded by urban areas. Exceptions are due to protected areas with legal restrictions, located in the plane areas of the northeastern sub-basins.

Figure 2: Urban areas and interfered drainage evolution. A. decade of 1970; B. decade of 1980; C. decade of 1990; D. decade of 2000 and E. decade of 2010




RIO DE JANEIRO STATE
Guanabara Bay Hydrographic Basin - GBHB
Legend
urban area - 1990
interfered drainage - 1990
NW and NE sub basins
SW and SE sub basins
Rio de Janeiro state
ATLANTIC OCEAN
km


RIO DE JANEIRO STATE
Guanabara Bay Hydrographic Basin - GBHB
Legend
urban area - 2000
interfered drainage - 2000
NW and NE sub basins
SW and SE sub basins
Rio de Janeiro state
ATLANTIC OCEAN
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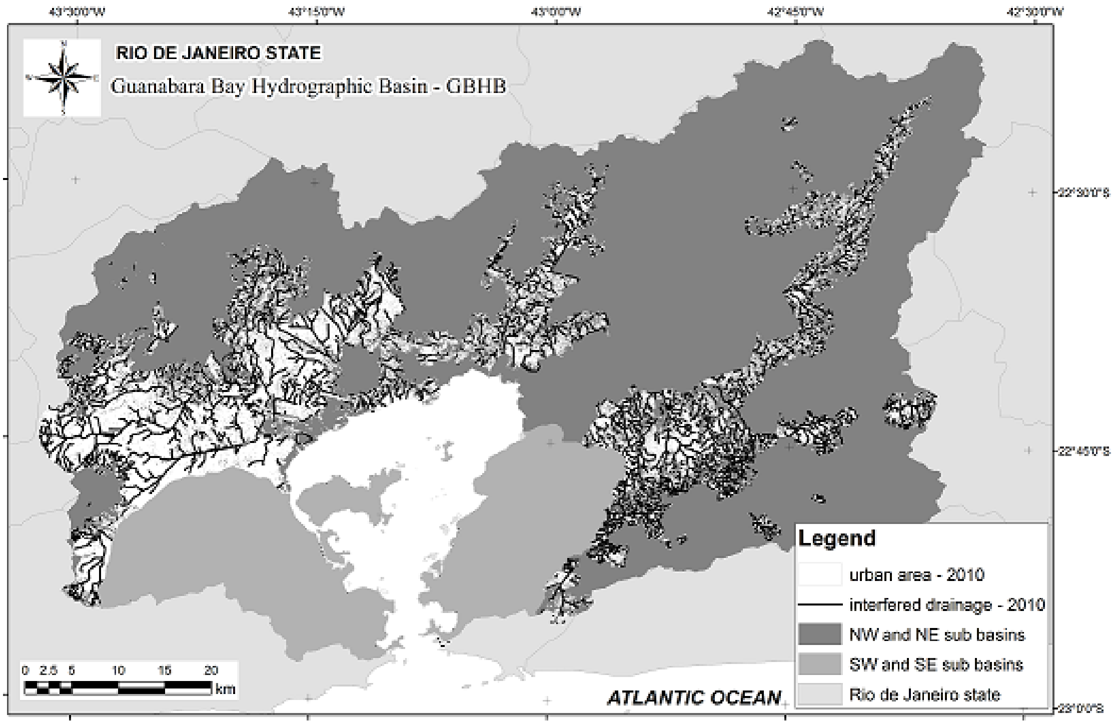


Urban areas represented 10.5 km² in 1940 and 621.6 km² in 2020. In 1940, less than 0.5 percent of the total studied area was occupied by urban structures, mainly households. With the beginning of the industrialization in the region (GEIGHER; SANTOS, 1954; SOARES, 1962), the urban areas grew faster in the two next decades, 11.5% per year in the 50s and 15.2% per year in the 60s. By the decade of 1970, urban areas experienced a deceleration of their growth rates, and at present they are reaching stable levels. The mean growth rate was estimated at 5.3%. The methodology employed does not consider a verticalization process, which can explain the verified stability. By 2020, 25.8% of the total studied area has urban structures and about 29% of the total studied area is considered as protected areas of biodiversity conservation, as previously stated. Table 2 presents the urban areas estimated in each decade with their derived indicators.

Table 2: Urban areas and derived indicators for each decade

Decade	Urban areas		
	Area (km²)	Percent of total area	Annual growth rate (%)
1940	10.5	0.4	-
1950	31.2	1.3	11.5
1960	128.4	5.3	15.2
1970	208.3	8.6	5.0
1980	326.0	13.5	4.6
1990	443.9	18.4	3.1
2000	592.8	24.6	2.9
2010	609.3	25.3	0.3
2020	621.6	25.8	0.2

Estimation of direct interference of urban areas on freshwater resources – rivers and channels

According to the maps presented in Figure 2, the interfered drainage is intensive in the plane areas of the GBHB. As urban areas increase from plane areas to high altimetric elevations, interfered drainage has the same trend, towards low interfered or non-interfered freshwater resources. Similar to the results of urban areas, the freshwater resources directly interfered by urban areas have absolute results, in terms of length, and some derived indicators. Being related to urban areas, growth rates are equal for the decades of 1950 and 1960, and present a decreasing trend for the period of 1970 to 2020. In 2020, the drainage interfered by urban areas was estimated at 1,218.2 kilometers, about 18.1% total drainage length (6,711.3 kilometers) of the studied area. Significant part of freshwater resources are part of protected areas of biodiversity conservation estimated at 3,129.2 kilometers. The interfered drainage provides important data to manage and evaluate the resilience of freshwater resources facing pollution effects. This indicator is also useful in estimating the loss of forest cover and riparian vegetation. More information can be found in Table 3.

Table 3: Drainage directly interfered by urban areas and their derived indicators

Decade	Freshwater resources direct interfered by urban areas – selected rivers and channels		
	length (km)	Percent of total drainage	Annual growth rate (%)
1940	11.3	0.2	-
1950	33.6	0.5	11.5
1960	137.9	2.0	15.2
1970	223.9	3.3	5.0
1980	498.0	7.4	8.3
1990	736.6	11.0	4.0
2000	1114.6	16.6	4.2
2010	1194.1	17.8	0.7
2020	1218.2	18.1	0.2

Integration of geographic data with official environmental, social and economic indicators.

The integration of geographic data with the indicators provides an analysis of the trends of urban phenomena on dimensions of environmental, social and economic sustainable development applied to the GBHB area. The institutional dimension can be observed in all the other ones, being a result of the government's role on sustainability (UNCDS, 2007). To propose a system of indicators for the GBHB is not the objective of this study. Here, the intention was to demonstrate with indicators how unplanned urbanization and inefficient public policies can be understood as drivers for the depletion of the environment and of the humanitarian situation. Table 4 presents the group of indicators and the detailed results estimated for each decade.

Table 4: Indicators related to geographic data - urban areas and interfered drainage

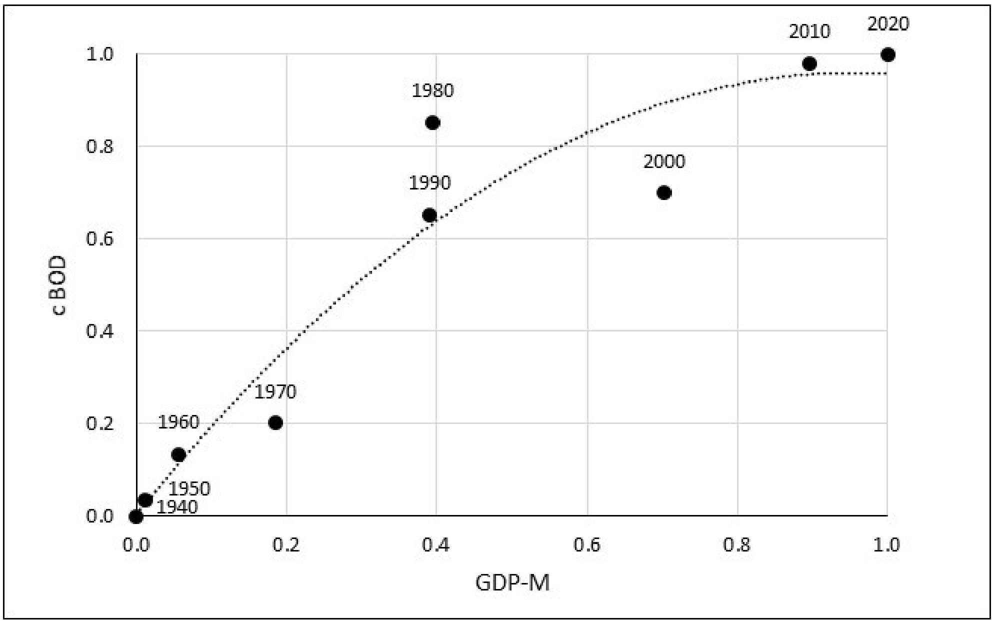
Decade	Environmental dimension		Social dimension	Economic dimension	
	cBOD (mg.l-1)	Households with sewerage (%)	Urban Population (inhab.)	GDP-M (1,000 US$)	Minimum wage (US$)
1940	2.5	3.4	95,695	112,299	326.4
1950	2.8	5.1	219,985	298,068	487.6
1960	3.7	10.0	562,138	961,058	529.9
1970	4.3	10.0	1,340,015	2,871,055	417.6
1980	9.9	20.0	2,025,771	5,999,973	378.9
1990	8.2	20.0	2,547,766	5,932,434	245.2
2000	8.6	26.0	3,157,961	10,586,369	341.8
2010	11.0	25.0	3,332,459	13,483,051	515.5
2020	11.2	47.1	3,421,253	15,024,809	571.0

The environmental dimension presents the indicators for cBOD and households with sewage facilities, relative to the total households. Both are connected to the efficiency of public policies of sanitation defined for the municipalities. The cBOD values can be evaluated in terms of interference of urban areas on freshwater resources, water quality and, in an indirect manner, in terms of access to sanitation facilities. Interfered freshwater resources and cBOD indicators had a high correlation (Spearman test rho value = 0.95, significant at 0.05). Regarding the water quality, the cBOD values estimated for the decade of 1970 are greater than the Brazilian directives for waters that could be useful after conventional treatment techniques – 5.0 $mg.l^{-1}$. In 1980, the cBOD values are compatible to the worst cBOD limits for freshwaters – 10.0 $mg.l^{-1}$ (CONAMA, 2005). By the decade of 2010, the organic matter concentration in the GBHB rivers and channels acquires an increasing trend. The return to satisfactory conditions could be a hard task for the governments and requires a robust financial investment (BIDONE; MADDOCK; CASTILHOS, 2002). In terms of access to sanitation facilities, the mean annual growth rate of households connected to sewerage is 1.3% per year, derived from the results presented in Table 4. This rate is 4 times lower than the growth rate of the urban areas, which demonstrates deficient sanitation public policies. A recent study demonstrated that each 1 US$ destined to sanitation improvement generates about US$ 7 on well-being (HUTTON, 2013). Households connected to sewerage and cBOD indicators showed a high correlation (Spearman test rho value = 0.93, significant at 0.05).

The social dimension is represented by the urban population indicator. From 1940 to 2020, urban population had a mean annual growth rate estimated at 4.6% per year. From 1950 to 1970, the mean annual growth rate was about 9.2% per year. This high rate can be associated with a migrant population due to the improvement of industrial and service activities and more job opportunities (ABREU, 1997). During the period of 1940 to 2020, the mean annual growth rate of the urban population was 3.5 times greater than the mean growth rate estimated for the households' sewerage access. The environmental and social indicators demonstrate that the GBHB region suffers from both a deficit as well as from inequalities in the access to sanitation facilities. Other studies also corroborate the notion that inefficient public policies are an important factor (MARQUES, 1996; QUINTSRL; BRITO, 2014; QUINTSRL, 2018).

The economic dimension, especially the indicator GDP-M (sum of the municipalities' GDP), can be identified as the metrics of well-being of the population, in a classical economic approach (HARRISON, 1989; PESKIN, 1991; CONSTANZA et al., 2007). Values are expressed in US dollars for the year 2000 because the indicator expressed in BRL is related to 2000 values (IPEA, 2020). The absolute values of GDP-M indicate that the GBHB has a rising trend of income growth (mean growth rate of 6.4% per year). Here, we propose the use of this indicator paired to the environmental indicator the cBOD. Figure 4 presents a graph with these two indicators plotted by decade. This graph communicates that both GDP-M and cBOD have increasing trends during the period 1940-2020 and the main interpretation of this graph is that in the GBHB, the wealth of the region has an important environmental counterpart: the growing trend of freshwater pollution (Spearman test rho value = 0.98, significant at 0.05). This tendency can be translated as environmental inequalities in terms of freshwater access and the decreasing trend of freshwater quality. In other words, wealth metrics do not consider environmental depletion and associated costs (BIDONE; MADDOCK; CASTILHOS, 2002; CONSTANZA et al., 2007).

Figure 4: Total GDP of municipalities vs. cBOD, for each decade. Values of indicators are normalized.



Minimum Wage is not an indicator of sustainable development as recommended by the UNCSD. GDP *per capita* is the recommended indicator of a society´s income (UNCDS, 2007). However, a significant portion of the urban population of the GBHB has no income or less than two

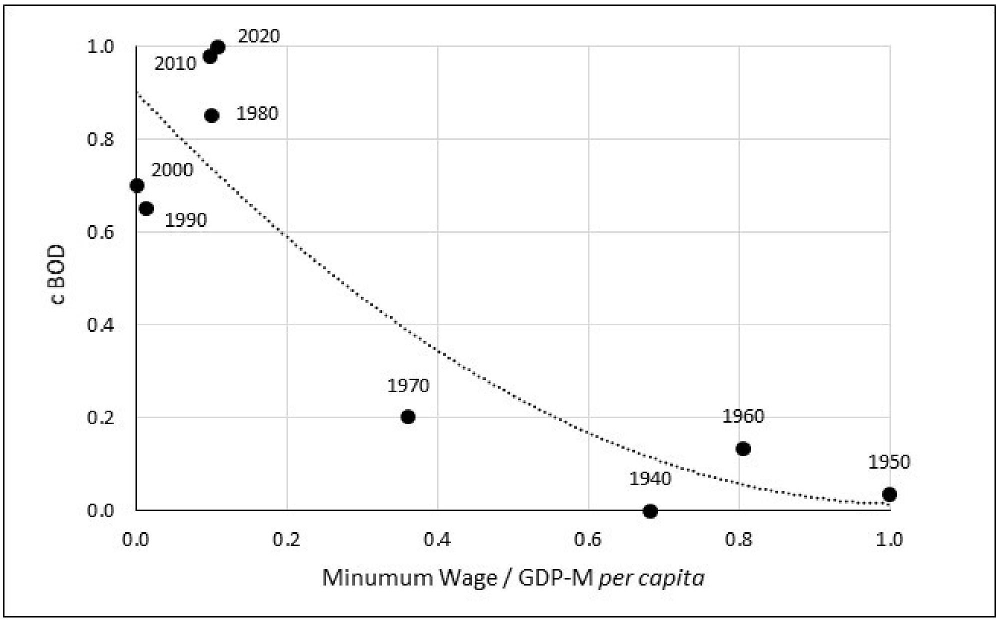
Minimum Wages. Thus, the adoption of a more realistic income indicator applied to the real conditions of the urban population of the GBHB is reasonable. Table 5 presents the two indicators here discussed referring to the GBHB region: GDP-M *per capita* and the alternative indicator for income metrics here proposed, the ratio Minimum Wage (data from Table 4) and GDP-M *per capita* (PAES-DE-BARROS et al., 1996).

Table 5: GDP-M *per capita* and Minimum Wage and GDP-M *per capita* ratio

Decades	GDP-M per capita (US$)	Minimum Wage and GDP-M per capita ratio
1940	1,173.5	0.28
1950	1,354.9	0.36
1960	1,709.6	0.31
1970	2,142.6	0.19
1980	2,961.8	0.13
1990	2,328.5	0.11
2000	3,352.3	0.10
2010	4,046.0	0.13
2020	4,391.6	0.13

The indicator GDP-M *per capita* has similar trends to the total GDP-M, and in a classical point of view, income of the GBHB population is increasing, despite other environmental and socioeconomic issues. However, the indicator Minimum Wage and GDP-M *per capita* ratio reveals important inequalities in terms of income. Minimum Wage represented less than 50% of the GDP-M during the entire period, and since 1970, less than 20% of GDP-M *per capita*. This indicator means that the GBHB region exhibits an increasing trend of poverty. Figure 5 presents a graph with the relation between income inequality, revealed by the evolution of Minimum Wage and GDP-M *per capita* ratio, and environmental inequality as a function of freshwater quality depletion, the increasing trend of organic matter on freshwaters measured by the indicator cBOD.

Figure 5: Minimum Wage and GDP-M *per capita* ratio and cBOD for each decade. Values of indicators are normalized



The graph presented on figure 6 has at least three fundamental interpretations. The decades of the 1940s, 1950s and 1960s had less income and environmental inequalities, even though these periods presented the higher increments on urban areas and the urban population. From 1980 to 2020, a cluster of high income and of environmental inequality can be observed. The 1970s can be considered a decade of transition in terms of income and environmental inequalities.

Conclusion

The integration of geographic data and indicators provides a complex analysis of the evolution of urbanization in the GBHB and its environmental and socioeconomic corollaries. During the period 1940-2020, the increasing of urban areas, urban population, and GDP-M (total and *per capita*) could explain the transition of land use, demographic and economic forces of the region, from an agricultural economy to an urban and industrial economy. Migrations had an important role on the demography of the region. Also, during the same period, environmental corollaries of urbanization could be associated with deficient public policies of urban planning and sanitation improvement, which resulted in loss of water quality, forestry and riparian vegetated areas. Socioeconomic corollaries could be associated with the fact that income inequality kept increasing during the entire period and contributed to gentrification and residential segregation in the GBHB dynamics.

The study concluded that unplanned urbanization and inefficient public policies depleted the environment and human condition in an increasing trend, making the GBHB an interesting local case where these elements of Anthropocene theory were verified.

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