Interaction Between the Urban and the Physical Environment: GIS Methods for Environmental Engineering Analyses

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***Abstract*—**A geo-environmental evaluation for urban land use planning often requires a large amount of spatial information. Geographic information systems (GIS) are capable to manage large amounts of spatially related information, providing the ability to integrate multiple layers of information and to derive additional information. A GIS-aid to the geo-environmental evaluation for urban land use planning is illustrated for the urban area. This evaluation incorporates topography, and physical geographical environment, and the socioeconomic data (the population, migration) and the interaction between the two main geographical factors-group. Urban land-use is categorized according to the types of land-use and projects planned, and the model of the near future conditions. The prognoses, multi-criteria analysis is performed to evaluate development suitability of the geo-environment for each category, according to appropriately measured and weighted factors. A suitability map for each category is developed using an algorithm that combines factors in weighted linear combinations. It is demonstrated that the mathematical formula and GIS methodology has high functionality for geo-environmental assessment.

***Keywords*—**GIS methods, mathematical analyses, urban development, applied physical and social geography, environmental evaluation

I. Introduction

TO assess the conditions and the developmental opportunities of a settlement, mathematical approaches and numerical analyses of geographical factors are needed. All the qualitative and quantitative weighted elements of these variables play an important role on the modeling procedure. Formerly, prior to the industrial revolution, settlement location and development were primarily determined by physical geographical factors. The primary influencing factors included water quality, soil fertility, relief, mesoclimatic conditions, and the length of vegetational period. Nonetheless, with increasing population concentration the importance of physical factors gradually has been decreasing. With the technical revolution, the role other factors, such as spatial distribution of energy and mineral resources have also became increasingly important.

Generally speaking, with the exception of the past two centuries, it was indispensable to consider the role of physical factors for selecting the optimal settlement location.

However, it is challenging to accurately estimate the time interval that was required for Rome, the "eternal city to achieve the heydays of its development, or to reach its final stage of destruction in 476 AD. The ancient cities of Mesopotamia, primarily by the improper irrigation and agricultural practices, disappeared in the desert almost without any sign. By looking at these outcomes, the following research questions need to be answered. The agricultural revolution produced an extremely high population, was it the problem? To what degree does land capacity influence settlement development? Landscape has evidently changed parallel with the infrastructural development of settlements. The infrastructural elements, such as roads and utility network have been continuously altering the original physical environment. The anthropogenic land changes began in the very first moment of the birth of the settlement, for this reason all landscapes around areas of intense the human activities have been significantly altered and transformed. Due to the complete destruction of natural ecological islands and corridors around developed areas, natural habitats are often entirely erased in and around settlements of high population concentration. This new anthropogenic landscape is artificial and often unsuitable for revitalization. Nevertheless, there exists a significant difference between the human effects on natural environment in terms of ancient settlement development and modern processes. Over the ancient times agricultural and industrial production changed in accordance with the inherent physical land capacities of the area. There was sufficiently long time available for the renewal of water resources, as well as for long-term maintenance of adequate soil conditions, and revegetation of deforested areas.

Over the last two centuries, however, physical and social factors have been totally separated. The economical factors overwrite the process of the settlement development. This is an intense and profit oriented stage of the urbanization. The elements of this new period are absolutely suitable for numerical analysis and modeling. Road and utility network data and quantitative demographical and migration parameters, as well as tertiary and quaternary services are also ideal subjects for numeric evaluation of urban conditions, developmental stage, and for comparison with other settlements. These parameters are organized, structured and accessible in databases, the main remaining issue is the method of their analytical approaches, how they are weighted, and how we find the exact place and role of the factors in the process of the settlement development in the future. Some factors which were very important in the past, such as relief (e.g. defending a fortress) has lost its importance, but

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nowadays it got a new esthetical function (panoramic view) as urban developmental factor. The energy sources and their roles in the global economy turned the process of the urbanization in a new direction. For example the oil countries built up new cities sometimes at wrong and improper places. The infrastructural development of these expensive and state-of-the-art cities may not be sustainable following the 'century of the oil'. It is time to contemplate, when water becomes the primary driving factor for urban development (or human survival) again, like it was millennia ago. The answer is that sooner than we think. This scientific research and data analyses with the model provides a scenario for the future urban developmental process on local, regional and even at global scales. The authors have thoroughly studied the interaction between physical environment and the socio-economic factors based on the results of the last three decades of the European urban processes, controlled with exact mathematical formulas. All data were then analyzed with GIS tools in ArcGIS software environment.

This article is part of a large geo-environmental assessment research which aims to produce a universal model for systematic analysis of settlements, based on weighted geographical factor analysis, with mathematical formulas and GIS modeling. These GIS models will provide data for both short and long-term synopsis, and use demographic, economic, infrastructural and social statistical data as input parameters.

The current study presents a case study, where the model and the methodology is fitted and accommodated to the former urban geographical scientific experience and results. When we studied the Pécs agglomeration (Hungary), data obtained with the traditional method was used as control data for comparison with the model output. Model applicability was also verified on the example of the towns of Komló and Kozármisleny (Southwest-Hungary).

We also studied the earlier physical and social geographical GIS models in order to derive further information on geo-spatial urban modeling [11,12, 3, 4, 5]

In the current research we studied and analyzed 26 indicators that reflects the following spatial and temporal components of settlement development:

a) Available natural and environmental sources,
b) Social-demographic parameters,
c) Average household income,
d) Position of the given settlement in the hierarchical settlement,
e) Economical position and role of the given settlement,
f) Infrastructural conditions and development and
g) Direction and rate of the settlement development.

The selected 26 indicators are divided into four groups, namely the *physical environmental*, *social, economic* and *infrastructural groups*, containing 7, 6, 8 and 5 indicators, respectively.

II. Selection Of Indicators For The Characterization Of Settlement States And Conditions

The physical factors have always played a crucial, but variable-magnitude role on settlement development throughout human history. These factors might be studied individually or in a complex, multi-criteria way. Some environmental factors, such as e.g.: temperature, precipitation, soil conditions are directly measurable and consequently can be quantitatively evaluated, while some other factors include subjective elements, like topography, energy resources or esthetic value of the given area. The effects of these factors are strongly variable in time. Based on the results of the earlier studies in this research field, we developed an exact weighted rank among these factors. The primary role of the healthy potable water has not changed during the human history. Obviously, under the current technical level, any settlement can be maintained in the middle of a desert when water needs to be transported form a great distances, but the economy factors indicate an unsustainable situation [1, 2].

The second factor, with increasing weight over the past 100 years, is the energy resource that indicates a large spatial heterogeneity. Our mathematical model attempts to generate a prognosis and forecast for the future development of settlements, based on energy resources as an economic factor. The increasing role of fertile soils, as energy resource and source of human food, is obvious, indicating a close correlation with demographical (migrations) and population density changes.

The fourth factor is the climate, which has an increasing effect on settlement development over the past decades, due to the decreasing return period of extreme weather phenomena, as a direct consequence of global climate change. Extreme weather lately has been generating an increasing number of undesired and often catastrophic problems in the life of the settlements.

The current study pinpoints the importance of these factors and identifies connection among them with the help of the matrix model.

The development and changing of settlements and urban regions and agglomerations can be characterized by different social and economic factors [6, 7, 8].

It is important to point out the demographic indicators (from these), because the changing of the numbers of population show clearly the settlements' developing tendency.

In Hungary, the difference of the numbers of births and mortality and the migration define together the changing of the numbers of population. Similarly to the East- and Central European countries, since the beginning of the 1980's decade the number of population have been decreasing permanently, nowadays this number is under 10 millions. At the same time, the number of young people is decreasing, the elders' is increasing. Moreover, since 2007 the middle-aged people's number have been moderating. With population ageing, the active-aged person's numbers are decreasing gradually and the dependency ratio of elders' is increasing. In the long term/(run), it would cause a numerous social, economic and financial problems.

The changing of numbers of population's other component is migration, which assists measurably in turning of regions' social structures into a favourable or an unfavourable direction. According to our study's aim, it is worth to be searched the internal migration. One type of internal migration is suburbanization. It has been presented in Hungary since the 1990's decade and it means the migration between 'the city and the region'. The Hungarian towns' migration-balance has been negative since 1990, the capital's balance since 1991 in contrast the villages' have been positive since 1991. The suburbanization appeared the most notably in the urban region of Budapest, but it also appeared in each big Hungarian urban regions, actually it also presents in cases of smaller towns [9, 10].

In Hungary the numbers of settlements with natural growth had been minimized. Essentially, the urban conformation of population's number decides the migration: if it is positive the number of population increases or stagnates or shows a slight decreasing. Those towns, where the migration is negative, fight against odds. Where the migration associates with other demographical, social and economic odds, this problem appears more firmly. The most accurate method to measure the urbanization is studying the indicators concerning the migration's size and direction.

The population ageing – it means the increasing of the elder aged numbers and its rate inside the population – can be seen also in Hungary like in the bigger groups of European countries. The ageing index illustrates well the ageing process that defines the elders' number rate in relation to children's number. In the last decades, it has been increasing dynamically: in 1990, 100 under-age reached 64 elder, in 2009 this number is 110 (it means the numbers of children exceeded the elders).

The indicators -representing the population's age- mean important parts of the developing-ability of settlements, because in any town, with a high percentage of elderly people compared to the number of active aged people, does not attract investment and the economy doesn't developed. The education level is also an important indicator in terms of population-characterization. Primarily, we considered the proportion of graduates that is a defining factor related to the status of settlements.

The economic factors define the economic potential and financial status of the settlement, these factors suggest the population's purchasing power. So, the unemployment rate, the indicators of population's income – like the indicators of high priority of the economic status-, the proportion of active employees and the numbers and incomes of enterprises were also placed in this block. The indicators related to the tourism – the specific values of the guests' numbers and guest nights- were also placed in this group.

During our study, we would like to describe a development, a state, which is independent from the (right)status and size of settlements. Certain infrastructure characteristics are bounded strongly to the sizes and status of the settlements, for instance an institution of higher education or a hospital are built rarely in a smaller settlement.

Infrastructure was characterized by the changes in the public utility gap, number of properties and the number of automobile.

It was extremely important focus point during the development of the model to get all factors properly weighted in the mathematical model. The weight of each factor was determined based on the magnitude of their geographic impact and role. The methodology used for the determination of the weight factor of each parameter is not shown in detail here.

III. Principle Of The Settlement Development Stage Analysis

Every settlement can be represented by a Settlement Stage Matrix (S_t). S_t has n x m elements, where each of the elements ($p_{11}...p_{nm}$) stand for an attribute that describe the development stage of the settlement.

$$p_{nm} \in N \ n,m \in Z^+$$

The elements of the S_t matrix are classified and originally derived from various data sources. These sources can be distinguished by the type of the data. In addition to social and economic statistics we used geographic information system (GIS) to determine those environmental and infrastructural information, that have effect on the development of a settlement. In order to achieve this we collected several raw database like digital terrain model, land cover database, road network etc., and made various GIS analysis on them.

Sorting matrix elements into columns by the source type of the data allows easy process with computer and gives the opportunity to compare the significance of environmental, social and economic factors in the development.

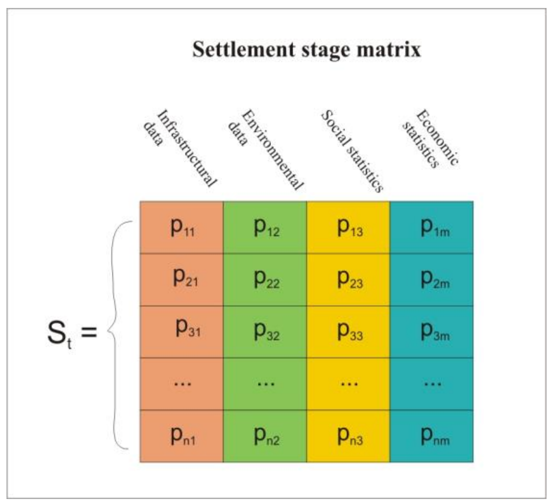

Fig. 1 Schematics of the Settlement Stage Matrix

The lower index in the name of S_t matrix represents the year from which the data are (for example: S_{1990}, S_{2013}) (*fig 1)*. It gives the possibility to analyze the time-series of the development. We can calculate the intensity of the alteration by defining the Settlement Change Matrix (C_{t2-t1}):

$$S_{t2} - S_{t2} = C_{t2-t1} \rightarrow S_{t1} + C_{t2-t1} = S_{t2}$$

The C_{t2-t1} matrix gives the opportunity to compare directly 2 or more settlements' development during the specified interval (t2-t1), so not only the current state of development but the intensity of the progress can be characterize.

To analyze the disparate environmental, social and economic capabilities of a settlement we can define the Average Matrix (A_t) with elements from a_{11} to a_{nm}:

$$a_{ij} = \frac{1}{n \times m} \sum_{i=1}^{m} \sum_{j=1}^{n} p_{ij}$$

Comparing the average with the individual elements of the S_t matrix points out those social, environmental and economic parameters that stimulate or inhibit the development of the settlement (*fig. 2*). To reveal these factors we can define the Imbalance Matrix (I_t) with elements from i_{11} to i_{nm}:

$$i_{ij} = p_{ij} - a_{ij}$$

$i_{ij} > 0$ means that the factor represented by the matrix element plays key role in the current development and may has such a significant role in the future too. $i_{ij} < 0$ indices a factor that needs to be developed.

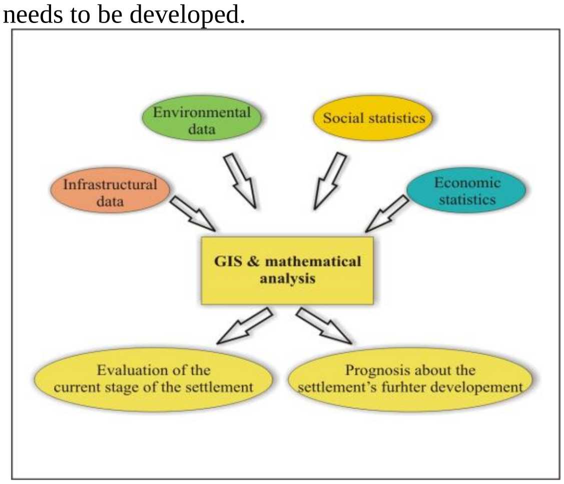

Fig. 2

The input data and the output results of the analysis

We can characterize the balance of the development stage with a single value derived from the Imbalance Matrix (I_t) by summing up the elements of the matrix:

$$b = \sum_{i=1}^{m} \sum_{j=1}^{n} |i_{ij}|$$

The sum of the values of the I_t matrix in conjunction with the standard deviation of this calculation reveals whether the settlement has a one-sided development or it has a balanced progress.

IV. Conclusions

Organizing the classified data into a well-defined matrix has several benefits. At first it allows to automate the characterization of the settlements with software. This also means that the comparison of every settlement can be automated too. The other advantage of this method is that we can analyze a single settlement by revealing the connections between the parameters that represent the development stage of the settlement. It helps to understand and quantify the key factors that may have primary effect on the further development, so we can provide prognosis about the probable future of the settlement.

TABLE I
POTENTIAL USAGE OF THE SETTLEMENT STAGE MATRIX AND ITS DERIVED DATA

	Potential usage
Settlement Stage (S_t)	Comparing the past or current development stage of 2 or more settlements
Settlement Change (C_{t2-t1})	Analyzing the pace of the development during different time intervals, finding correlation between socioeconomic tendency and the development in the same period.
Average (A_t)	Tool for characterizing the average development stage of a settlement.
Imbalance (I_t)	Revealing those environmental, infrastructural, social and economic parameters that have role in the current and further development or regression.
Imbalance indicator (b)	A single value that imply the rate of the imbalance between environmental, infrastructural, social and economic development stage. The bigger the value of the indicator the more uncertain the further development of the settlement is.

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