ANALYSIS OF POPULATION DYNAMICS OF CHANIA COUNTY USING REMOTE SENSING AND CENSUS DATA

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Abstract

Information about the size and the evolution of a place’s population has been sought from ancient times. That kind of information can be secured by periodic census enumerations. The Hellenic Statistical Authority provides data about the population and social conditions, also economical indices for each economic sector and the industrial trade. The study area, the county of Chania, is located in the island of Crete and the population resides mostly in the lowlands. Their main source of income, beside agricultural activities, is the high tourism during the summer months. In order to study the density, distribution and evolution of the population, many quantitative geographical methods were used, like the triangular diagram, the Location Quotient (LQ), the Coefficient of Specialization (CS), the Coefficient of Localization (CL) and the Gini – Hirschman Index. The dataset chosen to execute the models, is derived from the Hellenic Statistical Authority’s website, for the years 2001 and 2011, the most recent census available data and is free of charge. To examine the distribution and the density of the population in accordance with the urban sprawl in the area the results were correlated with remotely sensed image. The satellite images are acquired from the Landsat archive because it covers the desired timespan. To do so, the Built – up index was calculated and for each municipality in the county and the mean value was used in a linear regression model with the population. In conclusion, the analysis combines the results of the quantitative methods for the productive sectors, the population density and growth with the urban sprawl, to examine the way the population of the county evolved.

Keywords: Population Density, Triangular diagram, Location Quotient, Gini Index, Remote Sensing, Built-up Index, Linear Regression

1. INTRODUCTION

The increase of the population throughout the years is directly linked to the expansion of urban areas (Osgouei et al, 2019). As the population grows the form of the Earth’s surface is changing because of the urban spread causes land surface changes and environmental degradation. Especially in Mediterranean cities, the augmented population leads to urban sprawl which results to an uneven distribution of population. So, it is important to examine the way and the reasons behind the evolution of the population. Information about the population is distributed from the Hellenic Statistical Authority and it provides useful information about the social and economic conditions.

To fully understand the population dynamics, is important to combine different scientific disciplines, like Population Geography and Quantitative Methods in Geography. Those methods, allow the researcher to study evaluate and comprehend all the different factors that
form the population’s composition. Thus, there is a need for accurate, up-to-date, and periodical maps of the population and the urban expansion in order to develop efficient decision making mechanisms and effectively manage and plan cities (Osgouei et al, 2019).

With the advances in satellite technologies and the availability of free global and historical satellite data it is possible to map and estimate constantly and effectively the urban sprawl. Remotely sensed images are usually converted into useful information such as land cover or vegetation maps. In this study, satellite data from the Landsat Collection are used to monitor and detect changes in the urban and semi-urban areas.

The study area is the county of Chania, which is the second largest regional section of Crete, the largest island in Greece. The island of Crete due to its location has a high rate of tourism and the tertiary productive sector is the main source of income. The tourism “forms” the economy of the island because the majority of the population is employed to hotel units, travel and car rental agencies. Counter to the island, Chania is the only regional unit which is based on the primary productive sector and has highly developed agricultural activities.

Chania is divided in 7 municipalities according the plan of Kallikratis (3852/2010), those are Chania, Apokoronas, Gavdos, Kandanos – Selinos, Kissamos, Platanias and Sfakia. In Chania, it is also located the Technical University of Crete and most of Cretan businesses and according to the Hellenic Statistical Authority, in the area closer to the university (Kounoupidiana) resides the most educated part of the population. In addition, the south part of the county, like Elafonisi, Samaria’s canyon, Agia’s lake, Georgiopoli beach, and islands Gaudos and Gaudpoula, belongs to the Natura 2000 network of protected areas.

This paper aims to examine the way and the reasons behind the evolution of the population of Chania. To do so, it combines the results from the quantitative methods for the productive sectors and the results for the urban spread which were estimated through remotely sensed images. In recent years, it became more evident that studying the size and the evolution of a place’s population is important and many methods for population dynamics were proposed. Such methods, were the Location Quotient (LQ), Coefficient of Specialization (CS) and Coefficient of Localization (CL).

The Location Quotient was proposed by Haig in 1928 and is a way of quantifying the concentration of a particular cluster (spatial distribution), like an industry or a demographic group, in a region as compared to the nation. The Coefficient of Specialization comes from a financial theory (North, 1995) and its used to measure the diversity in a region. The Coefficient of Localization also stems from a financial theory and it measures the characteristics of

2. BACKGROUND AND LITERATURE REVIEW

This paper aims to examine the way and the reasons behind the evolution of the population of Chania. To do so, it combines the results from the quantitative methods for the productive sectors and the results for the urban spread which were estimated through remotely sensed images. In recent years, it became more evident that studying the size and the evolution of a place’s population is important and many methods for population dynamics were proposed. Such methods, were the Location Quotient (LQ), Coefficient of Specialization (CS) and Coefficient of Localization (CL).

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specialization or diversification of an area to determine which of the economic activities employ a greater proportion of the workforce (Hoover, 1936).

Also, one more proposed index for cluster concentration is the Gini – Hirschman Index. The Gini – Hirschman Index is the most popular method and was developed to study industry concentration and market competition during the 70’s and 80’s (Jacquemin and Berry, 1979; Clarke and Davis 1983). The index measures inequality and is strongly affected by the number of individuals in an area. To better understand those indices, a Greek book by Lafazani (2018) was used.

In combination with those methods, remote sensing techniques were applied in order to detect the changes to the built up area. Through the years, many algorithms were developed such as the NDBI (Normalized Difference Built – up Index), the BUI (Built – up Index), Shannon's entropy and landscape metrics. In this paper, a combination of the spectral indices NDVI (Normalized Difference Vegetation Index) and NDBI (Normalized Difference Built-up Index) was used, the BUI (Built-up Index). The BUI separates the built up area from the remaining land cover e.g. vegetation (Karanam & BabuNeela, 2017). NDVI was conceived by Rouse et al (1973) is the most common vegetation index and distinguishes various vegetation covers such as thick or low vegetation and barren land. NDBI (Zha et al, 2003), like NDVI is easily calculated using spectral bands and it represents the build-up areas.

All the results were mapped because it is easier to depict them with the right symbols. To choose the respective symbol and color palette for each result, quantitative and remotely sensed, the books from Robinson H. et al (2002) and Livieratos E. (1985). Those books provide helpful information for creating a map.

3. ANALYSIS

Between 2001 and 2011, the smaller municipalities were incorporated to larger and a new system of demarcation was instituted. The former system, the Kapodistrian, was until 2001 and included 910 municipalities and 125 municipal communities. The new system as of 2011, is called Kallikratis’ plan and it includes 325 municipalities, in which each municipality corresponds to the sum of its nearest Kapodistrian boundaries. The data of the census of 2011 was in the new system, so the analysis was based on that.

The quantitative indices were calculated for both years for each economic sector. The sectors were separated based the table below. All the data used for the analysis are derived from the Hellenic Statistical Authority’s website (http://www.statistics.gr/).

<table>
<thead>
<tr>
<th>Sectors</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary sector</td>
<td>Agriculture, fishing, livestock</td>
</tr>
<tr>
<td>Secondary sector</td>
<td>Mining, quarries, salts, energy production, industry, constructions</td>
</tr>
<tr>
<td>Tertiary sector</td>
<td>Public and private business, trade, safety, health, financial institutions, transportation, education</td>
</tr>
</tbody>
</table>

*Source: Hellenic Statistical Authority*
3.1 Quantitative methods

The Location Quotient quantifies the spatial distribution of a cluster. It is also useful in demographic studies because it shows what makes the region’s demographics unique in comparison to its state and/or the nation. If \( LQ > 1 \), it indicates a higher rate of development in the study area compared to the region, if \( LQ = 1 \), then they develop in accordance and if \( LQ < 1 \), then the study area has a lesser rate (Lafazani, 2018).

The Coefficient of Specialization measures the diversity and its values range from 0 to approximately 100, which is the highest possible value (Hoover and Giarratani, 1971). The lowest value, 0, means that the employment is distributed in the region in the same way as the nation. Therefore, if the CS values are decreasing over time, the region is becoming more diversified (Hoover and Giarratani, 1971). If the value is 100, or close to 100, it means that all employment in the region is in one sector and that there is no employment elsewhere in nation in that sector (Gomez & Stair, 2017). The Coefficient of Localization determines which of the economic activities employ the greater proportion of the workforce and if it’s zero it means equal distribution of economic sectors in the spatial economy and if it’s 1 means concentration in certain locations (Rana & Hossain, 2013).

Lastly, the Gini–Hirschman Index measures the inequality among values of a frequency distribution and is often used as a gauge of economic inequality. The coefficient ranges from 0 (or 0%) to 1 (or 100%), with 0 representing perfect equality and 1 representing perfect inequality (Lafazani, 2018). Values over 1 are theoretically possible due to negative income or wealth. In the table below, the formulas for each coefficient is listed.

### Table 2: The formulas for each quantitative coefficient

<table>
<thead>
<tr>
<th>Index</th>
<th>Location Quotient</th>
<th>Coefficient of Specialization</th>
<th>Coefficient of Localization</th>
<th>Gini–Hirschman Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula</td>
<td>(QL = \frac{A_i}{A_j} / \frac{A_{in}}{A_{jn}})</td>
<td>(CS = \frac{1}{2} \sum \left</td>
<td>\frac{A_i}{A_j} - \frac{A_{in}}{A_{jn}} \right</td>
<td>)</td>
</tr>
<tr>
<td>Ai: the number of products in sector i in the sub-region</td>
<td>Aj: the total number of products in the sub-region</td>
<td>Ain: the number of products in sector i in the region</td>
<td>An: the total number of products in the region</td>
<td>Xi: the variable x in region i</td>
</tr>
</tbody>
</table>

After calculating the coefficients, the results for the LQ, the CS and CL are noted on table 3. The LQ is over 1, in the secondary and the tertiary sectors, which signifies that their development is in higher rate than the country. The rates for the primary sector are under 1 and according to the coefficient, it’s the sector that develops in a lesser rate. In 2001, LQ’s values are higher than in 2011, especially in the secondary sector. The results for the CS are close to zero, so the employment in each sector corresponds with the respective national employment rate. Finally, the result of CL is close to 0, this signifies that the workforce is equally distributed in each sector.
<table>
<thead>
<tr>
<th>Rates</th>
<th>Primary Sector</th>
<th>Secondary Sector</th>
<th>Tertiary Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>LQ</td>
<td>0.836</td>
<td>0.767</td>
<td>1.068</td>
</tr>
<tr>
<td>CS</td>
<td>0.039</td>
<td>0.034</td>
<td>0.011</td>
</tr>
<tr>
<td>CL</td>
<td>0.020</td>
<td>0.029</td>
<td>0.008</td>
</tr>
</tbody>
</table>

**Figure 2.** Map for the Location Quotient of the primary sector for 2001 (left) and 2011 (right)

**Figure 3.** Map for the Location Quotient of the secondary sector for 2001 (left) and 2011 (right)

**Figure 4.** Map for the Location Quotient of the tertiary sector for 2001 (left) and 2011 (right)
Figure 5. Map for the Coefficient of Specialization of the primary sector for 2001 (left) and 2011 (right)

Figure 6. Map for the Coefficient of Specialization of the secondary sector for 2001 (left) and 2011 (right)

Figure 7. Map for the Coefficient of Specialization of the tertiary sector for 2001 (left) and 2011 (right)
The results of the coefficients can be seen in accordance with the actual percentage of workforce per sector. The tertiary sector gathers the majority of the workforce in all municipalities except Sfakia. While observing table 4, the northern municipalities have largest percentages of workforce in the tertiary sector and that is due to the fact that they are more populated than the others. Also, because of that they have more facilities, like schools, hospitals and hotels.
Table 4: Percentage of workforce per sector in each municipality

<table>
<thead>
<tr>
<th>Municipality</th>
<th>Primary Sector</th>
<th>Secondary Sector</th>
<th>Tertiary Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chania</td>
<td>6.07</td>
<td>3.53</td>
<td>19.83</td>
</tr>
<tr>
<td>Apokoronos</td>
<td>32.66</td>
<td>20.44</td>
<td>18.15</td>
</tr>
<tr>
<td>Gavdos</td>
<td>40.43</td>
<td>29.41</td>
<td>27.66</td>
</tr>
<tr>
<td>Kandanos – Selino</td>
<td>55.08</td>
<td>47.17</td>
<td>9.42</td>
</tr>
<tr>
<td>Kissamos</td>
<td>46.04</td>
<td>35.62</td>
<td>18.75</td>
</tr>
<tr>
<td>Platanias</td>
<td>49.79</td>
<td>29.99</td>
<td>9.64</td>
</tr>
<tr>
<td>Sfakia</td>
<td>61.90</td>
<td>56.94</td>
<td>7.58</td>
</tr>
<tr>
<td>Total</td>
<td>19.97</td>
<td>11.31</td>
<td>17.66</td>
</tr>
</tbody>
</table>

Source: Hellenic Statistical Authority

Figure 11. Map of the percentage of workforce in the primary sector for 2001 (left) and 2011 (right)

Figure 12. Map of the percentage of workforce in the secondary sector for 2001 (left) and 2011 (right)
The Gini – Hirschman Index measures inequality, as it is seen on the table below, the results are closer to 100. This means that there is inequality in the distribution of the workforce between the sectors. As it was mentioned before, the majority of the working population lives in the northern part of the region, so it’s expected to have inequalities.

<table>
<thead>
<tr>
<th>Gini – Hirschman Index</th>
<th>Primary Sector (%)</th>
<th>Secondary Sector (%)</th>
<th>Tertiary Sector (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>44.66</td>
<td>74.80</td>
<td>78.65</td>
</tr>
<tr>
<td>2011</td>
<td>43.87</td>
<td>77.78</td>
<td>80.21</td>
</tr>
</tbody>
</table>

3.2 Remotely Sensed Techniques

The dataset consists of 6 images from the Landsat Collection, which were mosaicked together in order to have the full scene. The date of the images corresponds to the most recent census data, 2001 and 2001, and the current year, 2019. All the acquired images are downloaded from the USGS website (https://earthexplorer.usgs.gov/) and are free of charge. The images are generated at a 30 - meter spatial resolution and they are in Level – 2 format. That kind of format provides an estimate of the surface reflectance as it would be measured in the absence of atmospheric effects like absorption at ground level (USGS,2019). As mentioned above the spectral indices NDVI (Normalized Difference Vegetation Index), NDBI (Normalized Difference Built-up Index) and the BUI (Built-up Index) were calculated.

<table>
<thead>
<tr>
<th>Index</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDVI</td>
<td>( \frac{NIR - RED}{NIR + RED} )</td>
</tr>
<tr>
<td>NDBI</td>
<td>( \frac{SWIR - RED}{SWIR + RED} )</td>
</tr>
<tr>
<td>BUI</td>
<td>( \frac{NDBI - NDVI}{NDBI + NDVI} )</td>
</tr>
</tbody>
</table>

Before calculating the indices, the images were stacked using only the desired bands, RED, NIR and SWIR (3-4-5 for Landsat 5 and 7 and 4-5-6 for Landsat 8). Also, as it was mentioned above, the 6 images were mosaicked, to 3 for the purpose to have the full scenery. Then, the
images were clipped by a vector mask layer to the extent of the study area to minimize the size of the data and make them more manageable. After completing those steps, the indices were calculated and the outputs are 3 binary images for each year, with value range -1 to 1. In NDVI 0 means the absence of vegetation, the negative values represent the water features and the positive the thickness of the vegetation. In NDBI the urban areas have positive values and the unbuilt area like woodland and farmland pixels and waterbodies have negative values (Zha et al, 2003). After calculating the indices, the results were visually interpreted to maps with the most suitable colors for each case.

From NIR to SWIR band, the values which represent built up areas experience a major increment compared to vegetation, whose DNs are not appreciable (Zha et al 2003; Karanam & BabuNeela, 2017). This increment can be seen between the bands and it allows the separation of the built up pixels from the other land cover. That’s the reason NDBI has positive values for urban regions. Therefore, the subtraction of NDBI and NDVI equals the BUI who allows the built up area to be mapped automatically (Karanam & BabuNeela, 2017). The relation between the DNs of each land cover type between the bands is shown in the following figure.

![Figure 14. NDVI for 2001 (left) and 2011 (right)](image1.png)

![Figure 15. NDBI for 2001 (left) and 2011 (right)](image2.png)
While observing the maps, the NDBI values for 2001 and 2011 are similar, even if the population in 2011 was larger than in 2001 (2001: 148,450 and 2011: 156,585). So, it’s safe to imply that the number of buildings or the percentage of built up area is not affected by the population. The built up index has almost the same result as the NDBI.

As far it concerns 2019, there are not available population data to compare the indices. So, a population estimate model was used. The model takes into account the population for the two past censuses and was proposed by Rives and Serow (1984) and can be used to estimate the population size of a subset of the population, or the total size of a population between census periods.

Table 7: Population estimate for 2019 and formula

<table>
<thead>
<tr>
<th>Municipality</th>
<th>2001</th>
<th>2011</th>
<th>2019 estimate</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chania</td>
<td>98,202</td>
<td>108,642</td>
<td>116,994</td>
<td>$P_{est} = P_1 + \frac{n}{N}(P_2 - P_1)$</td>
</tr>
<tr>
<td>Apokoronos</td>
<td>12,112</td>
<td>12,807</td>
<td>13,363</td>
<td>$P_2$: Population of the last census</td>
</tr>
<tr>
<td>Gavdos</td>
<td>81</td>
<td>152</td>
<td>209</td>
<td>$n$: number of months from $P_1$ census to the date of the estimate</td>
</tr>
<tr>
<td>Kandanos – Selino</td>
<td>6,302</td>
<td>5,431</td>
<td>4,734</td>
<td>$P_1$: Population of the second to last census</td>
</tr>
<tr>
<td>Kissamos</td>
<td>11,470</td>
<td>10,790</td>
<td>10,246</td>
<td>$N$: number of months between $P_1$ and $P_2$</td>
</tr>
<tr>
<td>Platanias</td>
<td>17,864</td>
<td>16,874</td>
<td>16,082</td>
<td></td>
</tr>
<tr>
<td>Sfakia</td>
<td>2,419</td>
<td>1,889</td>
<td>1,465</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>148,450</td>
<td>156,585</td>
<td>163,093</td>
<td></td>
</tr>
</tbody>
</table>

Source: Hellenic Statistical Authority; Rives & Serow, 1984

The value of NDBI for 2019 is lower than in 2001 and 2011. This is may due to the fact that many buildings might been demolished. However, the BUI value is close to 1, this could be justified because the predicted population is larger than the one in the last census. Nevertheless, the results for 2019, are estimates and they don’t represent realistically the present situation.

Figure 16. BUI for 2001 (left) and 2011 (right)

Figure 17. NDVI (left), NDBI (center) and BUI (left) for 2019
3.3 Linear Regression

After, comparing the results of the indices with the population models, the values of NDBI and BUI were correlated with the actual population data of each year. To do so, a simple linear model was executed which had as input the population of the different municipalities in the county and the mean built up value for each corresponding to a municipality polygon. Linear regression is used for finding the relationship between target and one or more predictors. Its equation is of the form $Y = a + bX$, where $X$ is the explanatory variable and $Y$ is the dependent variable. In this case the population was set as a dependent variable and the indices as explanatory variables.

![Figure 18. Scatter plots for pop2001 – ndbi (left) and pop2019-bui (right)](image)

While observing the statistical relations between the variables, the ones with the strongest relations are the correlation between the population for 2001 and the NDBI and the correlation between the population for 2019 and the BUI. The other correlations had low significance therefore they are not considered statistically important. The strongest relation is between the population for 2001 and the NDBI with $R^2 = 0.327$. The result is of low statistical importance but it confirms the fact that the focalization of the population in a place can’t be confirmed by the percentage of a buildup index, but a quantitative method based on the rate of employment is more accurate. The estimated population of 2019 was correlated with the BUI and the result was also of low statistical importance ($R^2 = 0.25$).

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Chania</td>
<td>98.202</td>
<td>0.718</td>
<td>0.596</td>
<td>0.292</td>
<td>0.296</td>
<td>0.683</td>
<td>0.666</td>
</tr>
<tr>
<td>Apokoronos</td>
<td>12.112</td>
<td>0.646</td>
<td>0.612</td>
<td>0.276</td>
<td>0.293</td>
<td>0.980</td>
<td>0.411</td>
</tr>
<tr>
<td>Gavdos</td>
<td>81</td>
<td>0.68</td>
<td>0.307</td>
<td>0.576</td>
<td>0.269</td>
<td>0.127</td>
<td>0.148</td>
</tr>
<tr>
<td>Kandanos - Selino</td>
<td>6.302</td>
<td>0.661</td>
<td>0.641</td>
<td>0.288</td>
<td>0.271</td>
<td>0.529</td>
<td>0.481</td>
</tr>
<tr>
<td>Kissamos</td>
<td>11.470</td>
<td>0.701</td>
<td>0.498</td>
<td>0.357</td>
<td>0.260</td>
<td>0.864</td>
<td>0.756</td>
</tr>
<tr>
<td>Platanias</td>
<td>17.864</td>
<td>0.701</td>
<td>0.634</td>
<td>0.299</td>
<td>0.649</td>
<td>0.508</td>
<td>0.511</td>
</tr>
<tr>
<td>Sfakia</td>
<td>2.419</td>
<td>0.694</td>
<td>0.661</td>
<td>0.334</td>
<td>0.286</td>
<td>0.580</td>
<td>0.270</td>
</tr>
</tbody>
</table>

4. CONCLUSIONS

Chania is one of the most developed regions in Crete. Especially the southern part is the most flourished. The southern part includes some of the most visited places in the island, like Chania, Elafonisi, Paleochora, Balos, Chora Sfakion and Agia Roumeli. Because of that the tertiary sector is the most developed than the other two, this is also confirmed by the results of the coefficients (e.g. LQ = 0.767). So, the majority of the population is clustered in the northern
part, consequently the largest part of workforce, because of the augmented tourism. Throughout 2001 – 2011, the tertiary sector is the one with the most employees, comparatively with the primary and secondary, which has the lesser number of workforce. The results of the analysis are summarized to the table below.

**Table 9:** Percentage Change of workforce in the production sectors between 2001 and 2011

<table>
<thead>
<tr>
<th>Percentage (%)</th>
<th>Primary Sector</th>
<th>Secondary Sector</th>
<th>Tertiary Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chania</strong></td>
<td>- 44.42</td>
<td>- 18.12</td>
<td>16.48</td>
</tr>
</tbody>
</table>

*Source: Hellenic Statistical Authority*

According to the analysis and the table, the tertiary sector is the most developed and the one with the most employees. Notably, it was the only sector who had an augmentative rate compared to the other two sectors. The last years because of the high tourism the majority of the Cretan workforce is employed to hotels, restaurants, travel and car rental agencies, leaving behind the agricultural production. That’s why the primary sector has the most reduced rate.

As it was mentioned before, the most developed part of the region is the southern. Also, it’s the more habituated and that could be observed at the NDBI and BUI maps (Higher value of indices at the northern part). However, the urban spread is not directly linked to the population as it was confirmed by the regression. The population growth depends more to the employment vacancies, so the people move by that. In conclusion, it is perceived that the population growth in the study area depends to the also augmented tourism.

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