“Spatial Typology of the Greek Territory based on Transport Accessibility Indicators: A Cartographical Approach using G.I.S.”

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ABSTRACT

Accessing the infrastructure networks, the urban concentrations, the commercial and other activities or key locations is considered by the spatial planners a significant and sensitive variable for the territorial analysis. The spatial policies are determined today by the principals of equal and balanced distribution of human resources and activities, as well as by the systematic study of territorial disparities in the deepest territorial analysis detail level possible. The traditional calculative methods of accessibility indicators do not take into account the entire space of the study area. On the contrary, they are mainly based on calculating the travel cost on linear networks using the ‘arc-node’ topologies. According to these methodologies, the variables (time, distance, or other types of cost) are calculated only for the network elements (nodes, lines). In the recent years, some published studies have appointed the above issue. Accessibility is faced as continuous data, thus it is valued and attributed to the entire study area and not just to the network’s body.

This study’s main objective is to generate an accumulative travel cost indicator for the Greek territory, using all major transportation means. In addition, the respective spatial typology will be created. The indicator is produced using three distinctive spatial levels representing the three transportation means (land, sea and air transportation). The study’s methodology is based on the formation of a continuous cost surface model, in raster format, using all the aforementioned transportation nodes. The travel cost value that each cell on the surface will be assigned to is the absolute time of travelling towards the transportation nodes or towards specific linear network elements. An emphasis is given to the study’s cartographic component as well as to the comprehensive use of spatial analysis techniques which are available in GIS software.

1. INTRODUCTION

A very essential component of the economic and social development of human societies has always been the way that people and goods move and travel through space. *Transport* plays a vital role in the structure and the organization of land and territories. Its purpose is to defeat space which is formed by a combination of natural obstacles (i.e. climate, topography, hydrography) and human constrains (such as political issues, traffic and travel facilities). “Space is a constraint for the construction of transport networks. Transportation appears to be an economic activity different from the others. It trades space with time and thus money.” [Merlin, 1992]. Increase of mobility and higher levels of accessibility are consequently desirable targets for the formation of planning regulations and economic policies.

There are numerous definitions and concepts of *accessibility*. In brief, accessibility is an aggregate measure of how reachable locations are from a given position. [Bailey, 1995]. Therefore, all locations are not equal, simply because some are more accessible than others, which is translated into spatial inequalities. Measuring the accessibility to ‘key’ locations (infrastructure networks, urban concentrations, commercial and other activities) is regarded by the analysts a significant and sensitive element for spatial planning.

An effective way to comprehend notions which are an amalgamation of several measurements is the use of *indicators*. Accessibility indicators can differ in complexity. More complex accessibility indicators take account of the connectivity of transport networks by distinguishing between the network itself and the activities or opportunities that can be reached when using it. These indicators always include in their formulation a spatial impedance term that describes the easiness of reaching other such destinations of interest. Impedance can be measured in terms of travel time, cost or inconvenience. In general though, accessibility indicators describe the location of an area with respect to opportunities, activities or assets existing in other areas and in the area itself, where 'area' may be a region, a city or a corridor. [Wegener et al., 2002]. Over the last decades, a vast number of accessibility studies addressing European core-periphery [Bruinsma and Rietveld, 1998; Wegener et al., 2000, 2002] and regional issues [Mathis, 2000; Wegener et al., 2000, 2002] have been published.

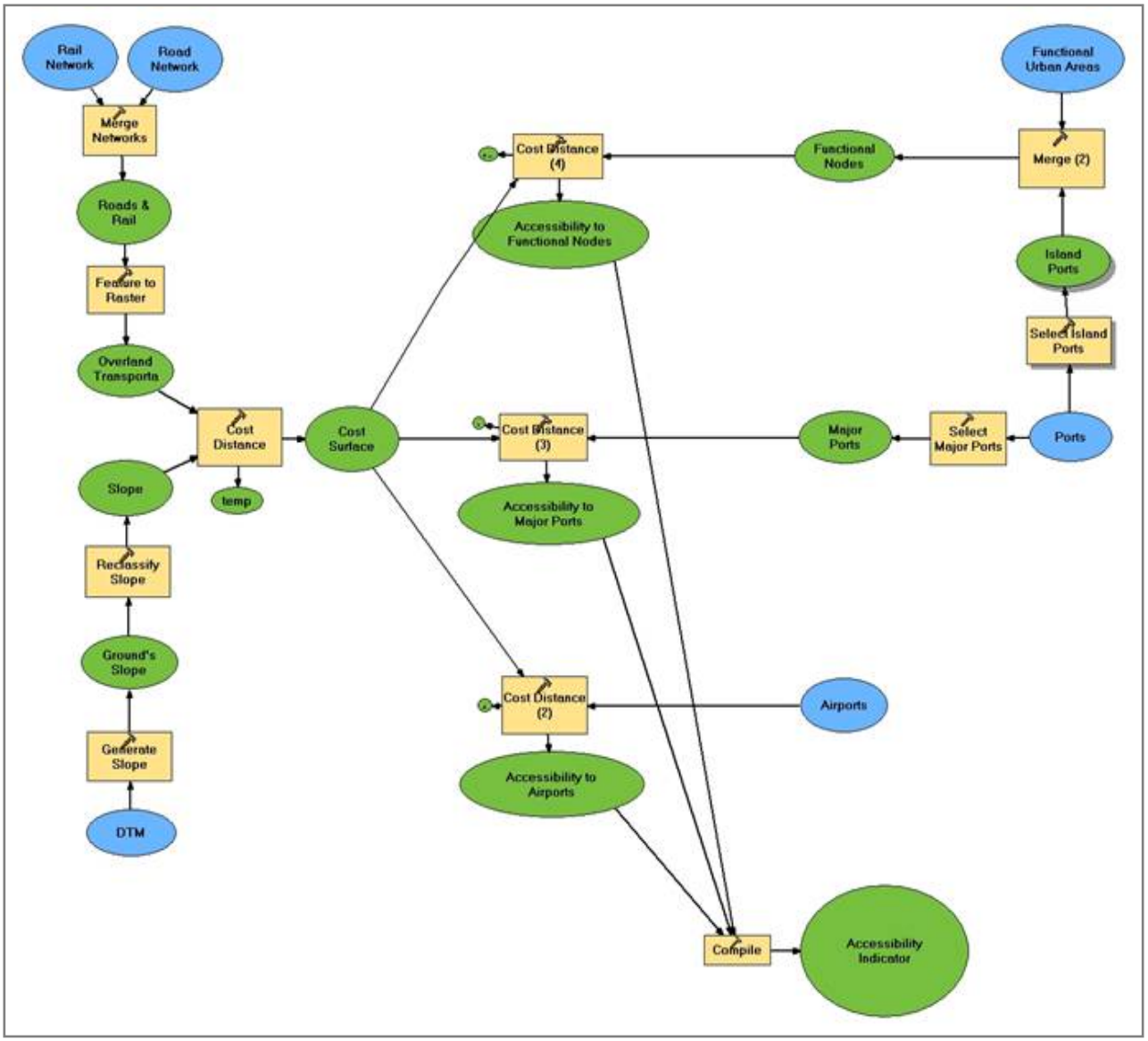
Geographic Information Systems (GIS) are used as a scientific and methodological tool to measure the accessibility, monitor produced indicators, identify spatial inequalities and ultimately give solutions in order to support territorial planning.

Considering numerous studies and observing the Greek territory as well as the transportation network, demonstrated the necessity of shaping accessibility indicators and measuring the spatial disparities which would arise. This study’s main goal is to produce a selection of indicators using distinctive spatial elements representing the three transportation means (land, sea and air transportation). In addition, a transportation spatial typology will be created for the entire study area. Moreover, the study aims to the formation of a cartographic-statistical data framework, which will be adequate to offer to the decision makers the appropriate material for a region’s spatial analysis with respect to the transportation infrastructure. This data framework will contribute to the clarification of vital parameters for urban planning, such as locating spatial disparities, examining the reasons of their existence, exploring alternative development scenarios and allocating funds.

2. METHODOLOGY

The study's methodology is based on the formation of a continuous cost surface model, in raster format, using all the aforementioned transportation nodes. The travel cost value that each cell on the surface will be assigned to is the absolute time of travelling towards the transportation nodes or towards specific linear network elements. An emphasis is given to the study's cartographic component as well as to the comprehensive use of spatial analysis techniques which are available on GIS software. The following tasks were accomplished using ESRI's Model Builder. This environment was chosen for its ability to manage and automate the geoprocessing work flow. It contains a number of interrelated processes which can be deleted, modified or increased. Moreover, some parameters and values were modified to experiment with alternative outcomes (i.e. different time-limits to calculate the cost weighted distance). The diagram below illustrates the model that was created in ESRI's Model Builder environment and portrays the data preparation and processes which will be described in detail in the following paragraphs.

Figure 1. *The Accessibility Model constructed in ESRI Model Builder environment*



2.1. Data acquisition and Preparation

As already mentioned, the study area is the entire Greek territory which has a total size of 132.000 sq. km. The chosen resolution for all the resulted datasets is the 300 by 300m cell size. The data were acquired between 1995 and 2004 from various agencies and official sources as outlined below. To carry out this application, several datasets are necessary. Some of them come in the appropriate format and some others have been later processed to meet the study's standards. The selected data are illustrated on Map 1 that follows:

a. Digital Terrain Model - derived from the Hellenic Military Geographical Service (HMGS) height information. The dataset's scale is 1:250.000 and the contours' interval is 100m. The resulted DTM's cell size is 100X100m. This is the dataset where the construction of the cost surface is based.

b. Road network – acquired from HMGS, scale 1:250,000. The network was classified using each arc's mean travel speed, as well as the road type:
1= National Roads, 2= Regional Roads, 3= Local Roads, 4= Rural Roads.

c. Rail network - acquired from HMGS, scale 1:250,000. The rail network is not classified.

d. Main airports – acquired from the Geographic Information System of the European Commission (GISCO) (updated in 2004) classified upon their size and their connections:
1= International, 2= International Connections, 3= Regional, 4= Others.

e. Main ports – acquired from GISCO (updated in 2004) classified upon their connections:
1= Island Ports, 2= International Connections and Others.

f. Administrative divisions – according to 'NUTS[1] 2, 3 & 5'.

g. Built-up Areas - acquired from HMGS, scale 1:250,000 with 'polygon' and 'region' topology. Tabular data: administrative codification and population (2001).

h. Functional Urban Areas (FUA's) [2] – derived from the previous dataset (geometry and tabular data).

[1] NUTS: "Nomenclature d' Unités Territoriales Statistiques" (Nomenclature of Units for Territorial Statistics)

[2] FUA: "Functional Urban Area": Agglomerations of municipalities that are grouped together according to their functional orientation in order to reflect the actual daily operational conditions of people, enterprises, and community organisations. ESPON has been using national definitions of FUAs, and only considered those with at least 20.000 inhabitants. [ESPON Project 1.1.1, 2nd Interim Report, 2003]

Airports

- International
- International Links
- Regional
- Other use

Ports

- Island Connections
- Other use

Road Network

- National
- Regional
- Local
- Rail
- Built up Areas

Cartographic Projection: "EGSA '87"
Data sources: G.Y.S., Ministry of Environment

MAP 1.
TRANSPORT INFRASTRUCTURE
IN GREECE (2000)

2.2. Constructing the accessibility model

A key issue to calculate distances, hence accessibility, is to determine the cost surface over which the processes will take place. The cost surface identifies the "cost" of traveling through every cell [Mitchell, 1999]. The cost can represent various values such time, money, energy and so on. Furthermore, the cost surface can be an accumulation of several criteria. In this case Slope, Road and Rail Network influence the accessibility, so they will be included to the key cost surface model.

Afterwards, processes will undertake the calculation of accessing the Airports, Ports and the Functional Urban Areas. Finally, the three accessibility indices will be combined to an overall accessibility indicator.

2.2.1 Constructing the Cost Surface Model

The main issue when calculating a network's accessibility is to specify the Cost Surface Model which in this case is the combination of Digital Terrain Model (DTM), road and rail network data. These datasets are in different measurements systems as they represent different features. It is essential to reclassify them to a common scale and make them comparable. Therefore, all data must be converted to a 'time related' dataset. The final product will represent the time needed to cross a cell depending on the slope and the transportation means one is using.

It must be mentioned here that the product's accuracy is directly connected to the DTM's accuracy which in this case is 100x100m. Although it is possible to use this cell size for the application, it was decided to reduce it in order to keep the process time low and the derived files small in volume. Therefore, the final product, on which the indicator's calculations are based, has a 300m resolution. That inevitably means that the accuracy is reduced; nevertheless, for the specific study area's size it can be considered particularly satisfactory.

The next steps describe the construction of the 'Overland Transportation Means' and the 'Slope' rasters:

a. *Preparing the 'Overland Transportation Means' raster*

Road and rail networks were taken into account to construct the 'overland transportation means' raster. These two networks were initially merged and then converted to a 300x300m raster using the 'vector to raster' algorithm. However, the travel time needed to cross each cell varies according to the network's category mean speed. Using the following formula, the travelling time was computed:

$$CTT = \frac{CS \times 60}{MTS \times 1000}$$

where: CTT: Cell Travelling Time (in minutes)

CS: Cell Size (300m)

MTS: Mean Travel Speed (kilometres per hour)

The aggregated results of the aforementioned formula are shown in the following table. At the end of this task, each network's cell has one of these values:

Table 1. *Travel speed and cell traveling time by type, on overland transportation means*

Network's Classification	Mean Travel Speed (Km/h)	Cell Traveling Time (min)
National Roads	100	0,225
Regional Network	60	0,300
Local Network	40	0,450
Rural Network	30	0,600
Rail Network	80	0,225

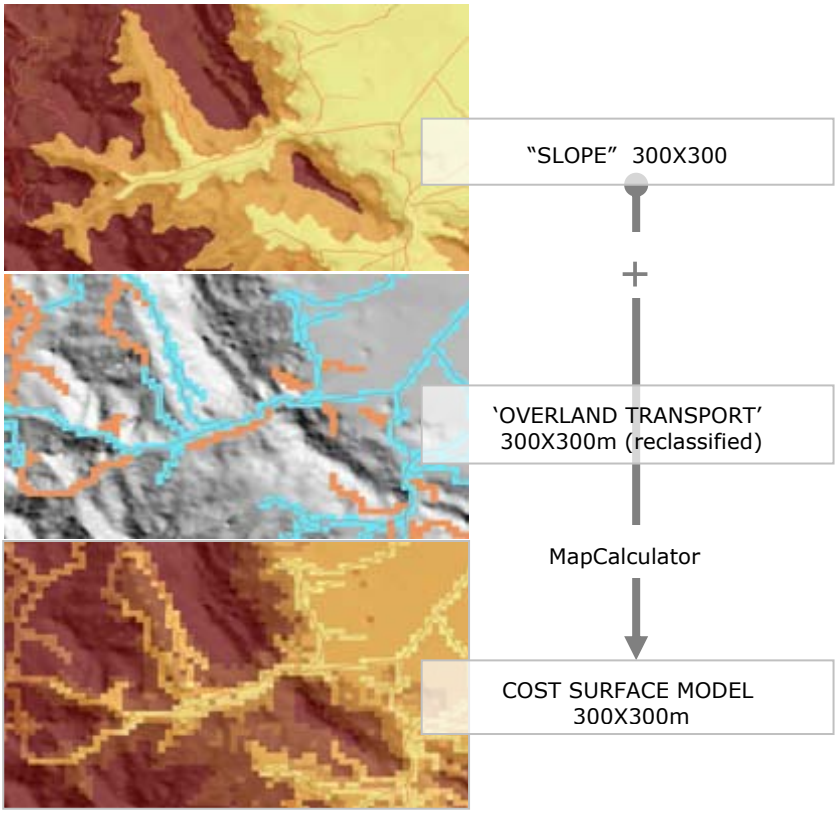
b. <u>Preparing the 'Slope' raster</u>

This dataset represents the difficulty or the easiness to cross a cell in relation to the ground's slope. First the area's slope was generated and ranked to a 1-10 range. Therefore, to each cell a value is attributed which corresponds to the ground's slope. This dataset proved to be so high in detail, and consequently an extremely large file with high processing time, that it was necessary to amend it before using it in further tasks. Therefore, the raster file was reclassified using the CTT.

To generate the cost surface model, the two aforementioned rasters where combined using ESRI's Map Calculator. A 'cell to cell' addition took place, thus each cell's value of the new raster is the added CTT's from the Overland Transport and Slope rasters:

$$\text{Value}_{(Cost\ Surface\ Model)} = \text{Value}_{(Overland\ Transport)} + \text{Value}_{(Slope)}$$

Figure 2. *The cost surface's work flow and a sample area*



2.2.2 Calculating the accessibility to Functional Urban Areas and Island ports

According to ESPON (Project 1.1.1, 2nd Interim Report, 2003), the Functional Urban Areas in the Greek territory are the following:

Table 2. *Functional Urban Areas in Greece (Source: ESPON Project 1.1.1., 2003, Annex 1)*

Rank	FUA Level	Functional Urban Areas
3	Metropolitan Region	Athens
2	National/Transnational Region	Thessaloniki Iraklion, Rhodes, Patras, Volos, Chania, Larissa, Chalkis
1	Regional	Komotini, Kavala, Ioannina, Mitilini, Kalamata, Xanthi, Serres, Katerini, Lamia, Argos, Rethimno, Drama, Kozani, Corfu, Corinthos, Ermoupolis, Levadeia, Kilkis, Alexandroupolis, Trikala, Karditsa, Ierapetra, Edessa, Arta, Agrinio, Chios, Thiva, Amaliada, Pyrgos, Tripoli, Giannitsa, Veroia, Ptolemaes, Egio, Orestias, Naoussa, Igoumenitsa

In addition to the above, all the ports located on islands have been regarded as accessibility points (equivalent to FUAs), because of their critical role in the spatial formation of the Greek territory.

In order to calculate the accessibility to FUAs and the Island Ports via the main overland transportation network, two vector datasets are combined to an input dataset: the 'FUA' layer, and the ports which are located in the islands. To take into account the area's relief, the calculated Cost Surface is used in the calculations. The next step was to use the *'Cost Weighted Distance'* [McCoy and Johnston, 2000] function to compute the time that is needed to travel from any cell of the surface towards the nearest Functional Urban Area or port using overland transportation means. Given the fact that any time limit is allowed to execute the algorithm, a 30 min. 'good service' time parameter was selected. Consequently, the final cost weighted distance raster comprises of values within a 0-30 min. range for the 'served' areas, and total absence of values for the 'non-served' areas (Map 2). Moreover, for data comparison purposes, the raster dataset was reclassified into a 1 to 10 range (1=0min, 10=30min).

2.2.3 Calculating the accessibility to major ports

The next task was undertaken to measure the accessibility to the major ports which connect the islands with the mainland and/or international destinations. The travel time from each cell to the nearest port via the overland transportation network had first to be calculated. In this case, the chosen time-limit for a 'good service' was 60min. Applying the Cost Weighted Distance function towards the Cost Surface Model gave every cell a value from 0 to 60 min. The raster was then reclassified into a 1 to 10 range. Consequently, each cell was ranked upon its accessibility to the major ports. The diagram below describes the undertaken tasks for the accessibility calculation, and the following figure portrays the results in a sample area.

Figure 3. *Calculating the accessibility to major ports*

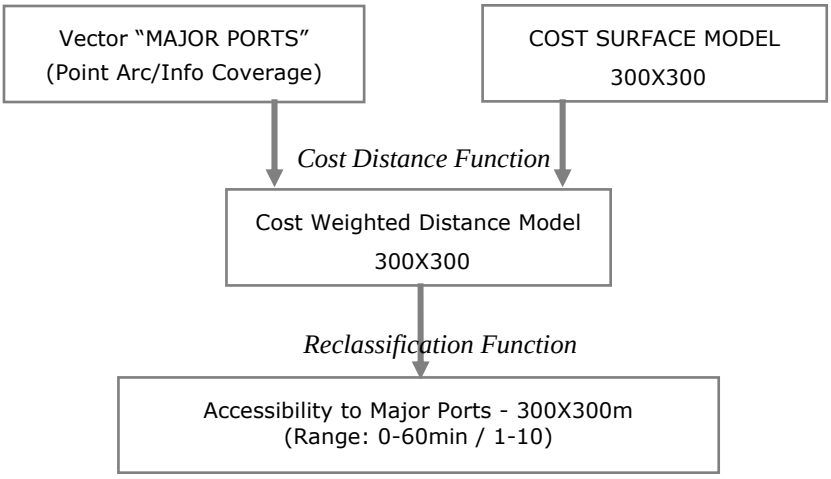
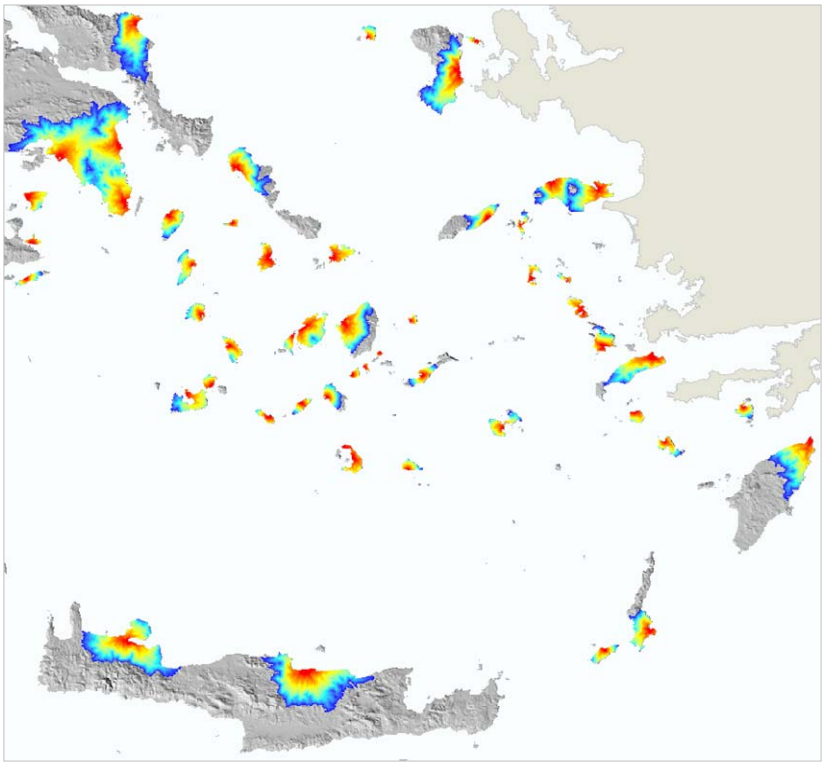


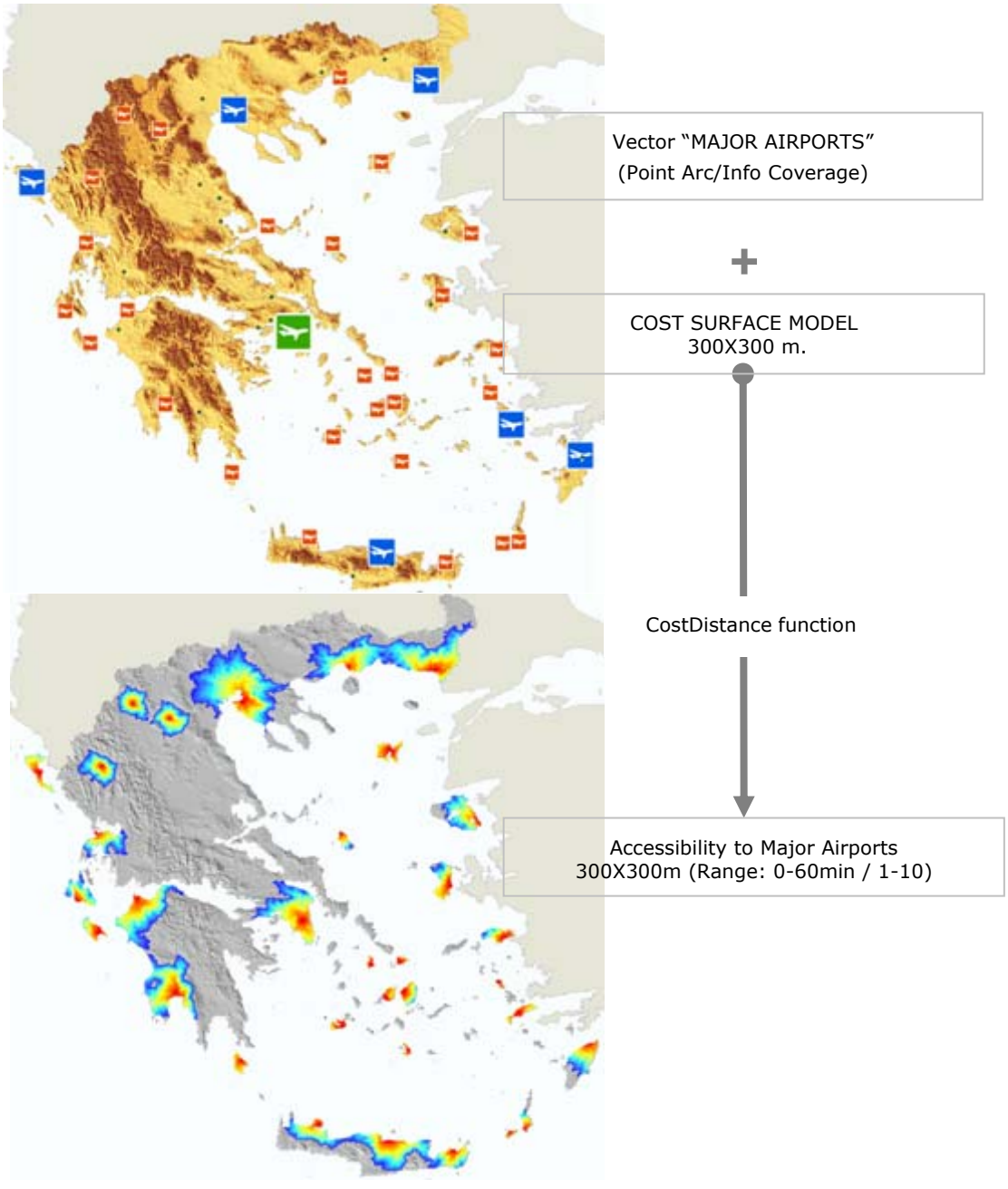
Figure 4. *Accessibility Indicator values (0-60min.) to islands connection ports in a sample area*



2.2.4 Calculating the accessibility to major airports

Similarly to the previous process, this task involves the calculation of the accessibility to the country's main airports. These airports essentially connect minor urban areas with Athens and Thessalonica and other international destinations, and the accessibility is defined as the travel time from a cell to the nearest airport via the overland transportation networks in a comparable to the previous datasets scale. The cell size, the time limit and algorithms are the same with the ones used to calculate the accessibility to the main ports in the previous paragraph. The following diagram shows the work flow accompanied with corresponding maps.

Figure 5. *Accessibility to Major Airports*

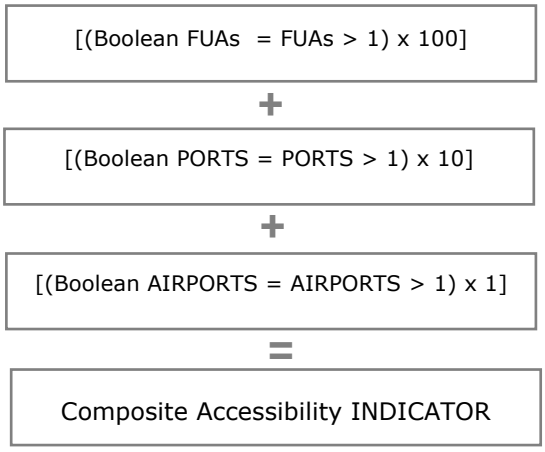


2.2.5 Compiling the accessibility index to main transportation nodes

Up to this point, three accessibility datasets have been generated. Each of them shows the accessibility to the main transportation poles whether these are ports and airports or urban areas which can serve potential passengers.

The paper's second goal is to create an accessibility typology index. To do that it was essential to convert the generated surfaces to Boolean grids, hence to separate the cells that have values from those who do not. This is a necessary process in order to get an overall impression of each cell's type of accessibility to the main transportation means. The typology of the transportation is then clarified in a way one can identify the nature of the transportation means that a cell can access, within the time limit. The next step was to create a composed raster where each cell would 'inherit' the information from the three derived accessibility datasets. Multiplying the rasters by 100, 10 and 1 gave the desirable result.

The composed accessibility to the main transportation nodes was calculated using Map Algebra formulas '*greater than*', '*plus*' and '*times*' (ESRI- MapCalculator).



Hence, the value given at each 300x300m cell is in accordance to the table:

Table 3. *Cell codes by transportation means and combinations*

Cell Code	Transportation Means		
	OVERLAND	AIR	SEA
111	•	•	•
110	•	•	
101	•		•
100	•		
011		•	•
010		•	
001			•
000			

3. RESULTS

According to this study's main goals and the methodology that was followed, the analysis of the results is focused on depicting spatial disparities, which are a consequence of the accessibility's *quality* and *quantity* in the Greek territory.

Based on a cartographic approach and by undertaking a visual analysis of accessibility patterns, it is feasible to compose a series of derivative layers and maps which will be used in:

- calculating the accessibility indicators
- understanding the spatial distribution of the indices and other features (i.e. relief, infrastructure, demographics)
- extracting statistical results

In order to identify such areas and use them as an example for further examination, it is possible to use any combination of the following levels:

a. Spatial Level: To measure and depict spatial disparities it is necessary to use a predefined space as a reference. For example, the pixel itself which is a 300 by 300 meters area can be perceived as the spatial level. In this study, analysing the results was done by using the administrative divisions in two levels[3]: a) Regions (NUTS 2) and b) Prefectures (NUTS 3).

b. Qualitative Level: This approach is based on the typology of transportation as it was described in paragraphs 2.2.2-2.2.4 ('Overland', 'Air', 'Sea' and combinations). It is also possible to create alternative scenarios by modifying the GIS algorithms which are executed to calculate the accessibility (i.e. adding or removing transportation nodes, modifying the 'good service' time, etc.). The system also allows creating future scenarios by adding upcoming infrastructure features and analysing the results with respect to the new transportation network.

c. Quantitative Level: Analysing the accessibility based on the previous two levels, using the two following factors: a) served space and b) served population.

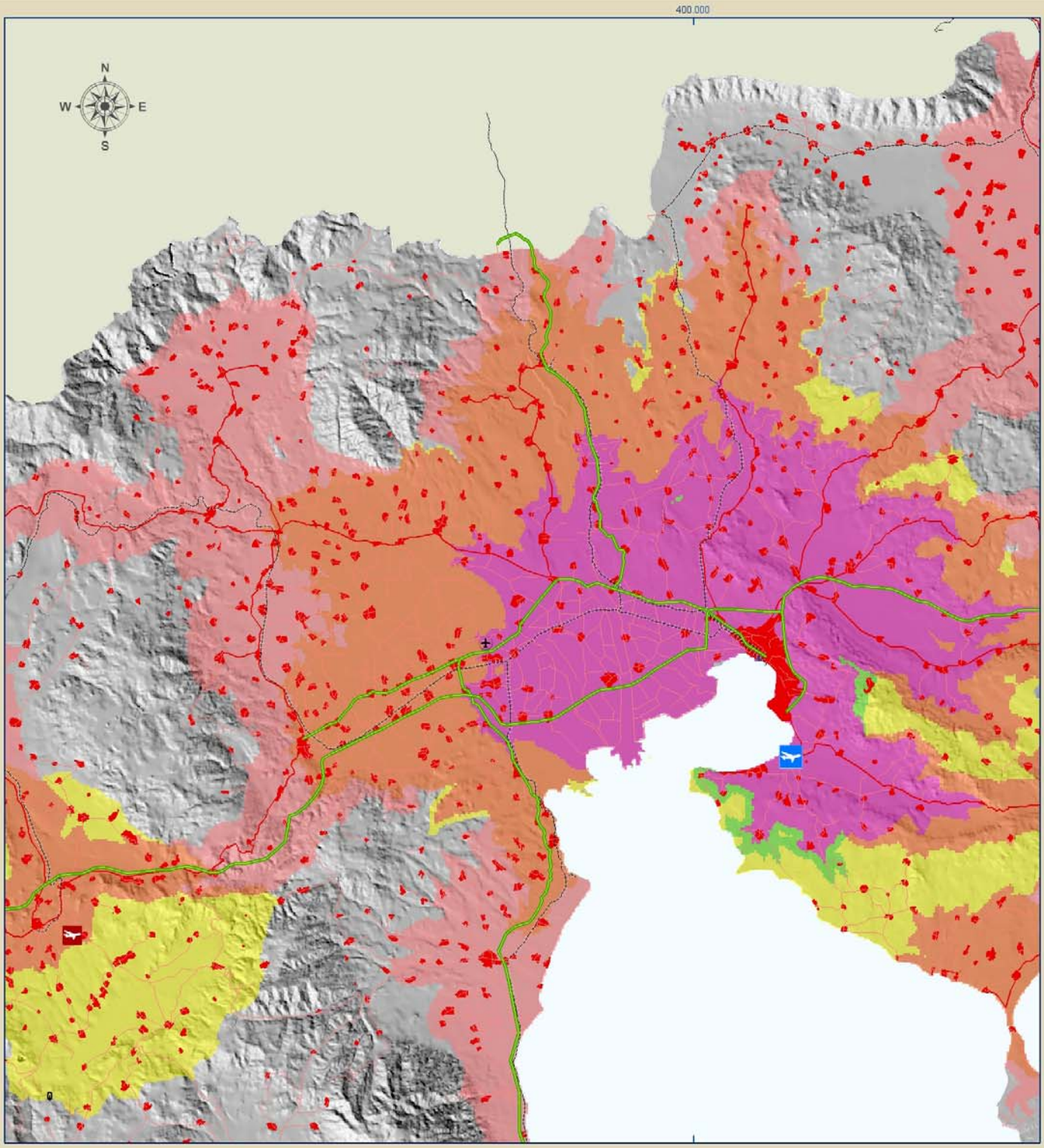
From all the possible combinations of the above levels, the following examples were chosen to be portrayed here:

[3] these two levels are often used for the same purpose (identifying spatial disparities) in numerous European programmes as a way to justify the funding distribution (E.U. Structural Funds)

Example A. Space served by the transportation infrastructure (per type) in the entire Greek Territory

Type of Infrastructure	Number of Pixels (300X300m)	Area (sq. Km)	Percentage (country)
Overland - Air - Sea	139.884	12.590	10%
Overland - Air	172.356	15.512	12%
Overland - Sea	29.835	2.685	2%
Overland	370.626	33.356	25%
Air - Sea	32.154	2.894	2%
Air	104.252	9.383	7%
Sea	31.649	2.848	2%
None	586.253	52.763	40%
Total	1.467.009	132.031	100%
Overland (sum)	712.701	64.143	49%
Air (sum)	448.646	40.378	31%
Sea (sum)	233.522	21.017	16%

The first conclusion that can be derived with respect to the space which is served is that nearly half of the Greek territory is inadequately accessible by any transportation means. This is partially an effect of the country's rough relief, but is also a result of the sparse road network. As far as the air and sea transportation means are concerned, what is seen the table above, is just a first approach. In order to further analyse the results, it is essential to examine the detailed characteristics of each area separately. In this way, it will be possible to take into account important issues that play vital role in the accessibility of each location, by air or sea, such as the specific geographic location of the under examination area.



Accessibility Type*
- O+A+S
- O+A
- O+S
- O
- A+S
- A
- S
- None

(*) O = Overland, A = Air, S = Sea

Airports
- International
- International Links
- Regional
- Other use

Ports
- Islander - Continental Link
- Other use

Road Network
- National
- Regional
- Local
- Rail

Built up Areas

Cartographic Projection: "EGSA '87"
Data sources: G.Y.S., Ministry of Environment

MAP 2.
ACCESSIBILITY TO TRANSPORT INFRASTRUCTURE
Territorial Typology by Transportation Means - 2000

Example B. Spatial Typology of the accessibility to FUAs

This cartographic analysis concerns the accessibility to the FUAs using the overland network. The spatial typology is examined and measured by looking into the travel time that one must spend moving a cell to the nearest FUA using the overland transportation network. The accessibility patterns are illustrated in the following map and the accumulated results are portrayed in Table 4. Afterwards, the spatial typology measurements are applied to the urban agglomerations (with appropriate cartographic techniques) and consequently attribute the relative population. Hence, it is possible to demonstrate the percentages of the population which are underserved or satisfyingly served by the overland transportation network. Charts 1 and 2 illustrate the percentages of land and population which are served by the overland transportation network.

Map 3. *Spatial Typology based on the travel time to the nearest FUA (0-90 min)*
(Detail: Region of Thessaly)

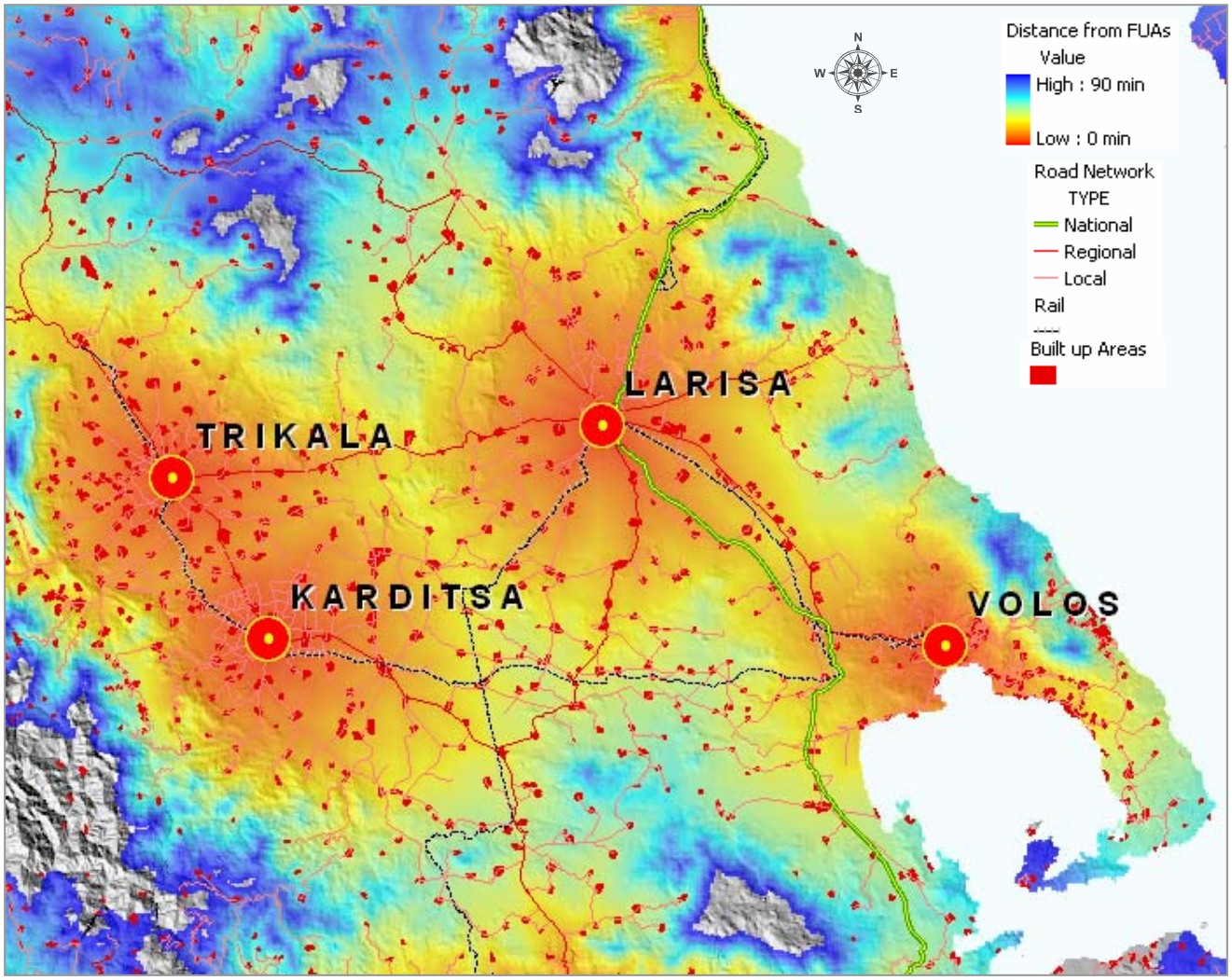


Table 4 *Accessibility to FUAs (territorial coverage)*

Distance from FUA	Number of Pixels (300X300m)	Area (sq. Km)	Percentage (country)
0-15'	185.413	16.687	13%
15-30'	336.653	30.299	23%
30-45'	286.789	25.811	20%
45-60'	186.969	16.827	13%
60-75'	132.056	11.885	9%
75-90'	85.715	7.714	6%
Over 90'	253.114	22.780	17%
Total	**1.466.709**	**132.004**	**100%**

Chart 1. *Accessibility to FUAs (served space)*

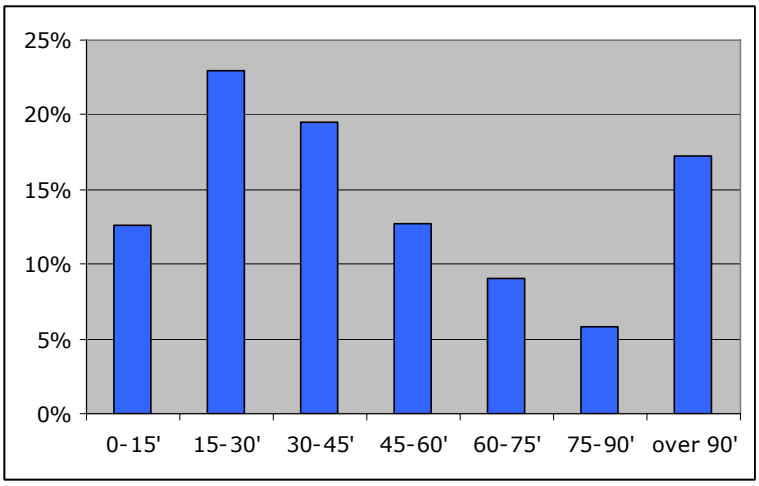
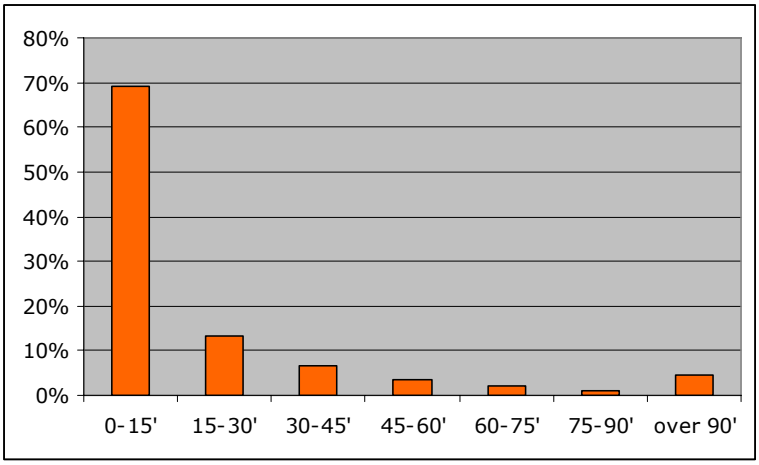
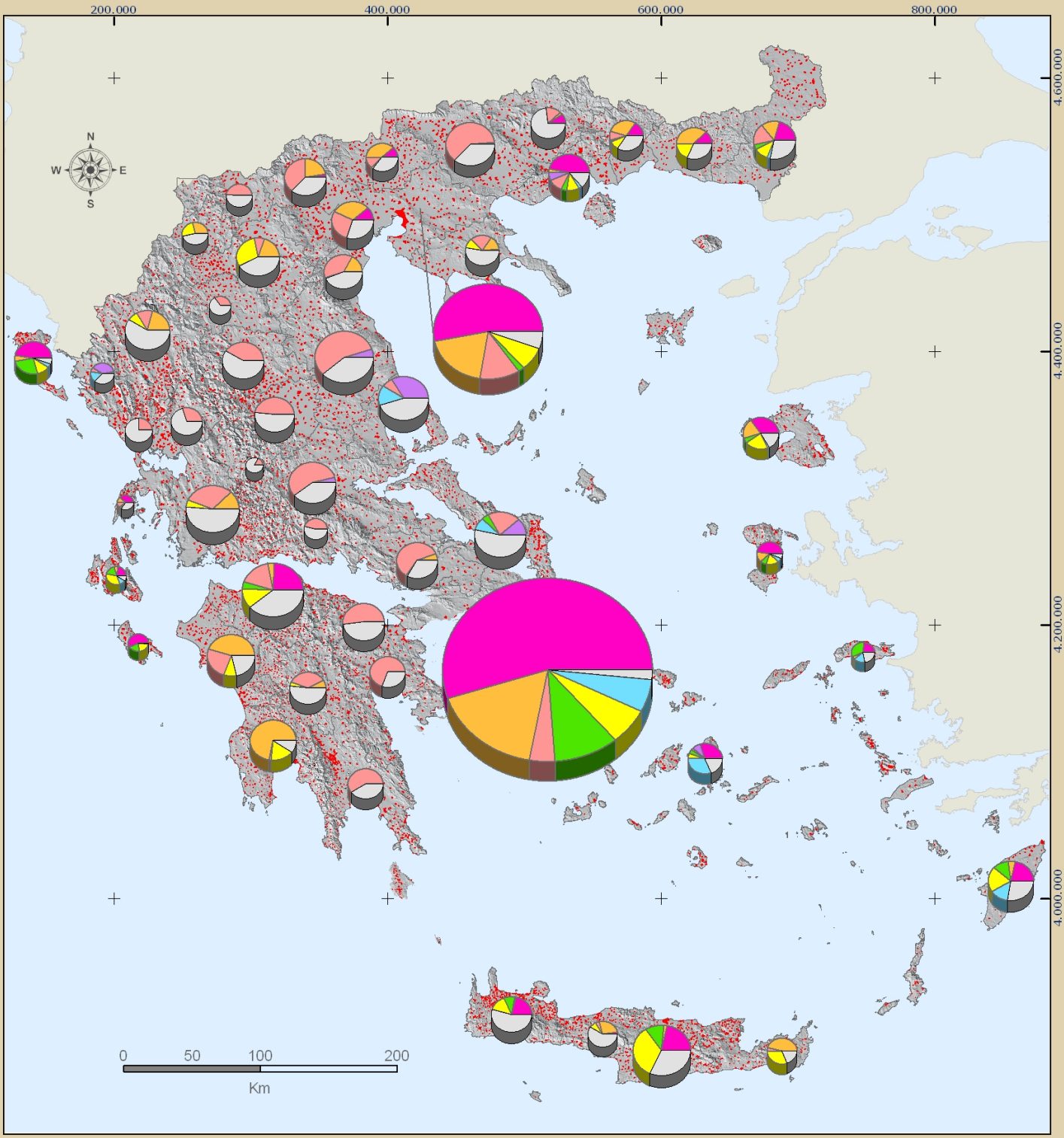


Chart 2. *Accessibility to FUAs (served population)*



Example C. Analysing the accessibility with respect to administrative regions (NUTS-3)

This example illustrates the findings after applying zonal statistics to the administrative divisions of each prefecture and giving values that correspond to each transportation means and their combinations. The results represent percentages of land, in a chart format, that are served from transportation means or one of their combinations (Map 4).



Accessibility Type (*)

150.000 Inhabitants

- O+A+S
- O+A
- O+S
- O
- A+S
- A
- S
- Underserved
- Built up Areas

(*) O = Overland, A = Air, S = Sea

Cartographic Projection: "EGSA '87"
Data sources: G.Y.S., E.S.Y.E., Ministry of Environment

MAP 4.
ACCESSIBILITY TO TRANSPORT INFRASTRUCTURE:
Served Space - NUTS-III - 2000

4. CONCLUSIONS

While summarising and coming up with the conclusions of this study, it is essential to keep in mind that any indicator presents just a simplified model of understanding and explaining reality; by definition, it just ‘indicates’ certain aspects of the problem or the concept being studied, while other aspects remain dark. Scientists argue that successful indicators, rather than trying to explain everything, have to be focused on key aspects (ESPON Project 3.2.1). This means that by illuminating those aspects which are totally associated with the problem under examination others can be left to be inspected later in a more detailed assessment.

The cartographic approach in this study has many advantages regarding the range of combinations that can be generated between various accessibility indicators. In this way it is feasible, as demonstrated in the previous paragraphs, to comprehend the features’ spatial distributions, the detection of any spatial disparities and lagging regions. It is possible, as well as desirable, to illustrate the appropriate directions and methods that must be adopted in order to address issues relevant to the territorial cohesion of the study area.

Furthermore, the GIS methods and tools that have been used can be easily modified and enhanced with related parameters according to each analysis’ needs or the spatial policy aims. Hence, multiple alternative scenarios regarding the spatial planning can be examined and compared. The statistical and cartographic representations can be prepared using any desirable combination of scale, spatial, time, qualitative and quantitative level as it was described in Chapter 3.

In this study the general framework that can be used for a greater view of the accessibility conditions in a study area was demonstrated. Nevertheless, the proposed methodological approach using accessibility indicators ought to be enriched when used for detailed studies or as a decision tool. Some vital parameters concern: distinguishing public and private transportation means, travel costs, economic factors such as GDP or income, reason of travelling (leisure, work etc), destination typology, climate, traffic, speed limits, road works, vehicle typology, small ferry ports and bridges and finally the accuracy of the geographical datasets.

5. REFERENCES

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