Urban Planner – model for land use suitability assessment

Jaroslav Burian, Jan Brus, Stanislav Stastny

***Abstract*—** The paper describes model Urban Planner (released as an analytic extension for Esri ArcGIS for Desktop) designed to evaluate the land suitability and to detect the most suitable areas for spatial development. The model uses a multi-criteria analysis and respects the principles of sustainable development. The core of the model focuses on the evaluation of land suitability according to input data, its values, and weights. Land suitability is analyzed for selected categories of land use (housing/residential, recreation, public facilities, industry and agricultural production).

***Keywords*—**ArcGIS, land use, modelling, urban planner

I. Introduction

MANY authors deal with the topic of land suitability assessment Baran-Zglobicka [1], Kenderessy [2], Picher and Romero [3], Kolejka [4, 5], Sklenička [6] and Růžička [7]. All of them used GIS technologies on very limited levels and the capacity of GIS analysis, modelling and simulation is not fulfilled.

On the other hand, the current advances in spatial planning and modelling have induced the development of many different computer models and applications (e.g. Burian et al. [8], Pechanec et al. [9], Paszto et al. [10], Pechanec et al. [11]. Brail and Klosterman [12] describe in their book several programmes (METROPILUS, INDEX, TRANUS, CUF I, CUF II or CURBA) that are commonly used for the purposes of regional planning, primarily in the USA but also in other countries. Klosterman, in his numerous publications (e.g., Klosterman [13]), describes his software solution for creating scenarios – the tool "What if?" – Which belongs to a group of planning support systems (PSS) and is an extension of the Esri products.

Several models and software are described by many authors: LADSS [14], Geogracom 5W [15], SUDSS [16], UrbanSIM [17]. Burian [18] describe detailed comparison.

This paper was supported by the project nr. CZ.1.07/2.3.00/20.0170 co-financed by the European Social Fund and the national budget of the Czech Republic.

Jaroslav Burian is with the Department of Geoinformatics, Palacký University, Olomouc, 779 00, 17. listopadu 50 Czech Republic (corresponding author provide e-mail: jaroslav.burian@gmail.com)

Jan Brus is with the Department of Geoinformatics, Palacký University, Olomouc, 779 00, 17. listopadu 50 Czech Republic (e-mail: jan.brus@upol.cz)

Stanislav Stastny is with the Department of Geoinformatics, Palacký University, Olomouc, 779 00, 17. listopadu 50 Czech Republic (e-mail: stastny.stan@gmail.com)

These models can create highly advanced results (especially UrbanSIM microsimulation sub-models). Suitable data (e.g., detailed data about income and traffic data) are needed to utilize them in the Czech Republic. These data are very concrete and missing on a detailed level. These situations make all the mentioned models virtually unusable, and this was the main reason to develop new model/extension which would be fully applicable in Czech Republic.

The model was created based on the study of Czech and foreign approaches to the assessment of land suitability [4, 5, 7, 13, 19], finding conflicting areas and proposals for optimal land use.

In comparison with existing models, Urban Planner is much more applicable not only as a new methodological approach but also as a practical tool for urban planning processes [20].

II. Land Suitability Calculation

The core of the model focuses on the evaluation of land suitability according to input data, it's values and weights. Land suitability is analyzed in three levels (pillars, factors, and layers) for the 6 predefined categories of land use:

1) Housing/Residential - smaller areas used mainly for housing purposes or mixed residential areas with services of local importance.
2) Recreation - areas used primarily for recreation (holiday houses, cottages) usually limited by height limits.
3) Commercial/Public Services - larger areas used primarily for commercial public services - administrative centres, larger retail areas, entertainment centres, exhibit centres, mostly with high transport demands.
4) Heavy Industry - larger production areas of heavy industry with potential negative influence on the landscape and healthy lifestyle, usually with protection zone.
5) Light Industry and Warehousing - production areas of light industry and warehousing without production activities with negative influence on the landscape. If negative aspects exist, their influence is limited only to the area of activity.
6) Agricultural production - areas for building used for livestock, agricultural equipment and storage of crop production.

Beyond these categories, the user can set a custom category or edit selected categories.

ISBN: 978-1-61804-283-5

The total land suitability is calculated according to setting of the weights between the three classes (the three pillars): ecological, social, economic. Weight can acquire values from 0 to 100; the sum of the weights of all three pillars must be equal to 100. Extension allows the user to select from the predefined options, or set your own. By different weights settings, it is possible to create several scenarios of land suitability.

SCENARIO	Ecological	Social	Economical	SCENARIO	Ecological	Social	Economical
Sustainable	33%	33%	33%	Ecological pillar priority	60%	20%	20%
Acceptable	40%	40%	20%	Social pillar priority	20%	60%	20%
Viable	40%	20%	40%	Economical pillar priority	20%	20%	60%
Fair	20%	40%	40%	Custom	? %	? %	? %

Fig. 1 Scenario variants

Each of the three pillars (classes) consists of factors. Factors are divided into 3 groups - positive, negative and limits. Positive factors increase the value of land suitability, the negative factor decrease this value and the limits eliminate the value of land suitability. In some individual cases, the limits determine the purpose, method, borders and the conditions of land use. As in the case of pillars the combination of factors is based on weighted overlay method.

The most detailed level of settings are parameters that are described as properties of factors. They are represented by specific layers (shapefiles) and their attributes. Factors' weights can be set up in the range of scales 0-10. From a technical perspective, the most of calculations are based on raster weighted overlay. The results of this part of the model are raster layers of land suitability.

Parameters of the layer considered as the limits have to be set very carefully. If the layer is a hard limit eliminating any activity in the area, it is recommended to set its value to "NoData" (excluded land suitability). If the layer is a soft limit which only reduces the activity in the area, it is recommended to set its value to a higher value (starting from 1 to the higher values).

If any parameter of the layer within the selected factor is set to "NoData", the land suitability in this location will be excluded and non-other layers (even those with the highest land suitability) will affect total land suitability.

If any parameter of the layer within the selected factor is set to 0, the land suitability is inappropriate in this location (0 value), but other layers can increase total land suitability in this place.

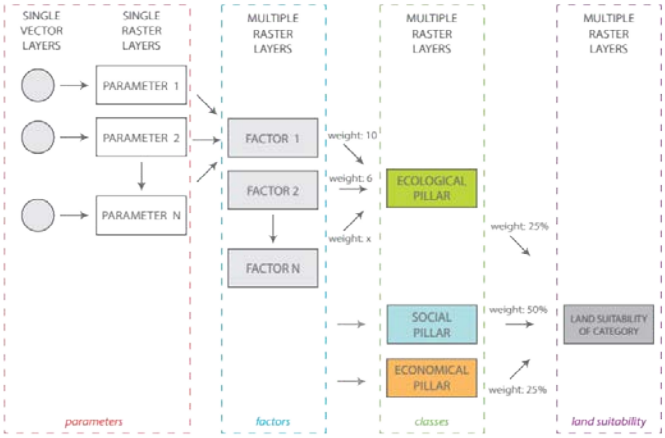

Fig. 2 Land Use calculation

III. Optimal Land Use Calculation

The second part of the methodology is designed to identify areas suitable for optimal allocation (optimal land use). Cadastral map (parcel units) can be used for allocation process, but due to spatial variability of land suitability in one parcel is recommended to use more regular units (hexagonal grid covering the studied area). It is possible to exclude build-up areas and non-buildable areas from the calculation. Each category of land suitability (housing, industry, recreation, etc.) has to be evaluated individually. The main variables, which affect the allocation, are the total area of allocation and minimum area of allocation.

The following procedure performs the allocation process. The whole area is covered with vector hexagonal network; the built-up areas are eliminated. It is recommended to use hexagonal network, which describes the spatial variability in more detail. The width of the hexagon is necessary to choose with respect to the grid size. Recommended size of one edge of the hexagon is 50 m. Smaller size of hexagon is not recommended because of the computation troubles. The larger size of the hexagon loses information value. By using zonal statistics the average value of the land suitability is calculated for every hexagonal unit. One percent of units with the highest value of land suitability are selected and combined into contiguous areas. If the conditions of minimum and total allocated area are fulfilled, the calculation is done. If the conditions are not fulfilled, the process of units selections is repeated (2 % of units with the highest value of land suitability are selected).

ISBN: 978-1-61804-283-5

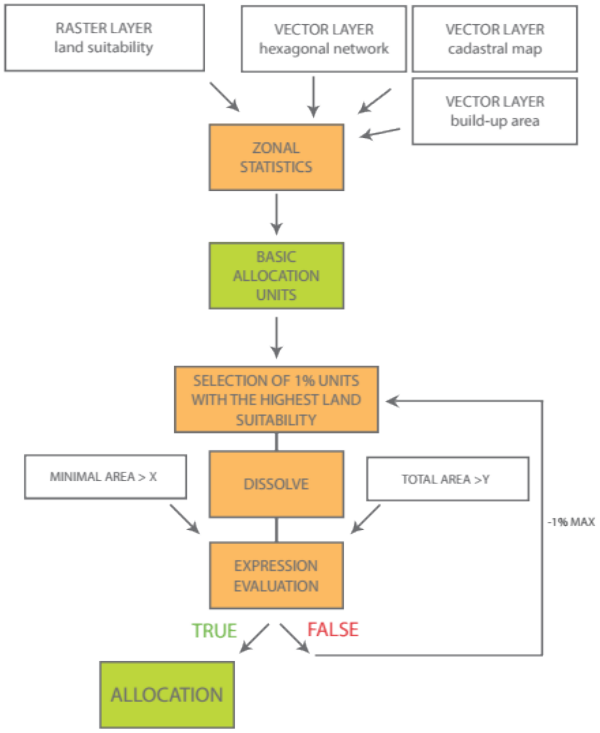

Fig. 3 Identification of optimal land use

IV. Application Interface

Urban Planner is released as ArcGIS for Desktop plugin (Add-In). For full functionality, ArcGIS for Desktop Basic license and Spatial Analyst extension is needed. The extension requires .NET Framework version 3.5 or higher.

The main extension toolbar is divided into four main sections (Land Suitability, Land Use, Data Manager and Settings). Land suitability component offers two sub-sections: Pillar Suitability and Land Suitability. Land suitability cannot be calculated without previous partial calculations of pillar suitability. Land Use component also contains two sub-sections: Suitability Transfer and Allocation, which must also be run sequentially.

Fig. 4. Urban Planner Toolbar

A. Application settings

Basic settings are used to define the main inputs used across applications in all calculations. All settings are stored in profiles that can repeatedly be run. All setting are stored automatically in Access database connected with current mxd project and can be exported or imported. This functionality can be used in case of multiple users or different scenarios. Profiles can be added, deleted or modified.

In the settings window is necessary to set up the area border, directory for analysis outputs and resolution of the output rasters. Especially raster resolution has to be set up according to the total area and according to the computational capacity of the computer (CPU and memory). It is recommended to work with the more detailed grid (about 10 m / pixel). Users are advised to test the performance of the calculation for one sub-analysis and according to the speed adjust the input resolution value. All outputs are stored in UrbanPlanner.gdb that is created automatically.

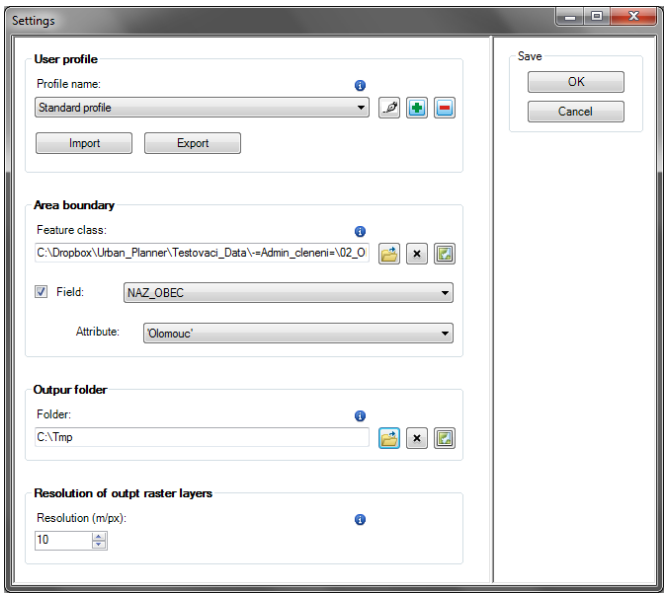

Fig. 5. Input Parameters Settings

B. Input parameters settings

In the case of Czech data of planning analytical material, the Data Manager can be used for automatic data import. In all other cases, the paths to all single layers have to be set up manually for all factors. If the user has its data model, application can be modified, and automatic data import can work too.

C. Land suitability

Land suitability analysis consists of two sub-parts. First of all is necessary to calculate land suitability of pillars (environmental, economic and social). Also, the category of land use (residential, recreational, commercial, industrial or agricultural), for which land suitability is calculated, has to be selected. These categories can be deleted, and new categories can be set up by user.

ISBN: 978-1-61804-283-5

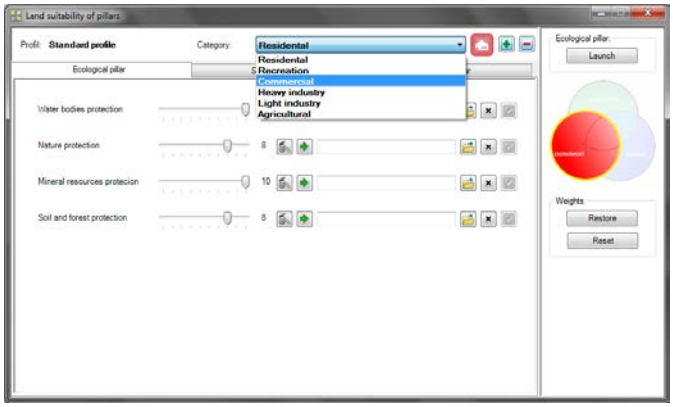

Fig. 6. Selection of the Category for Land Suitability Calculation of Selected Pillar

For each pillar is necessary to choose, what factors will enter into the calculation and what will be their weights. Default factors and their weights were calculated using the Saaty method [21] by several experts. According to the specific conditions of the territory, it is possible to change the factor's weights. Factors can be deleted or added, and there is no requirement concerning number of factors in each pillar.

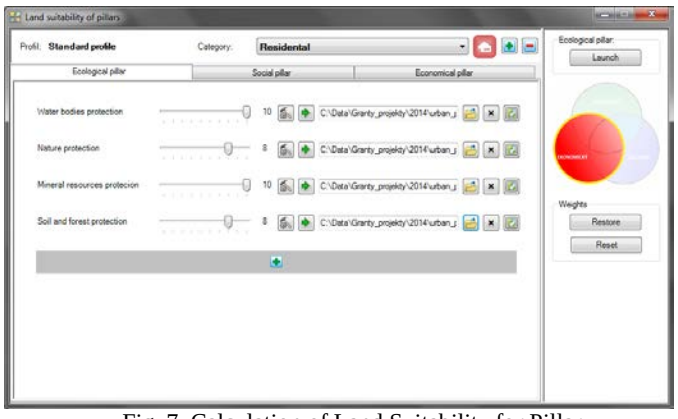

Fig. 7. Calculation of Land Suitability for Pillar

For each factor, it is necessary to check the settings for parameters that describe all factors. Each factor is composed of several sub-layers, where it is needed to set the path to the input data (possibly also choose a field attribute), and then specify the settings (values). If the user always uses the same data model, Urban Planner can be modified, and paths to the data can be uploaded automatically.

The parameters and weights for all layers already set, the user can change them in scale from the excluded potential (NODATA value) through inappropriate potential (value 0) to the optimum potential (value 10). There are two types of data: ordinal and interval. For ordinal data, the weight is assigned to the whole phenomenon, for interval data the weights (0-10) are divided into all range of values (such as gradients, distances).

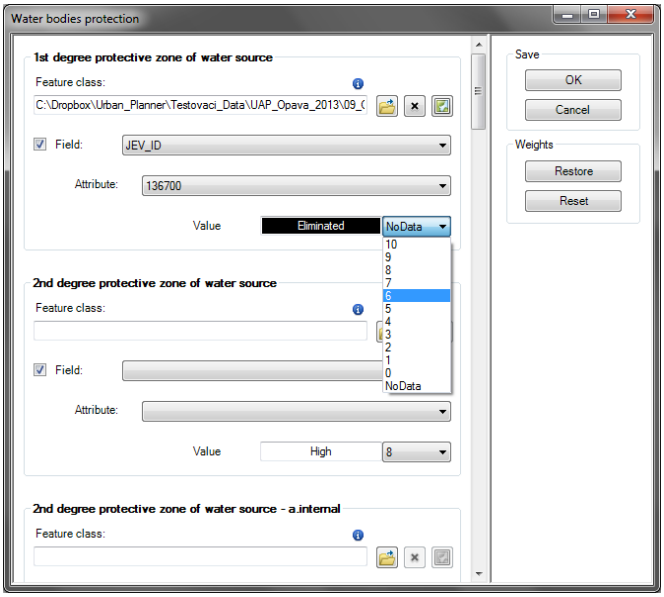

Fig. 8. Detailed Settings for Selected Layer

Each pillar must be run separately by using Start button in the upper right part of the window analysis. The user is informed about analysis results in a new window. After completing the calculation output, raster layers are loaded into ArcMap environment, and the path to the output layer is set up in the analysis window.

After the calculation of all three pillars, the total land suitability has to be calculated. If the previous calculations were correct, the path of each raster layer is set up automatically. Alternatively, they can be selected manually. The essential step during total land suitability calculation is selection of predefined scenarios of development. Several scenarios are predefined; user values can be set up too.

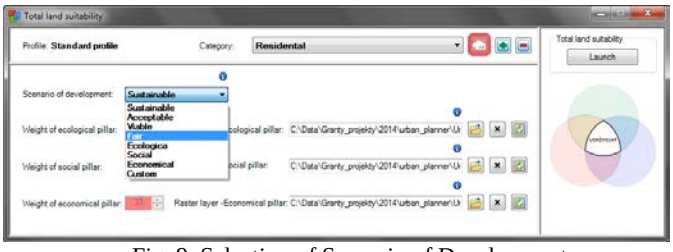

Fig. 9. Selection of Scenario of Development

The final output of Land suitability calculation is raster layer of land suitability for the selected category according to the selected scenario development. For the calculation of the other categories, it is necessary to repeat all the steps described above. For the calculation of different scenarios, it is sufficient to repeat only the final step of the analysis. During all calculations, many raster layers are created. Therefore, all outputs are named according to predefined abbreviations that are described in the extension manual.

D. Land use

The second component Land use allows to search (allocate) areas suitable for development on the basis of the previous

ISBN: 978-1-61804-283-5

total land suitability calculation. Land suitability is converted to the selected polygonal units. For each vector unit, average value of land suitability is calculated. As the polygonal unit typically cadastral map can be used. In the case of large parcels, land suitability can be very variable, so use of regular vector network is recommended (hexagonal grid). The hexagonal grid can be created by Repeating shapes extension [22] or by the tool Generate Pattern of Repeating Shapes. Unit size should be selected larger than the pixel size. Optional setting is layer of non-buildable area (usually the same as built-up area). If the layer is set up land suitability in this area is calculated as 0 values.

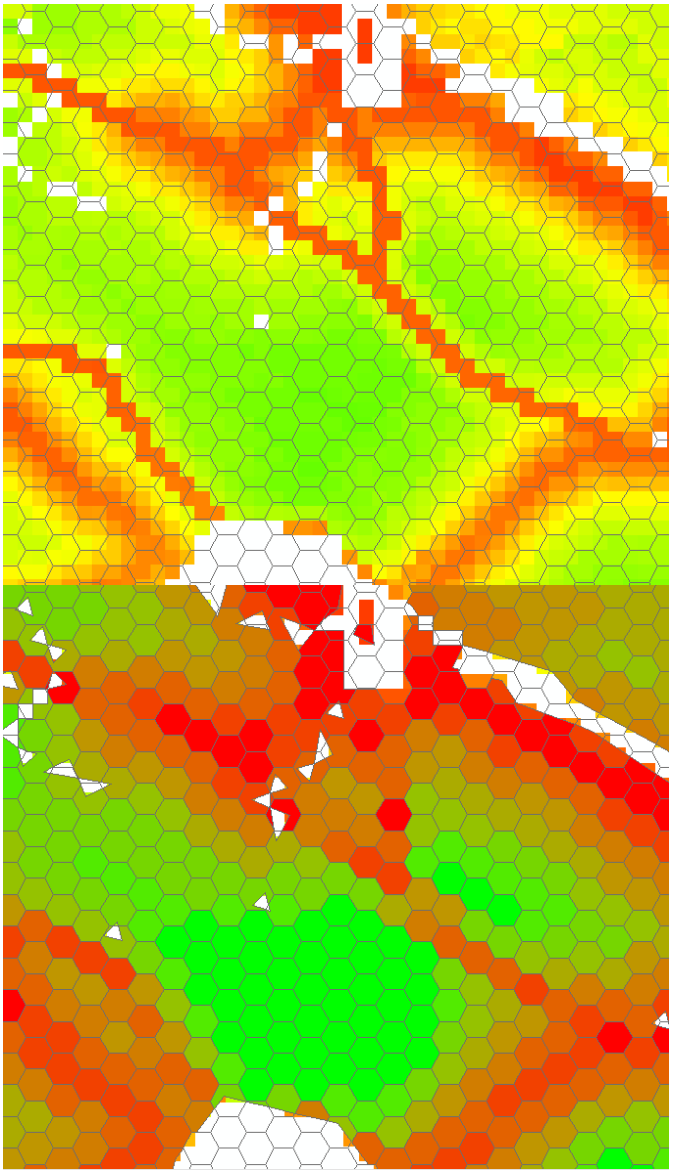

Fig. 10. Raster layer of land suitability covered by hexagonal network of basic allocation units (upper figure), Hexagonal network of basic allocation units with values of land suitability in attribute table (lower figure)

The last tool allows finding (allocate) areas with the highest value of land suitability for selected category of land use. Raster layer of total land suitability and the basic allocation units are the input layers. The most significant input values are the minimum size of the allocated area, which defines the minimum allowed size of areas intended for allocation and then the total allocated are. The result of the analysis is a vector layer showing areas with the highest value of land suitability for selected category of land use with regard to the total and minimal area of allocation.

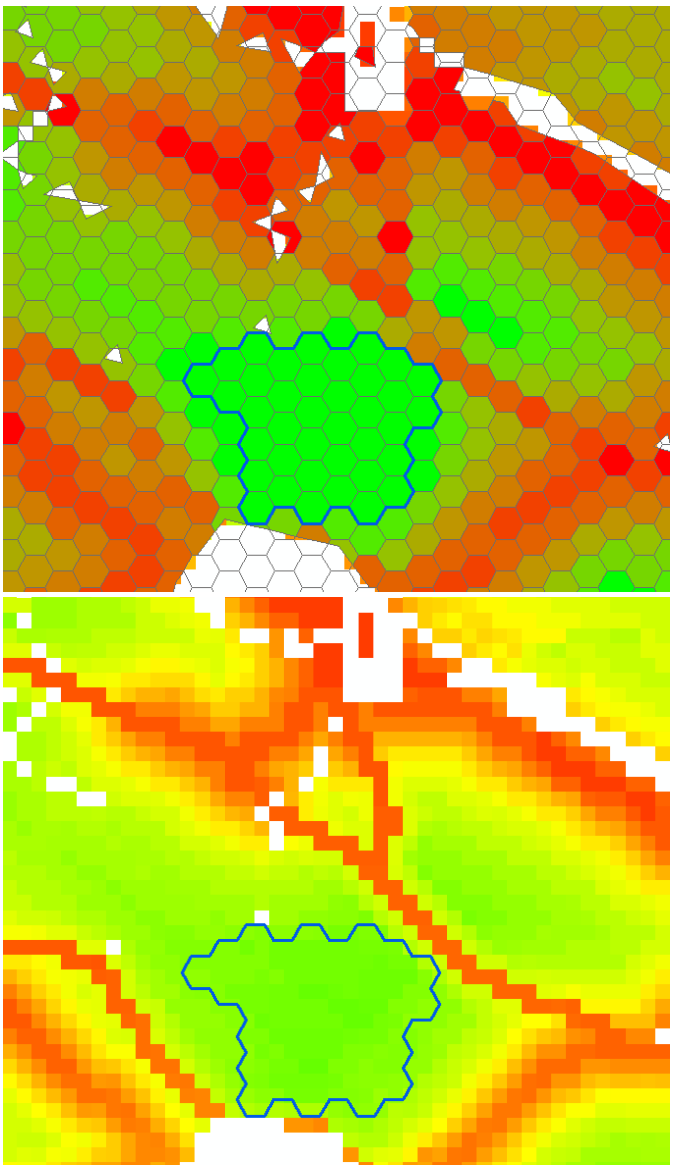

Fig. 11. Total allocated area with highest values of land suitability - conditions of the minimal and the total allocation fulfilled (upper figure shows this with basic allocation units, the lower figure shows this with raster layer of land suitability)

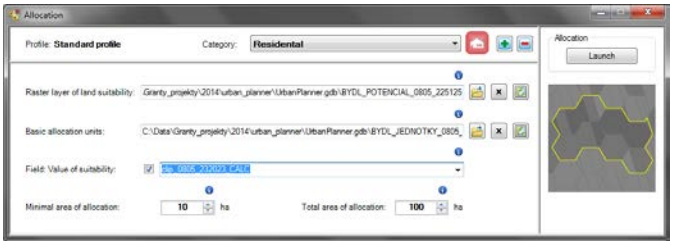

Fig. 12. Allocation Settings

ISBN: 978-1-61804-283-5

V. URBAN PLANNER OUTPUTS

A. *Outputs description*

The outputs of the components Land Suitability Analysis are mainly raster layer showing the potential of individual factors, the potential of the three pillars (A) and the total land suitability (B) for selected category of land use. These raster layers can be used for verification of existing or planned activities. The final analysis (calculation of the total land suitability) can be calculated in several variants (scenarios), which can be compared and evaluated. This type of analysis may be used for comparison of possible variants of land development.

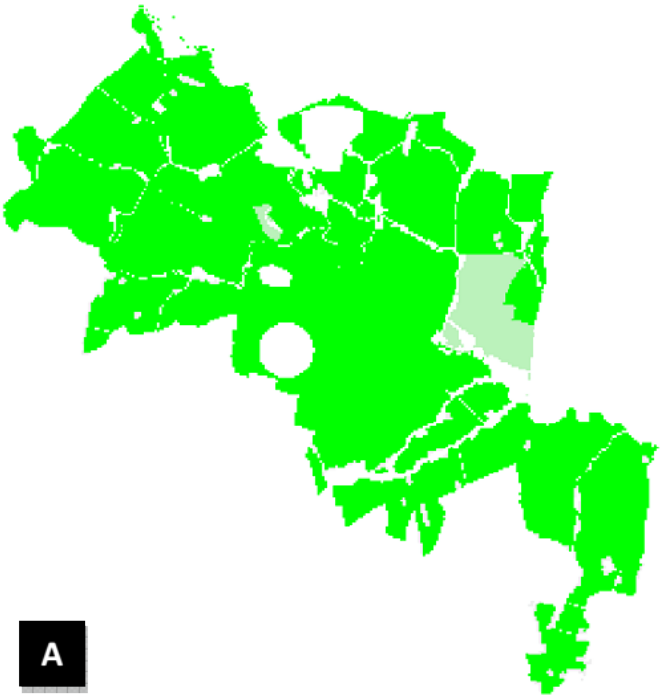

Fig. 13. Raster layer of land suitability of economic pillar (A)

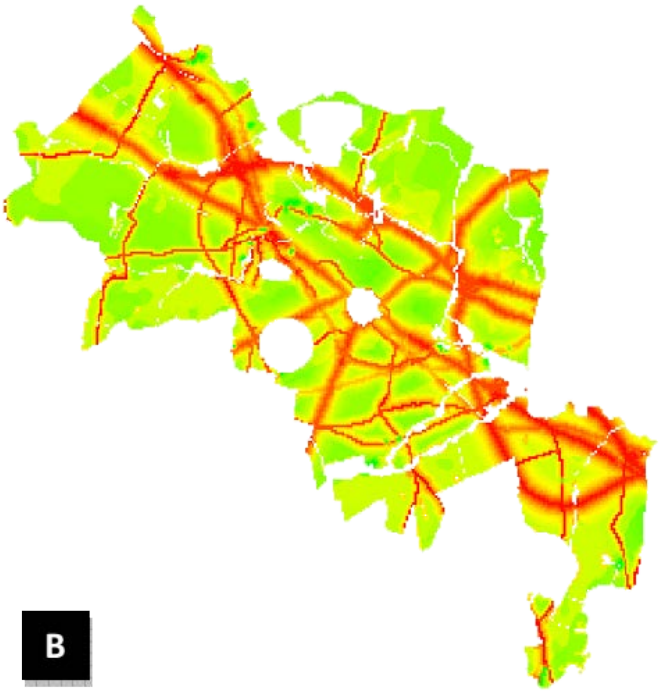

Fig 14 Raster layer of total land suitability (B)

The outputs of the second component (Land Use) are primarily vector layers (C, D) that show the total suitability shown in the polygon layer (the basic allocation unit) and the final areas suitable for allocation. If a vector layer polygon units used e.g. Layer municipal boundaries, basic settlement units, boroughs, etc.., the total suitability can be easily recalculated for different polygon units (municipalities, district, basic settlement units, etc.) as the average value.

Fig. 15. Basic settlement units with land suitability values in vector format C)

ISBN: 978-1-61804-283-5

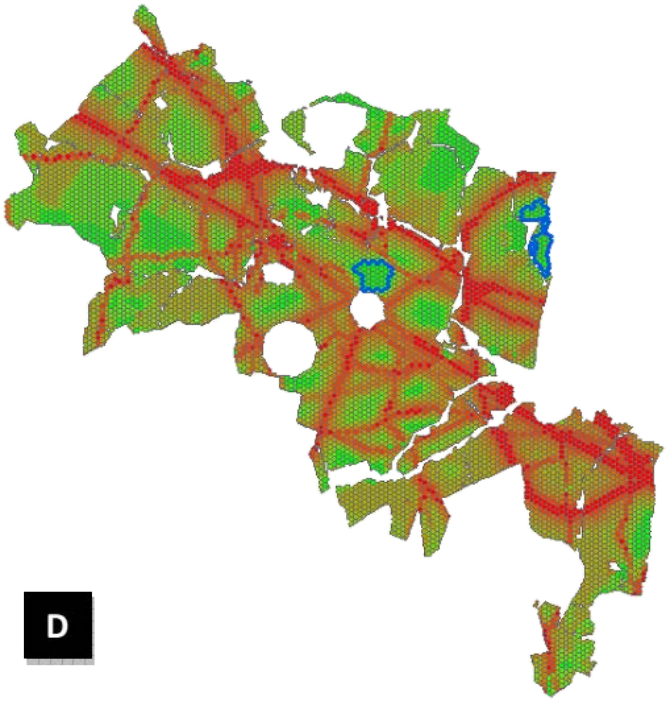

Fig. 16 Basic settlement units with land suitability values in vector format with final areas suitable for allocation (D)

Each category of land use is calculated separately and can cause overlapping of allocated space. This fact must be taken into account by expert estimate or integration of the input data.

B. *Use of outputs*

Urban Planner has high potential for use in all planning processes. First of all, can be used as a comprehensive tool to evaluate the land suitability and main principles of sustainable development. Result "Scenarios of sustainable development" can verify if current or proposed activities correspond to the areas with the highest land suitability. Based on the similarities and differences it is possible to determine what factors were omitted during urban plan creation and what should be improved. Overall it is possible to create six scenarios used in the scenario modelling and many others according to user settings. With this analysis, the user can determine which scenario has the highest potential in the chosen location.

The outputs from the second component can be used to detect areas with the highest land suitability for the selected category of land use. These areas can be searched according defined parameters (minimum area of allocation a total area of allocation) by using "Allocation tool" and can be used especially in cases when searching for the optimal development areas.

VI. Conclusion

This paper describes the extension “Urban Planner”, which is the first software product of its type in the Czech Republic. In comparison with existing models, Urban Planner is much more applicable not only as a new methodological approach but also as a practical tool for urban planning processes. A strong connection (and the development of a connection) with the data used in Czech urban planning is one of the largest advantages.

The functionality of Urban Planner was tested in two town regions - Hranicko Region and Olomouc Region, located in Moravian part of Czech Republic and Prague region. The extension was developed with strong cooperation with Olomouc local government officials. The scenarios of future development and all particular results (maps, text, and tables) were used in urban planning processes (local urban plan creation).

References

[1] B. Baran-Zglobicka, "Badania krajobrazove wybranych obszarów lessowych jako podstawa oceny moż liwości wykorzystania terenu w procesie planowania przestrzennego," PhD thesis, Maria Curie Skłodowska University, Lublin, 2004.

[2] P. Kenderessy, "Integracia GIS do tvorby krajinnoekologického plánu," *Životné prostredie*, vol. 2003, 2003.

[3] A. Picher and R. Romero-Calcerrada, "GIS-based spatial decision support system for landscape planning. New system of analysis for decision making," in *CORP 2006 & Geomultimedia06*, Vienna, 2006.

[4] J. Kolejka, "Geoinformační systémy v aktivním managementu životního prostředí: Data a možnosti hodnocení a modelování rizik," *Životne prostredie*, vol. 2003, 2003.

[5] J. Kolejka, "Krajinné plánování a využití GIS," in *Česká geografie v období rozvoje informačních technologií.* , Olomouc, 2001.

[6] P. Sklenicka, *Základy krajinného plánování*. Praha: Nadezda Sklenicková, 2002.

[7] M. Ružička, *Krajinnoekologické plánovanie-LANDEP: (Systémový prístup v krajinnej ekológii)*. Bratislava: Združenie Biosféra, 2000.

[8] J. Burian, J. Brus, and V. Voženílek, "Development of Olomouc city in 1930–2009: based on analysis of functional areas," *Journal of Maps*, vol. 9, pp. 64-67, 2013.

[9] V. Pechanec, J. Burian, H. Kilianova, and Z. Nemcova, "Geospatial analysis of the spatial conflicts of flood hazard," *Morav. Geogr. Rep. Moravian Geographical Reports*, vol. 19, pp. 41-49, 2011.

[10] V. Pászto, A. Brychtová, P. Tuček, L. Marek, and J. Burian, "Using a fuzzy inference system to delimit rural and urban municipalities in the Czech republic in 2010," *Journal of Maps*, pp. 1-9, 2014.

[11] V. Pechanec, J. Burian, and Z. Dobesova, "Integrating neural networks and GIS in modelling landscape changes," *14th SGEM GeoConference on Informatics, Geoinformatics and Remote Sensing*, vol. 1, pp. 651-658 pp, 2014.

[12] R. K. Brail and R. E. Klosterman, *Planning support systems: integrating geographic information systems, models, and visualization tools*: Esri Press, 2001.

[13] R. Klosterman, E, "The what if? Collaborative planning support system," *Environment and Planning, B: Planning and Design*, vol. 26, pp. 393-408, 1999.

[14] K. B. Matthews, A. R. Sibbald, and S. Craw, "Implementation of a spatial decision support system for rural land use planning: integrating geographic information system and environmental models with search and optimisation algorithms," *Computers and electronics in agriculture*, vol. 23, pp. 9-26, 1999.

[15] V. Bougromenko and M. Zakirov, "Geogracom 5W-expert system for sustainable urban and regional transport development," presented at the Computers in Urban Planning and Urban Management, Venice, 1999.

[16] P. Jankowski and M. Stasik, "Design considerations for space and time distributed collaborative spatial decision making," *Journal of Geographic Information and Decision Analysis*, vol. 1, pp. 1-8, 1997.

ISBN: 978-1-61804-283-5

[17] P. Waddell, "UrbanSim: Modeling urban development for land use, transportation, and environmental planning," *Journal of the American Planning Association*, vol. 68, pp. 297-314, 2002.

[18] J. Burian, "GIS analytical tools for planning and management of urban processes," in *GIS Ostrava 2008*, Ostrava, 2008, p. 13.

[19] M. H. Carr and P. D. Zwick, *Smart land-use analysis: the lucis model land-use conflict identification strategy*: ESRI, Inc., 2007.

[20] J. Burian, J. Brus, V. Pechanec, V. Vozenilek, and S. Stastny, "Urban Planner – model for optimal land use scenario modelling," *Geografie - sborník České geografické společnosti,* (to be published), 2015.

[21] T. L. Saaty, "Priority setting in complex problems," in *Essays and Surveys on Multiple Criteria Decision Making*, P. Hansen, Ed., ed Berlin/Heidelberg/New York: Springer, 1983, pp. 326-336.

[22] J. Jenness, "Repeating shapes for ArcGIS," ed: Jenness Enterprises, 2012.