Journal of Earth and Atmospheric Sciences
Vol. 2, No. 2, 2017, pp. 17-23
http://www.aiscience.org/journal/jeas

Implementation of GIS Analysis, Remote Sensing and Data Mining for Modelling and Retrodiction of Settlements Networks: Case Study of San Escobar

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Abstract

Main objective of this study is to further develop and tune the workflow for modelling of settlements networks, which would be capable to manage with uncertainty and low quality of data sets. Proposed methods were implemented for assessment of central potential of urban units in Middle-Earth and to compare them with settlement network of San Escobar. Results show, that it is possible to investigate and quantify central and peripheral areas. Further findings suggest also that different kind of fuzzy and misty logic are capable of illustrating both literary as well as unreal cartographic data.

Keywords

GIS, Literary Settlements Network, Tolkien Middle-Earth

Received: May 30, 2017 / Accepted: July 13, 2017 / Published online: July 27, 2017

1. Introduction

Spatial polarization is a phenomenon commonly observed in most parts of the modern world. No one is surprised by the increasing contrast between central and peripheral areas. In translation into the structure of the settlement network, this problem manifests itself in the faster development of central units dominated by the concentration of diverse functions, often combined with an increase in population. At the other extreme are the units which, as a result of various factors, have become peripheries of a given area and are characterized by slower development, stagnation or even downfall and reduction of functions.

The problem of polarization of space, however, is not merely the domain of the contemporary world. Concentration tendencies also occur in alternate and fictional worlds. Just ask yourself, who of the average citizen knows where Tigg really lies? Most people are aware of the significant role that Novigrad plays. Literary network analysis is not only a purely intellectual challenge but is a very interesting training ground for the development and testing of new research methods. In addition, it can be used to simulate the development of socio-economic space in a variety of scenarios, providing a desirable alternative to the contemporary world. A study of similar scope, although based on the historical determinants of the development of the settlement network, with the exception of the literary thread, was already conducted in Poland. A study on the influence of rivers on the development of the settlement network in Poland [1] and an analysis of historical changes in the location of the centre of gravity of cities and the development of settlement networks [2, 3].

The purpose of this paper is to present a new approach to the retreat and modelling of literary settlement networks. The proposed approach takes first and foremost the environmental and spatial determinants of development, and takes into account the problematic aspects of the use of often incomplete and inaccurate data. The methodological approach applied includes the integration of the latest

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developments in the field of exploration of data with spatial analysis conducted in the geographic information system (GIS) environment. The most important research question is how to deal with significant uncertainty in geospatial data.

This methodology (described in more detail in section 2) has been used to model and classify Middle-Earth areas [see 4, 5, 6]. When choosing this area, its representativeness was taken into account, as well as the superior availability of source data. It was also noteworthy that this area was relatively well studied and described, both in terms of land formation [7] as well as climatic zones and vegetation formation [8], as well as social relations and their Perception [9, 10, 11]. Second study area was San Escobar, which was invented by [12]

Taking into account some of the terminological inaccuracies associated with the definitions of "centre" and "periphery" [13], the following scope of these terms was adopted in this paper. The centre concept will be understood as those entities within which a concentration of different functions has been concentrated over a given period of time, and the level of this concentration is significantly higher than the average for the whole analysed area. At the same time, it is important to remember the differences between the terms: centre, core, and central unit (Figure 1). Peripheral areas are considered to meet two conditions: they are lower than average and the range of functions they perform, but are also located at a distance that prevents the use of functions available in central units.

Within the framework of the presented study, nine basic functions of settlement units were analysed: political, commercial, industrial, cultural-scientific, leisure-entertainment, religious and defence.

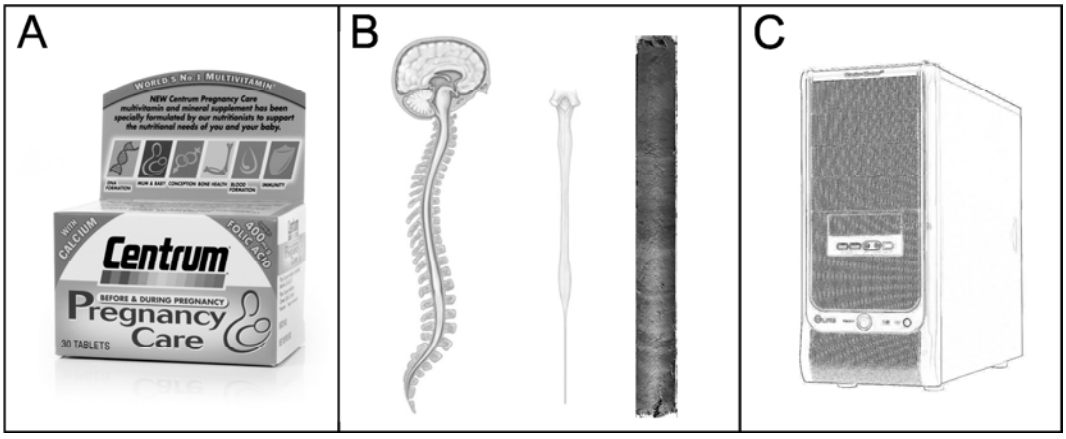

Figure 1. Differences between centrum (A), core (B) and central unit (C).

2. Methodology and Research Stages

2.1. Fuzzy Logic

This paper attempts to retell and model relationships within literary settlement networks. For this reason, one of the fundamental problems in the context of spatial analysis is the lack of precise cartographic data. Existing sources are often presented in an unfamiliar scale and mapping, which makes many standard algorithms impossible to use. For this reason, we have decided to use the elements of fuzzy sets theory in this paper. It is confirm by recent statement of [14], who suggest the need for looking on new kinds of logic.

In the traditional sense, a fuzzy set is a mathematical object that has a defined function of membership that takes values from the range [0,1]. Unlike classical harvest theory, for fuzzy sets, each element can take any value from that range [15]. It can be assumed that every element xi (i.e., a pixel) that is part of a larger set X (e.g. raster GIS representing land use) belongs to the fuzzy set K, and The degree of belonging depends on the particular function of belonging, which can be expressed as follows:

$$\mu_K : X \rightarrow [0,1]$$

where $\mu_K(x_i)$, is the degree of belonging to $x_i \in X$

In gearing to the GIS environment, this means that each pixel is assigned a degree of affinity between 0 and 1, so that its value is transformed from its original unit to a non-unit value scale [16]. The operation of assigning a specific degree of affinity for a particular pixel value is done by generating a fuzzy function, i.e., a curve that translates the relationship between the value of a given indicator (layer) and the corresponding degree of affiliation [17].

The use of traditional fuzzy logic was not enough to properly prepare the input data because they were affected by nonlinear distortions caused by the concept of mapping adopted by the author of Middle-earth. Tolkien did not include his own elaboration of the files containing the definitions of his adopted mapping. It can only be presumed that they were based on the Valar ellipsoid. In addition,

displaying the terrain in diagonal projection resulted in increased distortion (both horizontal and vertex) as the distance from the edge of the map increased. In this situation, as suggested by other researchers, a new formula for calculating the degree of uncertainty and membership function was defined as "misty logic" [18], taking into account inter alia the dispersion effect caused by the Misty Mountains. The use of this formula has allowed for the removal of all noise and errors related to the scale effect and diagonal mapping that occurred within the raw input data. The concept of misty logic was further promoted by [19] gaining increasing popularity within scientific circles.

2.2. Functions of Urban Units

As already mentioned in the introduction, this study analyses the nine basic functions performed by urban units. Below, the features analysed, the manifestations of their occurrences, and the cities, which at various times, were representative of the functions in question:

a. Political function: manifested in the concentration of diplomatic missions, headquarters of international organizations, political and parliamentary organizations (e.g. Brussels, London, Oldtown)

b. Administrative function: presence of government and / or local government units (e.g. Washington, King's Landing)

c. Commercial functions: presence of fairs, shopping centres, seaports and airports, banks, financial centres (e.g. Venice, Amsterdam, Singapore, Tokyo, Lannisport)

d. Industrial function: the existence of well-developed industrial plants (e.g. Manchester, Liverpool, Qohor)

e. Cultural-scientific function: concentration of monuments, cultural objects, universities, academies (e.g. Oxford, Cambridge, Rome, Myr)

f. Leisure and entertainment: access to tourist attractions (such as mountains or the sea), parks and entertainment centres, casinos (Zakopane, Las Vegas, Lys)

g. Transport function: the presence of land, sea and air transport (e.g. Singapore, Frankfurt, White Harbor).

h. The function of religious worship: the existence of a place of particular importance for a given religion (Mecca, Varanasi, Rome, Stoney Sept).

i. Military function: strategic location, presence of fortifications, military bases (eg Gibraltar, Kaliningrad, Winterfell)

j. Depending on the analysed area and historical period, each of the listed settlement functions is assigned specific values and shape of membership functions. Values used for the test area being investigated in this study are outlined later in this paper.

2.3. Accessibility of Urban Units

The procedure outlined in Section 2.2. It allowed to calculate the value of the degree of affiliation of each of the analysed functions for all examined settlement units. In this way, those units that have more or less central role in the whole area are identified. It is also necessary to estimate the availability of individual settlement units for the population living in the surrounding areas in order to try to designate the outlying areas. For this purpose, a set of layers has been set up to illustrate these environmental features that may hinder or facilitate access to a particular unit. It was further enhanced by adding new distance unit for San Escobar case study. Indicators representing these environmental features that allow easier access are defined as a set of BFs, which include:

a. Land transport routes: paths, roads, hills, railways, bridges, etc. As a special category, the Morii tunnels were treated here, which, depending on their racial and cultural affiliation, can serve as a transport or, on the contrary, a barrier.

b. marine (inland and inland) transport routes.

c. The CF collection contains indicators for those environmental characteristics that hinder access to area data. Belong to them:

d. paths that are a barrier to movement (eg, too fast to pass through them without bridges or use for transport purposes);

e. Terrain (a generalized principle has been adopted that, as the slope increases, the "cost" of travel increases).

f. cover the area. It was assumed that the plains and fields did not obstruct the movement. As for the forests, as suggested by other authors [8], it was assumed that some of the complexes (eg, the Dark Forest) were a barrier to the breeds belonging to the Free Peoples, while Fangorn and Lothlorien hindered the dispersion of functions for other settlements.

As with settlement functions, both barriers and facilities are strongly dependent on the area in question and the historical period. In order to take into account the effect of time shifts and related uncertainty in data, a modified version of fuzzy sets known as blear sets was used [20]. Comparison of this method with classic harvest theory and fuzzy sets is presented in Figure 2. The values adopted in this study are presented later in this paper.

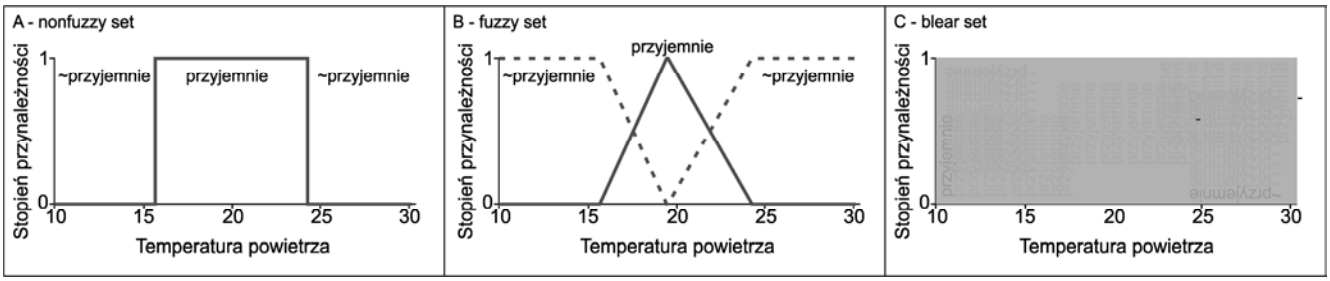

Figure 2. Comparison of classical theory of sets (A), fuzzy sets (B) and turbid sets (C) on the example of temperature sensing based on population data 300 [20].

2.4. Data Integration

Because of the non-deterministic nature of the issue under consideration and source data from multiple sources and of varying quality, the problem of integrating all of the information in one coherent GIS system has emerged. Neural networks have been used to solve this problem. Due to the difficulties associated with the proper configuration of neural networks, it was decided to use a simplified version containing only two components, the input and output node. This approach has already been used in modeling, and its usefulness is a high degree of consistency, faster computation time, and no need for assumptions about the hidden layer properties [18, 21].

2.5. Simulation of Remote Sensing in Real Time

Because of the specifics of the area under investigation (no satellite data or aerial photographs that would be made available for scientific purposes), traditional remote sensing methods could not be used to obtain coverage and terrain information and to provide a network of roads and waterways. For this reason, it was decided to use real-time data remote sensing simulation. The accepted method required the creation of a specialized test bench using which the information was obtained by the operator using built-in optical sensors and then passed to the segmented manipulators located at the end of the grips, from which the data were remotely transformed into digital form using a wireless display device. As input, aerial images have been used in existing publications [4, 5, 6]. This allowed the complete network of roads and watercourses to be extracted and the geological structure and geomorphological characteristics of the area examined. Data on San Escobar geography was taken from [12] and [22].

2.6. Sociological Research

Despite the use of advanced remote sensing techniques it was not possible to obtain the full data needed. Specific problems the authors encountered during the verification of classification results for non-existent satellite imagery, as a substantial part of the ground-truth field was in extremely inaccessible areas. While contemplating the possibility of orcs fighting and there was a good chance that the intellectual potential of our researchers and our dictionaries in smartphones would overwhelm the encountered trolls, years of scientific work and contacts with the university administration (see - Mora Morale) did not allow for a long journey To the land of imagination. Faced with these difficulties, it was decided to apply a Focus Group Interview technique to a representative group of Middle-earth people. One representative of all sensible races (Fangorn - verbal communication) was selected and contact was made with the help of innovative method of social remote sensing. It consists of carefully selecting a group of experienced RPG players and helping them to open a group interview session. By using this non-invasive technique, it was possible to obtain a series of information on the functions of all settlement areas. A more detailed description of the methodological aspects can be found in the publication currently in print - "What to do to make the elves not offended and how not to eat the hobbit".

2.7. Spatial Analysis

After calculating the indicators for each function based on fuzzy logic and "misty logic", a set of spatial layers was created containing the membership of each settlement unit to a fuzzy set representing a particular settlement function (political, administrative, etc.). The layers representing these features of the terrain and infrastructure were then calculated, which facilitates or hinders the accessibility of the population to the most resource-centric units. Due to the presence of several different layers, both on the benefit side and on the constraint side, it was decided to introduce aggregate layers. The resulting landscape of fitness benefits [16], ie the sum of all the layers containing the benefits, was calculated as follows:

$$BenKraj = \sum_{k} fuzzy_k(BF_k)$$

Where, $fuzzy_k(BF_k)$ Refers to the degree of overall Benefactor k. In a similar way, the cost layer was calculated, limiting availability to units performing specific functions using the formula:

$$NegKraj = \sum_{i} fuzzy_i(CF_i)$$

Due to the fact that least-cost modeling can be applied only to the so-called. Friction surface, that is to say that only the limiting elements are available, another transformation was necessary to generate a General Friction Surface (OPT), which would take into account both the criteria for the handicap and the ease of access. The BenKraj variable can be conceptually interpreted as the inverse of the NegKraj variable, so the OPT can be estimated from the formula:

$$OFL = NegKraj + (1 - BenKraj)$$

The next step in the study was to calculate the anisotropic distance (distance measured by costs, with particular reference to the bridges watched by the trolls) between each pixel for the analyzed area and the highest settlement unit in the settlement function. In this way, nine resultant layers were used, which were used to classify the terrain and indicate the central areas (with the most accessibility to the units performing important settlement functions), transition areas, and peripheral areas (lacking or very weak access to central processing units).

3. Results

In total, the settlement functions for the 24 major settlement units were identified in the Middle Ages (Table 1). The membership functions and characteristics of each settlement function, along with the values of their degree of affiliation, as well as the graphs showing the membership functions for these indicators are not shown in any of the figures. Analysing the spatial distribution of settlement units, it is clear that the greatest concentration of characterization The high indices of the individual functions are located in the middle of the area (Figure 3). The three units with the greatest center-of-mind potential during the second part of the third century are Rivendell, Barad-Dur and Minas Tirith. Between them, units with smaller ranks are scattered.

The most central areas are: (1) areas near Rivendell, (2) West Gondor, (3) Mordor, and (4) Rohan and Isengard. The areas of Gondor and Mordor were not merged into one area due to the ongoing war between these regions, as well as the presence of rivers and inaccessible mountain chains that prevented the crossing. Indirect areas include Bree and Shire and Gray Havens and Belgosta. This group also includes the coastal town of Umbar and the Dorwinion coastal area.

In the case of San Escobar, the most central is Santo Subito, the capitol of the country. This is related to the fact that as the only city it has direct, non-stop connection with Warsaw. Other important units are Guacamole, Santo Domestos and Audiovideo. On the other hand, some urban units in San Escobar suffer from being almost completely isolated – this is for example the case of Los Samogonos.

Table 1. Relation of settlement units to fuzzy sets of individual settlement functions.

City	Function								
	Political	Administrative	Trade	Industrial	Culture and Science	Transport	Religious	Military	Recreation
Grey Havens	0,0	0,2	0,5	0,2	0,0	1,0	0,0	0,2	0,5
Hobbiton	0,2	0,2	0,3	0,0	0,0	0,2	0,0	0,0	1,0
Bywater	0,0	0,0	0,1	0,0	0,0	0,1	0,0	0,4	0,3
Michel Delving	0,8	0,8	0,5	0,0	0,5	0,3	0,2	0,2	0,3
Belegost	0,8	0,8	0,8	0,8	0,0	0,0	0,0	0,6	0,0
Annuminas	1,0	1,0	0,6	0,2	0,6	0,2	0,1	0,6	0,3
Bree	0,0	0,2	0,4	0,0	0,0	0,0	0,5	0,0	0,0
Rivendell	1,0	1,0	0,5	0,2	1,0	0,5	1,0	0,5	1,0
Dol Guldur	0,0	0,8	0,0	0,2	0,0	0,0	0,2	0,8	0,0
Dale	0,3	0,3	0,0	0,2	0,2	0,5	0,0	0,5	0,0
Esgorath	0,6	0,6	0,7	0,5	0,2	0,4	0,2	0,5	0,3
Isengard	0,8	1,0	0,3	1,0	1,0	0,2	0,2	1,0	0,0
Helms Deep	0,2	0,4	0,0	0,2	0,0	0,1	0,2	1,0	0,2
Edoras	0,8	1,0	0,5	0,4	0,4	0,5	0,2	0,4	0,4
Minas Tirith	1,0	1,0	1,0	0,4	1,0	0,5	0,5	1,0	0,5
Osgiliath	0,0	0,4	0,0	0,0	0,0	0,4	0,0	1,0	0,2
Minas Morgul	0,0	0,2	0,0	0,2	0,0	0,4	0,0	1,0	0,0
Weathertop	0,0	0,0	0,0	0,0	0,0	0,2	0,0	0,0	0,0
Barad Dur	1,0	1,0	0,2	1,0	0,5	0,4	1,0	1,0	0,4
Umbar	0,4	0,6	0,8	0,4	0,2	1,0	0,2	0,4	0,2
Dorwinion	0,0	0,0	0,8	0,6	0,0	0,0	0,0	0,0	0,3
Orodruin	0,0	0,0	0,0	1,0	0,5	0,0	0,6	0,5	0,0
Dol Amroth	0,5	0,5	0,5	0,2	0,5	0,3	0,3	0,5	0,3
Pelargir	0,4	0,6	0,8	0,4	0,2	1,0	0,2	0,4	0,2

Source: own elaboration based on [4, 5, 6]

The results obtained so far prove that most of the analyzed settlement units have a center. This area is more or less central depending on the nature of the unit. One example is the center of Isengard, which is limited to the Saruman Tower. In contrast, it is also worth mentioning the central area of Hobbiton, which is very scattered and takes the form of four quarters.

Another important finding is the recognition of the presence of periphery beyond the impact of the analyzed units. These areas are so peripheral that they are beyond the reach of our current knowledge. Because of this, their thorough investigation went beyond the scope of this study. It was also very hard to reach this peripheral areas without a couple of pints.

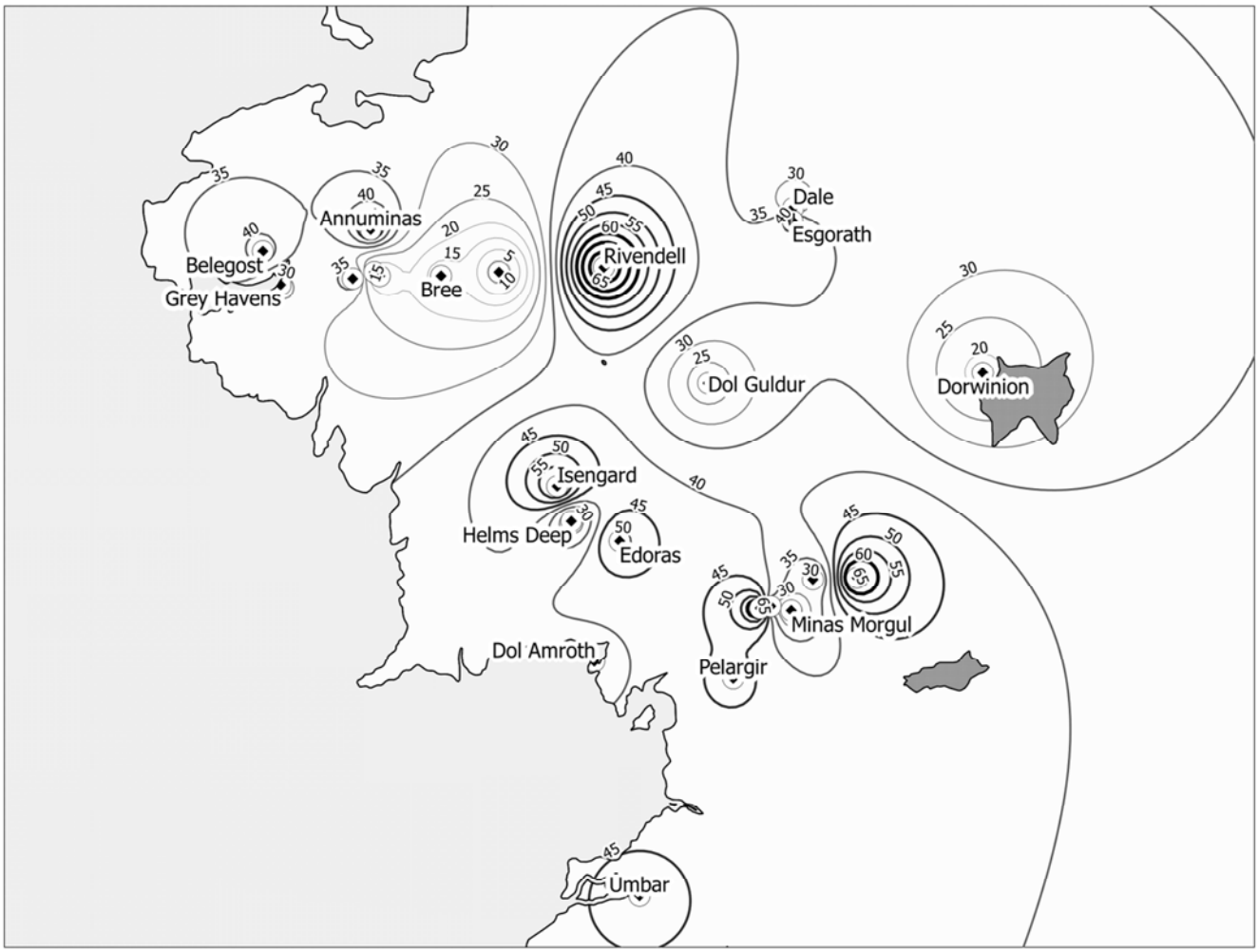

Figure 3. Center-centered position of settlement units in Middle-earth (To simplify the interpretation of membership values multiplied by 100 times).

Source: own elaboration based on [4, 5, 6]

4. Summary

The methodology outlined in this paper has shown that even with relatively uncertain literary data of varying quality, satisfactory results can be obtained that allow for analysis of the links between settlement units. The authors intend to continue research and complement them with, inter alia, consideration of the political aspect, as well as the development of settlement functions during the history of Middle-earth in various eras.

Nevertheless, the methodology used can also be used to model futuristic settlement networks (eg, due to future colonization of Mars or the Moon – see [23] [24]). With the adoption of appropriate assumptions (such as life based on silicon or fluoride - cf. [25, 26], it will also be possible to perform socio-economic polarization analysis in the case of extraterrestrial civilizations.

Acknowledgements

The authors express their thanks to Professor Oleg McNoleg of Brigadoon University of Longitudinal Learning, School of

Holistic Information Technology, Noplace, Neverland, whose work inspired this study. We are also very thankful to the professional reviewers and editors, which makes this paper much better and interesting for readers.

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