SPATIOTEMPORAL AND QUALITATIVE ANALYSIS AND EVALUATION OF URBAN GREEN USING A GEOGRAPHIC INFORMATION SYSTEM

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Abstract
Urban green is in our days a crucial parameter of the urban environment.Green should be analyzed and evaluated spatiotemporally as well as qualitatively in order to define what is satisfactory and what is not. This paper describes a research that took place in the city of Chania (Crete – Greece). The spatial distribution of urban green, its change through time and its qualitative characteristics are examined and the thoroughness with which this work is done, results to a system by which the local authorities can be supported to decide and to plan the actions needed to be taken to improve the quantity and quality of the urban green (where this is feasible). The use of a GIS system in this research, gives the opportunity to combine a set of data, dissimilar to each other, to find relations and differences and to classify the urban green into categories.

Keywords: urban green, GIS, spatiotemporal distribution, qualitative characteristics, classification

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1. INTRODUCTION

Urban green nowadays constitutes the lungs of the urban environment and contributes to its sustainable development. Urban green is defined as the overall amount of planted outdoor spaces (with trees, bushes, ornamental plants, or grass). Examples of such spaces are squares, parks, rows of trees in boulevards, groves, planted spaces in yards of public or private buildings (schools, residential complexes, etc) [Aravadinou et al., Evmorphopoulou et. al. 2003, Evmorphopoulou 2007, Georgi et. al. 2005, Georgi et. al., Giannas 2001, Giannouli 2007, Kaplan et. al. 1998, Kassios et. al. 2005, Kassios et. al., Kosmaki et. al. 1999, Papagiannis 1999, Skarlatos].

The present study involves the spatiotemporal and qualitative recording of green spaces in the Municipality of Chania, on the island of Crete. Following the creation of the appropriate database, the analysis of green distribution in the area and its evaluation take place, through the use of the appropriate spatial analysis tools of a GIS. The present study took place in the context of a thesis research, in the Department of Environmental Engineering, at the Technical University of Crete.

2. URBAN GREEN

The existence of green spaces in a contemporary urban environment is expected to improve air quality, reduce noise pollution and enhance its aesthetic quality. Urban green also constitutes a principal element of the city's urban planning. Specifically, urban green is a key factor for the overall city planning, as its benefits have a direct impact on the environment as well as on quality of life of its residents. Social studies clearly indicate a relation between cities-or parts of a city which are deprived of greenery and an endemic violence and crime, while suicide incidences seem to be on the rise. Urban green is undoubtedly the link that connects the human and the natural environment [EU 1994, ECUP 1998, Malkolm 1986].

3. THE URBAN GREEN IN THE MUNICIPALITY OF CHANIA

3.1. The Research Area

The city of Chania is the capital of the Chania Prefecture and is situated on its North East part and constitutes the administrative, commercial and transportation centre of the prefecture. The municipality of Chania is the largest one in population and consists of one municipal division, the Municipal Division of Chania. It covers an expanse of about 465 hectares of urban area, and borders the municipalities of Nea Kydonia, Akrotiri, and Eleftherios Venizelos.

According to the 2001 census, the population of the city is 53,373 inhabitants. The evolution of the population during the last century is illustrated in the following diagram (Diagram 1).

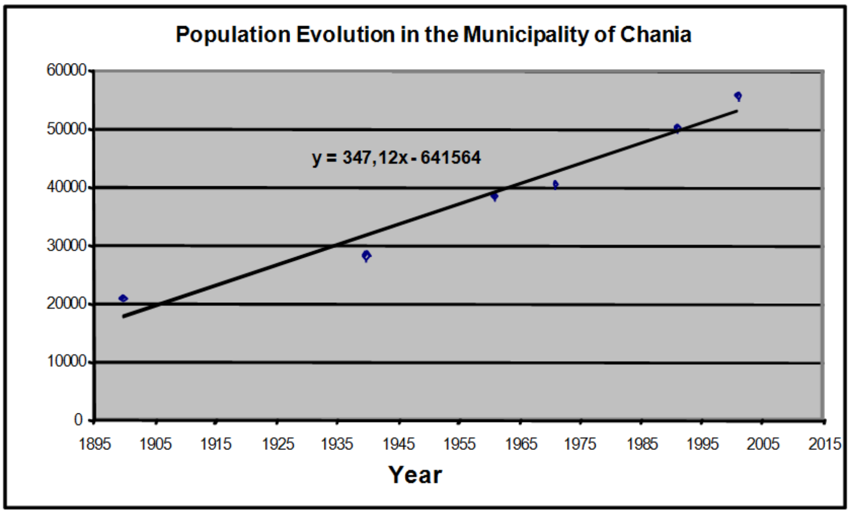


Diagram 1: Population Evolution in the Municipality of Chania

The climatic conditions in the area are characterized as mild. Recordings of the Meteorological Station based in Souda, show a temperature range of 5º to 10ºC. Based on these findings, the area can be characterized as coastal Mediterranean. Furthermore, the minimum recorded temperature is 0ºC and the maximum is 44.5ºC. And although the minimum temperature is normal, the maximum recorded temperature is considered extreme.

Rainfall season invariably starts in September, reaching its peak in December – January and gradually declines up until May. The maximum monthly rainfall recorded during January by the Meteorological Station of Souda is 516.1mm, which is quite considerable, taking into account that on certain years the average annual rainfall reaches these levels. July and August are practically dry. As far as the winds are concerned, they are usually westerly during winter.

The morphology of Crete is the result of various geological phenomena and tectonic movements. Mainly, the study's regional geology includes limestone and sandstone. The limestone is characterized compact, white-yellow to white-grey, including sea fossils and the sandstone is loose, containing sea fossils of mollusks. Generally, the geologic activity recorded in the overall area played an important role in the development and evolution of the flora of Crete. Considering the vegetation, the specific geology and along with the climatic conditions, favor the dominance of members of Oleaceae family and phrygana flora, while the maintenance of other species seems extremely difficult and costly.

3.2. Recoding the Urban Green

The recording of urban green took place through in situ research. A city map of a 1:2000 scale, dating from 1995 was used, and was provided by the correspondent municipal authority. All the open green spaces (parks, squares, gardens, road traffic islands with vegetation) as well as streets with an abundance of rows of trees, were indicated on the map. All the areas of the city which include green spaces, organized or undeveloped, public or private, have been recorded by the use of several means, namely the Google Earth application, the use of aerial ortho-photographs, and in situ observation. The green spaces which are not recorded officially by the Green Department of the Municipality are characterized in this research as “Non Organized Urban Green Spaces’. These spaces are recorded as they are usually large areas which contribute substantially to the environment of the city.

The spatial recording of urban green spaces involves the setting of exact boundaries of these spaces into a single reference system. This is achieved during the stage of the creation of a geodatabase (spatial database), where the spatial unit for the research, the scale and the reference system are established. In the presence research, the building block is defined as the spatial unit, the 1:2000 scale is used and the EGSA 87 as the reference system.

The diachronic recording of urban green spaces presupposes the diachronic existence of spatial and descriptive data. By spatially recording the urban green over periods of time, we are able to create maps of urban green for these periods of time, which enables us to observe any alterations that have taken place. In this research the recordings took place for three periods of time; for the years of 1995, 2002 and 2008, when there were available spatial data. The data concerning the year of 1995 were obtained through aerial photographs, for 2002 data were obtained via the Google Earth program and for 2008 through in situ recording.

3.3. Qualitative Recording of Vegetation Spreads on the Municipality of Chania

In parallel with the spatial and temporal recording of the green spaces, a recording of the species and varieties of vegetation was conducted (qualitative recording). Identifying the existing vegetation is an important factor in the analysis of the appropriateness of species [Ktirio 77]. Specifically, photos of all parks, gardens and squares were taken prior to identifying the prevailing species. The following table which comprises all prevailing species in the urban green spaces has been put together after collecting all relevant data.

Table 1: Table of Recorder Flora Species

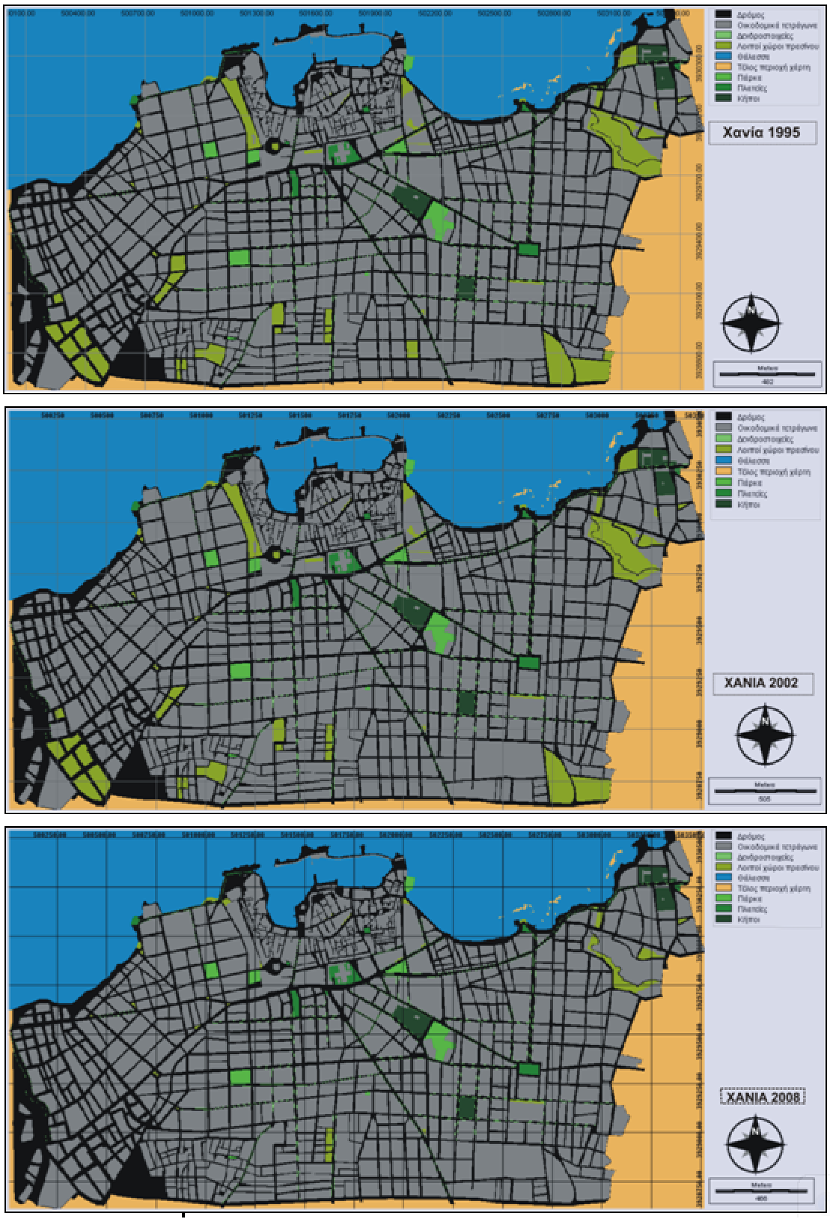
nn/n	**Species of recorded flora**	**(Family)**
	Pittosporum tobira	(Pittosporaceae)
	Acacia farnesiana	(Fabaceae)
	Tamarix sp.	(Tamaricaceae)
	Araucaria excelsa	(Araucariaceae)
	Bougainvillea sp.	(Nyctaginaceae)
	Jasminum primulinum	(Oleaceae)
	Yucca gloriosa	(Agavaceae)
	Quercus ilex & *Quercus aegilops*	(Fagaceae)
	Olea europea	(Oleaceae)
	Eucalyptus globulus labill	(Murtaceae)
	Hibiscus rosa-sinensis	(Malvaceae)
	Salix babylonica	(Salicaceae)
	Cedrus libani	(Pinaceae)
	Ceratonia siliqua	(Fabaceae)
	Cercis siliquastrum	(Fabaceae)
	Hedera helix	(Araliaceae)
	Cupressus sempervirens	(Cupresseaceae)
	Ligustrum ovalifolium	(Oleaceae)
	Pinus brutia & *Pinus halepensis*	(Pinaceae)
	Nerium oleander	(Apocynaceae)
	Platanus orientalis	(Platanaceae)
	Rosmarinus officinalis	(Lamiaceae)
	Acer negundo	(Sapindaceae)
	Rosa sp	(Rosaceae)
	Ficus elastica & *Ficus retusa*	(Moraceae)
	Phoenix canariensis & *Phoenix dactylifera*	(Arecaceae)
	Fraxinus excelsior	(Oleaceae)
	Ficus benjamin	(Moraceae)

The variety of the flora species may serve a number of purposes, such as to enhance or camouflage visibility depending on the needs of the area, to create a certain visual image and to filter out direct sunlight and its reflections.

[Ktirio 77]. They can also be used as natural fencing to indicate routes and itineraries. They also affect an area's microclimate [Evmorphopoulou et al., 2003], regulate the impingement of solar radiation and topical temperature. They can also determine the speed and direction of wind on a low level by serving as natural and adjustable obstacles, the intensity of rain, the humidity on a regional level as well as snow fall. Lastly, they are a regulatory factor of ground erosion.

4. GEODATABASE CREATION

The processing and analysis of spatial issues through the use of GIS systems, requires the existence of a spatial database (Geodatabase). The data that are input into the spatial database are of primary nature. Primary data can be input in a number of ways, depending on the process followed during their collection and on their actual form, whereas when it comes to spatial data on a mapping illustration, they are input into the GIS through the process of scanning, georeferencing, digitization and structuring of topology. Inputting spatial data on a spatial database is by common consent a time consuming and costly procedure [Tsouchlaraki 2006].



Figures 1: Green1995, Green2002, Green2008

The GIS IDRISI Andes software was used in the present research. IDRISI is a raster GIS but also enables its user to have vector display and management through a helpful tool, the CartaLinx. A basic advantage of using a raster GIS is that it allows for greater capacity for spatial analysis in case of continuous phenomena in an area, compared to using a vector system. It is also considered ideal for environmental research and applications, for example with flora exploration or land erosion research, inter alia [Tsouhlaraki 2006].

Based on their form and usage, the green spaces in this study are divided and encoded into five categories:

- Parks
- Squares
- Gardens
- Other green spaces (road traffic islands with vegetation, large undeveloped green spaces)
- Rows of trees

In order to create polygons which comprise tree rows, the AutoCAD software program was used, through which one meter (1m) polygons were designed, in a distance of 0.5m from building blocks.

5. ANALYSIS OF URBAN GREEN

An index that is often used to evaluate the sufficiency of urban green is the fraction of the square metres of green spaces by the number of a city's inhabitants (m^2 green spaces / inhabitants). Some characteristic examples of the index values for some megalopolises are: Athens=2.55, London=9.00, Vienna=20.00, Amsterdam=27.00, Bonn = 35.00, Washington = 50.00.

The average square cover of green spaces for cities in Greece (Program: Attiki SOS scheme, Ministry for the Environment, Spatial Planning and Public Works) reaches 7% in Athens and 4-5% for Thessaloniki. The correspondent average values for European cities amount to an average square cover of 25% of the overall city expanse [Mediterranean SOS 2005, MESPPW].

In order to calculate the m^2 green spaces / inhabitant index, the collective expanse of all green spaces categories (parks, gardens, rows of trees, squares etc.) is found for the years 1995, 2002 and 2008.

Table 2: Surface of Green Spaces per Category per Year

Green Categories	**1995 (m2)**	**2002 (m2)**	**2008 (m2)**
Streets	1.406.175	1.406.175	1.406.175
Building Blocks	2.863.859	2.881.855	3.059.988
Rows of Trees	31.518	31.518	31.518
Other Green Spaces	232.544	214.548	36.415
Parks	37.330	37.330	37.330
Squares	22.953	22.953	22.953
Gardens	44.115	44.115	44.115

Table 3: Results of Analysis of Urban Green Indices

	1995	2002	2008
Population of Chania Municipality [inhabitants]	50.941	53.370	55.453
Collective organized green (parks + squares + gardens) [m2]	104.398	104.398	104.398
Overall expanse of green open spaces (organized green + tree rows + other green spaces) [m2]	368.460	350.464	172.331
Collective built spaces (streets + building blocks) [m2]	4.270.034	4.288.030	4.466.163
Overall expanse of the city of Chania [m2]	4.638.494	4.638.494	4.638.494
Analogy of organized green [m^2 green spaces / inhabitants]	2,05	1,95	1,89
Analogy of collective green spaces [m^2 / inhabitant]	7,23	6,57	3,10
Analogy of organized green [m^2 /m^2 of city expanse] (%)	2,25	2,25	2,25
Analogy of collective green spaces [m^2 / m^2 of city expanse] (%)	7,94	7,55	3,71

The following charts illustrate the distribution of all green spaces in the city of Chania for the years 1995, 2002 and 2008 respectively.

The corresponding green open space for every citizen is calculated based on the organised green spaces. Such spaces are parks, gardens and squares. Other types of greenery can be found though, of non-recreational purpose, such as tree rows, in boulevards. These, fall under the category of "Other green spaces" and include a considerable expanse of greenery. In the present study the index m^2 green spaces / inhabitants was calculated twice; the first time by measuring the organised green spaces , the second time by measuring the overall urban green spaces expanse. The results are presented as follows:

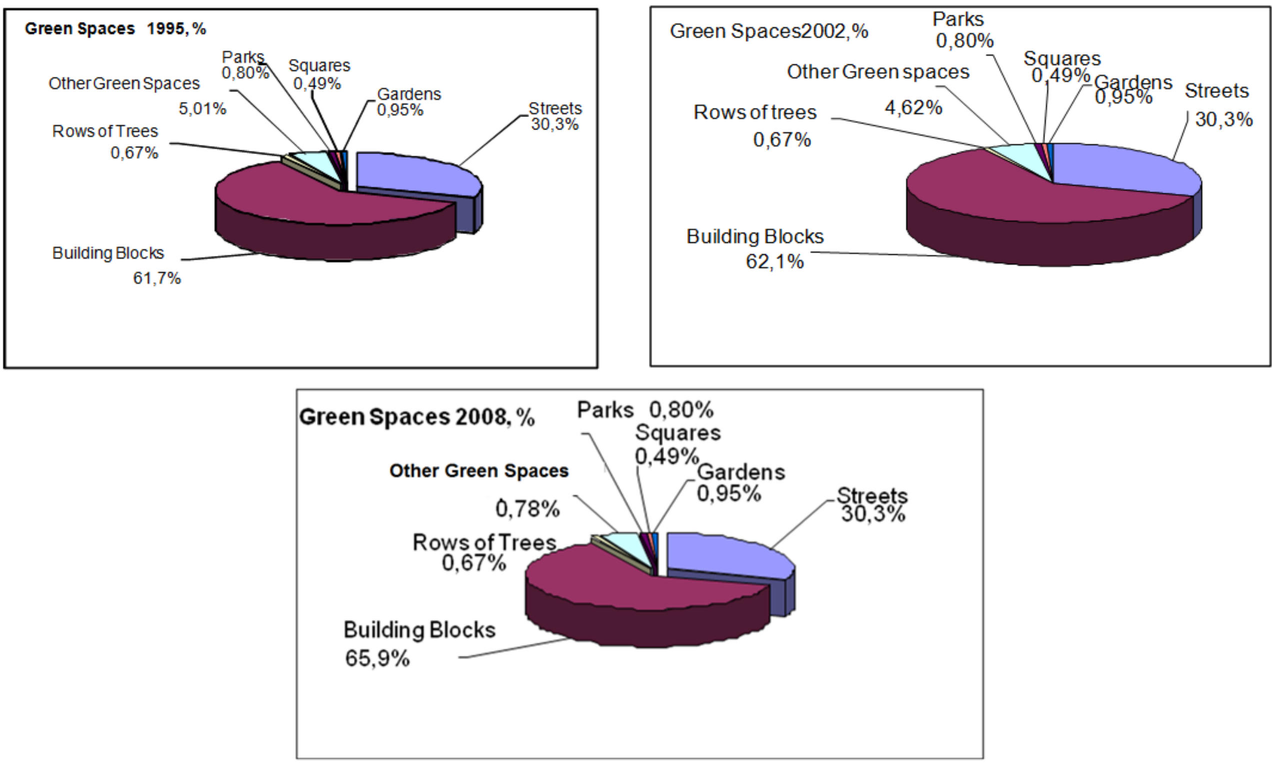
Table 4: Expanse Covered by the Buffer Zones of 300m

Year	**Expanse Covered (m2)**	**Percentage (%)**
1995	2016411	43.47

2002	2021864	43.59
2008	2099003	45.25

Another important index that reflects to what extent the inhabitants' needs for green spaces are met, is the distance of an area from the urban green locations. For the analysis of this index a crucial distance value (threshold) of 300 meters was established, which is considered an average walking distance to the nearest area of organized green. The areas of the city which meet the aforementioned criterion as well as the ones which are deficient, can be identified through the use of influence zones (buffers). Buffer zones were created for every period examined (2008, 2002, 1995) and for every category of organized green (parks, squares, gardens). Figure 2 illustrates the results for squares in 2002 (Figure 2).

The next step would be to calculate the overall expanse covered by the buffer zones of the organized green (collectively for the 21-parks, 22-squares, 23-gardens) for any given moment on the overall 4638494 m^2 expanse of the municipality of Chania.



Diagrams 2: Analogy of Green Spaces (%) for the Years 1995, 2002, 2008 respectively

6. EVALUATION OF URBAN GREEN

6.1 Quantitative Evaluation

Having evaluated the indices that describe the presence and evolution of urban green in Chania, it is necessary to also evaluate the results and reach conclusions. The next step is to evaluate every coefficient separately.

Organized green spaces (parks, squares, gardens)
An obvious first observation that can be made on the evolution of organized green spaces is that their expanse has remained stable throughout the examined period of time (Table 4). As far as the city parks, squares and gardens are concerned, there was no alteration of their expanse during a span of 13 years. The overall expanse is 104.398m2 and has been unaltered.

The diagrams that follow illustrate the evolution of the m^2 green spaces / inhabitant index throughout time. Notable stages in this graph are the years 1995, 2002 and 2008.

By observing the analogical coefficients of m2/inhabitant, it is apparent that their value decreases. This decrease is not particularly remarkable, as it amounts to 0.16 units within a 13 year period. Given the fact that, the expansion of organized green spaces remained stable, the alteration of the coefficient is solely due to the population increase in the municipality of Chania. The data are therefore suggestive of a declining course of the coefficient in the future, as the city population tends to increase, and there are no immediate prospects for the creation of new organized spaces, since vacant green spaces that remain undeveloped are very few.

Collective Urban Green Spaces

Diagram 4 results when we graphically illustrate the evolution of the m^2 of collective green spaces / inhabitant coefficient (Diagram 4).

The diachronic decline of the coefficient can be observed on the graph (blue curve). The orange line represents the average linear decline of the coefficient through time. A remarkable decline is observed in the period between 2002 and 2008. This decline is confined to the category of tree rows and other spaces of green, since the overall expanse of parks, squares and gardens remains stable during the period of 1995 to 2008. Taking into account that the expanse of tree rows also remains unaltered during that period, the decline comes from the category of other green spaces.

Through the use of information layers that record urban green spaces per category (Figures 1), one can conclude that other green spaces - undeveloped green spaces in specific - are gradually turned into built-in areas (building blocks). Most of the undeveloped spaces are private (plots of land which remained unexploited, containing either some kind of cultivation such as olive trees and orange trees or natural vegetation). The majority of undeveloped green spaces are located in areas peripheral to the city. As the city population increases, so does the demand for new built-in areas, which has led to the gradual conversion of the undeveloped land into new building blocks. It is therefore expected that vacant plots of land which are found on the outskirts of the city will be the first ones to be built on as the city expands. The considerable decline in these spaces in conjunction with the population increase of the city of Chania, have led to the sudden drop of the coefficient index.

Similar conclusions can be reached by observing the indices of m^2 green spaces / m^2 of city expanse. In Diagram 5, the blue curve shows the per cent reduction of the analogy index, while the yellow one shows the average linear course of the index through time.

As already mentioned, the decline can be accounted for by the change of land use of the areas characterized as “Other green spaces”. With the elapse of time the change of land use became a necessity due to the pressures of urban sprawl. The reduction of other green spaces (resulting in the reduction of green spaces in relation to the overall city expanse), can be ascertained by the increase in the volume of the built-in environment. The fact that the increase in building blocks from 1995 to 2002 amounts to 0.4 % (62.1-61.7) while from 2002 to 2008 equals to 3.8% (65.9-62.1) is characteristic.

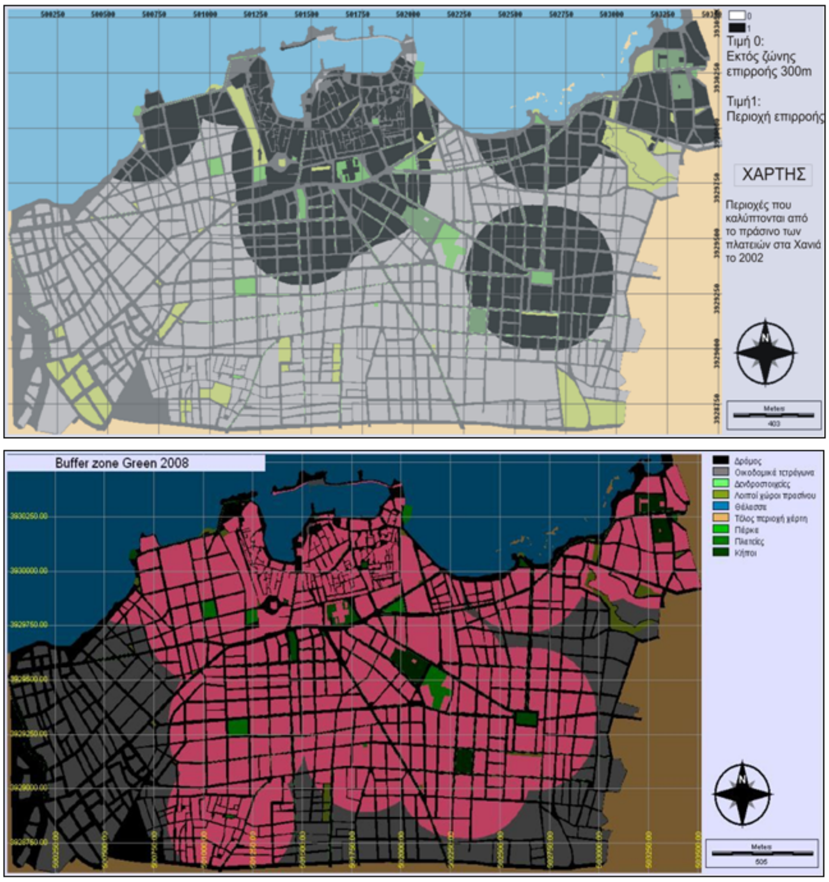
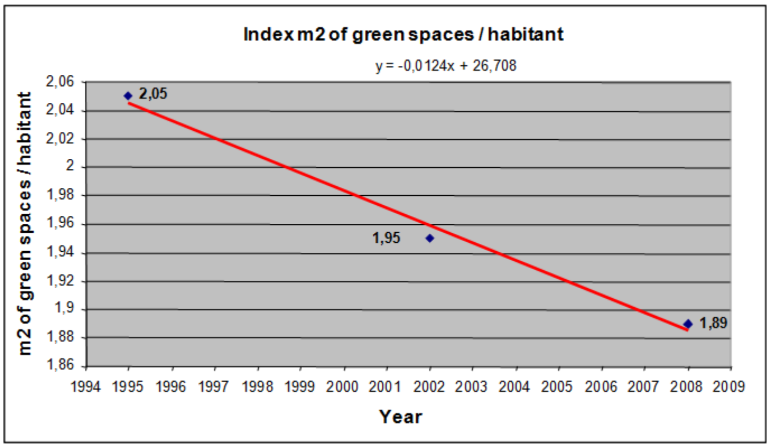


Figure 2: Buffer Zones of 300m around Squares in 2002

Figure 3: Buffer Zones of 300m around Organized Green Today (2008)



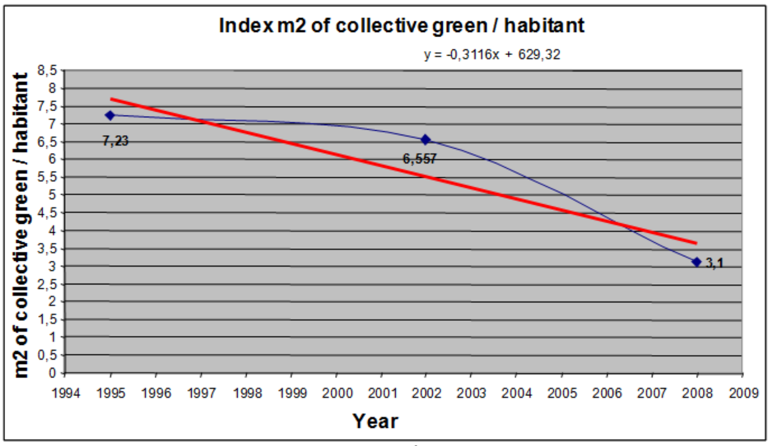


Diagram3: Diachronic Alteration of the m^2 green spaces / inhabitant coefficient
Diagram 4: Diachronic Alteration of the m^2 of collective green / inhabitant coefficient

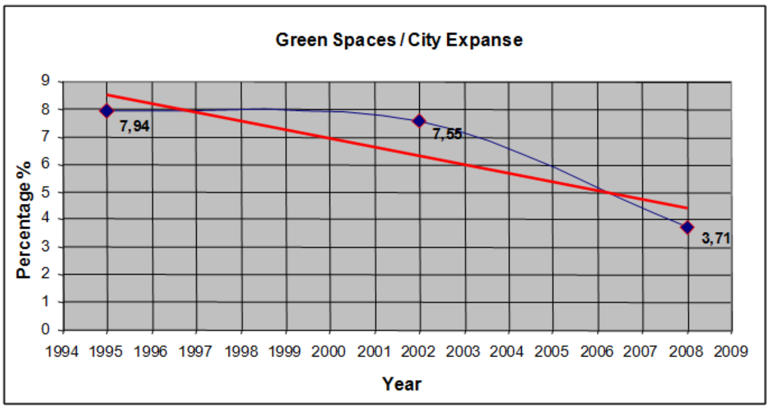


Diagram 5: Diachronic Evolution of the Index m^2 green spaces / m^2 of city expanse

By carefully observing the areas covered by the 300 meters buffer zones around the urban green, one can conclude that there is little increase in the areas that meet this criterion. In fact, there is no increase in the areas incorporated into the buffer zones, as the green spaces which are established as 300 meters buffer zones have remained stable through time. The slight alteration that was recorded resulted from the conversion of part of the “Other green spaces” included into the buffer zones, into building blocks, which raised the coverage percentage of the building environment. In present day, there are three large parts of the city of Chania which are not covered by the buffer zones, thus not meeting the criterion of 300 meters (last recording year, 2008). These areas are located on the boundaries of the urban core of the city (Figures 1).

6.2 Qualitative Evaluation of Urban Green

The vascular flora of Crete consists of about 1,600 taxa (species and subspecies). Approximately 160 (10 percent) of these taxa are endemic to Crete, which is characterized by a multitude of ecosystems created by topographical, geological, and climatic differences. In the city of Chania, the common areas between the buildings have been landscaped with ornamental species, some of which are not native to Greece or the Mediterranean. One of the most detrimental species planted on the base is the eucalyptus tree or blue gum (*Eucalyptus globulus*), which was introduced from Australia. It is invasive and considered noxious, as oils emitted from the tree inhibit the growth of any other vegetation under its canopy. Other ornamental species include, Canary palm (*Phoenix canariensis*), hibiscus (*Hibiscus rosa-sinensis*), *Pittosporum tobira*, *Araucaria excels* and *Rosa* sp., which are not suitable for Crete'a climatic conditions, considering the necessary amounts of water they need for their maintenance. Generally, the most appropriate flora for the specific location are members of Oleaceae family and phrygana vegetation, which is dominated by olive and carob trees with a few scattered kermes oak and prasium shrubs [.

The climate of Crete is characterized by moderately wet winter months, relative dryness in the spring, summer, and fall, extreme evaporation and almost no frost. The climate of Crete is strongly Mediterranean ranging in temperature from approximately 50ºF (10ºC) to 90ºF (32ºC). The prevailing winds come from the west in the winter and from the north in the summer. Hot dry siroccos from North Africa sometimes blast the island from the south and can cause extreme evaporation extending to the northern coast. Even though these seasonal winds come from fixed directions, their interactions with the rugged topography of Crete have produced a variety of rain shadows and rain excesses. This phenomenon has resulted in exceedingly diverse microclimates and has in turn contributed to the island's marvelous variety of plant communities. Given these specific climatic conditions only endemic species are suitable for "urban green" within the area of Chania, while ornamental species are strongly not recommended, as they need extra care, watering and preservation cost.

7. SUGGESTIONS

Urban green in the city of Chania is considered to be meagre in comparison to other European cities. This deficiency is becoming more intense with the elapse of time. It is vital to offer suggestions which would improve the quality of the environment. Having established its observations, this paper offers seven points of intervention:

- When landscaping new areas or replacing existing plants, native vegetation should be used. The use of native plants not only provides habitat for indigenous wildlife, but could also conserve water [Ktirio 77].
- Every effort should be made to eradicate introduced species such as eucalyptus.
- Whenever possible, eucalyptus trees should be cut down and their stumps removed and burned. These trees are basal sprouters and will re-grow if the stump remains in the soil.
- Plants which have high nutritious requirements should not be cultivated constantly in the same regions.
- Olive trees should be preferred, as they are native species and provide screening and wind protection as well as fruit in the fall.
- Implementation of schemes included in the Green Roof program, provided there are no available open spaces left that could be used for the development of new urban green [Skarlatos].
- The integration of green spaces into the green network with a view to achieve their maximum development and sustainability throughout the city and in every neighbourhood [Haaren 2004, Southworth 2005].

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