MAPPING URBAN WATER DEMANDS USING MULTI-CRITERIA ANALYSIS AND GEOINFORMATION METHODS

G. BATHRELLOS[a], H. SKILODIMOU[b], N. SOULAKELLIS[c], G. PANAGOPOULOS[d], G. TATARIS[e]

a: Univ. of Athens (gbathrellos@geol.uoa.gr); b: Univ. of Athens (hskilodimou@uoa.gr); c: Univ. of Aegean (n.soulakellis@geo.aegean.gr); d: Univ. of Aegean (gpanag@geo.aegean.gr); e: Univ. of Aegean (tataris@geo.aegean.gr)

ABSTRACT

Drinking water scarcity constitutes a growing problem especially in the islands of Greece. This paper presents a scientific approach for the spatial estimation of the present and near future water demands of the town of Mytilene of Lesvos Island using geoinformation methods and multi-criteria decision analysis techniques.

In order to forecast the future urban water demands which subsequently will allow a more sophisticated approach of the planning and construction of an optimum water supply system, different thematic layers were imported to a GIS environment. Since it is expected that Mytilene will experience a period of population growth and increased development of its surroundings in the near future, the prediction of the future population density in the spatial domain comprises a basic issue of this approach. Several factors and constrains were adopted for this scope, such as road network centre of the town, morphological slopes, land use, the General Urban Plan of the Mytilene municipality, the two storey buildings and multi-storey buildings area, the sewerage, obtrusive installations, the present population density, the existing water supply system, and the coastline. Each factor was grouped into various classes and the numerical classes were normalized, while the classes of the rest factors and the constraints were ranked as a form of a Boolean map. The Analytic Hierarchy Process was applied to rate the individual classes of land use and weight the impact of one factor against the other in order to determine their importance to water requirements. The results of AHP application in combination with GIS techniques were used to produce the water demand map.

The study area was divided into six zones for planning future domestic water supply projects. The very high priority areas located on the proximity of the town of Mytilene as well as on its suburb Vareia and Neapoli.

Keywords: Multi-criteria analysis, GIS, water demands, population density, Analytic Hierarchy Process, Mytilene

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1. Introduction

Water is essential to human life and all the activities of the man depend on a constant supply of fresh water. On a global scale and in the last decades urban development stresses water recourses by increasing demand (Howard, 1997). The expanding world population and the increasing demand for consumer goods is the source of this increase. The per capita use of water varies greatly around the world. The minimum need to sustain a person's life is about 3 liters per day; the per capita water use is much higher in developed than developing countries. For example in Canada and the U.S.A. daily water use in homes and settlements averages nearly 600 liters of water per person (Marsh and Grossa, 2002).

Drinking water scarcity constitutes a growing problem especially in the islands of Greece. Climate change and water mismanagement are the main reasons for groundwater quality deterioration and shortage of water resources. The absence of integrated water management plans in the wider Aegean area may lead to gradually increased problems of drinking water

scarcity. Many islands of the Aegean Sea experience now serious problems of water efficiency and cover their drinking demands with water transportation from other areas.
The water management is one of the oldest activities of the man worldwide. As today there is a greater demand for water supplies, the need to water management is stronger than ever (Marsh and Grossa, 2002). In the water management framework is important to estimate the present and future urban water demands in order to become the greatest planning for the cover of water requirements.
Moreover the anticipated urban water demands and the construction of the water supply and distribution system is essential for the development planning of regions (Cihakova, 2006).
The multiple criteria analysis is often applied for water resource planning and management (Reitsma, 1996; Cai et al., 2004; Hajkowicz and Collins, 2007; Van Gauwenberg Nm in print)
In addition the Geographical Information Systems (GIS) have become an integral and useful tool for spatial and statistical analysis in the water recourses management (Udovyk, 2006). Thus, methods based on spatial multiple criteria analysis in GIS environment have been developed for urban water management (Rao, 2005).
The aim of this paper is the mapping of urban water demands of the town of Mytilene of Lesvos Island using GIS and multiple criteria analysis. The paper presents an integrated technique of Analytic Hierarchy Process (AHP) and GIS to record the present and estimate the near future spatial water demands of the town of Mytilene. Moreover, it proposes an integrated methodology based on similar approaches of the international literature, and aims to estimate zones in which the authorities have to give priority in planning a rational water management system.

2. Study area

Lesvos is the third largest island of Greece (*Figure 1*), located at the northeastern part of the Aegean Sea, covering a total area of 1632 km^2. The total population is approximately 100,000 inhabitants. The main economical activities are farming (mainly olive trees) and livestock while, especially in the last decades, tourism plays an important role.

Figure 1. The Lesvos Island

The study area is geologically composed of the following four units: an autochthonous series of Permo-Triassic age, including mica schists, quartzites, phyllites and marbles, two

allochthonous units representing the volcano-sedimentary nappe and the ophiolitic nappe and metalpic sediments consisting of volcanic rocks and Neogene and Quaternaly deposits.
The climate is Mediterranean with a rainy period that begins in October and ends in May. The mean annual precipitation in the area is 650 mm and the mean temperature is 17.7 ^{0}C (Mytilene weather station).
The town of Mytilene is the capital and located at the eastern part of the island (*Figure 2*). The altitude fluctuates from 0 to 100 m and it has a smooth relief. The hydrographical network is poorly developed. The town covers 18 km^2 and counts about 36,196 inhabitants. The tourism is one of the dominant economic activities of the town.

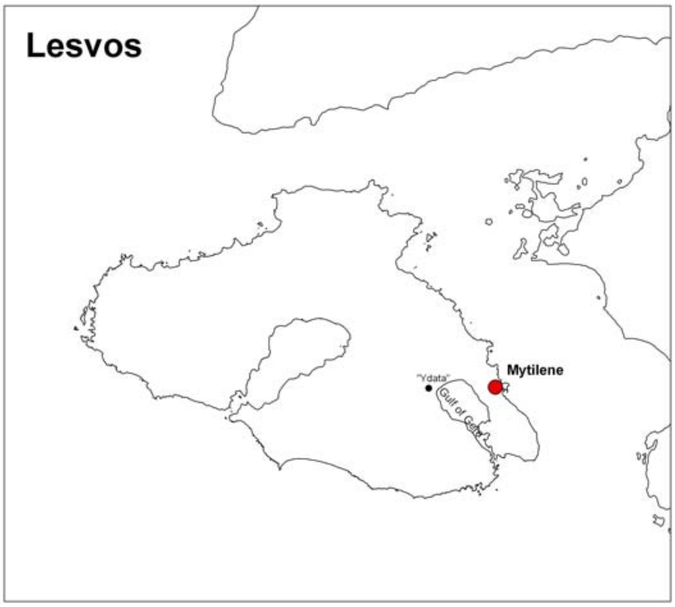

Figure 2. The town of Mytilene

The drinking water demands are covered from the large karstic spring Ydata located at the Gulf of Geras, 10 km westward of Mytilene, which has a mean annual flow 730 m^3/h. About 5.1 million litres per day (MLD) of water supply is being met from this spring.

3. Data and methodology

This study was carried out using the following sources of information: topographic map of the study area, scale 1: 50.000, of Hellenic Geographical Military Service, satellite images, the Urban Planning of Mytilene, the Municipal Enterprise for Water and Sewage of Mytilene and field work
A GIS database has been developed using ArcGIS ver. 9.2 software. The input data used for the urban water demands mapping have been recorded and saved as separate layers in the database. All the data layers are in vector format, transformed into 30x30 m grid cell size for spatial analysis.
The water requirements of any town are immediately depended from the urban growth of the town. Thus for the areas of the future water demands of Mytilene was studied the urban growth of the town. It is expected that Mytilene will experience a period of population growth and increased development of its surroundings in the near future.
The future water demands of an individual sector of the town can be estimated by multiplying the expected population density with the per capita domestic use of water. Following the legislation and literature the mean per capita use of water in Greece is 150 litres per day.
The experience of previous literature (Cheng & Masser, 2003, Rao, 2005) and the suggestion from experts were taken to account for the assessment of the factors that enhance or detract from the suitability of a specific alternative for the activity to the urban growth.
Moreover constraint was investigated. According Rao, 2005 a constraint serves to limit the alternatives under consideration and frequently will be expressed in the form of a Boolean map (1 or 0/true or false).

Twelve factors were considered as the most influencing parameters on the process of site collection for the future urban growth. These factors are: the road network, the centre of the town, the morphological slope, the land use, the General Urban Plan of the Mytilene municipality, the areas in which is allowing buildings with less than two stores, the areas in which is allowing buildings with more than two stores, the sewerage, the obtrusive installations, the present population density, the existing water supply system, and the coastline.
The road network (*Figure 3*) was extracted from satellite images and topographic maps. The distances of 50, 100, 150 and 200m were computed around road network using GIS capabilities.

Figure 3. The road network

It was considered that the future growth of Mytelene should occur close to the port, bus station, offices, banks, shopping center, schools, public services ect. These facilities are located in the center of the town. The town center was defined from the Urban Planning of Mytilene. A distance map was generated around the center varying from 100 to 1000m in length and with interval 100m.

The information on slope was obtained from topographical maps. The contour map (20m interval) and the trigonometric points were manually digitized and a digital elevation model (DEM) was generated using the capabilities of 3D Analyst extension. The slope map was derived from DEM and the slopes were grouped in four classes: 0^0 – 5%, 5 – 10%, 10 – 15%, >15%. Slopes greater than 15% are disadvantages for construction. Steeper slopes increase construction costs, limit maximum floor areas, and contribute to erosion during construction and subsequent use.
An accurate land uses map has been prepared using QUICKBIRD satellite images data of 2003. Six classes were identified: shrubby areas, natural grassland areas, barren areas, olive groves, cultivations, and urban areas.
The latest General Urban Planning of the Mytilene municipality, the areas in which is allowing buildings with less than two stores and the areas in which is allowing buildings with more than two stores, (*Figure 4*) were supplied from Urban Planning of Mytilene. The existing sewerage network was provided by the Municipal Enterprise for Water and Sewage of Mytilene. A map was created containing two classes: the areas covered from the General Urban Planning of the Mytilene municipality, two storey buildings, the multi-storey buildings, the, the sewerage and the areas not covered.

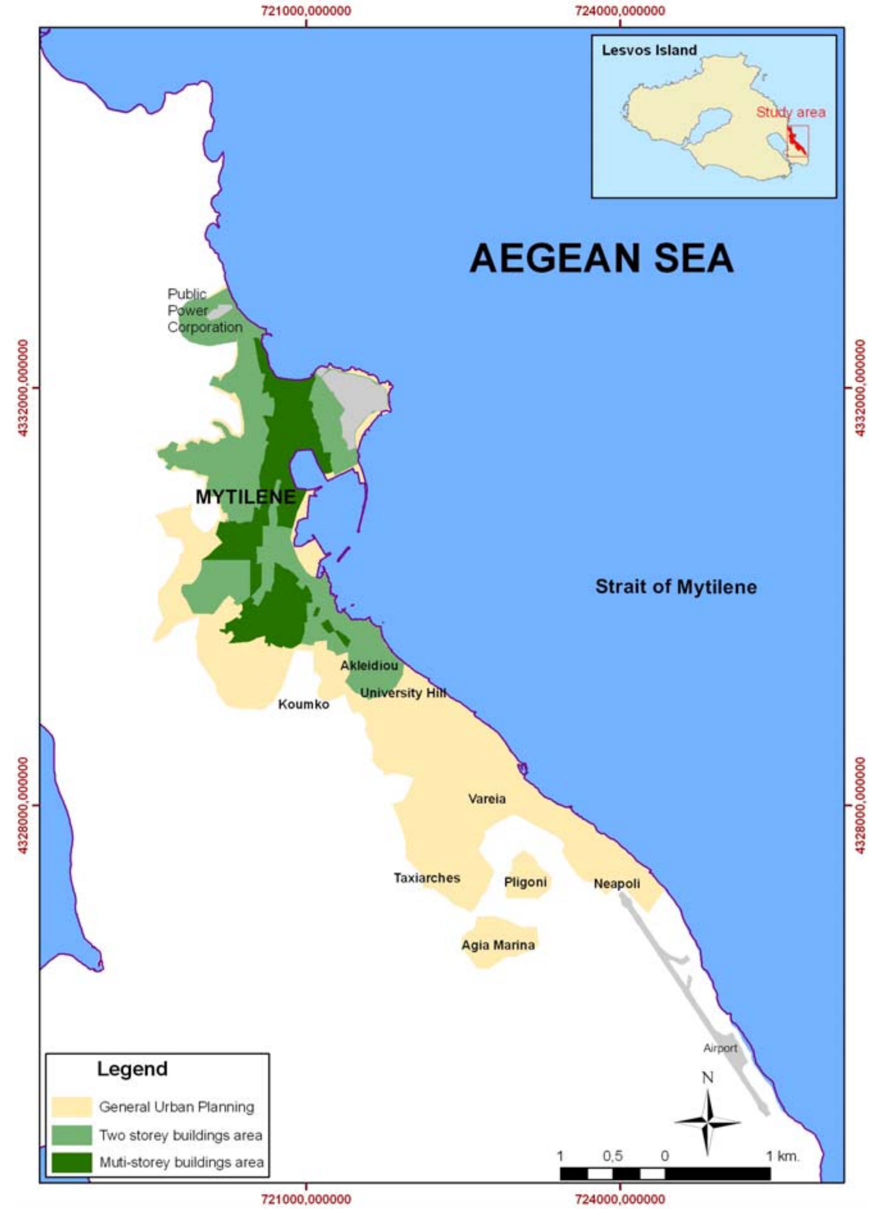

Figure 4. The General Urban Planning of the Mytilene, the areas of two storey buildings, the multi-storey buildings.

The major obtrusive installations near the town of Mytilene are the Public Power Corporation at north and the Airport at south. Ten buffer zones were built around these two areas with an interval 100m at a distance from 100 to 1000m.

The population densities (inhabitant per Km^2) of the area were calculated from 2001 census data and a population density map (*Figure 5*) was generated.

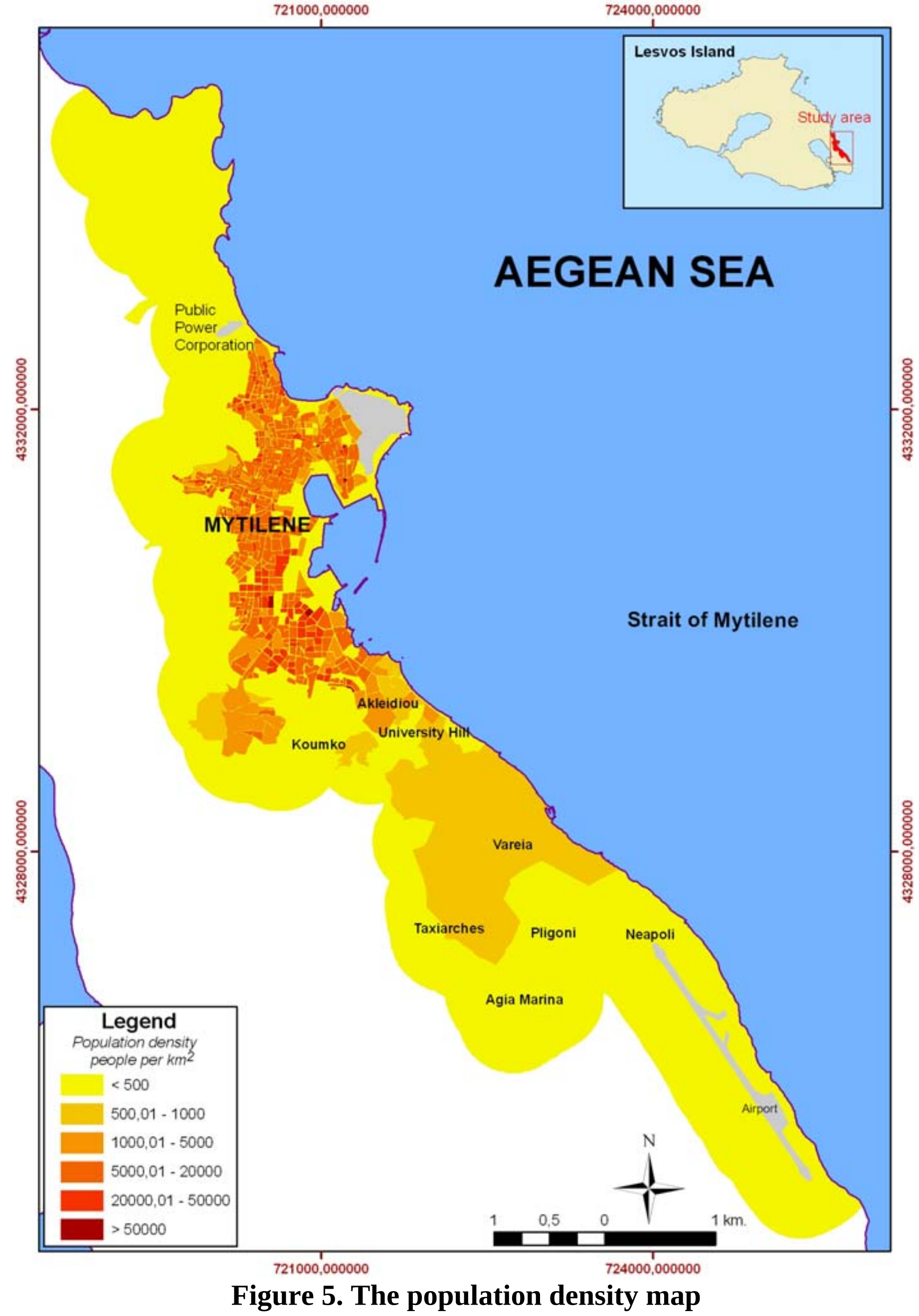

Figure 5. The population density map

The existing water supply system (Figure 6) was derived from the Municipal Enterprise for Water and Sewage of Mytilene. Five buffer zones were created around the water supply network with interval 100m and varying from 100 to 500m.

The coastline was derived from topographic maps and a distance map was made. The distance of 100, 200 and 300 m around the coastline were taken account.

The first step in this study was to calculate the priorities of the classes of each factor. The classes of the numerical variables, such as the road network the centre of the town, the slopes, the obtrusive installations, the population density, the water supply system, and the coastline were normalized and rating according the following equation:

V=Vmax-Vn/Vmax-Vmin

where V is the calculated class, Vmax is the maximum value of the class and Vmin is the minimum value of the class.

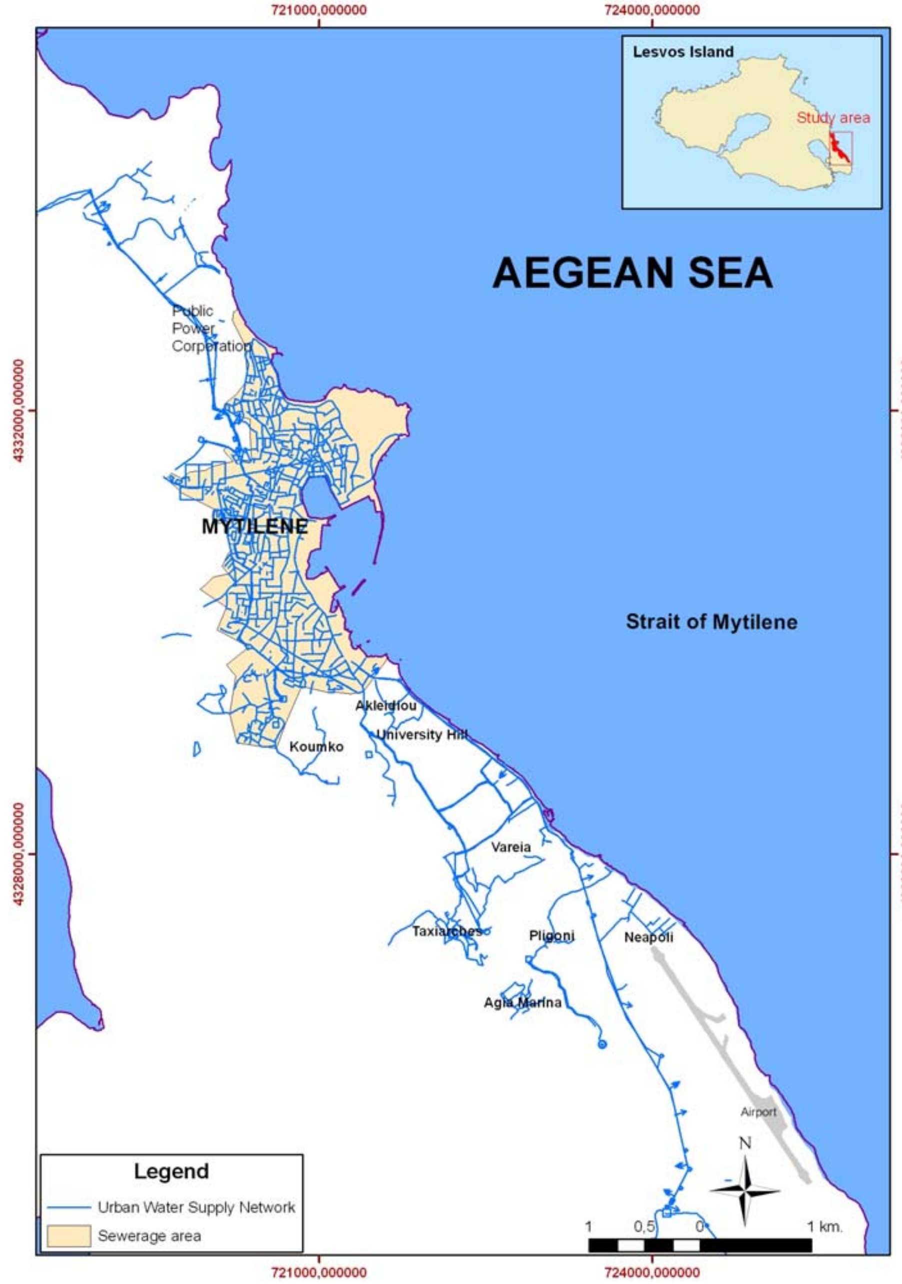

Figure 6. The water supply system map

The classes of rest variables were rated by the Boolean method. All the data layers were integrated in a GIS environment and for each class of factor the corresponding weight was assigned.

Apart from the above mentioned variables all the constructions and the development are limited to spatial extent of Urban Planning legislation. Thus a constraint map was generate and encompassed the forests, the covered area from the Castle of Mytilene and open areas such as parks, squares, etc. that should not to be constructed.

The AHP method was applied to evaluate the classes of the land use and all the factors for the mapping of the future growth of urban growth Mytilene. This method assesses the consistent weight of each factor via pair-wise comparison. The pair-wise comparison process performed using a nine point scale (Saaty, 1977; 2006).

A set of questionnaires within the AHP framework were generated. In this, the corresponsive should decide the controlling factors for the future growth of the town and determinate the

relative importance amongst the factors. The questionnaires were allocated to twelve people with expert knowledge.
The next step in this study was to identify the different significance of the factors on the future urban growth. From the questionnaires separate matrix were generated. In each matrix the AHP evaluation technique were applied and the matrices were further linearly combined using average mean to prepare the final matrix. Thus the AHP rule was used to get the final weights for each factor. The values of the relative weights for each factor were calculated between 0 and 1and they add up to 1. The consistency ratio was computed for these weights. All the pair-wise comparisons, the eigenvectors, the weights and the consistency ratio were calculated using the Expert Choice 11 software.
The implementation of the AHP results for all the maps was achieved in GIS environment by the capabilities of the Spatial Analyst extension. The final map of urban growth was derived by the linear combination comparison of the raster map of each factor and integration of the AHP results.

Results

Each class of the factors has different importance to the future growth of a town. The rating for each class of the distance to: the road network (DRN), the centre of the town (DCT), the obtrusive installations (DAF), the water supply system (DWSS), and the coastline (DC) are displayed in Table 1 while table 2 shows the rating of the slope. The rates of population density fluctuate from 0 to 1. The results of the application of AHP method to the classes of land use are shown in the table 3.

Table 1. The rates of each class for the distance to road network (DRN), centre of the town (DCT), obtrusive installations (DAF), water supply system (DWSS), and coastline (DC).

DRN (m)	rate	DCT (m)	rate	DAF (m)	rate	DWSS (m)	rate	DC (m)	rate
50	0,750	100	0,900	100	0,900	100	0,800	100	0,667
100	0,500	200	0,800	200	0,800	200	0,600	200	0,333
150	0,250	300	0,700	300	0,700	300	0,400	300	0,000
200	0,000	400	0,600	400	0,600	400	0,200		
		500	0,500	500	0,500	500	0,00		
		600	0,400	600	0,400				
		700	0,300	700	0,300				
		800	0,200	800	0,200				
		900	0,100	900	0,100				
		1000	0,000	1000	0,000				

Table 2. The rating of the classes of slope.

Class	Rate
0-5%	0,981
5-10%	0,962
10-15%	0,944
>15%	0,000

Table 3. The rating of the classes of land use.

Class	Rate
Shrubby areas	0,062
Natural grassland areas	0,062
Barren areas	0,045
Olive groves	0,098
Cultivations	0,098
Urban areas	0,635

The classes of the rest factors were ranked as the form of Boolean map. In each area covered by General Urban Plan of the Mytilene, two-storey buildings area, multi-storey buildings area and the sewerage assigned a value of one, while the areas not covered classified as unsuitable and given the value of zero.

Likewise, the constraint map is of Boolean type containing two classes: suitable and unsuitable. The unsuitable class comprises from areas with limitation to constructions.

As already mentioned the rating of the factors was accomplished used the pair-wise comparison of AHP method. The weights for each factor are shown in Table 4.

Table 4. The weights for each factor

Factor	Weight
Road network	0,018
Centre of the town	0,050
Slope	0,028
Land use	0,013
General Urban Plan of the Mytilene	0,118
Two-storey buildings	0,050
Multi-storey buildings	0,175
Sewerage	0,077
Obtrusive installations	0,245
Population density	0,118
Water supply system	0,077
Coastline	0,031

The matrix consistency was checked out through the computation of consistency ratio (CR). The CR was 0.03 and falls in the acceptance range CR ≤ 0.10 by Saaty (1977).

The rasterized maps of each factor were linear combined in order to estimate the overall score and product the final map for urban water demands. The overall score was determined by the following mathematical operator:

Equation 1 - Formula for overall score

$$O = \sum_{i=1}^{n} F_i W_i C_j$$

where O=the overall score, n= the number of the factors, Fi= the factor i, Wi= weight of the factor I and Cj the criterion score of constraint j.

Especially the obtrusive installations are disadvantage for constructions. In the case of the airport the landings and takes off of planes causes continuous noise. Moreover the operation of factory of the Public Power Corporation causes noise and pollution. Thus, they were considered as a negative factor and ablated.

At the final step the map for urban growth and accordingly the water demand area map was derived with continuous numerical values. The map was further reclassified into the quantlile system of classifiers because it was the method that best suits the objectives of our study. The map of urban water demands area was converted into a map with six classes: unsuitable, very low, low, medium and high, very high priority of all potentially developable areas in terms of their suitability for developing and constructing a water supply system *(Figure 7).*

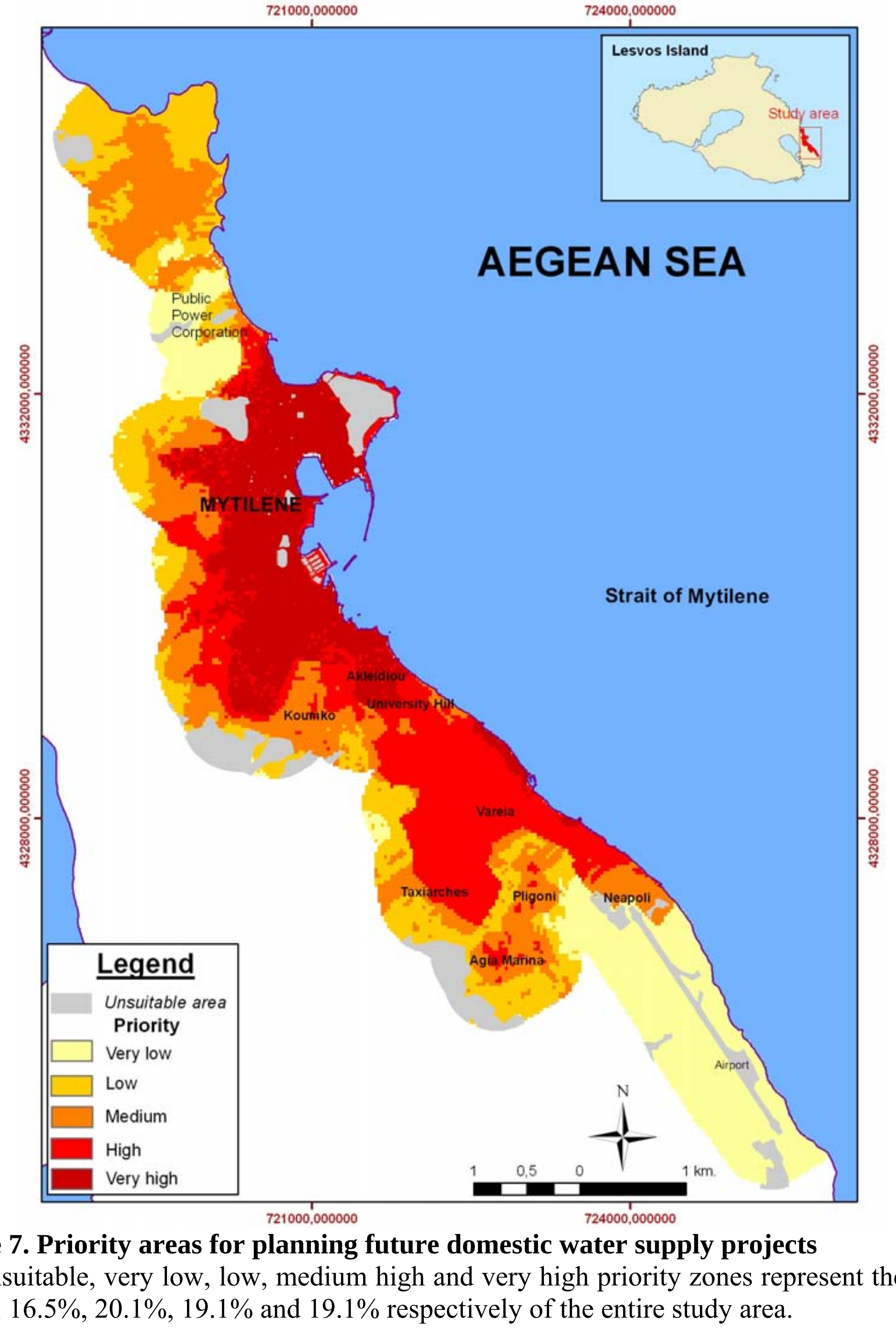

Figure 7. Priority areas for planning future domestic water supply projects

The unsuitable, very low, low, medium high and very high priority zones represent the 6.5%, 18.6%, 16.5%, 20.1%, 19.1% and 19.1% respectively of the entire study area.

The most suitable areas available for development are found close to the town of Mytilene, and that these areas are sufficient for urban growth. Two others very high priority areas can be found in Vareia and a small area of Neapoli, which are suburbs of Mytilene.

The high priorities areas are located southern of the town of Mytilene and the model validates the present situation since this area is of high interest and many buildings are constructed today.

Finally, the very low priority areas are focused around the airport and the Public Power Corporation, which verify the model results since no building activities are observed in these areas at present.

Conclusion

Water is the most fundamental ingredient of human life and in order to implement water management in a sustainable way, the water requirements of urban areas have to take into account. Drinking water scarcity is a growing problem in Lesvos Island. An effort was made in this study to estimate estimation of the present and near future spatial water demands of the town of Mytilene of Lesvos Island using geoinformation methods and multi-criteria decision analysis techniques.

Twelve factors the road network, the centre of the town, the morphological slope, the land use, the General Urban Plan of the Mytilene municipality, the two storey buildings and multi-storey buildings areas, the sewerage, obtrusive installations, the present population density, the existing water supply system, and the coastline were considered to obtain the water demand area map that was created in function of the determination and the correlation of the role of these factors.

The numerical classes of factors were normalized and rated, while the classes of the rest factors as a form of a Boolean map. Thus, in each area covered by General Urban Plan of Mytilene, two storey buildings, multi-storey buildings and the sewerage assigned a value of one, and the areas not covered given the zero. Moreover a constraint map was created containing two classes: suitable and unsuitable. The unsuitable class comprises from areas with limitation to constructions. The Analytic Hierarchy Process (AHP) method was applied in order to assign the weights of each factor and the classes of land use. The results of AHP application in combination with GIS techniques were used to produce the water demand map.

The study area was divided into six zones for planning future domestic water supply projects namely unsuitable(6.5%), very low(18.6%), low(16.5%), medium (20.1%), high (19.6%)and very high (19.6%). The area which is at very high scale of priority lies on the proximity of the town of Mytilene as well as on its suburb Vareia and Neapoli while, the high priorities areas are located southern of the town of Mytilene. The very low priority areas are focused around the airport and the Public Power Corporation.

The results of the map may be used as basic data to assist the authorities in the planning of a rational water management system.

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