

## ORIGINAL RESEARCH ARTICLE

# Changes in green area of two city halls in Mexico City from 1990 to 2015

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## ABSTRACT

Urban green spaces play a crucial role in urban sustainability because they provide a variety of environmental and social benefits, which is why every city claiming to be modern, safe, inclusive and sustainable must ensure that its residents have access to and use these spaces. Mexico City has been upgraded to a city in transition to sustainable development, which is why it has launched various plans and actions focusing on environmental protection. Therefore, the main purpose of this study is to compare the AVU area of the two urban centers of the city from 1990 to 2015 using the census of geographic information system (GIS) and National Institute of statistics and Geography. Information is used to understand the social situation of each mayor's office during the study date. The results show that although the social gap has narrowed in this period, there are great differences in the area and quality between the two cities.

**Keywords:** urban green space; GIS; sustainability; Mexico City

## 1. Introduction

At present, most of the world's population is concentrated in cities, which means that urban areas are expanding and many free lands will be used for urban purposes<sup>[1]</sup>. This is a huge increase for each of these cities in 2016. In order to maintain this production rate, many workers are needed, so the urban environment is the main source of job creation.

However, this population concentration has created a high demand for resources and services, so the current rate of urbanization has destroyed the

natural environment and greatly changed the environment<sup>[2]</sup>. That is why there is now a vision to achieve the so-called "sustainable city", which stems from the definition of "sustainable development", that is, "development that meets the needs of contemporary people without compromising the ability of future generations to meet their own needs"<sup>[3]</sup>. In other words, in an urban environment, our goal is to improve the quality of life while maintaining the speed of production without compromising the natural and social resources on which high production depends.

Urban green spaces are key spaces for sus-

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tainable urban development because they provide environmental, social and aesthetic benefits: They reduce noise, purify the air, allow water infiltration, minimize soil erosion and help regulate the micro-climate<sup>[4,5]</sup>. Public health is also beneficial because of respiratory, circulatory and mental disorders associated with the lack of these spaces, such as chronic pain, insecurity, loneliness and lack of identity<sup>[6-8]</sup>. In addition, the high urbanization rate makes AVU more and more important as a space for human nature interaction, because they create opportunities for social cohesion and outdoor activities<sup>[9,10]</sup>. This is why they must be integrated as an important part of urban planning, as in the United States, Canada, France and the United Kingdom<sup>[5]</sup>.

The environmental and social benefits of AVU are the reason why a modern, safe, inclusive and sustainable city must strive to provide and ensure free access and availability of these spaces for its residents<sup>[11]</sup>. In this regard, some cities have taken measures to increase and improve AVU, such as Malaga, Spain, which increased the green area from 14 million m<sup>2</sup> to 22 million m<sup>2</sup> between 2004 and 2012<sup>[7]</sup>. In addition, Beijing has increased the area of AVU after the 2008 Olympic Games. At present, the per capita green area is 44 m<sup>2</sup> (in m<sup>2</sup>/H)<sup>[12]</sup>. However, in Latin America, the explosive and planned urbanization process in the second half of the 20th century resulted in a shortage of open and leisure space<sup>[10]</sup>. In Mexico, cities such as Toluca and Merida provide 6 m<sup>2</sup>/H and 5 m<sup>2</sup>/H respectively<sup>[13,14]</sup>. In this regard, some studies have shown a correlation between social class and access to environmental benefits, including AVU<sup>[15]</sup>. This means that a city can accommodate space with more environmental benefits and services than other cities, which has a great impact on the socio-economic situation of its residents.

Mexico City has studies to estimate the total area on its territory, but the evaluation criteria are different, so these studies cannot be compared. For example, 2.4 m<sup>2</sup>/H was reported in 1987<sup>[16]</sup>, while a recent study noted 14 m<sup>2</sup>/H<sup>[11]</sup>. However, the area ratio index per capita does not explain the accessibility and distribution of these spaces in cities<sup>[10]</sup>. In

addition, despite research, few green lists can reliably determine the location, area and vegetation of Mexico City, which will contribute to the management, maintenance and planning of these spaces<sup>[11,17]</sup>.

This is why the purpose of this paper is to analyze the AVU of vegetation area and quantity of Miguel Hidalgo (AMH) on four dates. In addition, the location map of AVU is also made to visualize the distribution of the mayor's office. Finally, the findings are relevant to the information from the census to show the potential relationship between socio-economic conditions and the quantity and quality of green space, but it must be noted that this study does not intend to determine whether such a relationship exists.

The main guideline is to answer the following questions: What is the area of urban green space? How did the vegetation in these areas change? Is the amount of green space enough to accommodate the population of the municipal government?

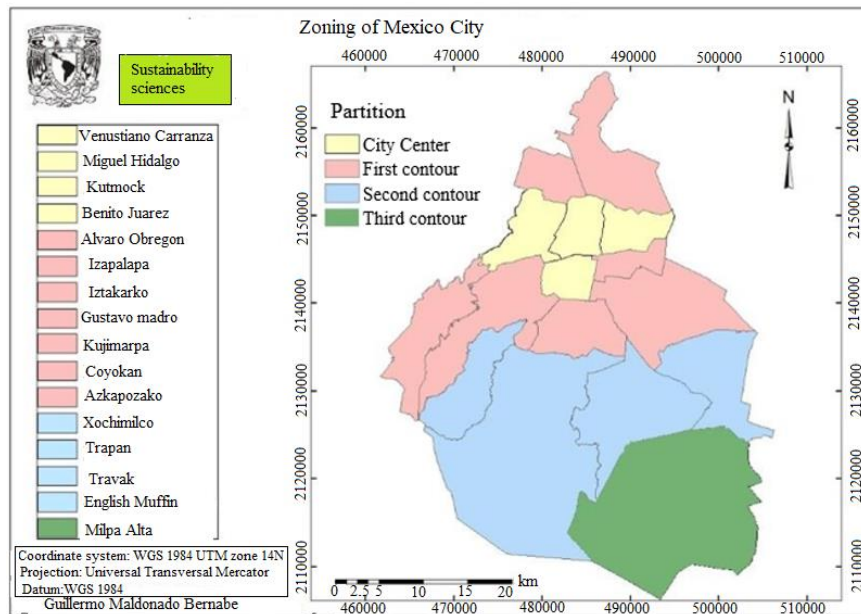
This work includes a section that outlines the efforts of CDMX in AVU, and then briefly introduces the method. Then it describes the study area, focusing on determining the main characteristics of space and population. Then the results and discussion are given, and finally a section of conclusions is given.

### **1.1. Mexico City is transitioning to sustainable development**

Mexico City (CDMX), the capital of the Republic of Mexico, covers an area of 1,485 square kilometers<sup>[18]</sup> and is divided into 16 cities and towns: Alvaro Obregon, Azkapozarko, Benito Juarez, Coyokan, Kujimarpa, Kuhetmok, Gustavo Madro, Izakarko, Izapalapa, Magdalena Contreras, Miguel Hidalgo, Mirpaarta, Travak, Trapan, Vinustiano Kianza and Xochimilco<sup>[18]</sup>. The development of cdmx is gradual. In 1930, CDMX was mainly concentrated in the territory occupied by the municipal government: Benito Juarez, Kutemok, Vinustiano Kalanza and Miguel Hidalgo, which is why they are

called central cities<sup>[19]</sup>. Other regions were subsequently merged through different urbanization processes, from 1930 to 1950, the mayor's office constituting the first contour was merged, while the

second contour was merged from 1950 to 1970, and finally, Mirpa Alta was added as part of the third contour (**Figure 1**)<sup>[19]</sup>.



**Figure 1.** The outline of the central city and Mexico City.

CDMX is crucial to the country because it generates huge revenue for gross domestic product (GDP), accounting for 23.9% of total revenue in 1990, but over the years, this figure fell to 16.7% in 2015<sup>[20,21]</sup>. The high economic output of CDMX is one of the reasons why its people's quality of life is considered to be one of the best in the country, because the marginalization, poverty and social backwardness rates of CDMX are generally low<sup>[22]</sup>. Of the 32 entities in the country, 30% are poor and 31% are extremely poor<sup>[22]</sup>.

Nevertheless, there are still some problems in service coverage, improving public transport, inse-

curity and the availability and improvement of green space. In this sense, CDMX promotes a sustainable or transitional urban image, starting with the action of soil protection. Air quality management and monitoring, more effective liquidity, and saving and protecting green space<sup>[18]</sup>. According to AVU standards, various plans have been implemented, focusing on the care, maintenance, restoration and improvement of these spaces (**Figure 2**), because of the shortage and allocation of public spaces and AVUs, and these spaces are generally abandoned and invaded to a considerable extent by informal businesses and street people<sup>[23]</sup>.

**Table 1.** CDMX green area plans and projects

Full name	Target
Mexico City Green Plan (Minister of environment, 2012b)	Guide the city towards sustainable development and ensure that it is a space suitable for residents.
CDM reforestation Program (environment Secretariat, 2017).	Clean up and re-forestate the city's main streets and camels.
Green city, urban life (environment Secretariat, 2016)	Make the city a green, modern, competitive and successful city and provide its residents with the best quality of life.
Protection of DF buildings and urban heritage Act (regional Legislative Council)	Protect the real estate declared to affect the urban architectural heritage (PUA), which can be: streets, canals, chinampas, playground, orchard, botanical garden, garden, urban park, walking.
Sixth federal legislature, 2014).	It stipulates the requirements, standards, norms and technical specifications that must be observed by authorities, natural or legal persons to promote, improve and maintain public green space.
Regional environmental standards	
Federal nadf-001-rnat-2015	
(Minister of environment, 2015b).	

The project in **Table 1** has a common goal, that is, to have a greener city with open space, allowing leisure, coexistence and promoting outdoor activities. In this regard, it is natural to believe that the actions taken should be implemented in the same way on urban territory to ensure that all residents have access to and enjoyment of these sites.

However, through social media and newspapers, allegations abound of indiscriminate logging and loss of green space in cities, where vehicle and housing projects are directly identified as the cause of these space losses, reductions and destruction<sup>[24–26]</sup>. In order to achieve the goal of this study, a method based on aerial photos and satellite image analysis is used to identify AVU and determine the area of these spaces in two towns. In addition, the estimation of standardized vegetation index helps to identify areas with high vegetation coverage in AVU, so that it can be compared every year to calculate vegetation area and detect the increase or decrease of vegetation area. For this purpose, QGIS 2.12, ENVI and Google Earth software are used.

It must be emphasized that these techniques are one of the most commonly used techniques for analyzing surface and vegetation changes<sup>[27–30]</sup>.

CDMX has different types of green space, including AVA (environmental value area), Gullies, water and soil conservation, urban green space, etc. This study uses the latter category, which is divided into two categories according to the following characteristics.

(1) Public green space: Gardens, parks, children's areas and other public places, including benches, corridors, gyms, toilets, etc., to promote outdoor activities.

(2) Road green areas: Roundabouts, camels and vegetated gardeners, which are located on public roads and have designated functions (camels) or are only used for meditation.

This work does not include areas of environmental value, soil and water conservation, gullies,

wastelands and other types of spaces. Although these spaces have vegetation, not all of them can enter public places or have entertainment or use functions on public roads. However, Miguel Hidalgo city hall has some gullies equipped with leisure furniture, so although it is AVA, it is also included in the analysis.

The aerial photograph was taken in 2008 with a resolution of 30×30 m per pixel and was provided by the office of the prosecutor for environment and territorial planning (PAOT). Satellite images are taken from Landsat missions in February (1990 and 2000) and March (2010 and 2015), and then any program is processed in ENVI software using radiation and atmospheric correction methods to reduce acquisition errors, information loss or atmospheric interference. Therefore, the detected changes can be attributed to actual changes in the surface<sup>[31–33]</sup>.

By using QGIS, AVU is identified with the support of aerial photos, so that the amount of space can be calculated and the total area and single area of AVU can be estimated. Subsequently, NDVI was performed on the satellite images to show the vegetation in the previously determined space.

The result of NDVI is an image in which the value of each pixel can range from -1 to 1. Values below 0 are interpreted as areas without vegetation, while values above 0 are considered as areas with vegetation<sup>[34,35]</sup>. However, aerial photos are used with NDVI images for random point sampling to determine the actual value of vegetation. It can be compared every year to calculate vegetation area and detect the increase or decrease of vegetation area. On the basis of this sampling, the images were reclassified to show areas with vegetation in green and other areas without vegetation in yellow (**Figure 2**).

Finally, through QGIS<sup>[29,36–38]</sup>, this information was used to compare and quantify the changes of green space in the selected study year. As long as the images are taken at the same time of the year, the values obtained from the analysis can be com-

pared, because the differences in vegetation behavior are reduced during the year<sup>[34]</sup>. For the images used, under similar atmospheric conditions, the acquisition date is at the same time of the year.



**Figure 2.** NDVI image of AMH. In green areas with vegetation and yellow areas without vegetation.

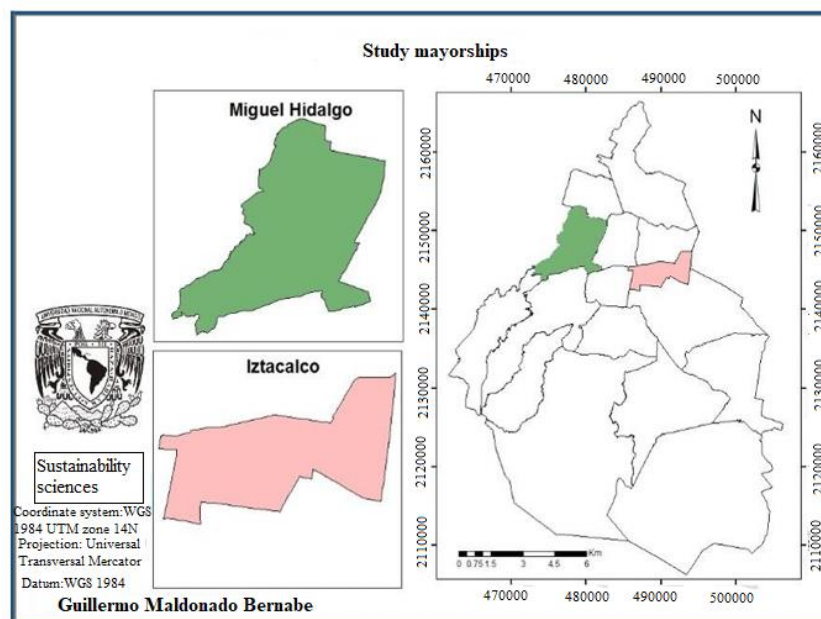
Finally, considering the living conditions of the population in the study year, the AVU results of

the two selected towns are discussed.

## 1.2. Research field

This work focuses directly on the urban green space, which is why Miguel Hidalgo (AMH) and Iztakarko (AIZ) were elected mayors mainly because they have similar development time as part of the central city (AMH) and the first urbanization contour (AIZ). In addition, as described below, the urbanization processes of the two regions are different, which may have an impact on the planning and improvement of their territory.

These towns cover an area of about 46.9 km<sup>2</sup> (AMH) and 23.3 km<sup>2</sup> (AIZ) (accounting for 3% and 1.5% of the urban territory), respectively, in the northwest and east of the city (**Figure 3**).



**Figure 3.** Mexico City and the mayor's office.

At present, AMH has occupied the territory of Tacuba, Tacubaya and Chaptepec, the three highest ranking villages under the former Spanish rule. The area had rivers and allowed the construction of aqueducts and mills, so it was used as a king's settlement in pre-Spanish and colonial times. Subsequently, during the tenure of Porfirio Díaz Ordaz, urbanization began with the construction of trams and the establishment of residential colonies such as San Rafael and Nueva Santa María<sup>[39]</sup>.

AMH is positioned as an area with high economic income. Residential and commercial areas are concentrated here. In addition to areas with environmental value, such as Chapultepec Forest<sup>[39]</sup>, it also has a 200th anniversary park opened in 2011. In addition, it has buildings of national importance such as the Mexico City Observatory, the National Conservatory of music, the national auditorium, the Army University and the air force<sup>[40]</sup>. In addition, AMH is a region with a socio-economic level high-

er than the urban average because most of its basic geographic statistical area classify it as very low poverty<sup>[41]</sup>.

AIZ, on the other hand, originated in the agricultural area that provided food for the city of Tenochtitlan during the pre-Spanish period, as it was an area of the Mexican Empire<sup>[42]</sup>. In 1929, a decree was issued to divide the then Federal District into 13 delegations and set up the mayor's office, because the area was previously part of Trapan, Izapalapa and even some towns in Mexico. The development of IDA began with people's colonies and informal settlements, and industrial zones and housing units were initially mixed<sup>[43]</sup>.

This situation has led to problems in the supply of services, coupled with weak territorial planning, resulting in a lack of public space and green space. However, on the territory of the city, in addition to buildings such as the sports palace, the sports city, the Rodriguez brother's racetrack, the interdisciplinary professional unit of engineering, social and Administrative Sciences<sup>[43]</sup>, temples and monuments of historical value are retained, such as the former monastery of Santa Matthias, the chapel of Santa Cruz and the temple of Santa Anita. For the mayor's office of Iztapalapa Fernández Alvarez<sup>[41]</sup>, it is classified as a moderately poor area.

Although the urbanization process and territorial composition of the two municipalities are different, the economic resources allocated to them are similar. In theory, this is beneficial for IDA because it has enough income to meet the needs of its people and is committed to achieving development similar

to that of the Ministry of health.

However, since the priorities and social conditions of each mayor's office vary, this similarity in the budget cannot be directly interpreted as equal investment in public works, social programs and the maintenance of green space. As an example, the population of each country can be cited, because historically, the population concentration of IDA has been higher than that of AMH, although the population decreased between 1990 and 2015 (**Table 2**). In the 2015 intercountry survey<sup>[44]</sup>, the agency for international development reported an increase in the population as the population may be resettling, but current data do not guarantee this trend.

**Table 2.** The total budget allocated to the mayor's office

City hall	Budget (%)			
	1990	2002	2010	2015
Alvaro Obregon	7	7	7	7
Azkapozako	5	5	5	5
Coyokan	8	6	6	6
Kujimarpa	5	3	3	4
Gustavo madro	11	12	12	11
Iztakarko	3	5	5	5
Izapalapa	11	14	13	13
English Muffin	3	3	3	3
Mirpa Alta	3	3	3	3
Travak	3	4	4	4
Trapan	5	6	6	6
Xochimilco	7	5	5	6
Benito Juarez	5	5	5	5
Kutmok	10	9	10	9
Miguel Hidalgo	7	6	6	6
Vinustiano kаланza	7	7	7	7

Source: 1990 Federal Register, Federal District register, 1999, 2009, 2014.

**Table 3.** Population comparison between the two towns

	Residents in 1990	Residents in 2000	Residents in 2010	Residents in 2015	Growth rate (1990–2015)
Miguel Hidalgo	406,868	352,640	372,889	364,439	-0.439
Iztakarko	448,322	411,321	384,326	390,348	-0.551
Mexico City	8,235,774	8,605,239	8,851,080	8,918,653	0.319

Source: National Institute of statistical geography and Informatics, 1997, 2000, 2011, 2015a.

Although the population density of AIZ (1.69 people per 100 m<sup>2</sup>) is more than twice that of DMH (0.77 people per 100 m<sup>2</sup>), the living conditions of

the population in the two territories are different, but they are balanced. If considering the scope of services and the characteristics of housing, in

terms of building materials (Table 3–Table 6).

**Table 4.** Characteristics of urban housing

	Miguel Hidalgo		Iztakarko	
	1990	2015	1990	2015
Total number of houses	98,051	128,042	93,816	110,174
Floor grounding	0.24%	0.03%	0.92%	0.10%
Wooden floor, mosaic or other	58%	89%	40%	74%
Cardboard wall	0.11%	0.08%	0.53%	0.03%
Partition	94%	99%	96%	98%
Roof board	3.2%	0.6%	6%	0.21%
Roof slab	85%	96%	78%	95%

Source: National Institute of statistical geography and information, 1997, 2015b.

The above figure shows that houses with floors, walls and cardboard roofs are almost non-existent, while in 2015, access to services such as drinking water, electricity, natural gas (containers and casings) and basic drainage exceeded 98%, which is a significant improvement in housing quality and access to services compared with 1990.

**Table 5.** Housing service coverage of municipal government

Access to services	Miguel Hidalgo		Iztakarko	
	1990	2015	1990	2015
Power	99%	100%	99%	100%
Drinking water	99%	100%	74%	99%
Drainage	83%	99%	97%	98%
Gas	SD*	98%	SD*	98%

National Institute of statistical geography and information, 1997, 2015b, 2015 \* SD: No data.

On the other hand, the characteristics of employment do not reflect significant differences in the number of employed people or areas of employment, as most of the population of the two municipalities work in the third sector.

Taking into account that the characteristics analyzed have changed from high inequality to low inequality, it can be explained that although mayors have different origins, their living conditions begin to undergo a process of homogenization, which is not reflected in their territorial structure.

**Table 6.** Classify economic activities

	Miguel Hidalgo		Iztakarko		Mexico City	
	1990	2015	1990	2015	1990	2015
Population over 15	301,209	305,043	314,656	315,498	6,217,435	7,128,836
Economically active population	54%	63%	51%	58%	47%	58%
Employed population	98%	97%	97%	95%	97%	95%
Primary sector	No data	0.09%	No data	0.18%	No data	0.49%
Secondary sector	23%	11.06%	27%	13.72%	2.69%	14.86%
The service sector; the tertiary industry	71%	68.65%	69%	62.03%	68%	61.57%

Based on the calculation of the National Institute of statistical geography and Informatics, 1997, 2015b.

In general, the CDMX population enjoys a good quality of life because it is one of the entities with the least poverty and social backwardness. In this regard, the study cities follow a similar trend, as AMH and AIZ are listed as political and administrative units with a small number of poor and socially backward people<sup>[22]</sup>.

## 2. Results and discussion

The results show that the AVUs of the two cities are very different. In AMH, these spaces account for about 19% of the territory, while in AIZ, they account for about 10% of the territory. As can be seen from Table 7, the AVU of AMH is more than three times that of AIZ.

**Table 7.** Comparison of the AVU surface area in Miguel Hidalgo and Iztacalco with previous studies: Environmental and Territorial Planning Office, 2010; Ministry of the Environment, 2003.

	MOE, 2003	ETPO, 2010	Proprietary data
Miguel Hidalgo	8,890,000 m <sup>2</sup>	14,673,613 m <sup>2</sup>	9,109,625 m <sup>2</sup>
Iztacalco	2,500,000 m <sup>2</sup>	2,885,196 m <sup>2</sup>	2,400,746 m <sup>2</sup>

On the other hand, compared with the previous AVU research results of CDMX, there are significant differences between them, mainly due to their

respective evaluation standards. Although they all reflect the significant differences between mayors, AMH always accounts for the majority of AVU, so



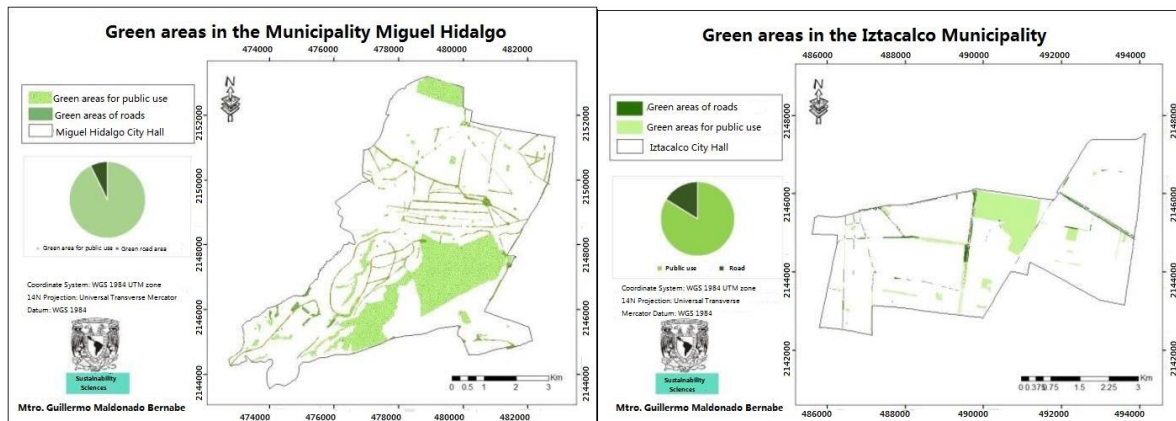
this phenomenon has not been ignored, but the actions taken to solve this problem are ineffective (**Table 7**).

These huge differences in the area occupied by AVU in each region may have an impact on the social development of the population. If considering the small area of the city, but the population concentration is higher than DMH, the situation of less AVU in AIZ is more serious, because AVU is not enough to provide necessary environmental services for residents. The lack of AVU may lead to increased insecurity, disease and demographic pressure, not to mention the entertainment of minors in the territory.

In this case, there is no significant so-

cio-economic difference at present, but the origin and development of the two cities are different. Therefore, whether this special urban history has an impact on the number of AVUs in these areas.

The following map shows the green space of the two cities and towns. It must be emphasized that they all have main space. On the one hand, there is Chapultepec Forest in AMH, which covers an area of 6.7 km<sup>2</sup> and is the largest green space in the city and the city<sup>[39]</sup>. This space contributes most of the municipality's AVU and provides great benefits to its population. In addition, the bicentennial park was recently created in the AMH, increasing the green area of the municipality.



**Figure 4.** The green spaces of Miguel Hidalgo and Iztakarko.

On the other hand, AIZ has 920,000 m<sup>2</sup> of Sports City as a representative AVU, which is much smaller than Chapultepec Forest. Therefore, it can be said that AIZ residents do not benefit from the environmental services of parks and urban AVU in the same way.

Nationwide, the greening area of AMH is larger than that of Monterey, as are Merida and Toluca. It must be noted that this comparison is made between different territories. On the one hand, AMH and AIZ are part of a city, while Monterrey is a complete city. However, these results are meaningful because they show that the lack of green space is a common problem in the country, and there is evidence that AMH is one of the largest AVU areas in Mexico (**Figure 4**).

In addition, both AMH and AIZ have less land and population than other cities, which affects the way people benefit from AVU, because AMH's AV/H index is 25 m<sup>2</sup>, while other examples only exceed 6 m<sup>2</sup>. If the recommended minimum green area per capita is between 9 m<sup>2</sup><sup>[10,12,45]</sup> and 20 m<sup>2</sup><sup>[46]</sup>, only AMH meets this standard.

Obviously, in this case, different regions (cities and towns) are compared, so if you consider the whole Mexico City, or only the area with the greenest space in the city, the results will be different. However, since no studies have accurately determined these data, these comparisons have been made to determine whether the selected territories are good or bad in terms of AVU. By doing the same work internationally, AMH can be even higher than Berlin and Leipzig in AV/H ratio compared



with London and other cities, which means that the city is in a very favorable position in terms of AVU

coverage (Table 8–Table 9).

**Table 8.** Green space in different parts of Mexico

City	Area (km <sup>2</sup> )	Green area (m <sup>2</sup> )	Relationship with territory	Resident	AV/H (m <sup>2</sup> )	Author
Mayor Miguel Hidalgo	47	9,109,625	19.23%	364,439	25	Proprietary data
Monterrey City	969	7,042,400	0.7%	1,135,000	6	Jiménez, Cuéllar, and Treviño, 2013
Yucatan, Merida	209	5,120,925	2.45%	830,732	6	Pérez-Medina and López-Falfán, 2015
Toluca Valley	452	4,097,805	0.9%	819,561	5	Galindo-Bianconi and Victoria-Urbe, 2012
Mayor of Izakarko	23	2,400,716	10.43%	390,348	6	Proprietary data
Durango City	10	1,178,307	11.78%	468,468	2	Durango, 2006

The above comparison reflects the differences between AVUs in each mayor's office, because national and international situations are different. These results are examples of a comparison between the planning of one region (AMH) and the unorganized urbanization (AIZ) of another region, even if they are located in the same city and have a similar development time.

The above results refer to the sum of AVUs, i.e. Two categories (public and road use), but the categories are then analyzed separately.

**Table 9.** Comparison with international cities

City	AV/H (m <sup>2</sup> )	Author
Beijing*	44	Hinojosa, 2014
London	27	Cvejic et al., 2015
AMH	25	Proprietary data
Leipzig	10	Berlin. Not applicable.
Santiago, Chile	2.4	Reyes Packe and Figueroa Aldunce, 2010
Malaga, Spain	7.6	Urban environment Observatory, 2015
Berlin	6	Berlin. Not applicable.

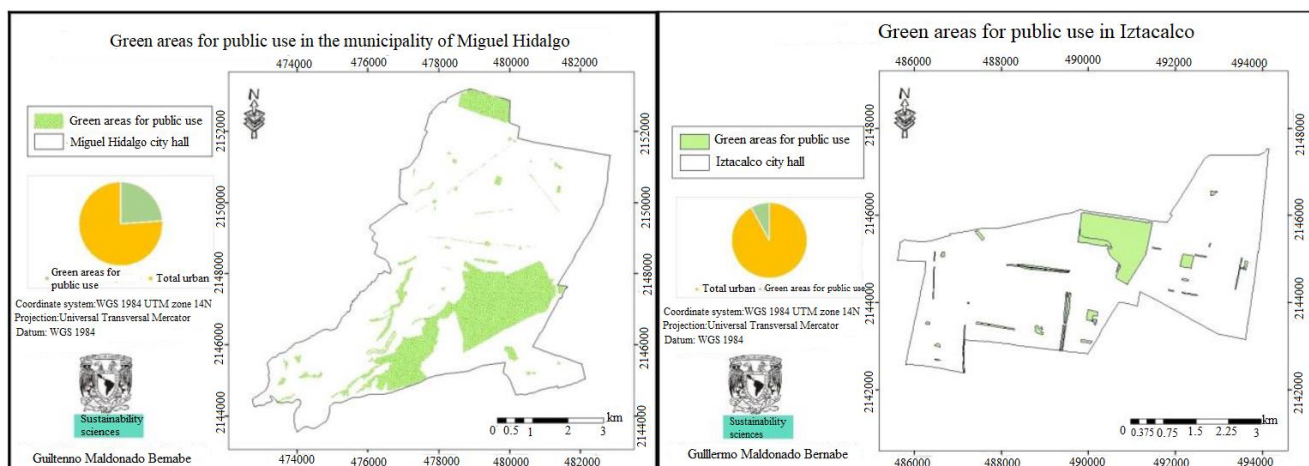
## 2.1. Miguel Hidalgo and Iztacalco public green space

The following maps (Figure 4) shows the spaces that each mayor's office is regarded as public green space, and significant differences are again found in the number and area of these spaces.

The results show that compared with AIZ, the AVUP of AMH is about twice that of AIZ, but its area is about four times that of AIZ. This means that in AMH, these spaces are richer and larger than AIZ (Figure 5).

**Table 10.** The greening area and total area of each municipal government

City hall	Total AVM	AVU area (m <sup>2</sup> )
Miguel Hidalgo	108	8,440,450
Iztakarko	52	2,011,247



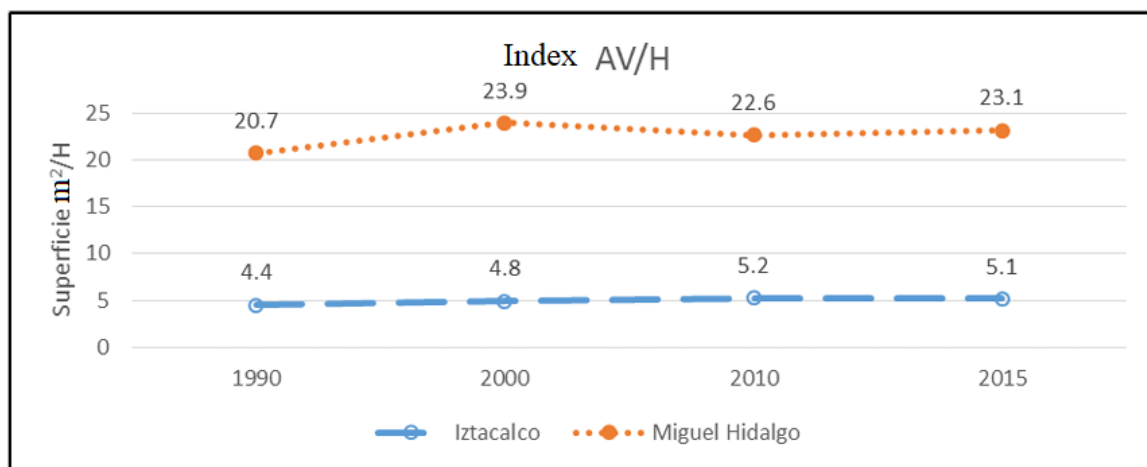
**Figure 5.** Study urban public green space.

This brings two realities to the study of cities, because more AVUP in AMH create more opportunities for leisure, coexistence and social cohesion for the residents of the city<sup>[47–49]</sup>. This reduces the risk of health problems such as anxiety, depression, obesity and even diabetes, as these spaces are used for exercise and other outdoor activities<sup>[6,47,48,50]</sup>.

On the other hand, the social behavior of AIZ may be affected by the lack of AVUP, because various studies have shown that people living in places with less vegetation 1 km away from home feel

lonely and have poor social skills<sup>[49]</sup>, while people living near AVUP (800 m) are more likely to socialize<sup>[51]</sup>.

Therefore, there are various suggestions in line with AVUP's ideal, that is, the per capita area of a city should be  $9 \text{ m}^2$ <sup>[10,12,45]</sup>. In Europe, it should be  $20 \text{ m}^2/\text{H}$ <sup>[46]</sup>. In this regard, the results of the study of cities are the opposite, because since 1990, AIZ has not exceeded  $5 \text{ m}^2/\text{H}$  in general, while AMH has exceeded  $20 \text{ m}^2/\text{H}$  since 1990. In both cases, this average has increased since 1990, but the gap between the two remains (**Figure 6**).



**Figure 6.** Considering the category of green area and furniture, AV/H ratio.

These results indicate the need for intervention within the territory of the international development agency to implement programs to restore public space and create new space. As mentioned above, plans and programs have been developed, but the analysis shows that they are not sufficient to improve the situation of IDA until at least 2015.

The AVUP analysis includes areas without vegetation cover, such as kiosks, parking lots, roads and other structures required for use, so the calculation does not reflect the actual vegetation area in these spaces. Therefore, NDVI was used to assess changes in vegetation at the study date. The next section presents the results.

## 2.2. Urban green space vegetation

Considering the total area occupied by AVUP (AMH is  $8,440,450 \text{ m}^2$  and AIZ is  $2,011,247 \text{ m}^2$ ),

the vegetation coverage in these areas is calculated through vegetation analysis (NDVI) by QGIS software. Therefore, the changes of vegetation coverage in these areas are calculated.

The following maps (**Figure 7–Figure8**) show 108 spaces classified as AMH “public green space” at the study date. They show green and yellow vegetation zones and non-vegetation zones, respectively.

Like DMH, the maps in **Figure 9–Figure 10** show the changes in green space area in 52 spaces calculated in DI.

According to the AVUP vegetation results of AMH, the vegetation coverage continued to improve from 1990 to 2015, reaching  $1,288,245 \text{ m}^2$ . In contrast, the vegetation coverage of AIZ fluctuated in the study year, but the final balance resulted in

the loss of 172,361 m<sup>2</sup> (Figure 11). The change of vegetation in the mayor's office can be attributed to the management and care plan of its green space, because the images analyzed are from the same date, so if the impact is caused by climatic conditions, both areas should be affected.

This negative trend indicates that AIZ has lost vegetation cover in AVUP, which reduces the quality of these spaces because vegetation provides services such as retaining contaminated particles, generating oxygen, water seepage and reducing heat island<sup>[4,5]</sup>.

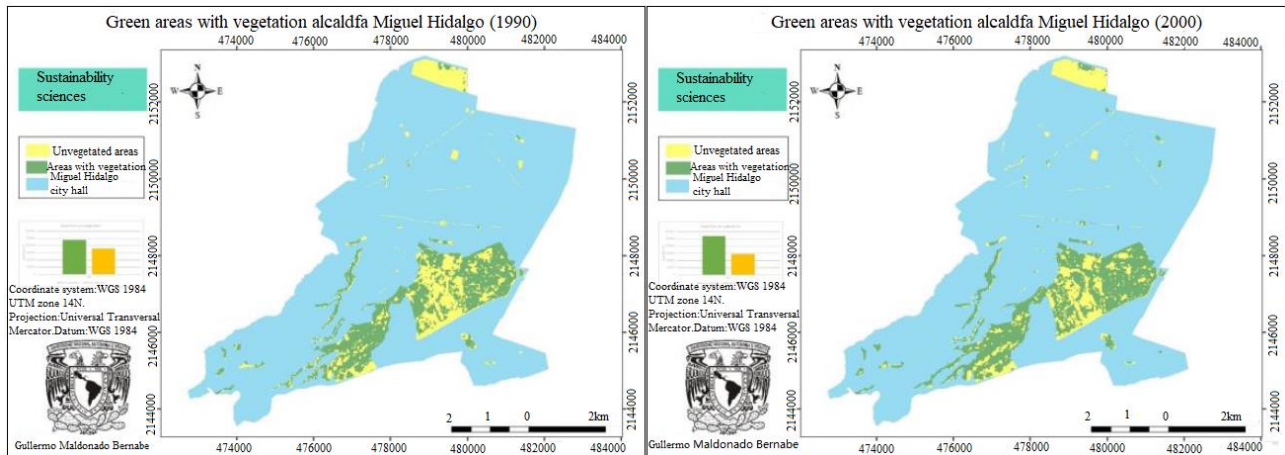


Figure 7. Miguel Hidalgo's vegetation coverage in 1990 and 2000.

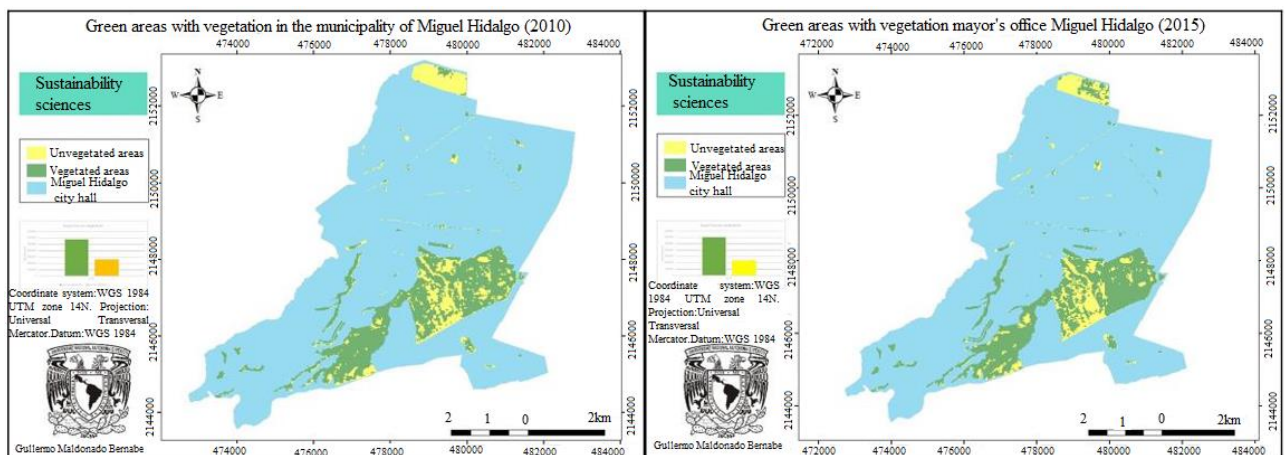


Figure 8. Vegetation coverage of Miguel Hidalgo in 2010 and 2015.

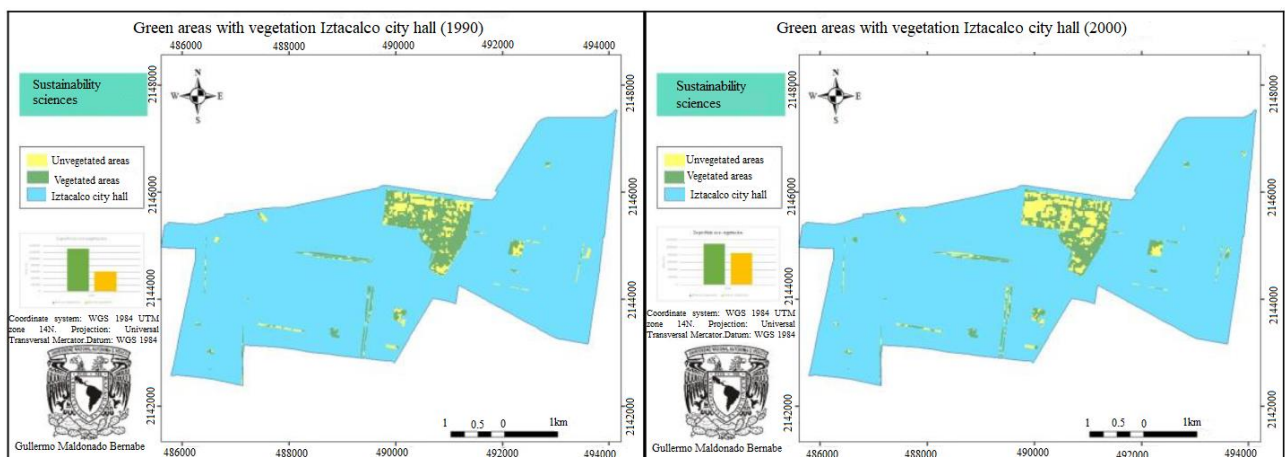


Figure 9. Vegetation coverage of Iztacalco in 1990 and 2000.

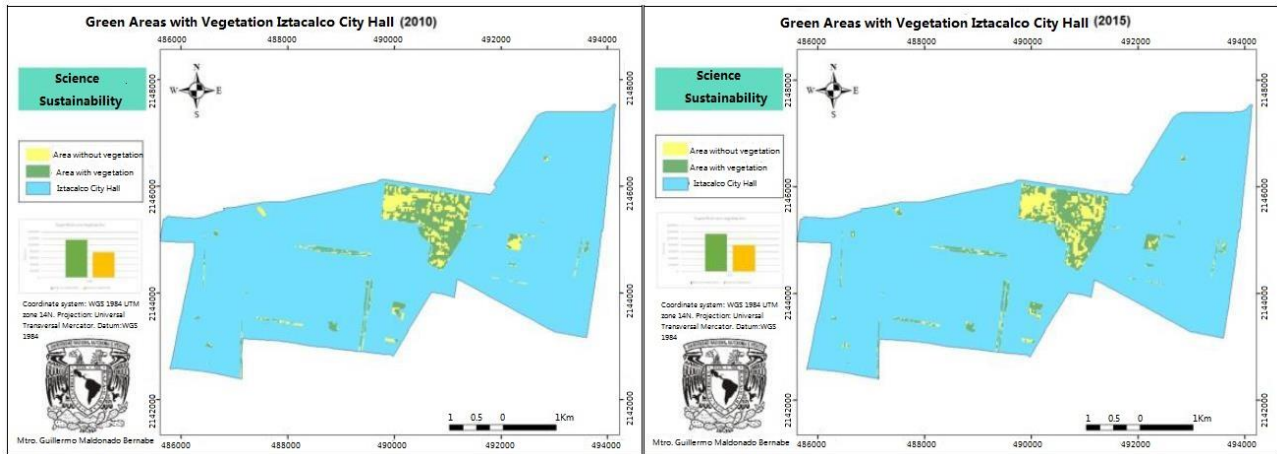


Figure 10. Vegetation coverage of Iztacalco in 2010 and 2015.

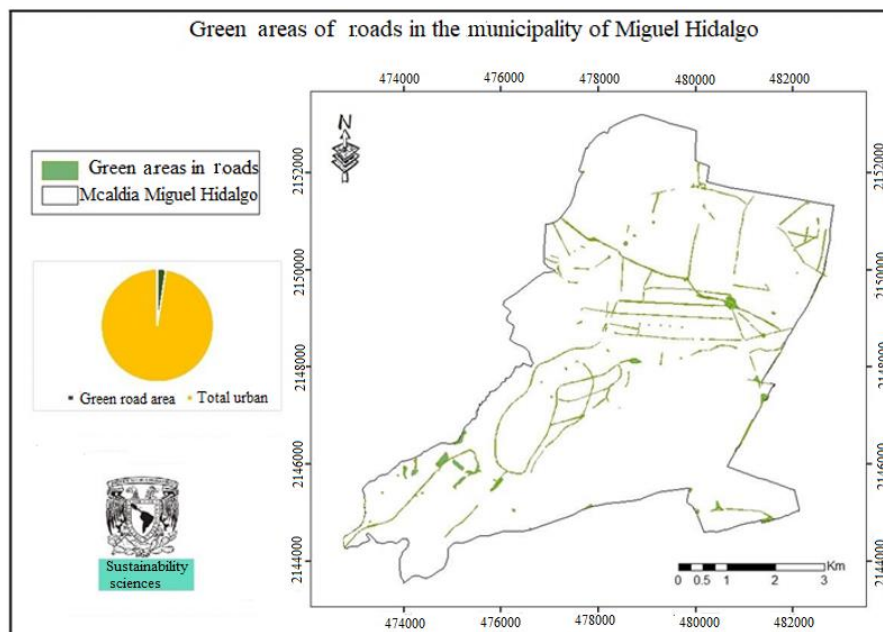


Figure 11. Green road area, Miguel Hidalgo.

Table 11. Vegetation coverage in the study year

City hall	1990	2000	2010	2016	Difference (1990-2015)
Miguel Hidalgo	4,711,204	5,398,979	5,750,953	5,999,449	1,288,245
Iztakarko	1,316,472	1,096,950	1,156,659	1,144,110	-172,362

This shows that if the budgets of the two cities are similar in general, AVUP has not received the same attention. The resources used to maintain AVUP are different. In addition, the lack of AVUP and vegetation degradation in di may lead to the cost of environmental services not incurred by the mayor's office<sup>[1]</sup>. The following table shows the estimated costs of some environmental services (Figure 11).

This negative trend indicates that AIZ has lost

vegetation cover in AVUP, which reduces the quality of these spaces because vegetation provides services such as retaining contaminated particles, generating oxygen, water seepage and reducing heat island<sup>[4,5]</sup>.

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cost of environmental services not incurred by the mayor's office<sup>[1]</sup>. The following table shows the estimated costs of some environmental services (**Figure 11**).

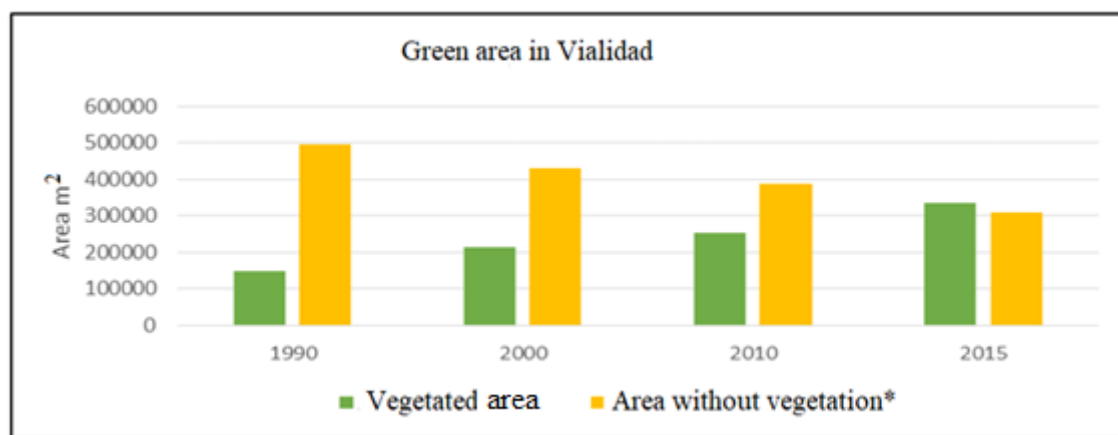
In this study, the economic value of environmental services is not a goal, but by understanding the cost of environmental services, we can imagine the benefits of healthy and vegetation rich green space.

Of course, the vegetation of protected areas, sidewalks, wasteland, roads and other spaces can also serve the whole environment, but the focus of

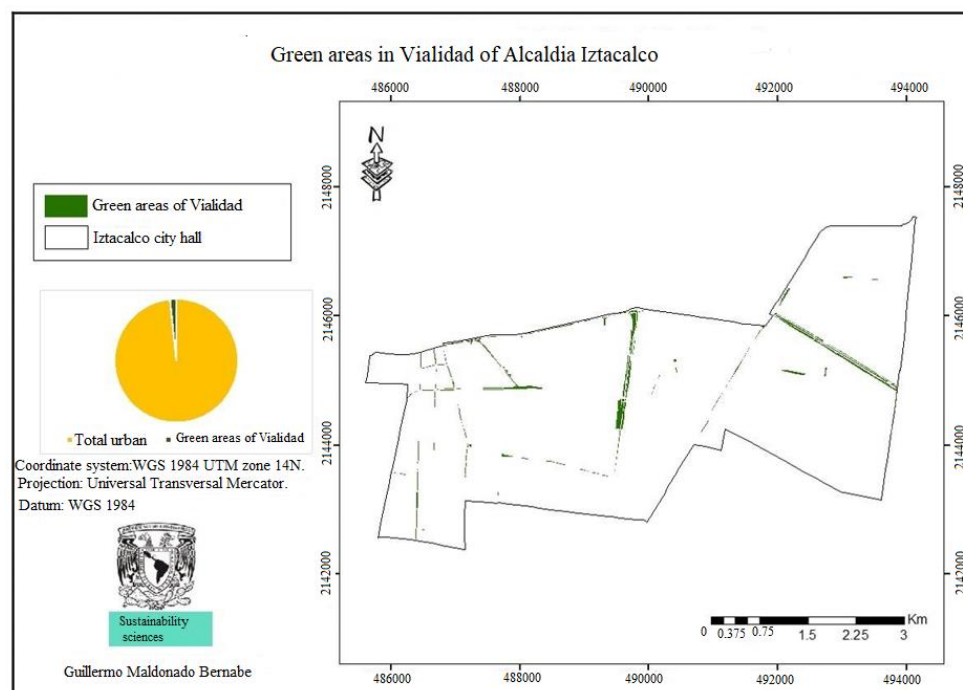
this study is public green space. Then the vegetation of these spaces is analyzed.

### 2.3. Road greening area

The space identified as road green space (AVV) in DMH accounts for 669,175 m<sup>2</sup>, accounting for 1.44% of the total area (**Figure 11**). Admittedly, these spaces are not regarded as leisure areas, but they are part of the urban green infrastructure. In addition to beautifying the urban landscape, they also have environmental functions, namely multi-functional spaces<sup>[52–55]</sup>. In general, the trend of AVV of DMH is the same as that of AVUP, that is,



**Figure 12.** Miguel Hidalgo's green road area has been changed. \*Space without plant cover.



**Figure 13.** Green Road area of Iztakarko.

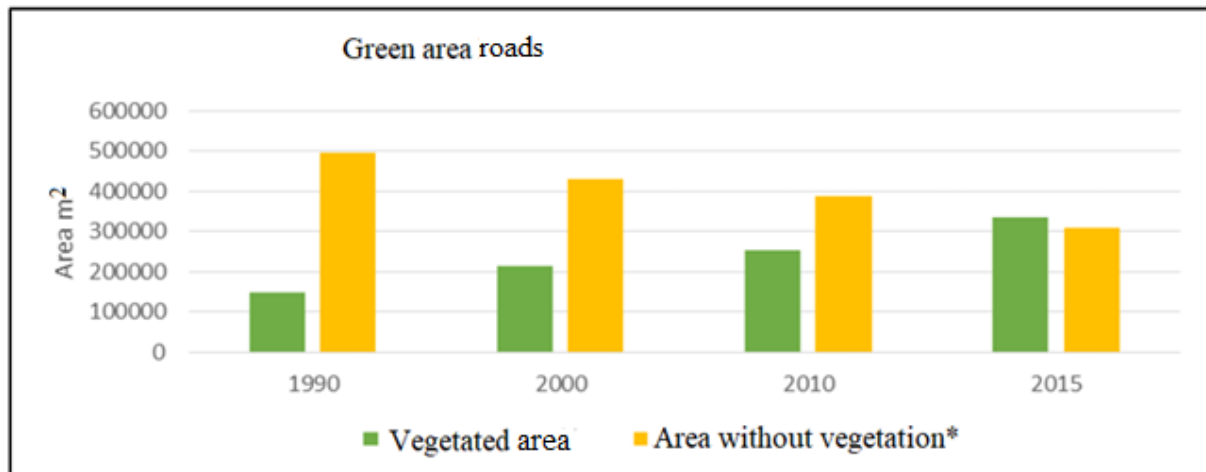


Figure 14. The road green area of Miguel Hidalgo has been changed.

Table 12. The average life span of each tree is 50 years

Service	Cost (USD)	Mexican Peso (May 2017)
Oxygen production	31,250	562,500
Air purification	62,000	1,116,000
Water infiltration	37,500	675,000
Soil erosion control	31,250	562,500

their vegetation coverage has more than doubled. As shown in the figure below, the total increase of vegetation is 186,003 m<sup>2</sup> (Figure 12).

In this case, the program directly related to road vegetation is the urban reforestation program, which aims to clean up and reforest the main roads and camels in the city, so it can be said to be effective at least in this regard. In terms of their share in local councils, the AVV of local councils' accounts for 1.68% of their territory, which means that they account for 389,496 m<sup>2</sup> of the general mayor's office. In AVV, the vegetation area increases, although to a lesser extent than DMH, which is directly related to the low number of DI camels and roundabouts. By understanding the cost of environmental services, we can imagine the benefits of healthy and vegetation rich green space. The following maps and figures show the area occupied by the road and the annual vegetation calculation respectively (Figure 13).

At least under this criterion, the reforestation program also played a role because it increased the vegetation coverage of 15,574 m<sup>2</sup> (Figure 14).

### 3. Conclusions

According to the censuses and information of INEGI and CONAPO, the gap in living conditions of residents in Mexico City has narrowed, as economic income and housing conditions and service coverage have improved, so it can be said that the social program has been successful so far<sup>[56–59]</sup>.

Mexico City is one of the entities with the lowest proportion of poverty and social backwardness among the population, but the origin and mode of urbanization affect the development of the territory and thus the opportunity to improve space<sup>[60–63]</sup>.

Specifically, there are great differences in the quantity, quality and distribution of green space in the study city, because as shown in the figure, DMH has more green space, partly due to Chapultepec Forest<sup>[64–67]</sup>. However, even without this space, the number of parks is much larger than di.

Therefore, the results show that urban AVU is concentrated in some areas, in this case DMH. Therefore, the residents of the study towns have different access to and enjoyment of these spaces, which can be confirmed by looking at the AV/H index of each town. Therefore, even if the per capita total green space rate of the city is acceptable, it does not mean that the distribution of these spaces is fair.

Environmental and social services are also unequal in different regions, which may lead to so-

cial deterioration in specific regions (DI in this case). These results are consistent with what Fernández Alvarez<sup>[68]</sup> said. He said that the distribution and accessibility of AVU are seriously biased towards the marginalized population, because the socio-economic characteristics of the population are directly related to the square meter of green space per resident<sup>[69,70]</sup>.

As far as the research mayor's office is concerned, it has been mentioned that these social gaps have been narrowed at present, but the different urbanization modes of the two regions are the factors that limit (AIZ) or promote (AMH) the improvement of their AVU capacity.

In addition, the deterioration of AVU is a serious problem for the whole city, because the benefits brought by vegetation help to reduce the ecological footprint and improve the quality of urban life. In this regard, Mexico City's efforts should focus on achieving welfare and social equity in its territory, taking into account factors such as quality of life, mobility, income, services, environmental quality and access to green areas.

The results show that considering the study city, the urban green space is unevenly distributed, and the area and vegetation coverage conditions are different, so the management and improvement program does not play a role (in the whole territory). This means that government, academic and social efforts must be strengthened to eliminate this inequality<sup>[71]</sup>. Therefore, for CDMX, the goal of becoming a green, inclusive and fair city is still far away.

Finally, it must be noted that this work can lay the foundation for the development of a system to monitor the progress of AVU protection and improvement, because the established method allows time comparison, so as to promote the planning and management of AVU. Finally, if higher resolution satellite images are used, the vegetation status in these spaces can be estimated more accurately, and the results may be clearer.

## Conflict of interest

The authors declare no conflict of interest.

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