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Statistical Analysis of Environmental Quality Indices in an Urban Street Network

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1. Introduction

Nowadays, 80% of Europeans live in urban areas, facing a continuous degrading of the quality of the urban environment. The development of economy has reached high levels during the last decades, followed by an increase in the mobility of people around the city, the excessive use of passenger cars, and the concession of a substantial part of the city's vital space to the development of the public transportation network (Vlastos & Siolas 1994; Pitsiava, 1991; Raccioppi et al., 2002; Siddhartha, 1999; Dekoster & Schollaert, 1999).

The consequences of this policy and of the citizens' attitude are apparent, especially in the central city areas, which constitute a focal point of the transportation network, because of the density of the population in them and the diversity of their functions. Furthermore, it is observed that increasingly frequent occurrences such as conditions of traffic congestion, parking problems, accidents, noise, environmental pollution, functions, and visual obstructions of the central arterial routes, lower the citizens' quality of life and consist the major causes of a tendency to decentralize, thus creating the need for further expansion (Aravantinos, 1999; Masters, 1991; Vlastos & Polyzos, 1999; Porta & Latora 2007; Ferrarini et al., 2001).

It is therefore considered essential to design a geodatabase in a GIS, where environmental quality indices are developed. This geodatabase enables us to provide a specific and detailed description and analysis of the environmental indices of the urban roads. It can also become a convenient tool in the hands of specialists and of representatives of the state authorities, by facilitating their decision making on a number of issues concerning measures and interventions in the urban web. At the same time it will enable continuous observation and updating of the urban environment. Local communities which lack such a tool can attempt only occasional interventions which are difficult to evaluate as far as their effectiveness is concerned (Tsouchlaraki et al., 2009; Tsouchlaraki & Zoaki, 2008; Yildiz, 2008).

Such a geodatabase though, is useless if the data that are kept within it, are uncertain and do not contribute significantly towards the research of the environmental quality of urban streets. It is therefore considered critical to statistically analyse these data.

This chapter discusses the effort to research various indices and to statistically analyse the descriptive part of the geodatabase. Using methods of descriptive, inferential and multivariate statistics, it is attempted to examine the indices, to research their correlations, to

define their degree of importance, as well as to evaluate and to classify the environmental quality of the urban streets.

2. The research

2.1 The research outline

In this context, the Department of Environmental Engineering of the Technical University of Crete attempted to build a methodology for the assessment of the environmental quality of urban streets. The aim was to create a useful tool to assist in decision making regarding measures and action within the urban web. Towards this direction, a pure research project, titled "Development of indices for recording the environmental quality in cities' streets using GIS – GPS" developed 124 qualitative and quantitative indices describing the environmental quality of the urban street web (Abdulaal, 2007; Aisopos, 2003; Aravantinos, 1997; Beckman, 2001; De Jong, 2008; Gehl, 2002; Kartalis, 1999; Lymberopoulos, 2003; Mendes, 2005; Nicol & Wong, 2005; Nikolopoulou, 2004; Tsouchlaraki & Zoaki, 2008; Yannas, 2001; Zivas, 2003).

These indices have been categorized into eight definable groups: Urban Planning and Architecture, Construction Materials, Road Infrastructure, Traffic, Real Estate Use, Pollution, Climate, Other. The indices within these groups are further categorized into 20 sub-categories (Tables 1, 2).

a.	Urban Planning And Architectural	1. Urban planning indices 2. Architectural indices 3. Road geometry
b.	Construction Materials	4. Road surface materials 5. Paving materials
c.	Road Equipment	6. Street equipment 7. Street facilities
d.	Road Traffic	8. Static road traffic indices 9. Dynamic road traffic indices
e.	Land Uses	10. Commercial uses 11. Services 12. Communal spaces 13. Other uses
f.	Pollution	14. Air pollution indices 15. Noise pollution indices 16. Visual pollution indices
g.	Climatic	17. Climatic indices
h.	Other	18. Economic indices 19. Hygiene indices 20. Other indices

Table 1. Categories and Sub-categories of the Selected Indices (left)

The Municipality of Chania is the largest in population in the Prefecture of Chania, with 53373 inhabitants, (2001 population census) and has an expanse of approximately 7000 hectares. This one-division municipality borders with the municipalities of Nea Kydonia,

Akrotiri, Souda, and Eleftheriou Venizelou. Figure 1 (Figure 1) is a map which depicts the urban complex of Chania.

The municipality is divided into five urban units which diversify in terms of their building permit, building density, building system, height of buildings, their distance from the city centre and the different uses of land. There are further diversifications as to the morphology of the ground, and the geometrical, functional, financial and traffic characteristics of the roads.In order to record the indices which contribute to the environmental quality of roads, especially those of the urban complex of the municipality of Chania, a part of the city of approximately 500 hectares is selected, including parts from sections I, II, III, IV (Figure 1). Of these, some are part of the city centre (sec. I, II), others border the city centre (sec. III), while sec. IV represents a more remote part of the city.

a. Urban Planning And Architectural Indices
1. Urban Planning Indices
Building Permit Limit
Plot Coverage Percentage
Building System
Entrance Gardens
Length Of Building Blocks
Maximum Permissible Height Of Buildings
Existing Minimum Floor Number
Existing Maximum Floor Number
Surface Area Of Building Blocks
Arcades (In Parallel Or Across Streets)
2. Architectural Indices
Level Of Enclosure
Number Of Listed Buildings
Hypsometric Distribution Of Buildings
First Year Of Building Construction
Newest Year Of Building Construction
Average Year Of Construction
Subterranean Domiciles / Semi-Subterranean Domiciles
Building Shape
Building Color
Façade Details
3. Road Geometry
Pavement Width
Road Width
Road Orientation
Road Gradient
Multi-Level Footpath

Table 2. First Category (URBAN PLANNING AND ARCHITECTURAL INDICES) and its Three sub-categories (right)

The task of conducting research on the entire municipality of Chania was not feasible given the budget and time limits of this particular research project. It was additionally recommendable

to conduct a pilot scheme, to make observations, to reach certain conclusions and based on them, to reorganise the investigation and improve it where it is necessary, and if feasible, to re-conduct the research on a larger part of the city, or throughout the city as well.
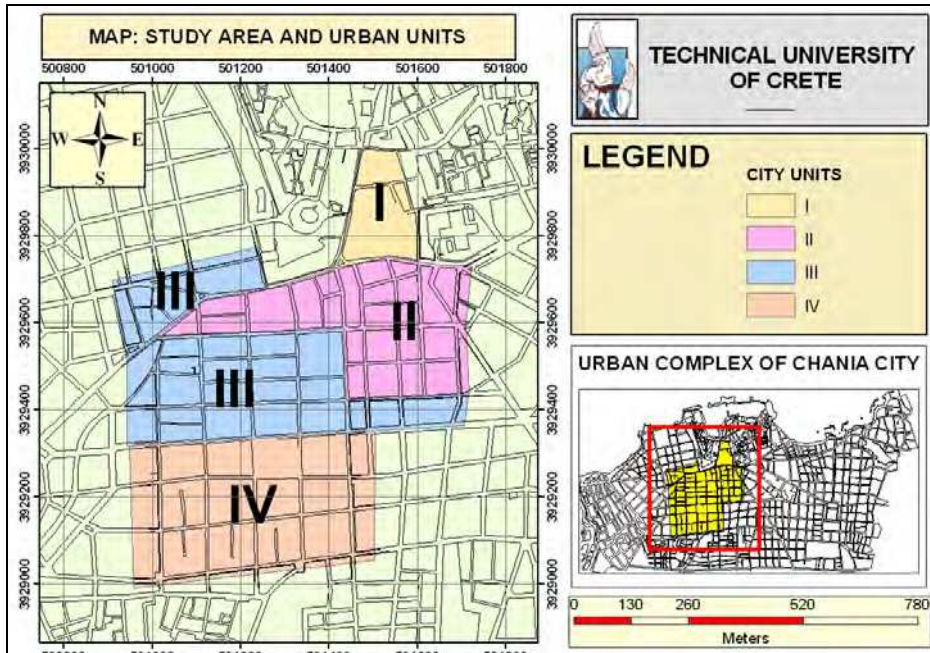

Fig. 1. Urban Complex of Chania, Research area and the four of the five Urban Units (right)

2.2 Data collection

The collection of data and the measurement of the values of indices of the selected area were conducted through public bodies, while the collection was based on already existing research and mainly on site recording (Tsouchlaraki et al., 2009). At the same time analytical photographical shootings were taken for every junction, facing all directions.

The collection of most indices was carried out via on site observation. Such indices were the archives, the existence of underground basements, semi underground / lower ground residences, informative signs, the existence of water draining grids, roadside handrails for pedestrians and so on. Other indices were digits of numbers, for example the number of preserved buildings in a street, the minimum and maximum number of floors of a building, the number of bus stops, etc. As for other indices such as the width of a street, they are estimated by providing a range of fluctuation, namely between 1 and 1.5 meters. Other indices define the material that was used either on the road surface or for layering the pavements. There were also indices that took the values of satisfactory, average and poor, for example when characterizing the appearance of a building.

Some of the indices were obtained through several governmental bodies. The building permit limit, the plot coverage percentage and the building system for example were

provided by the Urban Planning Office of Chania. Noise levels, were obtained by the department of traffic planning of the municipality, while the commerciality index was obtained by the Tax and Revenue Office of Chania.

Apart from acquiring indices with the aforementioned methods – on site observation or through governmental bodies – other indices were obtained through a digital map of a software program. This digital map contained the urban streets layer and the building blocks layer and it was managed through the AutoCAD software which was very flexible to to the measurements. Such indices were the square surface of building blocks, the width of streets, the orientation of streets and the length of Building Blocks (B.B).

Measurements of some indices were practically impossible either because the access to some of the files of certain public offices was impaired (i.e. unknown date of building construction) or because there was a lack of relevant research, which would lead us to insufficient data.

The indices with no data were not taken into consideration in the evaluation of the streets. Those indices were the oldest, the most recent and the average year of building construction, those included in the category of dynamic traffic indices, and the ones which represent the concentration of COX , NOX, SO2, HC, of Ozone, of Suspended Particles and Dust. In addition, the indices of the average annual temperature, of wind speed, rainfall and absolute humidity, the indices of the value of land and buildings and of the population of building blocks as well.

In addition to the data collected in the ways described above, a survey was conducted on 192 inhabitants from all city areas. The answers were given either in writing or via interviews. The aim of the survey was to record the public's opinion on issues concerning the convenience, aesthetics and attractiveness of the roads, the traffic, the public transportation, pedestrian safety, drivers' safety, etc (Aravantinos, 1997). One of the basic questions that were included in the questionnaire was whether there was an index that had not been included and it should be taken into consideration. According to the outcomes, no new indices resulted.

2.3 The geodatabase

A database plays a major role in a GIS while it directly affects its cost. A database is the foundation of the use of a GIS enabling its user to do programming, develop an application, analyze and derive secondary data, which will in turn help in decision making (Arctur & Zeiler, 2004; Koutsopoulos, 2002). The distance between two junctions was selected to be the spatial unit, as in some cases the entire length of a street is heterogeneous and too large to be examined as an entity.

The junctions of the streets were photographed for the entire study area (Figure 2). Through these photographs one can make observations on the area, cross-check data of the base, possibly collect further data of interest, thus having a combined overall visual perception of the data. In this way, the photographic file provides evidence, reference, explanation and most likely a mechanism of cross-checking the database.

Three spatial information sources were used:

- A topographic map of the research area of a scale 1:200 (which results from field measurements in combination with an existing background map of a large scale). This

- map contained two layers, one representing the geometry of the urban street network and one representing the geometry of the urban blocks.
- A map of the city of Chania (a section within the administrative boundaries of the Chania Municipality) of a scale 1:2.000. This map contained two layers of information, the geometry of the urban street network (not as accurate as the information in the first map) and the second one with the administrative boundaries.
- Axes and major intersections of the road network of the research area. This information was in digital form and it was digitized from the first map (the topographic map).

Fig. 2. Typical examples of photo shootings

This spatial information contained in these layers, was in shapefile format within the ArcGIS system in an ESRI geodatabase. The geometry of the urban street network data was stored as a linear layer while the geometry of the urban blocks data was stored as a polygon layer. The axes of the road network (divided into straight line sections, from junction to junction) were also stored as a linear layer and the intersections of the road network were stored as a point layer.

The geodatabase contained these layers which were the spatial information of the research. The axes of the road network, as it has already been mentioned, are the spatial units of the research. All the values of the indices that were gathered were the non spatial information of the research. This non spatial information refers directly to the spatial units of the research and thus, it does not need a complicated geodatabase structure to be stored. A simple relational geodatabase structure was used and all the non spatial data were connected to the spatial units through a unique spatial unit code. The aim of the research was to provide a significant group of indices, well defined, in order to define the environmental quality of the urban streets, therefore the geodatabase best structure finding was not one of the research goals. If the results of this research are to be expanded in the whole area of the city of Chania or if they are to be applied in an another large city, then the geodatabase structure is important and special attention should be paid in order to optimize its performance.

The values of indices vary. Others are quantitative (i.e. building permit limit, height of buildings, area of building blocks, coverage percentage etc), while others are qualitative as for example telephone booth existence (yes or no), pavement surface condition (satisfactory – medium - poor) (Abdullal, 2007; Tsouchlaraki & Zoaki, 2008; Bata & Obrsalova, 2009; Button, 2002).

2.4 Methodology of evaluating the environmental quality

The research on the evaluation of the environmental quality of the streets was based on two ways of approach:

- Evaluation on a theoretical level
- Evaluation on a practical level

On the first approach of a theoretical basis, the minimum and maximum theoretical sum of values was calculated for each and every of the eight categories of indices. The minimum theoretical sum of a category may be 0 in the case where all the indices included have zero value (which means that all recorded indices are "of poor environmental quality), whereas the maximum theoretical sum is calculated by adding up all the indices included in that category. In case where all indices are 1, (which means that all recorded indices were of "satisfactory environmental quality"), the maximum theoretical sum would be 10 for a category including 10 indices.

In the case of approaching the environmental quality of streets on a practical basis, the actual sum is recorded every time. Subsequently, the minimum sum is obtained by the street with the lowest sum of indices while the maximum sum is obtained by the street with the highest sum of indices. An example of the criteria of the traffic indices is presented in Table 3 (Table 3). The classification of the indices into the two main categories (satisfactory or poor environmental quality of a street) was empirical and it was based on the opinion of experts in issues pertaining Urban Planning. The classification of these indices was based on a scale of 0 to 1, where 0 was given to the streets of poor environmental quality and 1 to the ones of satisfactory environmental quality.

Environmental Quality	Satisfactory	Poor
Indices: TRAFFIC INDICES		
Traffic Lanes in each direction	One-way streets and pedestrianised walkways	Two-way streets
Parking Scheme	Controlled Parking	Free parking
Existence of parking meters	yes	no
Pedestrians Crossings	yes	no
Ramps	yes	no
Traffic Lights	yes	no
Existence of Bus Routes	yes	no
Existence of Bus Stops	yes	no
Existence of cycling lanes	yes	no
Specially Paved Lanes for people with vision difficulties	yes	no
Special Routes for Handicapped People	yes	no
Reserved Parking areas	yes	no
Prohibited parking spaces (building entrances, garage entrances etc)	yes	no

Table 3. Evaluation Criteria for the Environmental Quality of Streets – Traffic Indices

It should be noted at this point that the classification was carried out with those indices for which recorded data were available. Principally, an assumption is made at this phase, and that is "all indices carry the same weight and consequently their importance is equal in the corresponding sums, whether they are theoretical or actual".

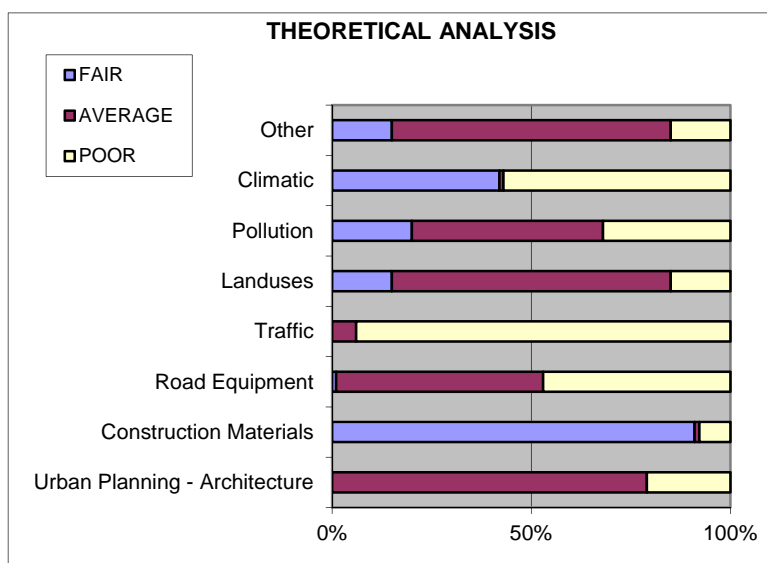|	Percentage of Streets %			Percentage of Streets %		
	FAIR	AVER	POOR	FAIR	AVER	POOR
INDICES	THEORETICAL			ACTUAL		
Urban Planning - Architecture	0.00	79.00	21.00	28.00	50.00	22.00
Construction Materials	91.00	1.20	7.80	91.00	1.20	7.80
Road Equipment	1.00	52.00	47.00	4.00	80.00	16.00
Traffic	0.00	6.00	94.00	8.00	21.00	71.00
Land Uses	15.00	70.00	15.00	15.00	70.00	15.00
Pollution	20.00	48.00	32.00	26.00	42.00	43.00
Climatic	42.00	1.00	57.00	42.00	1.00	57.00
Other	15.00	70.00	15.00	15.00	70.00	15.00

Table 4. Evaluation Results

The minimum and maximum sums – both theoretical and actual – are classified into three categories of environmental quality (poor, average and satisfactory). This is achieved by dividing the range of values between the minimum and the maximum sum into three equal sections, and defining at the same time the range of values for each of these sections. The classification of all the streets of the study area follows, into the three categories of environmental quality (poor, average, satisfactory) both on a theoretical and on a practical basis (Table 4, Diagram 1).

As defined by the theoretical approach, the evaluated streets are comparable to streets of any other areas, which can also be evaluated with the same method, which means that the evaluation is absolute. On the contrary, the evaluation of streets on a practical basis defines that the evaluated streets are only comparable among them, namely to the ones found within the same study area, which means that the evaluation is relative.

The first approach will help us intervene in an area in order to improve the streets which do not meet the environmental quality criteria, whereas the second approach will help us intervene in the study area in order to improve the streets which are in a disadvantaged condition compared to other streets in the same area.

All the previous results, concerning the environmental quality of the urban streets, were mapped through the ArcGIS system, using the geodatabase of the research. These maps represent the environmental evaluation of these streets, as this was defined through the research (Figures 3, 4, 5, 6).

After analyzing the urban and architectural indices, it can be concluded that area III is in a dire need of intervention, compared to the other areas, as there are indications of lowered environmental quality. The inspection of the exterior colour of the buildings, the maintenance of preserved buildings and the construction of pavements of a larger width are the courses of action that are recommended.

THEORETICAL ANALYSIS

Legend:
- FAIR
- AVERAGE
- POOR

Categories (top to bottom):
- Other
- Climatic
- Pollution
- Landuses
- Traffic
- Road Equipment
- Construction Materials
- Urban Planning - Architecture

Axis: 0% — 50% — 100%

ACTUAL ANALYSIS

Legend:
- FAIR
- AVERAGE
- POOR

Categories (top to bottom):
- Other
- Climatic
- Pollution
- Landuses
- Traffic
- Road Equipment
- Construction Materials
- Urban Planning - Architecture

Axis: 0% — 50% — 100%

Diagrams 1. Evaluation Results

The environmental quality of the streets of the study area is considered satisfactory as far as its construction material indices are concerned, except for area III, where there is room for improvement and change. For these problematic sections of the streets, the use of friendly layering materials for the road surface and for the pavements, as well as their maintenance are recommended.
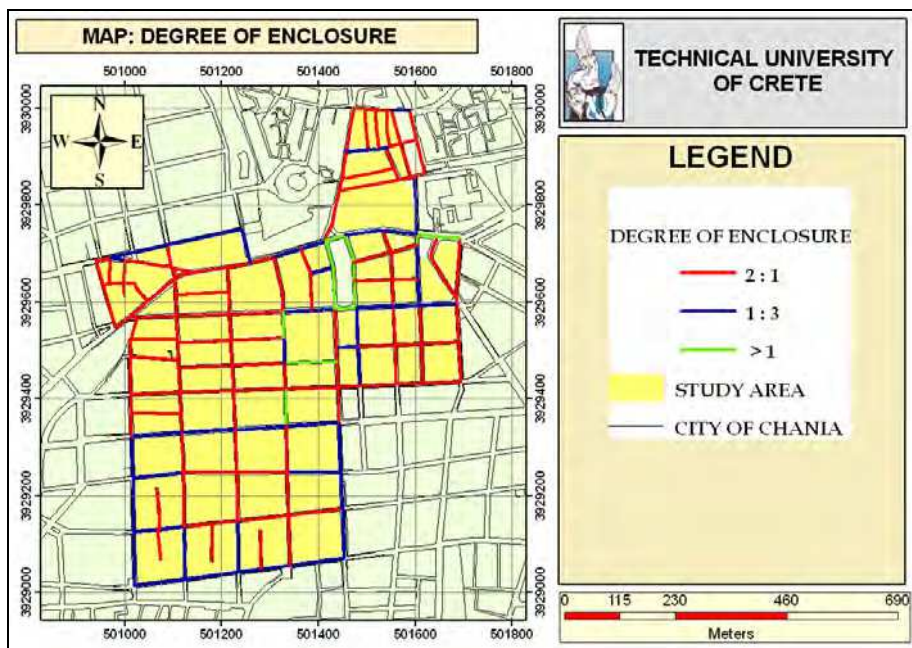
Fig. 3. Map – Degree of Enclosure
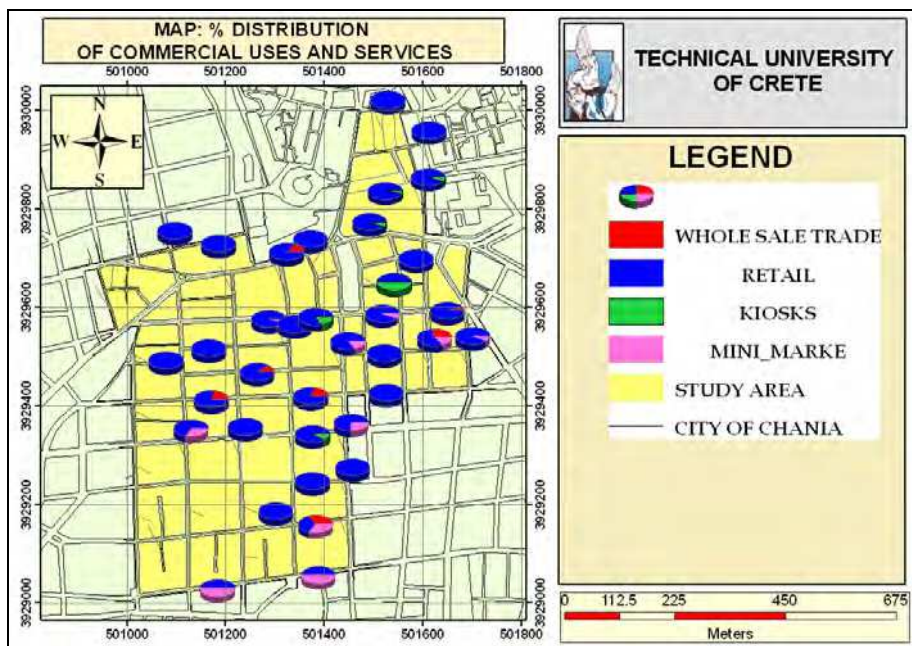
Fig. 4. Map – Percent Distribution of Commercial Uses and Services
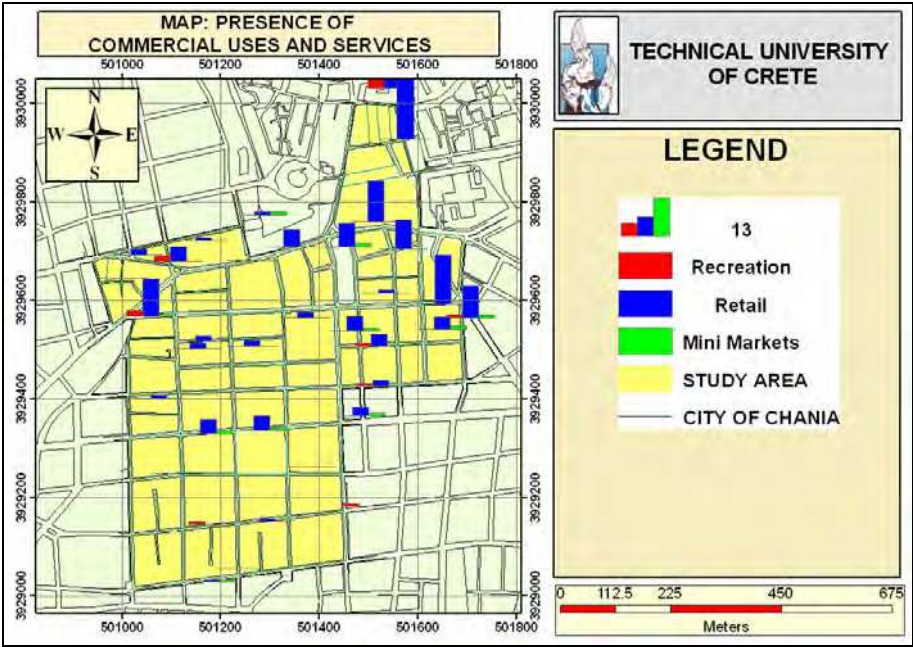
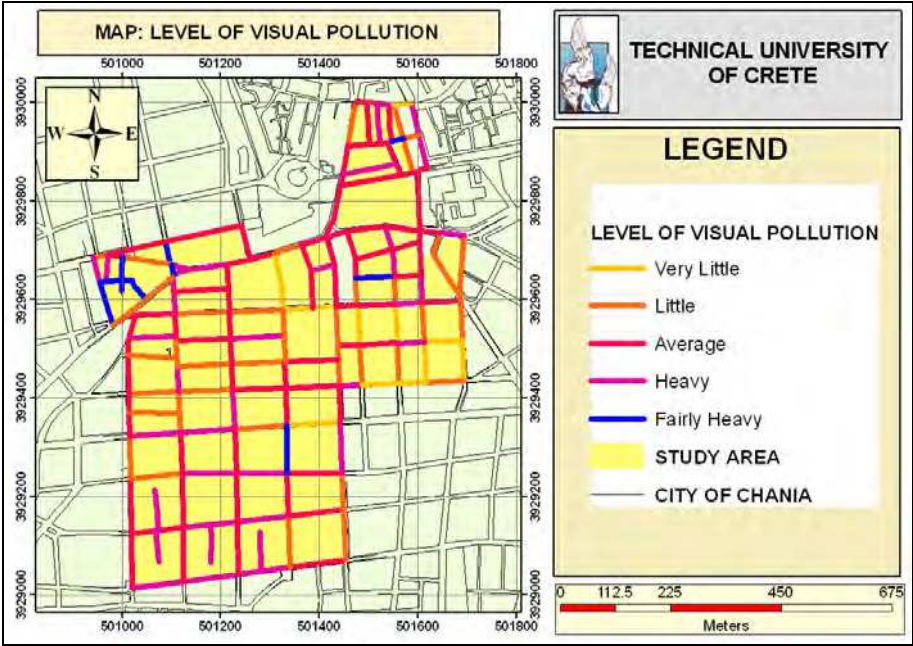Fig. 5. Map – Commercial Uses and Services

Fig. 6. Map – Level of Visual Pollution

The product of the analysis can be apparent and understandable provided that different mediums / forms of results presentation are used, and should be supervisory, easily understandable and provide with the capacity to compare and contrast between the results. Maps are such mediums of results presentation.

More specifically, the results enables one to:

- **Directly map the spatial distribution of the indices of the base**
  This form of mapping presentation enables researchers to observe the indices they are interested in and form a view on their spatial distribution. Observing this distribution leads to identifying the homogenous zones that are created and the spatial differentiations that appear. Examples of indices that can be depicted in this simple form are the index of enclosure level, of the presence of advertising signs, of cleanliness level, the index of building permit limit, and so on. Some of these indices appear further on. One can be either convergent with the area, or obtain data besides the environmental quality indices in order to draw useful conclusions about the picture of the indices in the research area.
- **Have a comparative inspection of the categories of the indices in the form of diagrams (histograms, pies, graphs etc), distributed in the area within the administrative boundaries that are being examined**
  The indices that are to be included into a group to be mapped must be comparable among them. For example, one can choose to chart the indices group concerning the commercial activity, some of them being the index of retail and wholesale transfers, of department stores, etc. In the event of indices being charted in the form of histograms then the comparison is full (indices directly comparable between them), while in the form of pie-charts the comparison is relative and on a per cent basis.
- **To search for certain sections of the area which adhere to certain criteria, spatial or not**
  The third way of depicting analysis products on a result map, is the creation of maps of multiple criteria search (spatial or not). This type of mapping reflects the logic of GIS since a search is conducted either on the spatial database or on the descriptive (non spatial) one. The search for parts of the research area which meet certain criteria (simple or complex) , helps the researchers to locate any occurrences – or lack of them - or even foresee any eventualities. The criteria could be so complex that it would be practically impossible to process without the use of a GIS.

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Concerning this research, examples of such searches could be:

- Which streets display high commercial activity but restricted pavement width
- In which streets the road and pavement surface quality is very low.
- The streets on which despite their restricted width, parking is permitted on both sides of it

In an effort to further research these various indices statistical analysis has been implemented on the descriptive part of the geodatabase. Using methods of descriptive,

inferential and multivariate statistics, it was attempted to reexamine the indices, research their correlations, define their degree of importance, as well as evaluate and classify the environmental quality of the roads.

The geodatabase that is designed enables one to further examine the factors which are more important to affect the environmental quality of streets while it also provides the potential for their modeling. This evaluation process can be a useful tool in the hands of authorities in order to prioritize their interventions in the urban web, aiming at the improvement of the environment.

3. Methodology of the statistical analysis

Statistical analysis is implemented in an effort to define the indices affecting the environmental quality of urban streets. Through processes of descriptive and inferential statistics, the indices are examined, the cross-correlations that may exist between them are researched and those with the greatest importance are determined. Statistical classification methods are, also, used to identify homogeneous areas in a selected part of the city of Chania, which are, then, evaluated according to the level of their environmental quality.

Statistically non significant indices are identified regarding the data from the selected study area. These include the indices with zero or near zero variances, i.e. whose values are the same for all or nearly all the reviewed road sections. Therefore, they have a negligible effect in the evaluation of environmental quality of the examined roads. These indices are not taken into consideration in the subsequent statistical processes (inferential and multivariate statistics).

Inferential statistics analysis and evaluation of the sum of results leads to the conclusion that most of the reviewed indices present significant correlations with, at least, another index, while several of them present strong-significant correlations. Of these, the Building permit limit and Commerciality coefficient are the most important ones, since they have the greater number of strong correlations while, at the same time, they present independency in the context of affecting without being affected by the rest of the indices. Along with the Length and the Square footage of the city blocks, Width, Orientation and Elevation of the Roads, they form a group of inherent road characteristics which hardly allow any changes.

In order to evaluate the level of environmental quality of the resulting groups of roads, at first the profile of each is identified, based on the frequency distributions of the same binary variables of each of the three groups. Then, the presence of each road characteristic is defined as either positive or negative.

SPSS software (Statistical Package for Social Sciences) has been used for the processing and analysis of data. Urban streets environmental quality indices represent the data variables while the road sections represent the data cases. Note that the data measurement level varies. There are either scale (e.g. Road width, measured in meters), ordinal (e.g. Traffic flow direction values: 1. one way, 2. two way or 3. pedestrian way) or nominal variables (e.g. Paving material values: 1. asphalt pavement, 2. stone tiles, 3. concrete tiles, 4. concrete pavement).

3.1 Descriptive statistics

As a first step, in order to statistically research the environmental indices, methods of descriptive statistics were used. In specific, indices were organised and presented using frequency distributions (frequency tables and charts), measures of central tendency (mean, median and mode) as well as measures of dispersion (standard deviation and variance). Contingency tables and the respective clustered or stacked bar charts were used for the combined presentation of pairs of variables.

3.2 Inferential statistics

Next step was the evaluation of the interrelations between the indices through inferential statistics methods. Purpose was to highlight the interactions and the degree of correlation. This allowed the identification of those which are most influential.

In detail, the relation between two indices at a time was studied. Depending on the nature of the indices, different parametric test methods were used. These are the Independent-Samples T test, ANOVA (Analysis of Variance) and Pearson correlation. For the categorical variables, the nonparametric Chi-Square test was used. In cases were the requirements for the parametric tests were not met, the respective non-parametric tests of Mann-Whitney U, Kruskal-Wallis H and Spearman correlation were used. For all statistical tests performed, a 0.05 level of significance, otherwise alpha level, was chosen.

3.3 Cluster analysis

Multivariate classification statistical analysis was the final step in the statistical investigation of the indices. In specific, Hierarchical Cluster Analysis was implemented for all indices which were or could be transformed into binary variables. The values of '1' and '2' of these variables indicate the presence and absence, respectively, of the road characteristic each index is connected with. In the process of cluster analysis, agglomerative method was used. The aim of the Hierarchical Cluster Analysis was the grouping of cases, as well as grouping of variables.

Grouping of cases was made in order to create groups of roads with common environmental quality indices, i.e. their road characteristics. Ultimate purpose was these homogeneous groups to be evaluated according to the level of their environmental quality and define the good, average or poor environmental quality of each. Based on this rationale, it was decided that the resulting number of clusters should be three. As far as cluster method and dissimilarity measure are concerned, Between-groups linkage and Squared Euclidean distance, respectively, were used.

On the other hand, grouping of variables aimed in creating groups of related indices. In this case, a dendrogram was created in order to determine the number of clusters. Squared Euclidean distance was used as a dissimilarity measure and Ward's method as a cluster method. The reason Ward's method was chosen is because it tends to create clusters of approximately same size, in contrary with the, equally good, Between-groups linkage method.

The level of environmental quality and the profiles of the three groups define the needs for remedial action for each. In this manner, Cluster 1 requires actions in almost every aspect related to the quality indices, while Clusters 2 and 3 only require partial improvements.

The differentiation of the three groups formed, makes sense. Cluster 1 refers to road characteristics met, primarily, in parts of city with dense construction, i.e. large built space coefficients (>1), commercial areas, public services, means of advertisement and promotion (such as signs and tents) etc. Cluster 2 is related with road characteristics met in the city centre, with plenty of commercial uses, since it includes indices referring to commercial related characteristics, squares, road furniture, traffic control infrastructure, atmospheric – visual pollution, sidewalk parking etc. Finally, Cluster 3 refers to road characteristics relevant to residential areas, which ensure a certain level of quality of life within the urban environment. These include indices such as no-parking areas, gardens, trees, good lighting and air quality etc. Overall, indices have been divided according to the different uses of the urban environment; Commercial for Cluster 2, Residential for Cluster 3. Cluster 1 combines commercial use and dense construction. These come as a verification of the importance of the Building permit limit and Commerciality coefficient identified through inferential statistics.

The selection of statistical analysis for the study of the environmental quality indices of the urban roads proves to be effective. At first level, allows for the identification of the indices worth considering. At second level, it picks out the most significant ones of the lot. Finally, it leads to the distinction between areas with different road characteristics, and therefore different level of environmental quality. The level of quality was also registered.

Summing up, statistical analysis results in significant conclusions regarding the relationship and the importance of the environmental indices, as well as the distribution and assessment of the environmental quality of the selected study area streets.

4. Results and discussion

4.1 Findings of descriptive statistics

Statistical analysis is implemented in an effort to define the indices affecting significantly the environmental quality of the urban streets.

Further to the presentation of environmental quality indices' distribution, through descriptive statistics, statistically non significant indices were identified regarding the selected study area. These include the indices with zero or near zero variances, i.e. whose values are the same for all or nearly all the reviewed road sections. Therefore, they have a negligible effect in the evaluation of environmental quality of the examined roads. This is why these indices were not taken into consideration in the subsequent statistical processes (inferential and multivariate statistics).
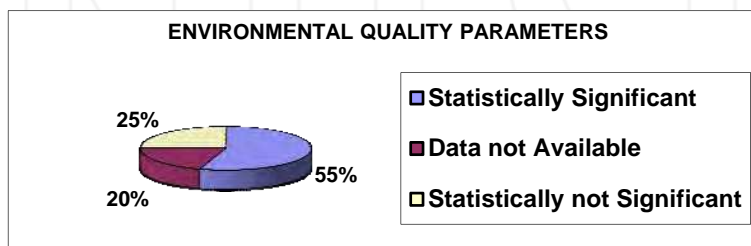

Diagram 2. Findings of descriptive statistics

As shown in Diagram 2 (Diagram 2), from the sum of the reviewed indices, statistically non significant accounted for 25%, while 55% represented statistically significant environmental indices which, through statistical analysis, can assist in deriving useful conclusions for the total of road sections and their environmental quality. Note that the remaining 20% represented indices for which no information was made available during data collection.

It is interesting to compare three frequency distribution diagrams of the indices Length of Building Block, Surface of Building Block and the index of Commerciality (Diagrams 3, 4, 5). If we look carefully, we can see that these frequency distribution diagrams present a clustering of three groups. The two first frequency distribution diagrams represent the geometry of the building blocks and therefore it is expectable to present a correlation. The third frequency distribution diagram, presents a relation with the other two (has a three group clustering). Probably, the areas have their commerciality index values based on the geometry of the building blocks and thus, commerciality index presents a similar distribution with the geometry indices.
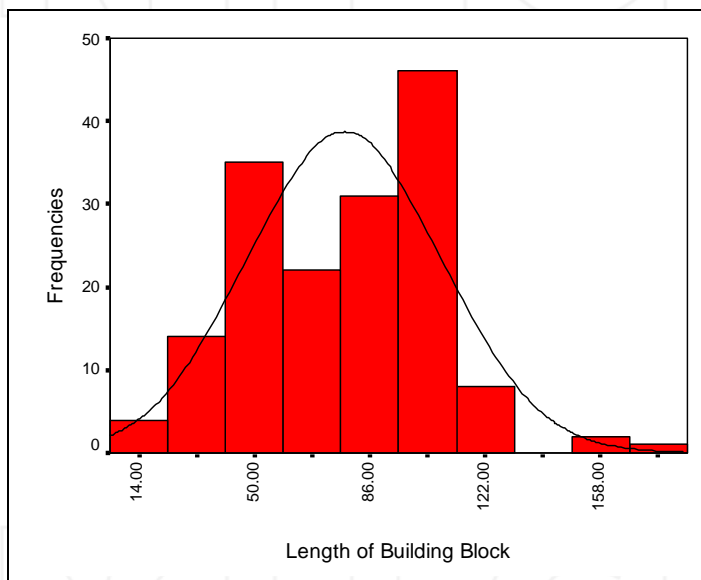

Diagram 3. Frequency Distribution Diagram of Index "Length of building blocks"

4.2 Findings of inferential statistics

The application of the inferential statistics analysis and the evaluation of the sum of results led to the conclusion that 98.5% of the reviewed indices present significant correlations with, at least, another index, while 69% present strong-significant correlations. Strong correlations are the ones for which the measures of association (Phi coefficient or Cramer's V) equal or exceed 0.4 (Bata & Obrsalova, 2009) or the correlation coefficients equal or exceed 0.6 (Button, 2002). Of these, the Building permit limit and Commerciality coefficient are the most important ones, since they have the greater number of strong correlations while, at the same time, they present independency in the context of affecting without being affected by

the rest of the indices. Along with the length and the square footage of the city blocks, width, orientation and elevation of the roads, they form a group of inherent road characteristics which hardly allow any changes.
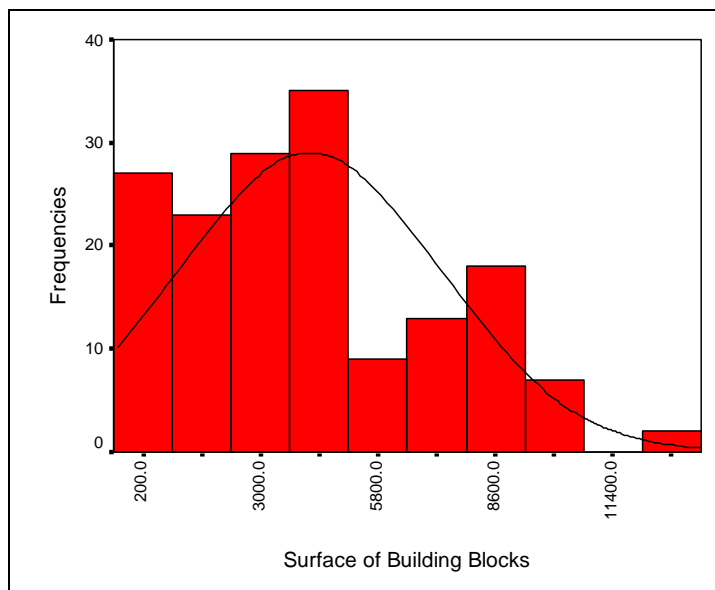

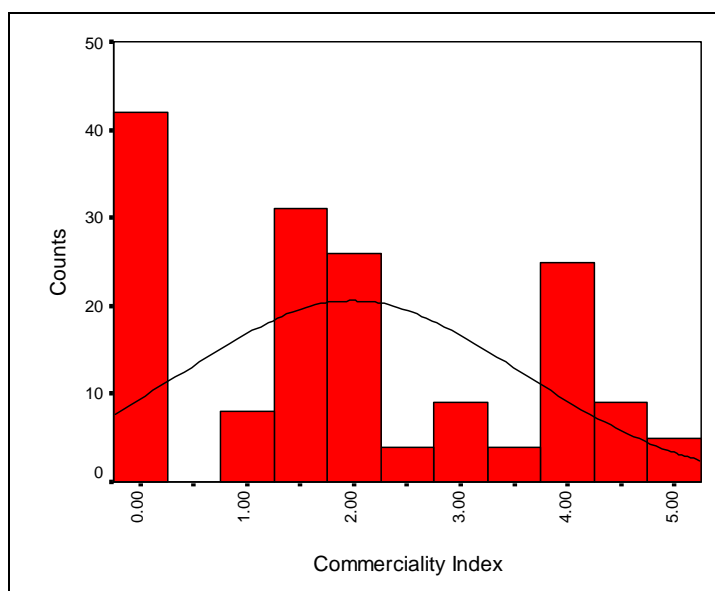Diagram 4. Frequency Distribution Diagram of Index "Surface area of building blocks"

Diagram 5. Frequency Distribution Diagram of Index "Commerciality"

Comparing two of the indices, the Length of Building Block from the Urban Planning group and the Hypsometric Distribution of Buildings from the Architectural Group, we can see some interesting remarks (Diagram 6, Table 5). It can be seen from the boxplot diagram that the three groups of data for the Hypsometric Distribution of Buildings Index (Aligned, Irregular, With Gaps) present a different mean value for the Length of Building Block Index. The Hypsometric Distribution of Buildings, values "With Gaps" are met at high values of the Length of Building Blocks Index (with a mean value of Length equal to 92.5m), while the values "Aligned" are met at low values of the Length of Building Blocks Index (with a mean value of 50.2m). This observation can be statistically tested and certified.

These differences can be explained if we take into account that that the high values for the Length of Building Blocks Index can be found in urban streets which are usually away from the city centre and therefore, there are usually empty spaces in those streets (spaces that have not yet been built).

4.3 Findings of cluster analysis

Regarding the classification of the cases, i.e. the road sections, into 3 clusters (Figure 7), Cluster Membership results were mapped in order to facilitate their overview (Figure 8).
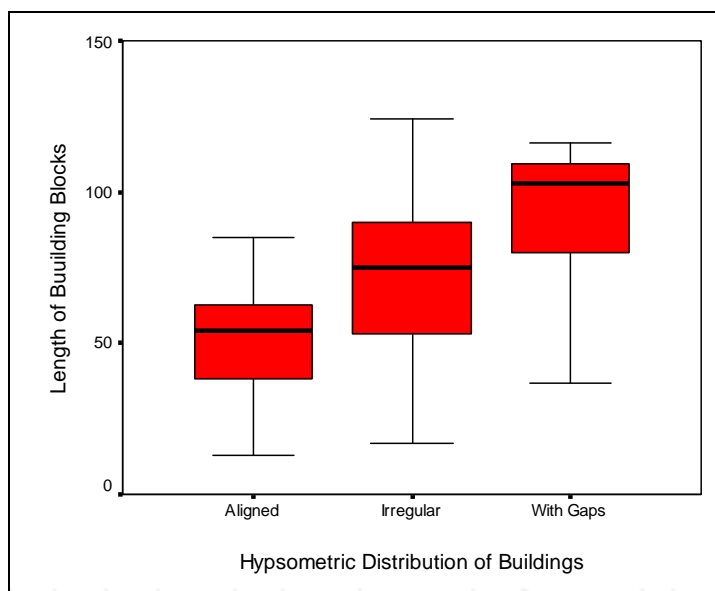

Diagram 6. Boxplot Diagram of the Hypsometric Distribution of Buildings and the Length of Building Blocks Indices

In order to evaluate the level of environmental quality of the resulting groups of roads, at first the profile of each was identified, based on the frequency distributions of the same binary variables of each of the three groups. Then, the presence of each road characteristic was defined as either positive or negative. The frequency of presence (or absence) of each index in each group was characterized by the symbols illustrated in Table 6 (Table 6).

For example, regarding the Recycle bins index, whose presence is considered positive, it appeared to 16% of Cluster 1 road sections, hence Cluster 1, according to Table 1 is characterized with the symbol ☹, 67% of Cluster 2 road sections, hence the symbol ☺/☺ and 32% of Cluster 3 road sections, hence the symbol ☹/☺. The same procedure was followed for each of the indices and ultimately, the total "score" for each group was calculated.

Length of Building (m)								
					95% Confidence Interval for Mean			
	N	Mean	Std. Dev.	Std. Error	Lower Bound	Upper Bound	MIN	MAX
Aligned	15	50.20	21.69	5.60	38.18	62.22	13	85
Irregular	93	74.00	30.92	3.20	67.63	80.37	17	181
With Gaps	55	92.53	22.84	3,08	86.35	98.70	31	116
Total	163	78.06	30.16	2.36	73.40	82.73	13	181

Table 5. Comparison of the Hypsometric Distribution of Buildings and the Length of Building Blocks Indices

Cluster 3 showed the best environmental quality of roads, scoring 36 ☺, 14 ☺ and 30 ☹. Cluster 2 comes second with a score of 32 ☺, 22 ☺ and 31 ☹ while Cluster 1 is the one with the lowest level of environmental quality, scoring a merely 8 ☺, 23 ☺ και 38 ☹.

Frequency of appearance of each index in each group	Symbol	
	Positive impact index	Negative impact index
0 %	☹ ☹	☺ ☺
0% - 20%	☹	☺
20% - 40%	☹/☺	☺/☺
40% - 60%	☺	☺
60% - 80%	☺/☺	☹/☺
80% - 100%	☺	☹
100%	☺ ☺	☹ ☹

Table 6. Indices' frequencies and symbols

The level of environmental quality and the profiles of the three groups define the needs for remedial action for each. In this manner, Cluster 1 requires actions in almost every aspect related to the quality indices, while Clusters 2 and 3 only require partial improvements.

As for the grouping of the variables, the cluster analysis results are presented in the form of a dendrogram, having emerged from the procedure (Figure 7).

One can notice that, at first level, nine groups are formed which, in return, form three larger clusters. Their differentiation makes sense.

First cluster refers to road characteristics met, primarily, in parts of city with dense construction, i.e. large built space coefficients (>1), commercial areas, public services, means of advertisement and promotion (such as signs and tents) etc.
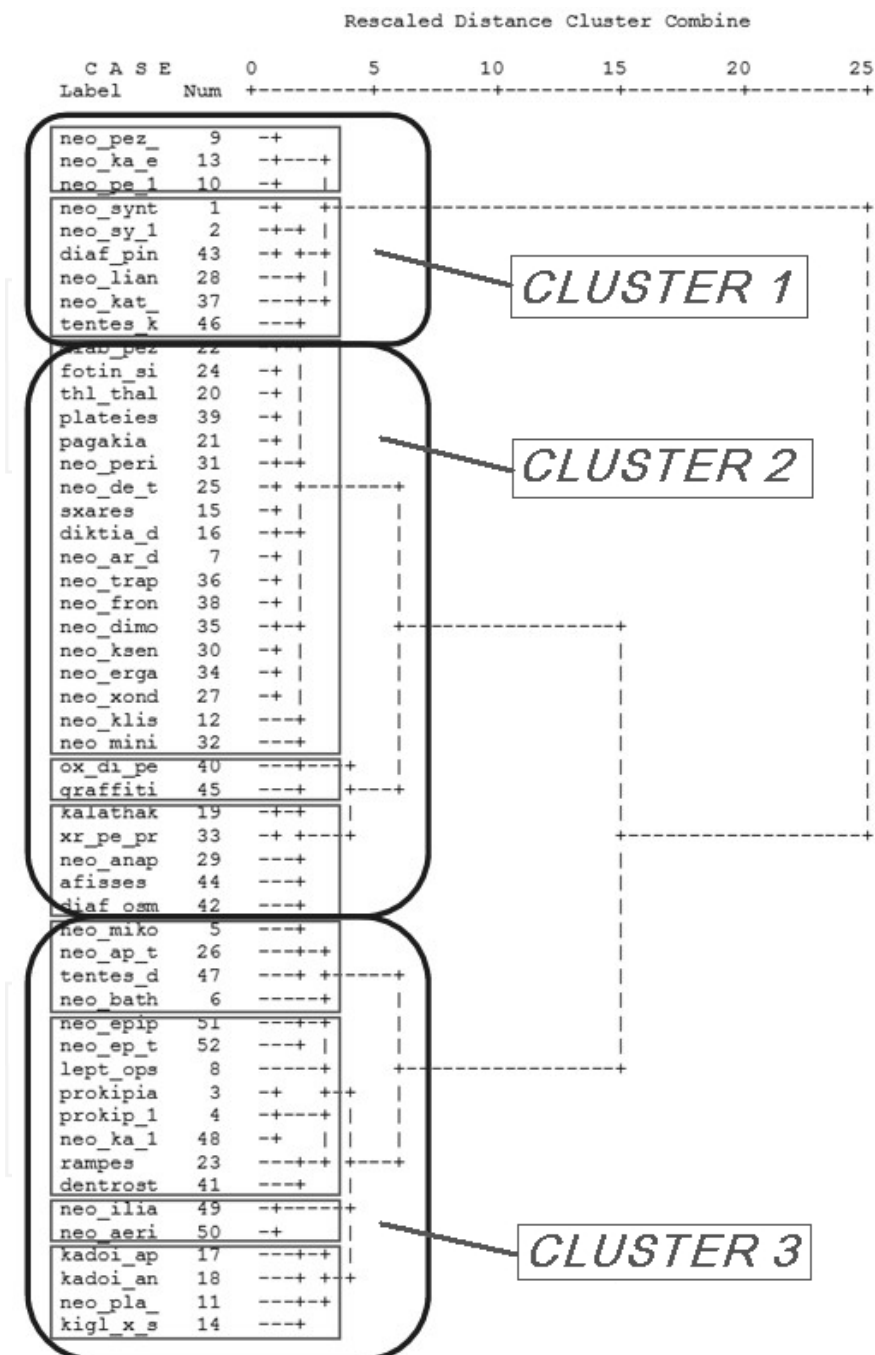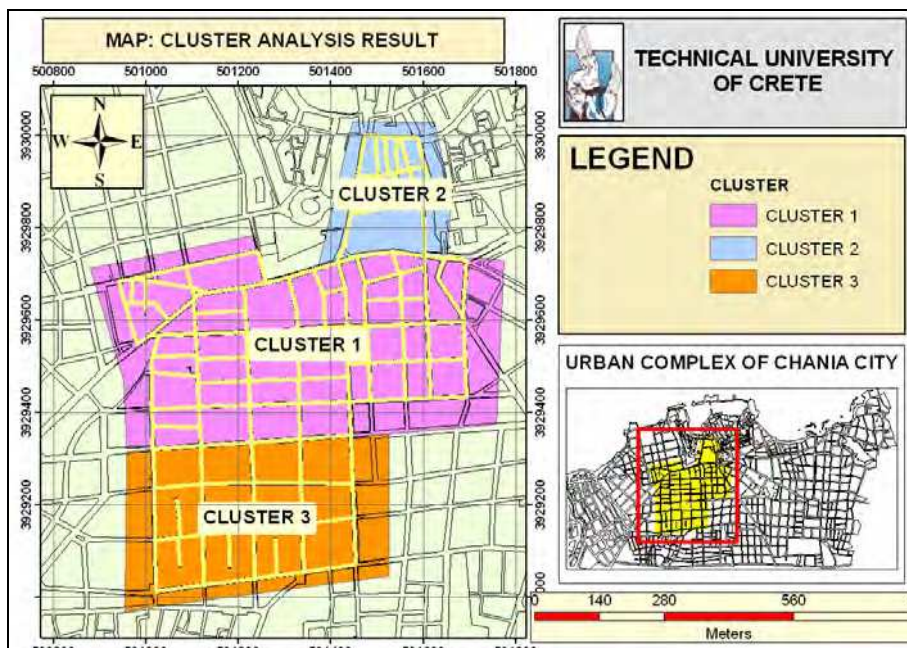
Fig. 7. Dendrogram using Ward's method

Fig. 8. Visual presentation of cluster analysis results regarding groups of cases

Second cluster is related with road characteristics met in the city centre, with plenty of commercial uses, since it includes indices referring to commercial related characteristics, squares, road furniture, traffic control infrastructure, atmospheric – visual pollution, sidewalk parking etc.

Finally, Cluster 3 refers to road characteristics relevant to residential areas, which ensure a certain level of quality of life within the urban environment. These include indices such as no-parking areas, gardens, trees, good lighting and air quality etc.

Overall, indices have been divided according to the different uses of the urban environment; Commercial for Cluster 2, Residential for Cluster 3. Cluster 1 combines commercial use and dense construction.

These come as a verification of the importance of the Building permit limit and Commerciality coefficient identified through inferential statistics.

5. Conclusions

The aim of this research was to design and develop a mechanism (a geodatabase within a GIS system) which would include all the elements relevant to the quality of the urban roads, so that the local administration bodies are facilitated in handling the urban environment and in their decision making.

This database was designed and could serve as a pilot research for the local administration offices. The 124 indices aimed to cover the whole spectrum of the environmental factors. The

potential for processing and analyzing is endless; mapping, classification of areas according to their homogeneity, environmental evaluation based on multiple criteria, and the diachronic updating and observing of the urban environment.

One of the problems encountered was that for some of the indices, no data was obtained. This is a problem that occurs frequently throughout Greece and is owed to the fact that every municipality have conducted their own projects, which means that the conclusive data is quite diverse.

This particular database though, includes fields for those indices that haven't been recorded so far, so that when more data becomes available, the base can be updated.

Another obstacle was that in some cases the available data were in relation to the city as a whole (i.e climatic indices, temperature, rainfall, etc). The variations throughout the city though, are unknown, which is why it is recommended that new research should be conducted, based on recording every individual street, or finding an accepted technique for interpolating these generalised spatial data on the spatial unit level.

Yet another problem is the specialization of the people who take part in on site recordings of data. Certain indices -such as colour variety, harmonious mixture of colours- should ideally be carried out by an architect. In such cases, the research team should consist of researchers from all related sciences.

The Geo-Database that was designed enables one to further examine the factors which affect the environmental quality of streets while it also provides the potential for their modelling.

In a subsequent research program we attempt the examination of the recorded factors in order to establish which ones are the most important and to compile them hierarchically according to their significance in urban planning as well as explore their modelling potential.

This evaluation process can be a useful tool in the hands of authorities in order to prioritize their interventions in the urban web, aiming at the improvement of the environment.

The selection of statistical analysis for the research of the environmental quality indices of the urban roads, proved effective.

At first level, it allowed for the identification of the indices worth considering.

At a second level, it picked out the most significant ones of the lot.

Finally, it led to the distinction between areas with different road characteristics, and therefore different level of environmental quality. The level of quality was also registered.

Summing up, statistical analysis resulted in significant conclusions regarding the relationship and the importance of the environmental indices, as well as the distribution and assessment of the environmental quality of the selected study area streets.

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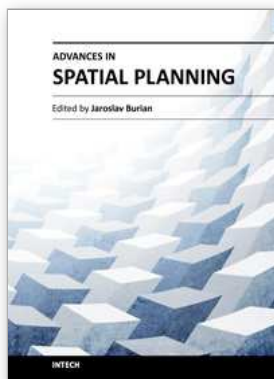
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