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Urban Environmental Quality Index Applied to the Popuca-Botinhas and Pedrinhas Watersheds in the Municipality of Guarulhos – SP

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ABSTRACT
The concept of urban quality of life describes the ideal conditions of inhabitable space in terms of comfort. The Brazilian Constitution foresees quantitative and qualitative diagnoses of space aiming at equal conditions for individuals in the city. Thus, applying environmental indicators is an important and effective tool for understanding the environment of the city, being used in decision-making for public policies. This study aimed to evaluate the environmental quality in the region of the Popuca-Botinhas and Pedrinhas river basins, in the Municipality of Guarulhos, SP, using Urban Environmental Quality Index – UEQI. The UEQI was created by crossing the indicators of Sanitary Sewage, Origin of Supply, Garbage Collection, and Environmental Conditions. Each indicator generated a georeferenced thematic map capable of interpreting its behavior. These maps were integrated to compose the thematic map. The results showed that the critical environmental quality of the sub-basins region is linked to uncontrolled urban development. Districts such as Jardim Nova Cumbica, Jardim Arapongas, and Jardim Vermelhão had low UEQI, highlighting urgent need for improvements by public authorities.

KEYWORDS: UEQI. Environmental Quality. Environmental Indicator.

1 INTRODUCTION

In general, the urban population in Brazil has grown disproportionately compared to the quality of the infrastructure in the country. In metropolitan regions, such as the São Paulo Metropolitan Region (RMSP), the range of professional and social opportunities motivates inappropriate occupations. Although population growth has slowed in recent years, urban development is still on the rise. In the state of São Paulo, home to around 22% of the national population, it is estimated that around 96% of the population lives in areas considered to be urban (IBGE, 2011).

The municipality of Guarulhos is part of the São Paulo Metropolitan Region (SPMR) and has undergone a process of disorderly growth not unlike other regions of the country, where the occupation of space has always started from a plain close to the main tributary of a micro-basin, heading towards the periphery, where springs are located (OLIVEIRA et al., 2006).

The constant need to accommodate citizens, especially those affected by social vulnerabilities, leads to the use of areas that are unsuitable for housing occupation, such as spring areas, among other spaces. These occupations usually involve invasions. Such a scenario reflects aggression against the natural system due to socio-economic need (MATTOS, 2005), and it is only inevitable that such occupations will result in habitable spaces, but with no guarantee of urban quality of life.

Quantitatively and qualitatively diagnosing a habitable space creates important elements for discussing the quality of life in cities, helping with strategic decisions for the proper occupation of urban spaces. It is also worth having an evaluation tool that allows us to measure whether the efforts made in this regard have been enough to achieve urban and e nvironmental quality of life (DIAS et al., 2011)

Based on the tools applied elsewhere to understand the quality of life in the city, developing the Urban Environmental Quality Index (UEQI) emerges as a viable proposal, integrating important elements for discussing the condition of habitable space in cities, as well as contributing to several of the goals of the 2030 Agenda, such as Health and Well-Being, Potable Water and Sanitation, and Sustainable Cities and Communities. Accordingly, this study aimed to assess the environmental quality of the Popuca-Botinhas and Pedrinhas sub-basins in

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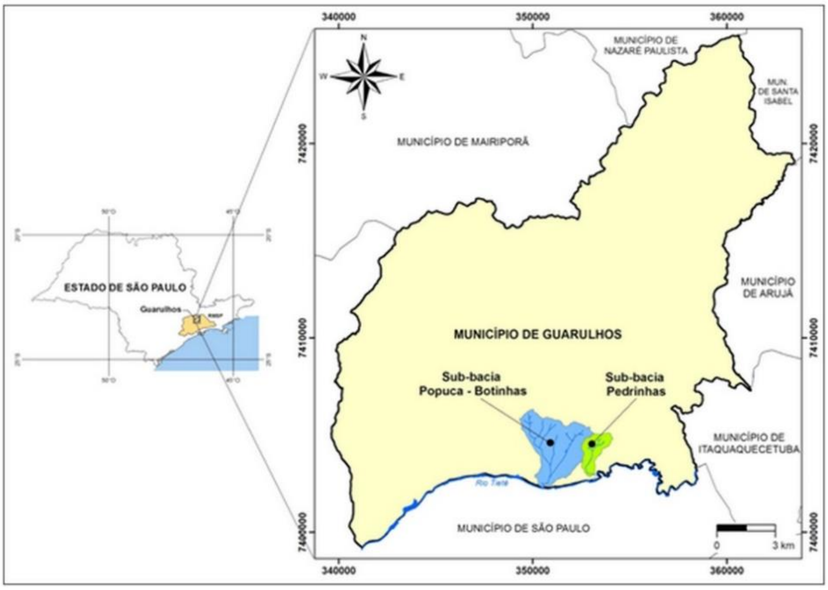
the municipality of Guarulhos, in the São Paulo Metropolitan Region, by creating and applying the Urban Environmental Quality Index (UEQI). Our aim in this study was not only to create an index and better understand the environmental quality in the lives of residents living in these watersheds in the city of Guarulhos, but also to propose a tool that could be applied to other regions, enabling public authorities to be provided with knowledge that contributes to formulating public policies and making decisions.

2 MATERIAL AND METHODS

2.1 Study area

The Popuca-Botinhas and Pedrinhas sub-basins are part of the Alto Tietê river basin (Figure 1). The Popuca-Botinhas sub-basin covers an area of 8.6 km^2, with a maximum altitude of 800 m and a minimum of 720 m. This sub-basin is named after the Popuca and Botinhas watercourses. The area covers the following districts: Cidade Industrial Satélite de Cumbica, Cidade Jardim Cumbica, Parque Uirapuru, and Vila Nova Cumbica. The Pedrinhas sub-basin covers an area of 4.7 km^2, with a maximum altitude of 830 m and a minimum of 720 m (OLIVEIRA et al., 2006). The Pedrinhas watercourse gives the sub-basin its name. It contains the following districts: Jardim Arapongas, Jardim Bela Vista, Jardim Brasil, Jardim Centenário, Jardim Dona Luiza, Jardim Leblon, Jardim Monte Alegre, Jardim Paulista, Jardim Pimentas, and Jardim Santo Afonso.

Figure 1 – Location of the Popuca-Botinhas and Pedrinhas sub-basins, Guarulhos (SP).



Source: Elaborated by the author.

2.2 Urban Environmental Quality Index

The Urban Environmental Quality Index (UEQI) was designed to analyze the environmental quality of the area studied. The index was based on indicators of environmental

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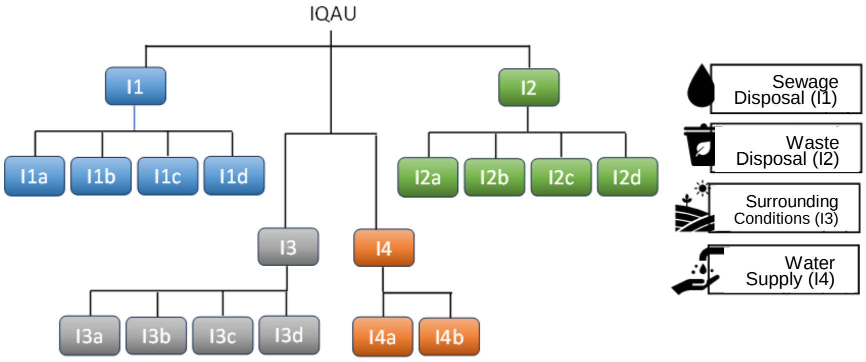
conditions, infrastructure, and urban services, with different weights depending on their ability to affect surface water quality. The following indicators were selected: sewage disposal (I1), waste disposal (I2), surrounding conditions (I3), and water supply (I4). Each indicator consisted of sub-indicators (Figure 2; Table 1).

Figure 2 – Urban Environmental Quality Index with its indicators and respective sub-indicators.



Source: Elaborated by the author.

Weight 1 was assigned to households using sewage service (I1a) and weight 0 to the others. For the Destination of garbage indicator (I2), weight 1 was also assigned to households using garbage collected by a cleaning service or skip (I2a) and weight 0 to the others. A weight of 0.25 was assigned to each sub-indicator for the Indicator Conditions of the surroundings (I3). The Water Service Indicator (I4) was assigned a weight of 1 for households using the general water distribution network (I4a) and a weight of 0 for the others.

Table 1 – Indicators and Sub-indicators used to compose the UEQI.

Indicators	Sub-indicators			
Sanitary sewage (I1)	Sewerage service (I1a) – households connected to a sewer or drainage system, even without subsequent treatment.	Ditch drainage (I1b) – households connected to an open ditch.	Drainage via a water body (I1c) – households connected to a water body.	Other means of sewage disposal (I1d) – households connected to septic tanks, rudimentary tanks, or other means of sewage disposal.
Waste disposal (I2)	Collected by a cleaning service or in a cleaning service skip (I2a) – waste collected by a service or deposited in a skip for collection by a public or private company.	Thrown on waste ground or public place (I2b) – waste thrown on waste ground or public place.	Thrown into a water body (I2c) – waste thrown into a water body.	Other means of disposal (I2d) – waste with a destination other than those already described (burned, buried, or other).
Surrounding conditions (I3)	Open sewage (I3a) – the face or side of the dwelling with a ditch, stream, or body of water where sewage is discharged; or a ditch where open sewage flows.	Accumulated garbage (I3b) – face or side of the dwelling with a place where garbage is deposited and accumulated.	Paving (I3c) – in the stretch of road, on the side covered, there is paving covered by asphalt, cement, cobblestones, stones, etc.	Afforestation (I3d) – the presence of trees along paved or unpaved stretches, sidewalks/walkways, and/or in the median that divides lanes of

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				the same street, even if only partially.
Water service (I4)	Service by the general water distribution network (I4a) – household, land, or property connected to a general water distribution network.	Other means of supply (I4b) – water supply from a well or spring outside the property, water tanker, stored rainwater, river, dam, lake, stream, or other means of supply.		

Source: Elaborated by the author.

The information on the Indicators and Sub-Indicators comprising the UEQI was gathered from the "Database of the 2010 Demographic Census: Results of the Universe by Census Sector"). The Household Data Table (IBGE, 2011) provided the data for the Sanitary Sewerage, Waste Disposal, and Water Supply indicators. The Data Table - Surroundings File 01 was used for the Surroundings Conditions Indicator (IBGE, 2011).

Each indicator was calculated as the arithmetic mean of its sub-indicators, according to Equation 1: In = (Ia+Ib+⋯+Ix)/n, where In is the calculated indicator and Ia,..., Ix is the sub-indicators used, and n is the total number of sub-indicators for the indicator analyzed.

The indicators were calculated according to Equation 2: Ix = (n/t), where Ix is the indicator analyzed, n is the number of households in each census tract, and t is the total number of households in each census tract.

The Afforestation Sub-Indicator (I3d) was calculated according to Equation 3: I3d= (A_{veg}/A_t), where I3d is the Afforestation Sub-Indicator, A_{veg} is the area of tree vegetation calculated for each census tract, A_t is the total area of each census tract.

These results were classified according to Oke (1973), who classified areas with vegetation cover of 30% or more of the total area assessed as ideal (index = 1), and areas with tree cover of less than 5%, typical of a desert, as critical (index = 0). Areas classified as having between 5% and 30% tree cover had their indices interpolated according to the percentage of tree cover found.

The final calculation of the UEQI consisted of adding up the values for each indicator multiplied by their respective weight (Equation 5). The Hierarchical Analysis Process (HAP) was applied to distribute the weights of the indicators comprising the UEQI. This process used Saaty's (2008) weighting scale with their respective consistency rates (acceptable when < 0.10). On this scale, the weights vary in terms of degree of importance: from 1 to 9 for the most important and from 1/3 to 1/9 for the least important. In composing the Initial Weighting Matrix, the scale was applied by observing the relationship between each Indicator analyzed and the respective related Indicator. Ten environmental management professionals weighted each Indicator, and the average of the answers was extracted, thus deriving the values of the initial matrix (Table 2).

Table 2 – Initial weighting matrix of indicators by the PAH method.

Indicators analyzed	Related Indicators			
	I1	I2	I3	I4
Sanitary sewage (I1)	5	7	7	1
Waste disposal (I2)	3	1	5	1
Surrounding conditions (I3)	7	9	1	5
Water supply (I4)	1	1	5	1
Vertical sum	16	18	18	8

Source: Elaborated by the author.

For each cell, a representative weight was obtained based on the sum of all the values in the columns, represented by the line called "Vertical Sum" (Equation 4): PAH cell weight = ((Cell Value)/(Vertical Sum)). The weights found were added together and consolidated in the Final Weighting Matrix (Table 3).

Table 3 – Final Matrix of Weighting of Indicators by the PAH Method.

Indicators	I1	I2	I3	I4	Horizontal sum
Sanitary sewage (I1)	0.31	0.31	0.39	0.13	1.14
Waste disposal (I2)	0.19	0.06	0.28	0.13	0.72
Surrounding conditions (I3)	0.44	0.56	0.06	0.63	1.68
Water supply (I4)	0.08	0.06	0.28	0.13	0.53
Vertical sum					4.07

Source: Elaborated by the author.

The weighting was completed by re-applying Equation 4 to the horizontal sum column of the Final Weighting Matrix (Table 3), yielding the final weights for each Indicator (Table 4).

Table 4 – Final weighting by UEQI indicator.

Indicator	Weight
Sanitary sewage (I1)	0.28
Waste disposal (I2)	0.16
SurroundingY conditions (I3)	0.42
Water supply (I4)	0.14

Source: Elaborated by the author.

Table 5 shows the partial indices and the weight of the indicators. The UEQI is calculated from the sum of these products, as shown in Equation 5: IQUA=I1*28+I2*16+I3*42+I4*14.

Table 5 – General outline of the proposed system of indicators and their respective weights.

Indicators	Partial Indices	Weight of indicators
Sanitary sewage (I1)	0 - 1	28
Waste disposal (I2)	0 - 1	16
Surrounding conditions (I3)	0 - 1	42
Water supply (I4)	0 - 1	14

Source: Elaborated by the author.

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Finally, the UEQI results were classified according to the Urban Environmental Quality level in Table 5.

Table 5 – Classification of the Urban Environmental Quality Index.

UEQI Value	Level of urban environmental quality
86-100	Excellent
66-85	Good
51-65	Intermediary
31-50	Bad
0-30	Very bad

Source: Adapted from Dias et al. (2011).

2.3 Map creation

For the Land Use and Occupation Map and each Indicator, the Census Sector (CS) was established as the geographic unit, which is the smallest territorial unit, formed by a continuous area, entirely contained in an urban area, with a size suitable for carrying out surveys and with a set of sectors covering the entire study area.

The data for the UEQI Indicators by CS were spatialized in a Geographic Information System (GIS) environment, using the "2010 census tract grid", available in shapefile format by IBGE (2011). ArcGIS 10.2 was used, and the micro-basins studied were mapped by the Maximum Likelihood classifier (MAXVER). It is based on statistical criteria of mean, variance, and covariance so that the calculation estimates the probability of a pixel belonging to a predefined class (training samples) (JENSEN, 2005). The training samples were the 17 types of geometric land cover pattern and their combination, according to Stewart & Oke (2012). They were based on multispectral orbital images corresponding to the violet, visible, and near-infrared bands of the WorldView-3 satellite from October 2016. This same image base was used to determine the vegetation cover of the watersheds studied (Sub-indicator I3d).

The kappa index - k - assessed the accuracy of the tree cover map classification, Equation 6: k = N ∑ Xii - ∑ Xi+ X+i / N2- ∑ Xi+ X+i, where Xii is the observed agreement; Xi+ and X+i (product of marginals) is the expected agreement, and N is the total number of elements observed. The measure of difference and the probability of agreement between the reference and classification values are calculated from reference areas (n) randomly distributed in the image (CONGALTON & GREEN, 2009). The reference areas used were 50 polygons (CONGALTON, 1991) representing this class, seen in the high spatial resolution images from the Google Earth Pro software (FERREIRA et al., 2017).

2.4 Fieldwork

We visited the micro-watersheds studied to document the information gathered from the IBGE data and learn how the indicators appeared in the study area. This consisted of touring the region and photographing the conditions of the indicators in situ.

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3 RESULTS AND DISCUSSIONS

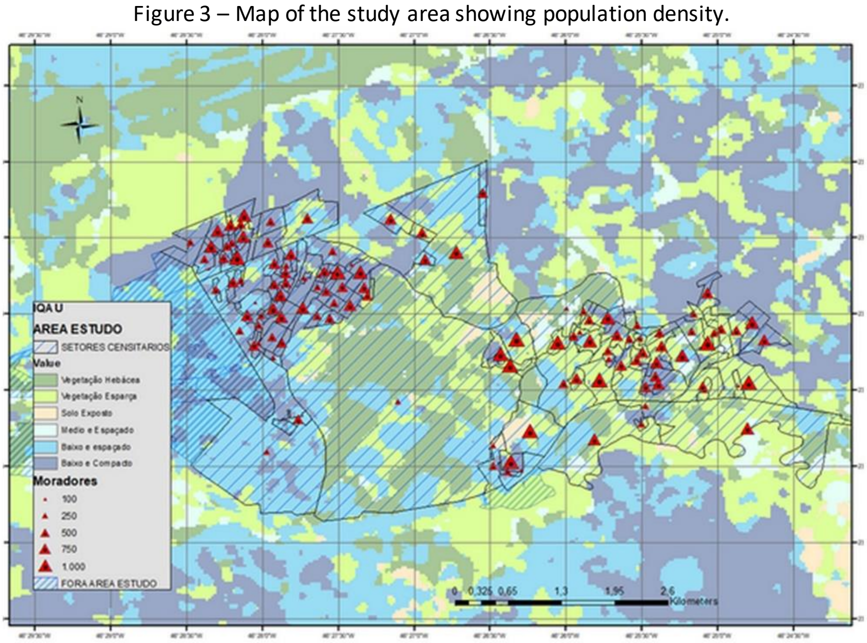
The Use and Occupation Map of the Popuca-Botinhas and Pedrinhas sub-basins showed a large extent of low and compact land cover, especially in the eastern and northern sectors of the study area (Figure 3). By associating the type of soil cover with population density, population density is high in regions classified as low and compact. The herbaceous vegetation cover type appeared more in the center, as did the low and spaced cover type (Figure 3). This region is characterized by heavy truck traffic that supplies the activities of the industrial warehouses found in large numbers in the region (Figure 4). In addition, the demographic density is low in these areas, since there is little housing occupation on the site.

The Sanitary Sewerage, Waste Disposal, and Water Supply Indicators are presented first, as they have a less complex analysis and are correlated with the sub-indicators required to formulate the Surrounding Conditions Indicator Figure 5).

The Sanitary Sewage Indicator showed a small portion of the studied area belonging to the good or excellent classification, i.e. few households in the study region have sewage collection infrastructure (Figure 5). Three locations had very low values and were classified as very bad, including the area around Rua Cararu, in the Jardim Arapongas neighborhood.

The terrain here facilitates the dumping of waste into the environment. There is a slope to the land on the south side of the street, where the buildings are below street level, causing waste to be dumped at the back of the land, very close to one of the tributaries of the Pedrinhas stream. There are several irregular buildings over the water body of the tributary (Figure 6). There is also a large volume of sewage being discharged from homes into the water bodies of the tributaries in the area, and the public sewage system is not being used (Figure 6B).

Figure 3 – Map of the study area showing population density.



Source: Elaborated by the author.

The Jardim Cumbica II and Vila Nova Cumbica areas, on the banks of the Popuca stream, had very poor sewage disposal along the entire length of the stream. Land use and occupation in the region were predominantly low-rise, compact, and agglomerated homes, which are difficult to access (Figures 5 and 6C). There is a large concentration of small homes without infrastructure and sewage collection, reflecting a lack of urban planning. In many places, physical access to the homes is via alleys and lanes.

Figure 4 – Examples of A. Low and spaced cover. B Cover with sparse vegetation. C. Exposed soil.

Source: Elaborated by the author.

The Waste Disposal Indicator (Figure 5B) showed the best results in the entire study region, with optimum levels of service, except for one site with poor condition, in the Jardim Cumbica II neighborhood, specifically near Praça Imperatriz, on the banks of the Popuca stream. In this location, to the southeast, there is a large group of occupations without direct access to public roads, which hinders the correct disposal and collection of solid waste, thus explaining the outcome of the indicator in this area.

The Water Service Indicator (Figure 5C) also shows that most of the study region is covered by the water supply network, with an excellent rating. Except for the Jardim Vermelhão neighborhood, where some households had no access to water supply or sewage collection. Possibly, at the time the information was collected by IBGE (2011), not all households had paving and a water supply and sewage network, as a field visit to the neighborhood revealed it to be new and undergoing redevelopment. Some roads have been paved and water supply points have been installed. However, many houses were built without any planning, with no means of access to public services. They are located where the riparian forest of the Pedrinhas stream used to be, despite signs prohibiting the occupation of the site and fences cordoning off the forest (Figure 7).

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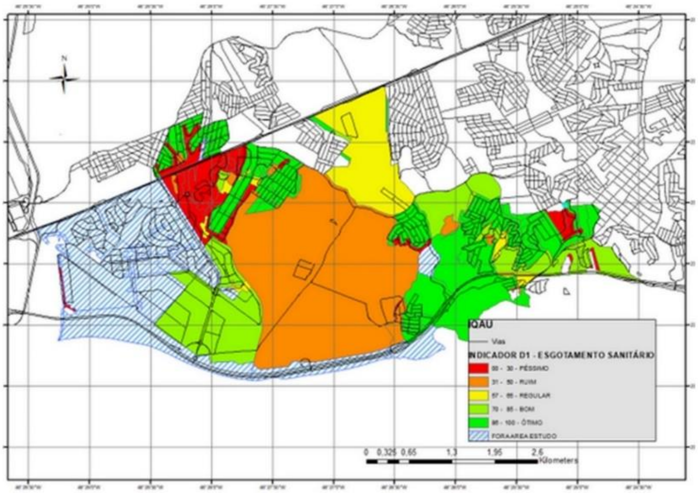
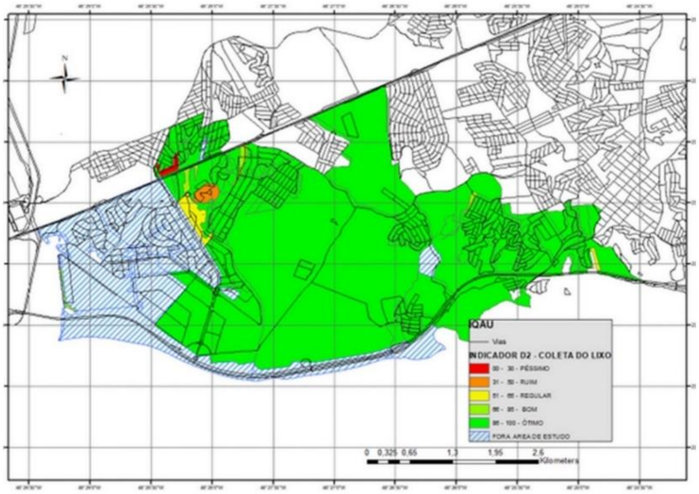
Figure 5 – Maps referring to Indicators: A. Sanitary sewage. B. Waste disposal. C. Water supply.

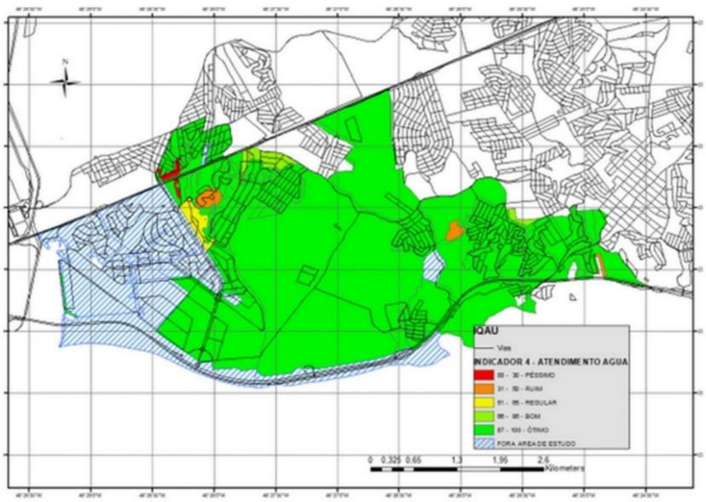
A



B



C



Source: Elaborated by the author.

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Figure 6 – A. Irregular constructions near the Tributary in Cararu Street. B. Dumping sewage directly into the Tributary in Cararu Street. C. Occupation on the banks of the Popuca stream in the vicinity of Cataguases Avenue.

Source: Elaborated by the author.

The behavior of each sub-indicator could be analyzed in detail for the Surrounding conditions indicator. The results of the first sub-indicator, open sewage, showed a much worse condition than the results of the sanitary sewage indicator (Figure 8A). Even though sewage service is available in the region, it is still inadequately provided in many places. On these sites, many of them in Vila Nova Cumbica, buildings are clustered on top of the stream itself, and household sewage is piped directly into the Popuca riverbed.

Figure 7 – A. Signposting and fencing off the riparian forest of the Pedrinhas stream. B. Irregular constructions in the riparian forest of the Pedrinhas stream.

Source: Elaborated by the author.

Regions with features like the study areas have shown that as space is occupied, poor sanitary sewage systems are installed, leading to non-use of the public service offered (FOBIL et al., 2010). In addition, communities with such conditions dispose of wastewater, with excess nutrients, in the open, which attracts insects, rats, and other disease vectors.

The land use map (Figure 3) showed the highest concentration of low-rise, compact buildings and the highest density of housing occupation in these areas, clearly exposing many people to various types of disease. Most of the buildings are multi-storage, confirming the high population density.

The result found for the open-air garbage sub-indicator (Figure 8B) showed sites with a regular rating, while the open-air sewage sub-indicator scored very poorly. The studied region has solid waste on the surface at most of the points showing open sewage problems. Some sites have deteriorated collection bins and the practice of dumping garbage directly into the stream and its tributaries.

The paving availability sub-indicator (Figure 8C) showed that most of the studied regions had a poor or very poor rating. Large areas of the region are unpaved, with alleys and streets with paving adapted to the design that the occupation has taken over time, i.e. irregular shapes, with no access to garbage collection trucks.

The score for the Arborization sub-indicator (Figure 9) revealed a critical situation, especially at the points with sanitary sewage problems, further evidence of disordered use and occupation in the region. Ferreira et al. (2017) point out that regions with a critical situation in terms of afforestation suffer flooding problems due to high surface runoff and low absorption of water by the soil. Surface water runoff in the region transports solid waste such as garbage, which is disposed of on public roads without any control.

The Surrounding conditions indicator (Figure 10) showed garbage and open sewage to be the sub-indicators that contributed most to the poor and very poor results. In addition, the map shows that the places with bad or very bad ratings match the points that had the same rating for the Sanitation indicator. These regions were also considered critical for the Sub-indicator afforestation, further accentuating the low quality of the habitable environment in those places.

The lack of urban public services and awareness among some residents suggests that the population often disposes of household waste in the wrong way, without realizing the risks to their health. Dias (2003) carried out a study in the metropolitan region of Salvador and found that surface garbage and open sewers tend to grow in some regions. Thus, such a problem can become a permanent factor in the daily lives of the urban population. Garbage disposed of improperly in the environment leads to contaminated water and soil, creating environments prone to the presence of disease-transmitting animals, impacting the lives of all residents (FUJIMOTO, 2002; FOBIL et al., 2010; YEPRINTSEV et al., 2018).

The calculation of UEQI was finalized after assessing each of the indicators separately (Figure 11). The map shows that the UEQI was very dependent on the Sanitary sewage and Neighborhood conditions indicators since the Garbage disposal and Water service indicators were in good and/or excellent condition. Esrey (1996) observed that water and wastewater services usually manage to follow population growth, whereas sewage services, in general, do not.

A considerable area of the consolidated index map presented a regular condition. The indicators of Sanitary sewage and Surrounding conditions were poor in these areas. Much of it does not consist of housing, given the low population density (Figure 3), although a very diverse group of people live here. There are many industries and/or commercial warehouses and workers from different parts of the SPMR, all in search of local opportunities. The relationship between these groups and this region exposes them to a great risk of disease contamination since there is no good urban environmental quality. Open-air garbage also contributed to the regular UEQI in the central region of the map. The presence of garbage in the area could mean that those who frequent the area lack guidance, contributing to the improper disposal of solid waste, further increasing the environmental problems in the area.

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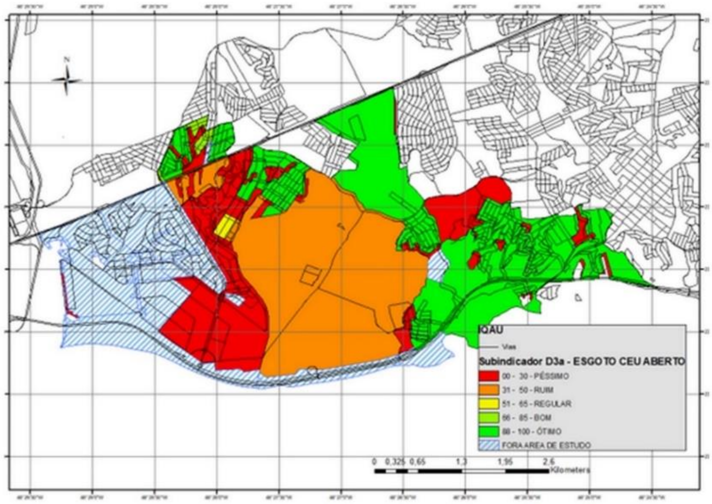
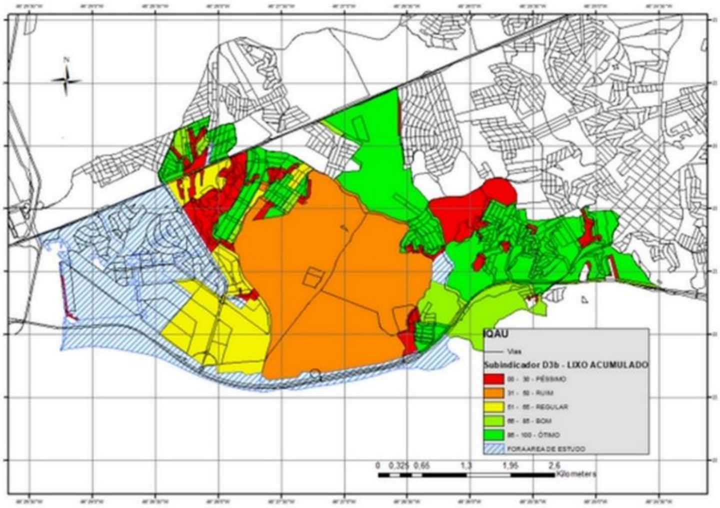
Figure 8 – Maps referring to the sub-indicators: A. Open sewage. B. Open-air garbage. C. Existence of paving.

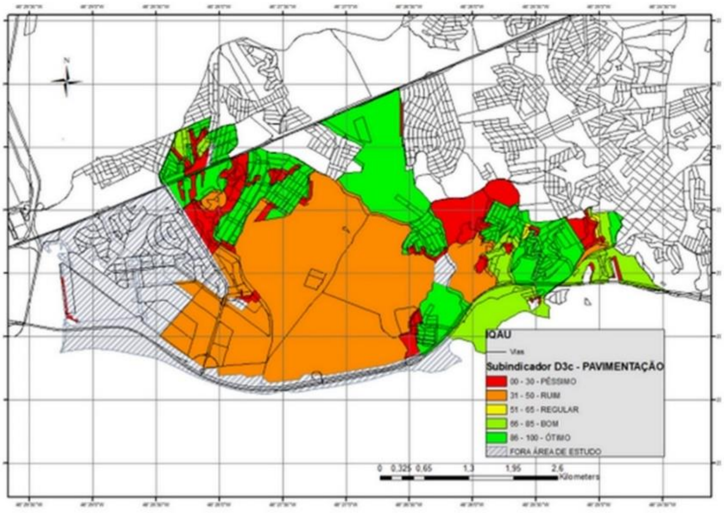
A



B



C



Source: Elaborated by the author.

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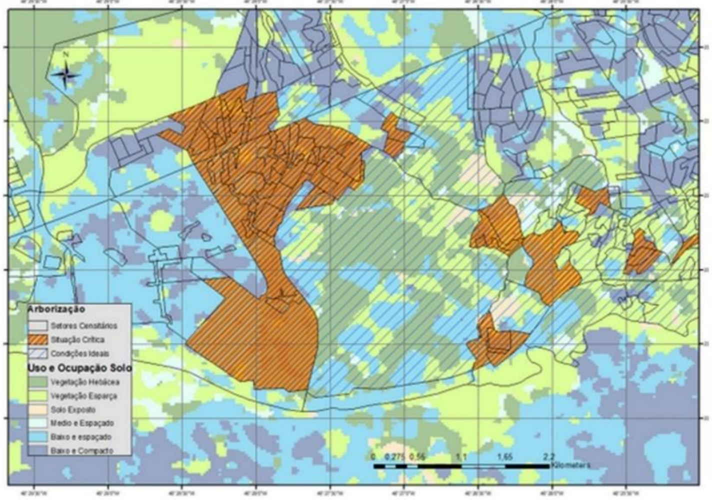
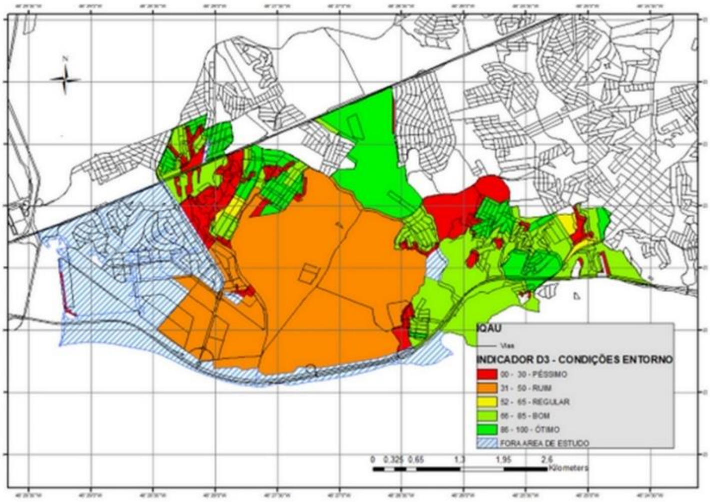
The UEQI showed higher values (66 to 100) in the eastern region and the areas closest to the Pimentas region. The indicators that comprise the UEQI ranked excellent and/or good in this region, which is entirely used for housing and was historically occupied before the other studied areas.

Figure 9 – Map referring to the sub-indicator Afforestation.



Source: Elaborated by the author.

Figure 10 – Map referring to the Indicator Conditions of the surroundings.



Source: Elaborated by the author.

Jardim Vermelhão was the only district in the eastern region to show problems. It is a recently occupied neighborhood, and the poor sanitation conditions are likely to become even worse over the years, given the many buildings under development and disorganized, showing a lack of support from the public authorities. In the neighborhood, many homes were found too close to the riparian forest of the Pedrinhas stream, which needs to be removed due to legislative issues, as well as the safety of residents (BRASIL, 2012). It is also worth considering the lack of policies aimed at preserving the streams in the region. Passers-by are certainly unaware of the importance of the stream in the area.

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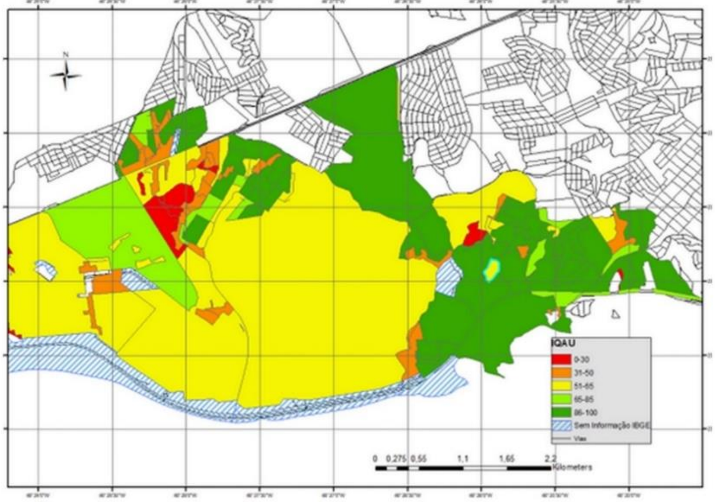
The districts in the western region of the study area, where UEQI was also very poor, had low values for the Sanitation indicator, which most influenced the low UEQI value. Lack of sanitation is a major cause of ill health among the population. A study carried out in Japan showed a reduced incidence of disease after improvements in domestic sewage disposal (ISEKI et al., 2004). Similarly, Fobil et al. (2010) found that improvements to the sewage system could reduce the spread of diseases such as malaria in Ghana. A closer look at this region of Guarulhos, as seen in Japan and Ghana, could result in environmental measures that improve the collective health of the residents of the two sub-basins studied.

Figure 11 – UEQI map calculated for the Micro-watershed Popuca/Botinhas and Pedrinhas.



Source: Elaborated by the author.

The sites in the worst condition share a lack of infrastructure and urban services, as well as a high population density, which makes the problems more complex and increases the need for improvement actions (MELO; UENO, 2013; YEPRINTSEV et al., 2018).

Studies have been carried out in Brazil to create and/or apply an environmental quality index. Many of them have shown results similar to those found in this study: the lack of basic sanitation, especially adequate means of sewage disposal, is the main factor leading to low urban environmental quality. Such a scenario was found by Dias et al. (2011) for the city of Cuiabá, Fujimoto (2002) for Porto Alegre, Dias (2003) for the metropolitan region of Salvador, and Melo and Ueno (2013) for Belém do Pará.

4 CONCLUSIONS

The UEQI showed good and excellent conditions for the Waste Collection (I2) and Water Supply (I4) indicators throughout the study region. The regions considered to be very bad were always conditioned by the Sanitation Indicator and, in some places, were worsened by data from the Surrounding Conditions Indicator. The results for each sub-indicator of the Surrounding conditions indicator showed that the conditions of the physical environment reflect a region with very limited care for the environment, revealing the absence of environmental education

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policies combined with situations of neglect by both the local community and the public authorities.

Finally, the results as a whole show that changes to the natural environment and unplanned land use and occupation lead to compromised living space conditions. Moreover, the UEQI developed and applied to the Popuca-Botinhas and Pedrinhas watersheds in the municipality of Guarulhos, São Paulo, is an effective tool for assessing urban environmental quality and can help public managers make decisions for effective urban planning.

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