Analele Universităţii din Oradea – Seria Geografie Year **XXI**, no. **2/2011** (**December**), pp. **363-369**
ISSN **1454-2749**, E-ISSN **2065-1619** Article no. **212122-535**

USING GIS MODELING AND THE DAC STATISTIC TO ANALYZE THE SUSTAINABILITY OF DEVELOPMENT IN IALOMIŢA HYDROGRAPHIC BASIN

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Abstract: Sustainable development relies on three traditional pillars (economic, social, and environmental), to which a fourth cultural one was added, and has a territorial dimension, resulting into the creation of sustainable communities. Measuring the sustainability of a given area relies on indices covering all these chapters. In an attempt to identify the most relevant indices and pillars, this study uses similar analyses at the micro-scale level using administrative-territorial units covering the mountainous and sub-Carpathian space of an average sized hydrographic basin. The algorithm uses selected indicators reflecting the density of population, its dynamics and migratory increase, elder population, natality, unemployment, share of population working in agriculture, number of people who completed high school education, the number of physicians per 1000 people, and inhabited area per person. Data are analyzed using GIS modeling based on raw data and factor analysis, and the ordinary kriging interpolation of the values of the Drane - Aldrich - Creangă test. The results suggest that there are two *„rich"* zones, one in the mountain area and another close to the plain, while the poorer regions situate in between. This pattern is interrupted by the important communication routes, resulting into differentiated accessibility.

Key words: factor analysis, kriging, GIS, index of development, modeling

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INTRODUCTION

Synthesizing the researches attempting to identify solutions to the environmental issues a new concept emerged in 1987: sustainable development, defined as *„development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (Brundtland, 1987). The concept relies on three traditional pillars (economic, social, and environmental), to which a fourth cultural one was added later, and has a spatial dimension (Centrul de Cercetare, Proiectare, Expertiză şi Consulting, 2006; Petrişor, 2008b; Petrişor et al., 2010). Accounting in addition for the practical actions involved by its implementation, a more

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comprehensive definition is *„use of natural resources within the carrying capacity limits, conservation of diversity, ecological restoration of degraded environmental system and environmental protection measures embedded in sectoral development policies, aiming to assess the impact and internalize eventual environmental costs"* (Petrişor, 2009; Petrişor and Sârbu, 2010).

The key to understanding sustainable development is the interconnection of traditional pillars (Bugge and Watters, 2003; Ianoş et al., 2011; Ilieş et al., 2010). Therefore, environmental, social and cultural policies must be part of the general and sectoral development policies (Petrişor and Sârbu, 2010; United Nations, 1992). Spatially, sustainable development must ensure a territorial balance of the satisfaction of economic, social and environmental needs of present and future generations at the same rate (Petrişor, 2008a), and provide for the coherence of socioeconomic objectives reported to the territory and its environmental and cultural functions, aiming to improve the quality of present and future generations' life by creating sustainable communities able to manage ant utilize resources efficiently, exploiting the innovative environmental and social potential of the economy while guaranteeing the prosperity, environmental protection and social cohesion (Colignon, 2009). Consequently, from a territorial perspective, sustainable development leads to the creation of sustainable communities, defined by the Bristol accord as *„places where people want to live and work, now and in the future"* (Office of the Deputy Prime Minister, 2006).

Assessing the sustainability of development for a particular territorial unit or region involves data on indices reflecting the different pillars (Dobrin et al., 2010a, b; Ianoş et al., 2010). One of the most commonly used methodologies relies on the utilization of Geographical Information Systems (GIS), defined as *„decision support system involving the integration of spatially referenced data in a problem solving environment"* (Cowen, 1988). However, the use of GIS can be enforced when used in conjunction with statistical methods (Tache et al., 2010) based on economic, social, and environmental indicators. In addition to the simple indicators, aggregated indices are computed based on arithmetic operations performed using individual indices, according to the statistical principle of Paul Benzecri: giving up some information to gain relevance (Dragomirescu and Drane, 2009).

This aim of this study was to create and use a methodology for micro-scale level analyses of administrative-territorial units, *i.e.* about 40 communes covering the mountainous and sub-Carpathian space of an average sized hydrographic basin, attempting to pinpoints the most relevant indicator(s) of development, even if artificially built, and map its spatial distribution.

METHODS

36 base administrative units (communes and cities) of Dâmboviţa County were selected based on the geographical location in the mountainous and sub-Carpathian area of Ialomiţa river basin. The corresponding database contained data on 15 indicators, presented in table 1.

The first step consisted of using factor analysis based on principal components extraction in SPSS to identify the most important indicators: the number of high school graduates and the population employed in agriculture (Ianoş and Petrişor, 2010).

Using these results, GIS modeling was used to build an average index of development for each administrative unit based on all the 15 indicators considered, and another one based only on the key indicators pinpointed by the factor analysis with weights ratioed to 100 % (82 %, respectively 18 %). In the first case, the population employed in the agriculture had a weight equal to 8 %, the number of high school graduates had 14 %, and all other indicators 6 %. In the second case, the population employed in the agriculture had 18 % and the number of high school graduates 82 %. Two models, displayed in figure 1, were built using the indicators and weights mentioned before. Running the models resulted into maps displaying the level of development in each administrative unit, evaluated on a 1 to 5 scale, with 1 pointing the lowest level, and 5 the highest.

In the next step, the Drane - Aldrich - Creangă (DAC) test was used for an almost mathematical and over-generalizing analysis of the data. The DAC statistic was introduced in the statistical literature through a study by Drane, Creangă, Aldrich, and Hudson (Drane *et al*., 1995) in order to provide an instrument to detect spatial clusters, or, more generally, areas with health problems.

Table 1. Descriptive statistics of the indicators used in the study, for the 15 base administrative units of Dâmbovița County located in the mountainous and sub-Carpathian space of the Ialomița river basin.
(Data source: Interdisciplinary Center of Advanced Research on Territorial Dynamics, University of Bucharest)

Variable	Minimum	Maximum	Average	Std. deviation
Total population	1747.00	15691.00	4927.91	2680.53
Resident population	1748.00	15552.00	4935.31	2664.13
Livable area per inhabitant	28888.00	228805.00	70834.06	38242.60
Incoming migration	0.00	256.00	63.51	52.27
Outgoing migration	2.00	187.00	60.94	42.06
Number of people with a TV set	412.00	3812.00	1332.14	666.18
Number of pharmacies	0.00	6.00	0.63	1.14
Number of physicians	0.00	50.00	4.00	8.24
Population employed in the industry	21.00	1339.00	253.09	274.77
Total number of employed people	75.00	4312.00	681.69	785.74
Total number of unemployed people	9.00	1305.00	180.31	258.28
Population employed in the agriculture	29.00	1338.00	408.40	287.44
Active population	136.00	5166.00	1198.60	944.06
Population age 65 and over	413.00	1946.00	872.23	365.06
Number of high school graduates	155.00	3557.00	860.89	689.71

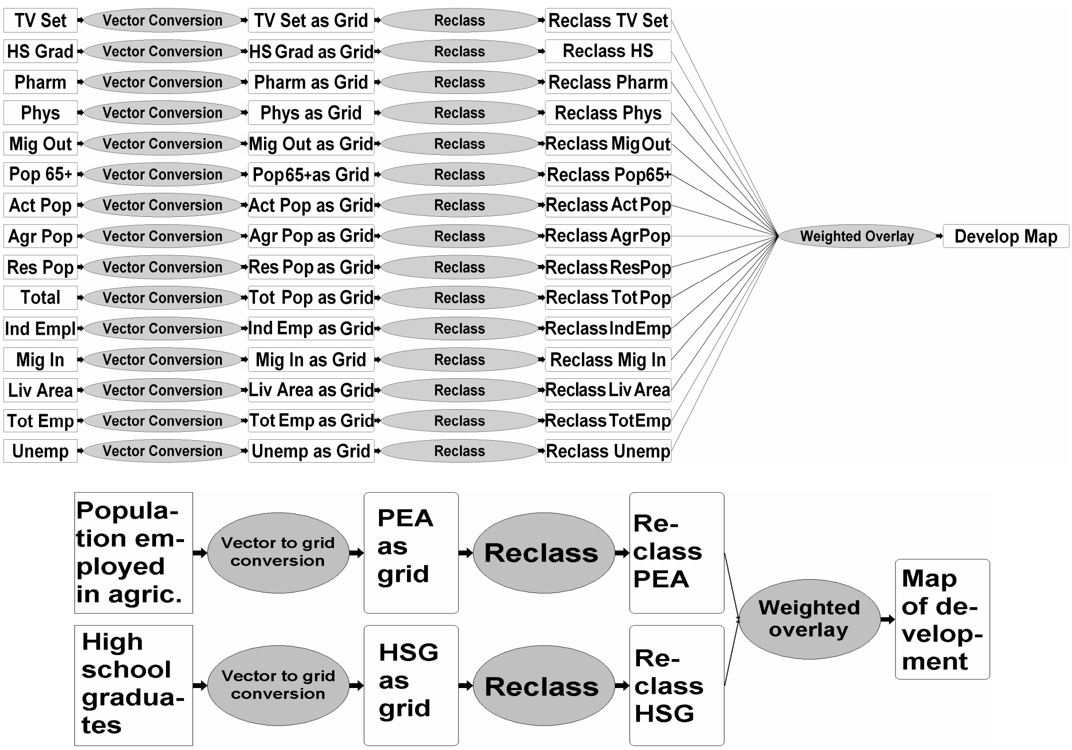

Figure 1. Displaying the GIS models used to map the level of development in the base administrative units (communes and cities) of Dâmbovița County located in the mountainous and sub-Carpathian space of the Ialomița river basin. The 15-indicators based model is displayed above, and the 2-indicators based model below.
(Source: GIS model produced by the author)

The computation of the DAC statistic is based on the empirical cumulative distribution function:

$$F_n(x_1, x_2) = m(x_1, x_2) / n \qquad (1)$$

where m(x_1, x_2) is the number of points of the sample of size *n* such that $x_1i \le x_1$ and $x_2j \le x_2$. As (x_1, x_2) covers the entire sample from (0, 0) to (max x_1, max x_2), m(x_1, x_2) spans the interval [0, n]. Within the sample, cases are defined based on a threshold value (*i.e.*, values lower or higher than a certain limit), and for each of them F_m is defined by analogy to F_n (Petrişor et al., 2006).

The DAC statistic is, for all possible values of (x_1, x_2),

$$DAC(x_1, x_2) = F_m(x_1, x_2) - F_n(x_1, x_2) \qquad (2)$$

F_m is the empirical cumulative distribution function of all cases, and F_n is the empirical cumulative distribution function of the total population (Petrişor et al., 2006).

To compute the DAC statistic, the actual coordinates of the centers of each administrative unit were obtained. A special Quick-Basic application (Petrişor et al., 2002) was used to compute the DAC statistic based on the threshold value of 911.5 of an aggregated index od development, built based on the results of factor analysis. The value was identified looking at the statistical distribution of the index using it histogram, built using an Excel plug-in called Histo (Dragomirescu et al., 2003). Ordinary kriging, a interpolation technique assuming that the spatial distribution of a certain variable depends only on the location of sampling stations (Johnston et al., 2001), was performed using the Geostatistical Analyst extension of ArcGIS to interpolate was used to interpolate the DAC values and derive a generalized distribution.

RESULTS AND DISCUSSION

The results of factor analysis indicate that two variables, the number of high school graduates and the population employed in agriculture, account for 84.6 % of the total variation. The first one explains 69.2 % of the variation, and the second, 15.4 % of it (Ianoş and Petrişor, 2010).

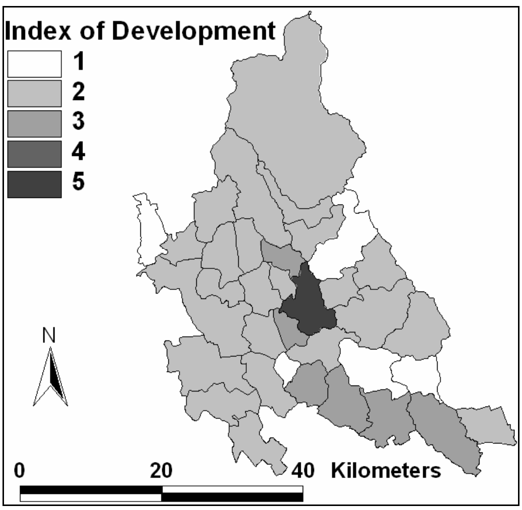

Figure 2. Showing the spatial distribution of the general level of development derived based on GIS modeling using all 15 indicators for the base administrative units of Dâmboviţa County located in the mountainous and sub-Carpathian space of the Ialomiţa river basin.
(Source: Authors' original work)

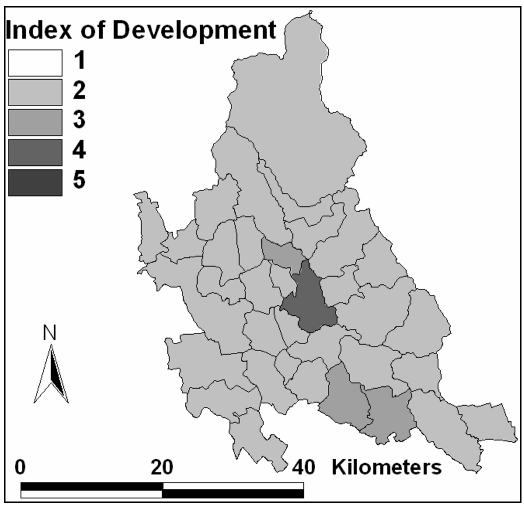

Figure 3. Showing the spatial distribution of the general level of development derived based on GIS modeling using 2 main indicators for the base administrative units of Dâmboviţa County located in the mountainous and sub-Carpathian space of the Ialomiţa river basin.
(Source: Authors' original work)

GIS modeling requires weights totaling 100 % instead of 84.6 %. Consequently, the new weights are 82 %, respectively 18 %. The results of using GIS-based modeling to compute the average level of development in the base administrative units of Dâmbovița County located in the mountainous and sub-Carpathian space of the Ialomița river basin is displayed in figure 2 and figure 3.

Figure 2 presents the spatial distribution of the index computed based on all 15 indicators, with higher weights assigned to those corresponding to the principal components identified using factor analysis and figure 3 presents the spatial distribution of the index computed based on the two indicators corresponding to the principal components identified using factor analysis, preserving their weights.

A potential aggregated index based on the results of factor analysis would be simply computed as 0.82 × the number of high school graduates + 0.18 × the population employed in agriculture. Its distribution is displayed in the histogram displayed in figure 4, drawn using Histo. The histogram indicates a bimodal distribution, requiring its separation into two unimodal distributions, one containing the lower values, and another the higher ones. Cutting the distribution pinpointed the threshold value used in the computation of the DAC static; the value was determined as the midpoint of the middle interval, *i.e.*, 911.5. Based on the threshold, the DAC statistic was computed and its spatial distribution mapped in figure 5. Furthermore, ordinary kriging was used to provide a generalized spatial distribution of the values, based on the location of the center of each administrative unit and its corresponding DAC value, regardless of the actual administrative limits. The kriging map is displayed in figure 6.

Regardless of the methodology utilized, all the maps displayed in figure 2, figure 3, figure 5, and figure 6 suggest the existence of two 'rich' zones, one situated in the mountainous region and another adjacent to the plain area, while the poorer ones are situated in between. Slight differences are due to the methodological approach concern the size and overall level of development of these areas. The spatial distribution is also changed by major communication routes and different accessibility.

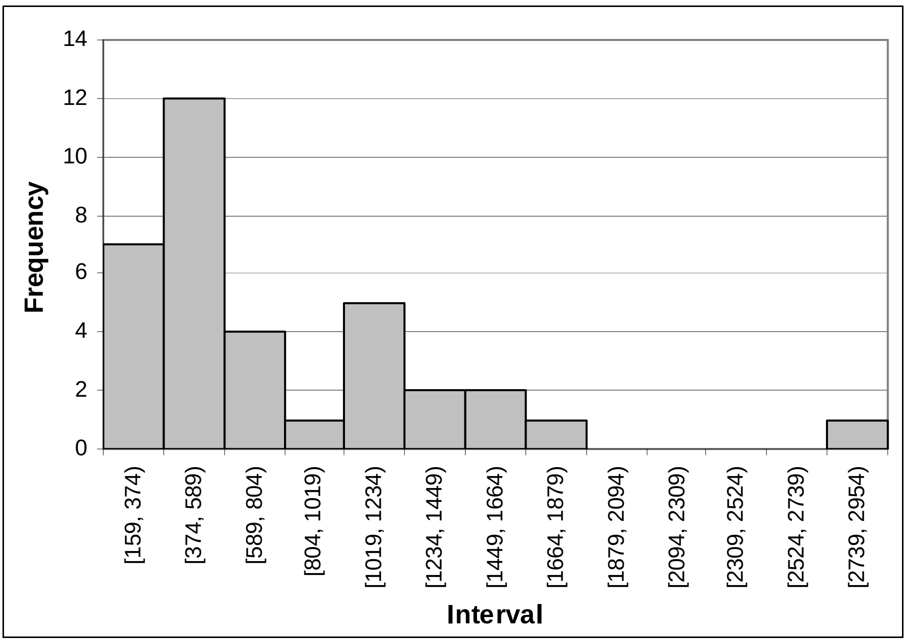

Figure 4. Displaying the histogram of the values of the general index of development derived using factor analysis. (Source: Authors' original work)

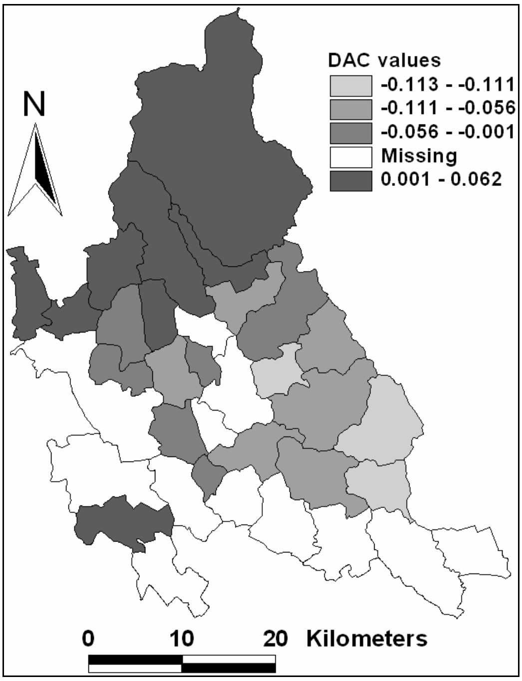

Figure 5. Showing the spatial distribution of the DAC values in the base administrative units of Dâmbovița County located in the mountainous and sub-Carpathian space of the Ialomița river basin. Higher values, indicated by darker shades, identify poorly developed areas.
(Source: Authors' original work)

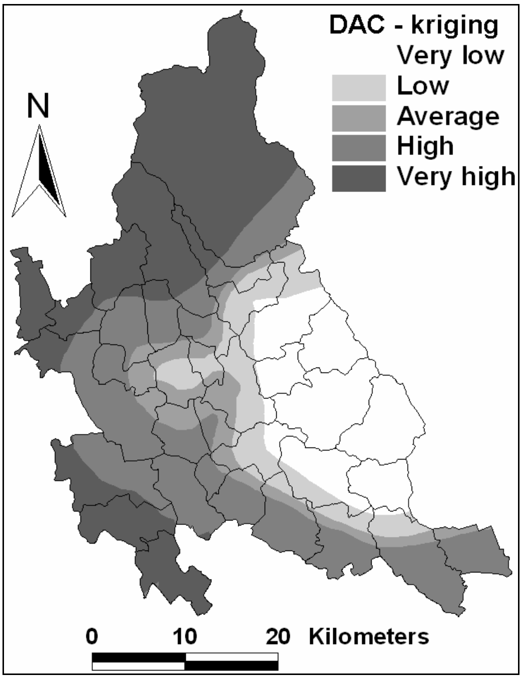

Figure 6. Showing the ordinary kriging interpolation of the DAC values in the base administrative units of Dâmbovița County located in the mountainous and sub-Carpathian space of the Ialomița river basin. Higher values, indicated by darker shades, identify poorly developed areas.
(Source: Authors' original work)

CONCLUSIONS

The results obtained by using GIS modeling and the DAC statistic to analyze the level of development in Ialomița river basin prove the advantages of correlative-integrative approaches. From the multitude of analyzed indicators, the population employed in agriculture and share of high school graduates stand out, explaining the large territorial variability of the index of development. The alternate distribution in territorial strips of the level of development in Ialomița river basin show the importance of available resources within the mountain areas, as well as within the contact areas (plain-hills), compared to those specific to the poorer plain regions.

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Submitted:	Revised:	Accepted and published online
June 15, 2011	August 23, 2011	September 03, 2011