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ASSESSMENT OF LANDSCAPE CARRYING CAPACITY AS A KEY METHOD FOR TERRITORIAL PLANNING

András Bánhidai[1,2*], István Valánszki[1]

[1]Hungarian University of Agriculture and Life Sciences, Institute of Landscape Architecture, Urban Planning and Garden Art, Department of Landscape Protection and Reclamation, Villányi út 29-43., H-1118 Budapest, Hungary
[2]Kecskemét Urban Development Ltd.; Csányi János krt. 14, H-6000 Kecskemét; Hungary
[*]Corresponding author's e-mail address: andrasbanhidai@gmail.com

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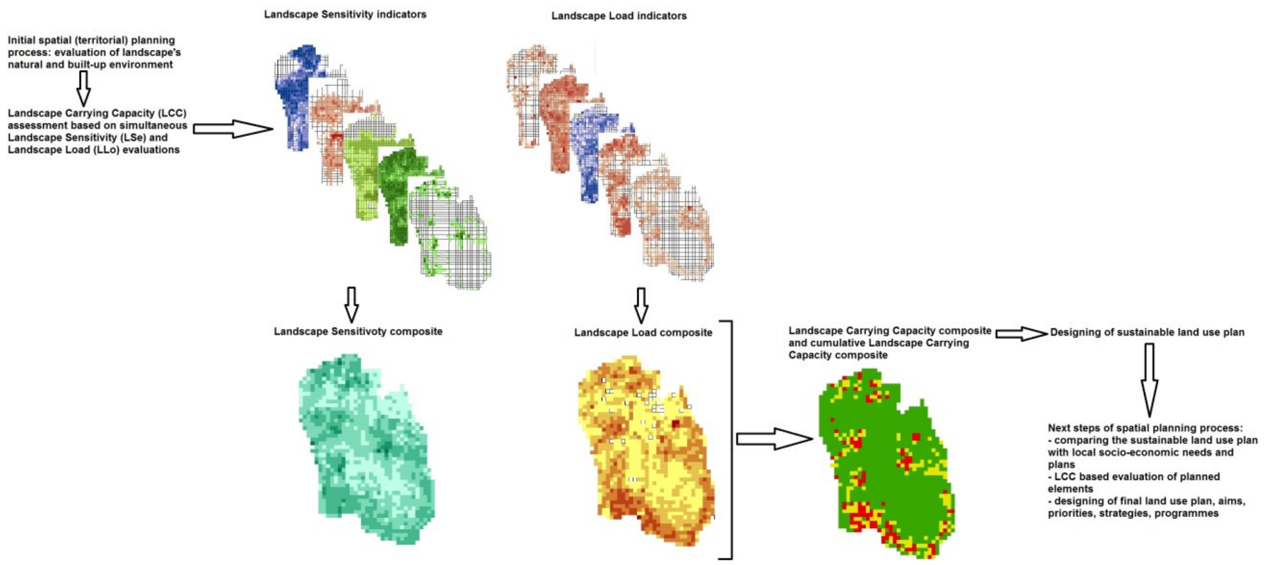
Abstract

Humanity needs sustainable solutions for all aspects of life to meet the challenges of the 21st century. Traditional territorial planning models also need development to ensure more nature's quality and landscape-centered planning process. Landscape carrying capacity (LCC) methods serve us potential basis for landscape evaluation based on its extensive literature. This research presents an approach to LCC based landscape assessment as an intial step of territorial planning. This article presents an ecological approached method for simultaneus evaluation of landscape sensitivity (LSe) and landscape load (LLo) based on analytical hierarchy process combined with GIS tools. This method was applied in Keszthely Mountain, a rural landscape, in western Hungary. The assessment of LSe and also LLo based on five-five indicators (e.g., Ecosystem Diversity Sensitivity; In-year Permanently Bare Soil; Landscape Protection Sensitivity; Artificial Agricultural Land use Load; Linear Fragmentation Load; Lack of Vegetation). The final LCC composite was provided by a multi-step evaluation progress. Comparing the LSe composite to LLo composite showed the marginal areas of Keszthely Mountain are maximum or over loaded. The central area of Mountain is generally more loadable despite some existing loads such as infrastructure or mines. LCC evaluations should assess the main impact factors of landscape. However, potential developing points are the assessments of more specific fastors (e.g., extremities of climatic conditions, landscape suitability). Comparing the sustainable land use plan (or its scenarios) with local socio-economic needs and plans should be the second step of territorial planning. The evaluation and the sustainable land use plan provide more rationalised possibilities for socio-economic needs make more sustainable decisions, plans and strategies.

Keywords: spatial planning, landscape carrying capacity, landscape sensitivity, landscape load, analytical hierarchy process

Graphical abstract



INTRODUCTION

By the 21st century, it had become clear that processes on the global scale – such as climate change – or regional and local scale – such as urban sprawl, highly concentrated pollutions etc. – need not only long term but also short term solutions. The sustainability and sustainable solutions are the only way for the humanity because of this approach treats together both of nature and humanity sides.

The challenges of 21st century highlight among other things traditional planning paradigm need to be shifted more sustainable and environment focused path (Pogliani et al., 2023). Traditional spatial planning might be hard to implement, has too complex planning system and types or has long approval processes such as in case of China (Liu & Zhou, 2021). It caused ecological destructions, environment pollution and imbalanced regional development (Liu & Zhou, 2021). Additionally, in case of 18 European urban regions Hersperger et al. (2020) examined the 'landscape role' of strategic spatial planning. On one hand plans are generally focused on housing, transport and economic development, on the other hand landscape role appeared to varying degrees (Hersperger et al., 2020). In these plans the main focus were (a part of the landscape) green infrastructure, cultural heritage tourism and recreation and nature conservation (Hersperger et al., 2020). Only half of the plans used holistic approach (Hersperger et al., 2020). Sustainable land use practicies should be widerly implemented what are environmentally, socially and also economically good because of reason of sustaining of landscapes in good condition, also called sustainable landscape management (H. & P., 2015). Furthermore, the spatial planning process can adapt to this approach. During the spatial planning process the properties of socio-economy and nature are mapped and examined (Tóth, 2011). In this context, called sustainable development, landscape planning (or territorial planning) is one of the main actions of controling human impacts in landscapes (Klaučo et al., 2015).

At this point it has to be mentioned that landscape carrying capacity (LCC) approach can strongly support this shifting with its extensive methodological basis. Moreover, sustainability – partly connected to LCC – in landscape management related to territorial planning is also actively researched field (Battisti et al., 2022). These researches were used wide range of methodolgical approaches such as multicriteria, participatory assessment tools, regression analysis, economic assessments, GIS-based assessments or quality assessments (Battisti et al., 2022). The aim of these researches to provide applicable methodologies for territorial planning to make better equality between the natural-social-agricultural-urban management and planning (Battisti et al., 2022).

Spatial/territorial planning is the highest scale of the regulation and orientation of human activities. Territorial planning is a conscious, structured and multi-step process what suitable for regulation of development of a given area (Tóth, 2011). The two main types of territorial planning are spatial planning and spatial development (Faragó, 2003). Spatial planning provides answers for 'What?' and 'Where?', spatial development provides answers for 'How?' (Faragó, 2003). Therefore, both must be applied in parallel for the efficient territorial planning. Basically, landscape carrying capacity (LCC) is that landscape changing process what the landscape can manage without irreversible degradation on its qualities and character (Swanwick, 2002; Tudor, 2019). On the other hand, also important definition is landscape sensitivity what is in fact the resilience and robustness of a given area against human activities (Tudor, 2019).

In the framework of landscape character assessments (LCA) landscape sensitivity (LSe) and LCC assessments are applicable for determination of capacity and sensitivity, monitoring of landscape changeing, provideing spatial databases (Tudor, 2014). We argue that the first step must be the LCC based assessment of natural and built-up (biophysical) environment during the spatial planning process, because of its spatial structure and qualities are highly impact to the socio-economic qualities.

Well-known, the natural systems are indispensable for the human needs, technologies and life quality (Westman, 1977). Nature's goods mostly identified as ecosystem services (De Groot et al., 2002). In the context of resource limit based examination, assessment of ecosystem services based on supply-demand evaluation approach also can be an efficient tool for land use planning (González-García et al., 2020). In this context we also argue that ecological aspect must be the prior of the landscape assessment at the initial of the territorial planning. For this reason, firstly we should understand the extent of impacts of human activities and the interactions between landscape and local socio-economic impacts (Klaučo et al., 2015).

After a detailed literature review and analysis LCC approach and methods are efficient tools for quantitatively also qualitatively evaluation of the landscape's biophysiscal properties. LCC's three main methodological groups are environmental, socially-focused and system-based methods (Lane, 2010). We argue, that LCC assessment have to be included landscape load (LLo) and landscape sensitivity (LSe) evaluation integrated in a complex system based analytical hierarchycal process. LLo assessment can be based on the evaluation of land use as areal loading (Gottero & Cassatella, 2017). LLo assessment can also be based on antropogene activities' mapping and qualification (Baby et al., 2014) as not only areal but also linear loading. Evaluation can also be specialised like mining activities evaluation as strong impacts on landscapes (Csüllög et al., 2017). The sensitivity assessment often meaning the evaluation of ecological sensitivity through spatial structure analysis of natural and built-up areas (Chi et al., 2019)., Furthermore, evaluation of environmental fragility through biological, socio-economic, climatic and landscape element factors (Cocheci et al., 2019). LSe assessment can also be developed as complex evaluation of ecological-visual-cultural factors' assessment (Manolaki et al., 2020).

Data is key point of evaluation process and spatial planning. Key issues are data availability, quality, quantity and its creation time. Existing, validated databases at national and international level are good baseline databases if they can be used to assess LCC. It was identified that data obtained by remote sensing provide better opportunities for landscape evaluation and landscape planning (Wellmann et al., 2020). It is also well-known, there are several databases and data types of remote sensing (Landsat, ASTER, Sentinel basic or derived datas or others). These databases are free-to-use and serve us timeseries datas what are perfect for evaluation of some landscape processes and changing.

Based on the prior introduction this paper's aims are:

- Present an ecological approached conceptual and multi-step LCC evaluation method for the territorial planning which symultaneously assess the main factors of sensitivity and load.
- Propose an approach for develop a supplemented general territorial planning process by remote sensing based evaluation.
- Present wider assessment opportunities of natural and built-up environment with regards main goals of sustainable landscape planning based on easy to use remote sensing based evaluation in addition to existing data based evaluation.

This LCC method also focuses on providing an evaluation process of territorial planning based on assessment of natural and built-up environment for defining the further opportunities of socio-economic.

STUDY AREA

The case study area is Keszthely Mountain, located at west part of Hungary, in Europe (Fig. 1). The study area delimited by lower and border areas of Mountain, public roads, edges of forests or agricultural areas, lake shores. This delimited area determined the 500x500 m grid assessment area (Fig. 1). The whole area of the assessment – hereinafter referred to as study area – is 302.25 km^2.

Basically, the Keszthely Mountain is an area with forest land cover and strong slopes. The hydrography is rare, its surrounding areas are hilly or flat, mostly with agricultural and artificial land covers and medium or soft slopes (Dövényi, 2010). Generally, the settlement network is dense, but most of the settlements are small (Dövényi, 2010). All of the main land uses – and its subtypes – could be found in the area. Because of Lake Balaton the area has a strong tourism, moreover agricultural sector also have big presence. The main land cover and land use category is the forest and grassland.

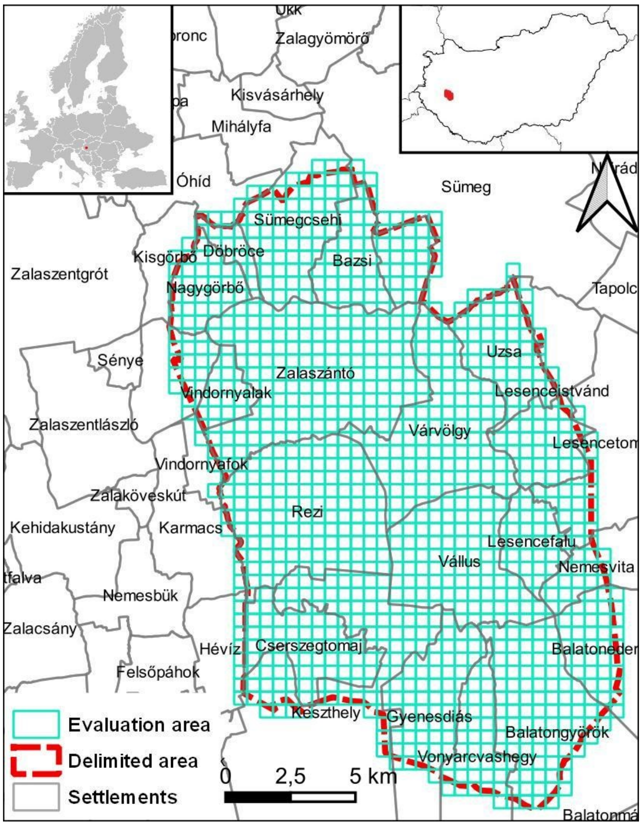


Fig.1 Study area in Keszthely Mountain, Hungary

METHODS

The research has developed a comprehensive method for landscape carrying capacity based on LSe and LLo evaluation throught analytical hierarchy process as the first step of territorial planning. As it mentioned above, the used scale of evaluation is the landscape by an 500x500 m grid. In this scale the grid evaluation (Chi et al., 2019; Store et al., 2015; Walz & Stein, 2018) could be efficiently informative for further planning. All of indicators and indices were counted on a six-degree scale (0-5), and we used symmetrical rounding method for intermediate and end result values. First of all, our method evaluated the landscape carrying capacity – from ecological aspect – through landscape sensitivity and landscape load assessment (Fig. 2). The method was partly developed based on other researches' applicable methods' elements (Baby et al., 2014; Chi et al., 2019; Cocheci et al., 2019; Csüllög et al., 2017; Gottero & Cassatella, 2017; Store et al., 2015; Walz & Stein, 2018) because of those evaluation focuses on main landscape elements. Joining this, the evaluation of main landscape elements (natural and built-up areas: habitats, water, topography, soil, areal and linear human land uses) should be the first step during the spatial planning process. However, we modified some elements for the evaluation's inner system and existing databases.

The used databases include Hungarian and European datasets, not only vector but also raster type of geospatial data. Datasets could be thematically identified such as ecosystem, habitats (Agrárminisztérium, 2019; Bölöni János et al., 2011), landscape and nature protection types and areas (Cave data, 2009; NSDP, 2019; NatProt, 2022), DEM and NDVI satellite datasets (Landsat Dataset, 2022; SRTM Dataset, 2022), land cover (European Environment Agency & European Environment Agency, 2019), water bodies (Water dataset, 2022). Method of this research needed some preprocessed datasets in case of exact assessment of some indicators. Arc-GIS 10.4 software were used for data preprocessing, intermediate analyses and indicators' results counting.

Landscape sensitivity indicators

Ecologicaly, we used five indicators to assess the landscape sensitivity. These will be presented according to ecological importance and weight. The results of indicators are represented in six class: 0 – null, 1 – low, 2 – moderate, 3 – medium, 4 – high, 5 – intensive sensitivity. This classification also adapted for landscape load indicators. Firstly, an ecological landscape assessment should be apply evaluation of biotic elements (Klaučo et al., 2015) qualitatively and/or quantitatively. The most important sensitivity indicator of this research is the *Ecosystem Diversity Sensitivity indicator* (*EDSei*). To measure the vulnerability of ecosystem, our research was used the EDSei through extent of natural habitats and its number of types evaluating (see Table 1.). It should be pointed, water and wetland habitats got bigger weight because of its vulnerability and essential role of life. Primer dataset was the National Ecosystem Basic Map of Hungary (NÖSZTÉP), it classifies 56 habitats in six ecosystem types (Agrárminisztérium, 2019). The base of the evaluation were the 'natural habitats', what had to be selected by the secunder dataset of this indicator, called General National Habitat Classification System (ÁNÉR) (Bölöni János et al., 2011) intersecting of NÖSZTÉP.

Soils are niches of thousands of species, have carrier surface and contact role, regulator and nutrient depot roles, soils are crucial elements of ecosystems (Bardgett, 2005). Human activity caused water erosion and defflation is one of the strongest soil degradation factors (Lal, 2001). The bare soils are especially ecological sensitive. We developed the *In-year Permanently Bare Soil Sensitivity index* (*IPBSSei*) for localize and assess these soils based on Normalized Difference Vegetation Index – NDVI dataset (Landsat Dataset, 2022) (Table 1). This data-demanded index shows those areas where the soil is uncovered for minimum seven months, include dormant period and three months of vegetation period. Evaluation time period is a calendar year, we used five NDVI images of 2022. Basically, NDVI value range of soils is between 0-1,5 (Defries & Townshend, 1994;

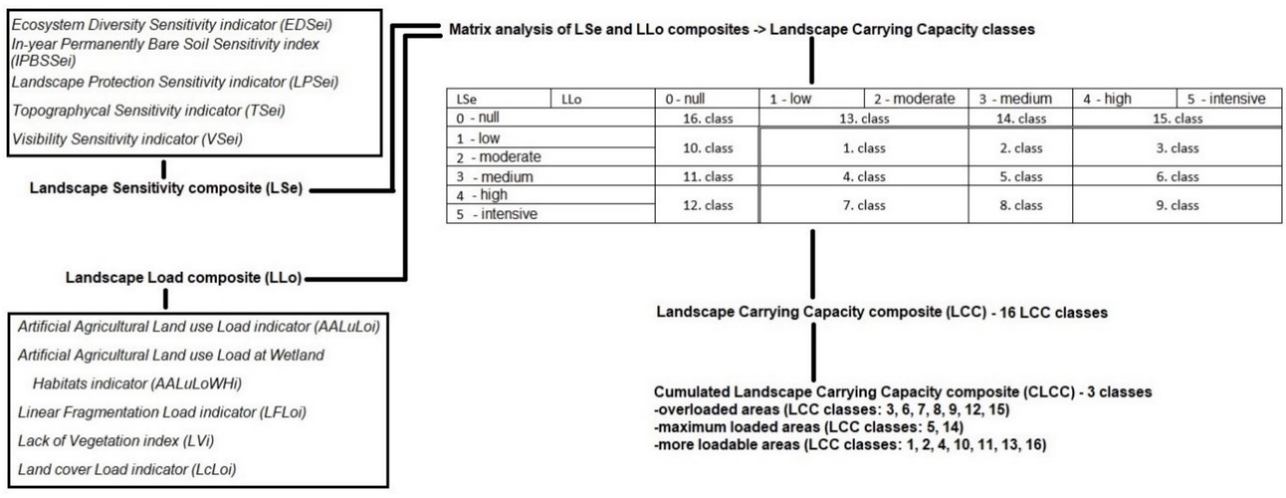


Fig.2 Flowchart of the Methods Used

Novák et al., 2018; Sotille et al., 2020). After some preprocessing steps, this indicator could select bare soils for seven months with completing some crucial selective criteria of data analysing. These selective criteria excluded built areas, mines, open rock surfaces, and show only those areas where are soil and/or vegetation.

Generally, landscape protection and nature protection areas are delimited with difference importance by laws, conventions, spatial plans, regulations. In this research, the *Landscape Protection Sensitivity indicator* (*LPSei*) summarised eight types – six national and two international – of important protection areas (Table 1). Followed the summarising of areal percentage of protection areas one by one, the results normalised between 0-5 points to represent the real sensitivity.

Geographycal sensitivity evaluation have been presented in some cases for example linked to vulnerability of geo-relief types (Klaučo et al., 2015). However there is example to assess topographic heterogenity linked to landscape attractiveness (Walz & Stein, 2018). Assessing – relief-energy and average slope percentage – of sensitivity of the carrier surface of most of all land ecosystem and artificial entities, shortly *Topographical Sensitivity indicator* (*TSei*) is an important step to indirect assessing of the soil sensitivity (Table 1).

Sensitivity of natural areas could be defined through its visual attributes (Store et al., 2015). In our opinion visibility evaluation of landscape could be take a place in ecological aspect of landscape assessment. Reasons for that are its natural elements' attractiveness and a point of view of further landscape planning (planned natural or artificial elements at sensitive areas, further conflict analysis etc.). Moreover, human mostly

Table 1 Evaluation system of sensitivity indicators

Ecosystem Diversity Sensitivity					In-year Permanently Bare Soil Sensitivity
number of natural habitat types (nonwetland)	number of natural habitat types (wetland)	summa areal percentage of natural habitats (%)	wetland habitats' areal percentage inside natural habitats' area (%)	Sensitivity point	Uncovered soil's areal percentage (%)
0	0	0	0	0 point	0
>4	>4	80-100	0.1-5	1 point	0-10
4	4	60-80	5-10.0	2 point	10-20
3	3	40-60	10-15	3 point	20-30
2	2	20-40	15-20	4 point	30-40
1	1	0.1-20	>20	5 point	>40

Landscape Protection Sensitivity				Topographical Sensitivity	
	Land and nature protection types	Land and nature protection type's summarised areal percentage (%)	Sensitivity point	Relief energy (m)	Slope mean (%)
International (double weight)	Natura 2000; Ramsar	0	0 point	0-30	0
		0-20	1 point	30-75	1-5
National	National park; Surface protection area of caves; Ex lege protection areas (marsh, salt lake); Zone of landscape view protection (NSDP); Zone of world heritage protection (NSDP); Zone of water quality protection (NSDP)	20-40	2 point	75-150	5-12
		40-60	3 point	150-200	12-17
		60-80	4 point	200-300	17-25
		80-100	5 point	>300	>25

perceptise landscapes on its eyes. In this method, result map of *Visibility Sensitivity indicator* (*VSei*) based on Digital Elevation Modell (DEM) derived from SRTM dataset (SRTM Dataset, 2022). The viewpoints of visibility were 10 famous locations of the Keszthely Mountain. The assessment had two parts: evaluation of maximum number of visibility (maximum number of viewpoints from where visible a given area) and evaluation of mean visibility (mean visibility – arithmetical mean of values of DEM's rastercells in the area of square of the grid).

Landscape load indicators

To the follow, five landscape load indicators will be presented based its influences significance to the ecosystem. Clearly visible, the human activities causing the major impacts on landscapes, and its assessment have been evolved several methods (Baby et al., 2014; Csüllög et al., 2017). It is easily identified two main types of anthropogen activities. Beside the built-up/artificial areas the agricultural areas have amount of extent on landscapes. Our method used the *Artificial Agricultural Land use Load indicator* (*AALuLoi*) based on NÖSZTÉP and ÁNÉR databases (Agrárminisztérium, 2019; Bölöni János et al., 2011) to evaluate of areal percentage of these loads. Firstly, NÖSZTÉP defined artificial (included agricultural areas) surface types – called 'artificial habitats' – had to be selected and mapped after that corrigated by water bodies dataset (Water dataset, 2022). Following this step, artificial surface types were qualified by its extent of load, expert decision made qualification based on its loading relation to each other.

In the framework of our method we developed an indicator strongly linked of methodology of AALuLoi to assess the artificial loads of the enviroment of water bodies. The water bodies' vulnerability and sensitivity are the reasons for the assessment by *Artificial Agricultural Land use Load at Wetland Habitats indicator* (*AALuLoWHi*) based on NÖSZTÉP, ÁNÉR and OSM databases (Agrárminisztérium, 2019; Bölöni János et al., 2011; OSM Road, 2022, 2022). This indicator has bigger weight in this method because of the role of water. Preprocessed NÖSZTÉP used to mapping the loads – artificial surface types called 'artificial habitats'. At the direct enviroment of wetland habitats were defined five distances with weight values. After preprocessing steps we could mapped the evaluation of loads beside wetland habitats. The AALuLoi assessed the whole load of the area, the AALuLoWHi assessed the load of the 100 m buffered area of wetland habitats which were a plus weight of evaluation of the earlier indicator.

Beside the direct habitat destructions by human activities, its fragmentation is – mostly – linear infrastructure also an harmly effective factor. Assessment of it, as landscape load (Baby et al., 2014) has strong relevance of our ecological method. Based on this reason we used the *Linear Fragmentation Load indicator* (*LFLoi*) to assess the fragmentation effect based on OSM dataset and some regional linear elements of National Spatial Development Plan (NSDP, 2019; OSM Road, 2022, 2022). The summarised length of the linear elements – categorised by five main types (and its impact area) meaning its direct enviroment – were evaluated. Under the evaluation, the impact area of the linear elements got bigger weigth than its length.

Finally, focus areas could be found by a specialised and well-scaled indicator. Certainly, artificial and natural areas have different plant cover with different NDVI properties in a year. To find these strongly influenced landscape load focus areas, we developed an NDVI based indicator called *Lack of Vegetation index* (*LVi*). Aim of this index is extremaly simple, to show those areas – without exact reasons – where the vegetation is destroyed or strongly influenced by human activities. Results were generated by statistical analysis. The indicator need NDVI data of vegetation period as much as possible. The evaluation based on the values (by increment of 0.02) of standard deviation of average NDVI (overlaped mainland raster cells) values in 500x500 m evaluation grid cells.

The last landscape load indicator of this research is the *Land cover Load indicator* (*LcLoi*). This indicator indirectly measures the land cover loading affect soils, used DEM and CORINE datasets (European Environment Agency & European Environment Agency, 2019; SRTM Dataset, 2022). The mean values of slope have classified into five classes (0-5%, 5-12%, 12-17%, 17-25%, >25%). Load pairs were defined by two axis matrix with the (three numbered e.g., 111) types of CORINE land cover and five classes of slope's mean values defined. These load pairs were got a load value (0-5) in load relation of these pairs to each other. After these load values' areal percentage calculating, summarised and rounded values represented the real load of land cover in evaluation grid cells.

Final stage of our method was the composite creation and its analyses. The composites are the LLo and LSe composites, LCC composite based on results of LLo and LSe composites. Indeed, the equal weightening of indicators and also uneqaul weightening couldn't showed the efficiently aggregated results. In case of LLo and LSe composites had to be used the indicator driven dynamic weightening. Meaning, if the biggest ecologically weighted indicators exceed a critical value, those will get bigger weight (Table 2). The production of these types of composites could efficiently represent the real state of an area based on many results of indicators, and minimise the chance of false results. After some version of weightening we got Table 2.

LCC composite created by the LSe and LLo composites through class generating based on those results intersection (Table 3). Finally, three groups of LCC classes are define the:

- more loadable areas (LCC classes: 1, 2, 4, 10, 11, 13, 16)
- maximum loaded areas (LCC classes: 5, 14)
- overloaded areas (LCC classes: 3, 6, 7, 8, 9, 12, 15)

Table 2 Weighted evaluation system of LSe and LLo composites

Landscape Sensitivity composite

Citeria	EDSei	IPBSSei	LPSei	TSei	VSei
EDSei=4 or 5 AND IPBSSei=4 or 5	0.4375	0.4375	0.05	0.04375	0.03125
EDSei=4 or5 AND IPBSSei <4	0.52	0.28	0.08	0.07	0.05
EDSei<4 AND IPBSSei =4 or 5	0.28	0.52	0.08	0.07	0.05
EDSei<4 AND IPBSSei <4	0.325	0.325	0.14	0.1225	0.0875

Landscape Load composite

Criteria If AALuLoWHi physically represented at the area	AALuLoWHi	AALuLoi	LFLoi	LVi	LcLoi
AALuLoi=4 or 5 AND AALuLoWHi=4 or 5 AND LFLoi<4 AND LVi<4	0.48125	0.39375	0.05875	0.05375	0.0125
AALuLoi<4 AND AALuLoWHi<4 AND LFLoi=4 or 5 AND LVi=4 or 5	0.05875	0.05375	0.48125	0.39375	0.0125
AALuLoi=4 or 5 AND AALuLoWHi<4 AND LFLoi<4 AND LVi<4	0.36	0.44	0.094	0.086	0.02
AALuLoi<4 AND AALuLoWHi=4 or 5 AND LFLoi<4 AND LVi<4	0.52	0.28	0.094	0.086	0.02
AALuLoi<4 AND AALuLoWHi<4 AND LFLoi=4 or 5 AND LVi<4	0.094	0.086	0.52	0.28	0.02
AALuLoi<4 AND AALuLoWHi<4 AND LFLoi<4AND LVi=4 or 5	0.094	0.086	0.36	0.44	0.02
AALuLoi<4 AND AALuLoWHi<4 AND LFLoi<4AND LVi<4	0.275	0.225	0.235	0.215	0.05

If AALuLoWHi physically NOT represented at the area	AALuLoWHi	AALuLoi	LFLoi	LVi	LcLoi
AALuLoi=4 or 5 AND LFLoi<4 AND LVi<4	0	0.55	0.2115	0.1935	0.045
AALuLoi<4 AND LFLoi=4 or 5 AND LVi=4 or 5	0	0.405	0.3025	0.2475	0.045
AALuLoi<4 AND LFLoi=4 or 5 AND LVi<4	0	0.405	0.3445	0.1855	0.045
AALuLoi<4 AND LFLoi<4 AND LVi=4 or 5	0	0.405	0.2475	0.3025	0.045
AALuLoi<4 AND LFLoi<4 AND LVi<4	0	0.25	0.3525	0.3225	0.075

Table 3 Sensitivity-load classes of landscape carrying capacity composite

LSe	LLo	0 – null	1 – low	2 – moderate	3 – medium	4 – high	5 – intensive
0 – null		16. class	13. class		14. class	15. class	
1 – low 2 – moderate		10. class	1. class		2. class	3. class	
3 – medium		11. class	4. class		5. class	6. class	
4 – high 5 – intensive		12. class	7. class		8. class	9. class	

1. class: low or moderate sensitivity AND low or moderate load
2. class: low or moderate sensitivity AND medium load
3. class: low or moderate sensitivity AND high or intensive load
4. class: medium sensitivity AND low or moderate load
5. class: medium sensitivity AND medium load
6. class: medium sensitivity AND high or intensive load
7. class: high or intensive sensitivity AND low or moderate load
8. class: high or intensive sensitivity AND moderate load
9. class: high or intensive sensitivity AND high or intensive load
10. class: low or moderate sensitivity AND null load
11. class: medium sensitivity AND null load
12. class: high or intensive sensitivity AND null load
13. class: null sensitivity AND low or moderate load
14. class: null sensitivity AND medium load
15. class: null sensitivity AND high or intensive load
16. class: null sensitivity AND null load

The LCC classes were listed by the compareing of degrees (null, low, moderate, medium, high, intensive) of aggregated sensitivity results (LSe composite) and load results (LLo composites). The classes of 1-9 can easily occur in real. The classes of 10-16 are more rarely or just hypotethical.

RESULTS

All indicators and indexes created and analysed of landscape sensitivity/load could be shown on 500x500 m scaled, uniform raster maps. We present on maps (Fig. 3) only the three most important sensitivity and load indicators by ecological aspect. In this case the most sensitive/loaded areas of the indicators were easily identified one by one (Fig. 3).

Landscape sensitivity, load indicators and indexes

The most sensitive areas of the local ecosystem are localising at the border areas of the Keszthely Mountain and northern side of the NW-SE centerline. The central areas and NE border areas have mainly low and moderate sensitivity in two big patches. Sensitive areas with uncovered soil are concentrated in five bigger and some smaller patches also at the border areas of the Keszthely Mountain and north side of the NW-SE centerline. The landscape protected areas are higher sensitive at the center of the Keszthely Mountain by three bigger and three small patches than at the border areas. Highly sensitive area localised also at the S-SE border of the study area. Moreover, there is a bigger unprotected area at the northern part of the Keszthely Mountain and a smaller area at the SW corner of the study area (Fig. 3).

In case of topographical sensitivity the central mountainous areas have extensive highly and mediumly sensitive areas and there aren't intensively sensitive areas at the study area. There isn't sensitivity at the most of border areas and a bigger patch between the northern and southern range of the Keszthely Mountain.

Artificial Agricultural Land use load (wetland and nonwetland areas) also concentrating at the edge of the Keszthely Mountain and at northern side of the NW-SE centerline. There are an extensive highly loaded area at the SW corner of the Mountain and northern side of the study area. Central areas mostly aren't loaded. The linear fragmentation load is represented at the whole study area, however intensively and highly at the E-SE-S-SW border areas and on double line oriented NNE-SSW. Nonloaded, mediumly, moderately and lowly loaded areas are in absolutely mixed structure in the central and NW extensive areas (Fig. 3).

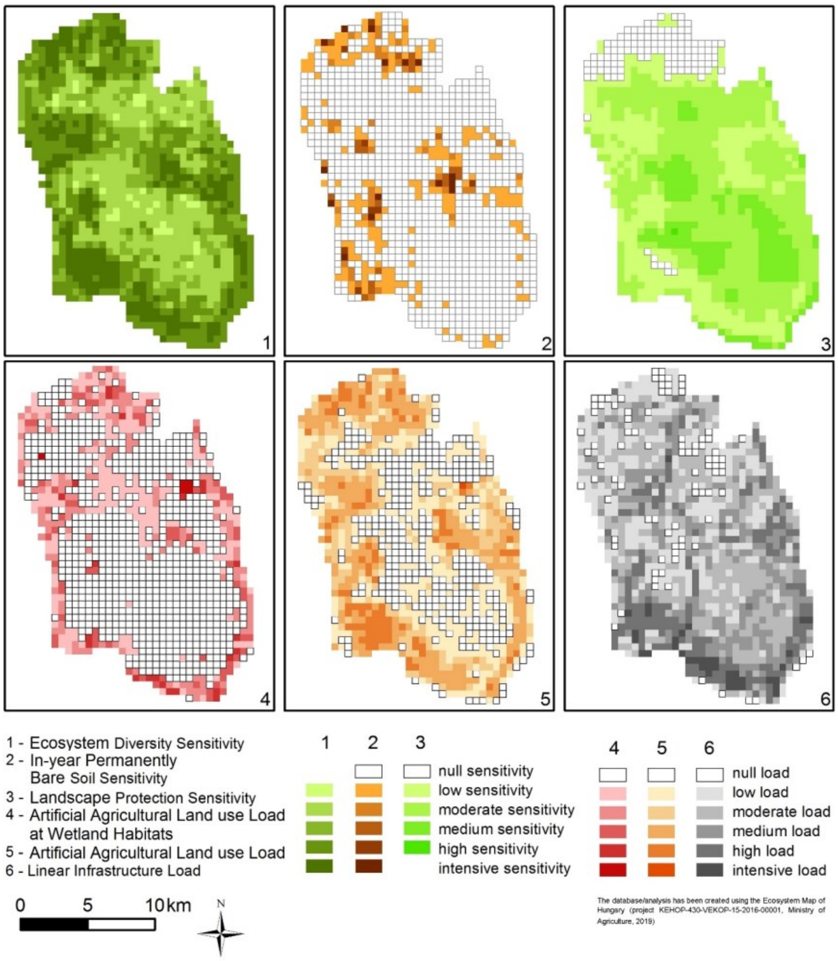


Fig.3 Main results of the landscape sensitivity, load indicators and indexes

Furthermore, there are 16 intensively loaded small areas, six bigger highly and mediumly loaded patches at the study area based on Lack of Vegetation index results. Cca. 65% of the Keszthely Mountain is moderately and lowly loaded. In case of Land cover load we can find intensively and highly loaded areas at some small patches near the NW-SE centerline. Mediumly, moderately and lowly loaded areas are concentrated at the edge of the study area and northern part of the NW-SE centerline. The two mountainous core areas aren't loaded.

Landscape carrying capacity

The second main step of the method was the composites generating. Firstly, the LSe and LLo composites were generated (presented in detail at method chapter). After that the LCC composite was generated based on the results of the LSe and LLo composites (Fig. 4). It could be identified, that intensively and highly sensitive areas are scattered by some small areas mainly at the west part of the Keszthely Mountain. There are extensive mediumly sensitive areas at the edge of study area. Moreover, the related areas with low and moderate sensitivity are localised in the central areas and north of the Keszthely Mountain. The sample of the LLo composite is same as LSe composite. Meaning, the intensively, highly and mediumly loaded areas are concentrated at the edge areas of the Keszthely Mountain and at northern side of the NW-SE centerline. The moderately-lowly loaded areas are mostly located at the center areas of the study area and, in some smaller patches at marginal areas. The different load classes show highly mixed structure. Nonloaded areas are represented by several small patches mostly at NW part of the study area.

LCC composite (Fig. 4) created by intersection of LSe and LLo (Table 3). Results of LCC composite were manifested in three classes: more loadable area, maximum loaded area, over loaded area. Maximum loaded and over loaded areas located at SW-S-SE edge areas, in two bigger patches at northern side of NW-SE centerline. Eventually in two smaller patches at northern side of the study area. More loadable areas extensively represented in central mountainous and edge areas of the Keszthely Mountain.

LCC focus areas

For example, if an area according to LCC composite is more loadable, it means ecologically suitable for more loading by human activities. However, if an area is maximum loaded or over loaded, it means ecologically isn't suitable for more human activities and need to initiate some landscape protection activities (Fig. 5).

Five critical areas can be indentified (maximum loaded or over loaded areas) with study area based on results of LCC composite. The biggest at SW part of the study area, one is at north of the biggest area, two are on the NW-SE centerline and one is at north of the study area (Fig. 4. and Fig. 5). These areas are the most sensitive and loaded by ecological aspect. Human activities are intensive at these areas (Fig. 5) through extensive agricultural usage, built-up areas and extensive mining activities. Natural areas are in small patches and spatial structure of it have strong lack of networking, strongly influenced by neighbour antropogen land uses. Most of the LSe and LLo indicators show intensive, high or moderate values (Fig. 3 and Fig. 4). The LSe and LLo composites also show intensive, high or moderate values of sensitivity and load (Fig. 4). There are several small maximum loaded or over loaded areas around the signed focus areas.

Generally, a typical pattern could be identified in case of indicators and composites too. The central mountainous areas with distinctly separate from hilly or flat edge of the area and alongside NW-SE centerline areas (Fig. 3, Fig. 4 and Fig. 5). In case of southern range of the Keszthely Mountain these two characters have thin transition zone; in case of northern range have thicker transition zone. Tendentially, the extent of

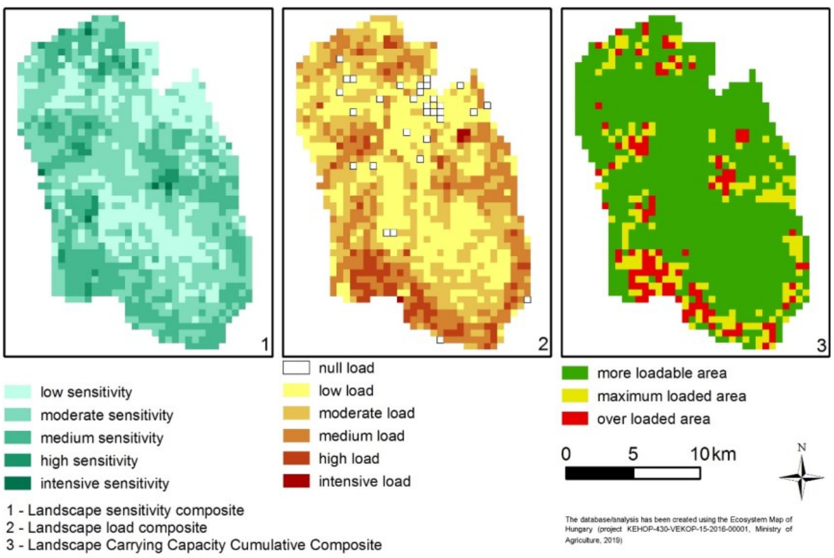


Fig.4 Result composite maps of landscape sensitivity, landscape load, landscape carrying capacity

sensitivity, load, and composites represented by generally higher values in one of these characterised area. Generally lower values in the other characterised area or vice versa. Certainly, there are several transition and other spatial structures between the spatial tendentials of values.

DISCUSSION

In this paper we present an approach that the LCC based evaluation of a given territory proposes one or more land use plans. This can be the basis for examination of socio-economic needs and plans during the further territorial planning. Sustainability can be efficiently implemented with this approach in the territorial planning because of it is based on analysis of spatial and nature resource limits, not socio-economic (sometimes excessive or unnecessary) needs or „rights". However, we have to also focus those cases when sustainability only can be 'more sustainable' than current state such as metroplicies' central areas or city centers. It is clear that classical planning systems need some changes by sustainability approach and more focus on nature (Pogliani et al., 2023). We thought that our proposed planning method can be a potential spatial planning way. In case of China, this process has started in recent years by its system based designing (Liu & Zhou, 2021). Moreover, the biggest European cities and urban regions should renew of its planning models because its recent strategic spatial plans focus partially the whole landscape system, for example focus only green infrastructure (Hersperger et al., 2020). The performance-based planning (PBP) approach also a high potential way nearby the sustainability (Pogliani et al., 2023; Ronchi et al., 2020). Moreover, several recent researches emphasised its own applied methods' strong relation to the spatial planning (Battisti et al., 2022; Cocheci et al., 2019; Kang et al., 2021; Manolaki et al., 2020; Ronchi et al., 2020; Wellmann et al., 2020). However, we argue that basic elements such as land use plans have to stay at a key planning tool in the spatial planning process (Faragó, 2003; Ronchi et al., 2020).

To sum, it was identified that in the SW-S-SE – cca. 3-5 km wide – border area of the Mountain is the most extended and related loaded area. This is a large ecological barrier between Lake Balaton and natural forested areas of the Keszthely Mountain. In this area the highest chance of maintenance of ecological corridor between Lake Balaton and the Keszthely Mountain is near the border of Balatongyörök and Vonyarcvashegy settlements. The high loading caused by extended built-up areas and agricultural areas and also the high density of linear infrastructure. The more loadable areas concentrated in an extended block in the central and northern areas of the Keszthely Mountain. Because of its extention, this area is more resilient for human activities, meaning less sensitive. These areas' dominant land covers are forest and grasslands with low density linear infrastructure. These areas are not only suitable for one or more economy sectors but also ecological suitable based on LCC results. The sustainable, just and equilibrium centered landscape development could be realized in this areas. Certainly, this planning attitude should be extended to over loaded or maximum loaded areas for decreasing of those extension or their loading value through land use type changing also based on LCC results. At this point need to be mentioned the role of focus areas. These areas were easily detected by analising the results' spatial structure of LCC composite. In case of Keszthely Mountain five focus areas were identified. The change of land-use structure is more important at these areas than at other maximum or over loaded areas. Firstly, the comparing of degree of sensitivity and load is needed based on LSe, LLo results. Secondly, the determination of decreasing of load's degree is needed through land-use planning where the land-use change can be the primary planning tool. Certainly, in focus areas' case the possibilities of the

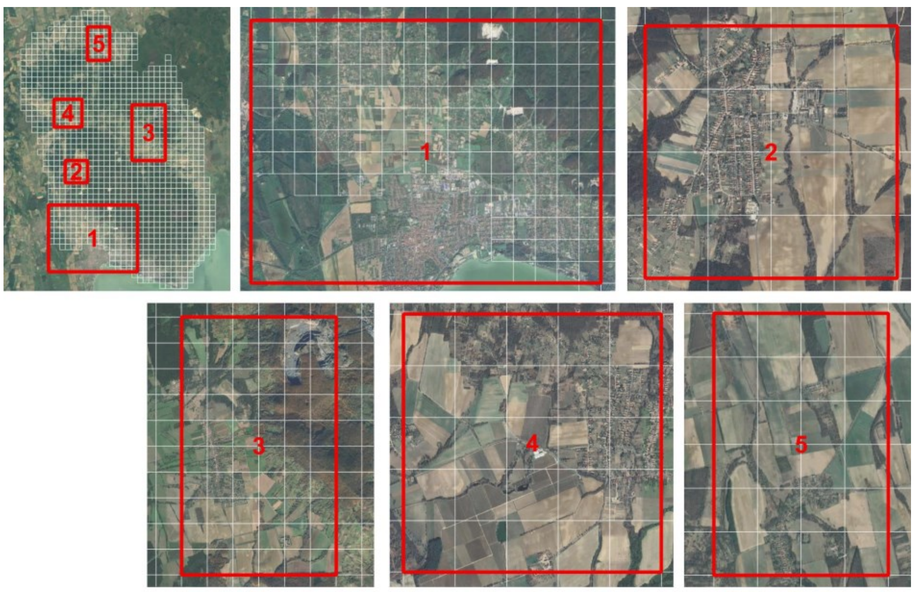


Fig.5 Satellite images of LCC composite focus areas (Google Satellite, 2023)

land-use change's types have to be considered under the planning process.

Manolaki et al. (2020) was evaluated the habitat network through patch analysis, however, they used 5 km^2 minimum mapping unite (MMU). Habitat network analysis is a developable point in LSe assessment's 0.25 km^2 MMU of our research's method. Several spatialy statistical indicators as landscape metrics are usefull for land-use/cover's patch-level evaluation or landscape's elements evaluation for example soil cover (Uuemaa et al., 2008, 2011). On the other hand, Cocheci et al. (2019) was integrated climatic and socio-economic factors in their method what is also provide a wider state of LSe. The integration of climatic factors have risen to the critical evaluation approaches (Cocheci et al., 2019; Kang et al., 2021; Pogliani et al., 2023) because of climate change intensity and effects. Also it is need to be mentioned that Baby et al. (2014) not only evaluated the existing antropogenic elements but also the planned antropogenic developments. Joining this, in our approach the LCC based landscape assessment's results are LCC composite and sustainable (or more sustainable) land use plan based on it. The LCC classes show that what classes meaning more loadable, maximum loaded, or overloaded areas. Based on results the basic datas' back-validation can determine the needed land use changes' extent. The assessment of the planned land use elements is a step of spatial planning process after the comparison of sustainable land use plan and socio-economic needs and plans of the given territory.

This research's LCC method focuses for the evaluation of basic landscape elements such as topography, soil, natural habitats, water, areal and linear built-up elements. However, the subsurface water and point-type pollution sources wasn't evaluated. Moreover, the climatic conditions' evaluation is also lack of the method. But, measure of climatic conditions has some issues (e.g., chosen factors, data limits, time period bases). We presented a basic method what use easily available and useable existed and remote sensing based databases. The indicators and its further weighted evaluation is efficiently implemented. However, it is not contain important approaches such as evaluation of ecosystem services or green infrastructure based landscape planning (González-García et al., 2020; Ronchi et al., 2020). The splitting to more subcomposites of LSe and LLo composites may be provide better subresults.

Also key aspect is the origin of data: remote sensing based, existed local data, basic or derived. In this research's method the existed databases are free to use not only the national and international databases but also remote sensing based databases. Special elements of the method are two of indicators based on statistical analysis of derived remote sensig data. In-year Permanently Bare soil Sensitivity index is an important element because of the extent of highly sensitive areas are often located in agricultural areas. We though that after the role of water the relevance of soil quality is the second key element of a landscape. Meaning in this context, soil quality factors (water content, surface structure) are more influenced by weather factors because of its permanent bareness. We used NDVI data also localise the most destructioned vegetation areas. However, the set of remote sensing based (Wellmann et al., 2020) indexes and databases are more wide (NDMI, EVI, Sentinel data). Our NDVI based indicators may need compare with other vegetation indexes for developing them providing more specified results. On one hand calculations of our method's indicators and indexes mainly based on areal percentage of indicator's elements. On the other hand the used weightening and selector criterias of indicator's elements highly refine the uniqe results. Qualitative and quantitative assessmenst also realized because of inner criteria system of indicators and composites. Moreover, LLo and Lse composites' results calculation based on indicator driven dynamic weightening to minimise the false values.

Finally, the weightening might be not the perfect to express all LSe-LLo cases. This weightening method developed after several versions (e.g., equal or unequal weightening independently of values). The weightening also need developing, because of some highly loads (e.g., a pair of mines) wasn't manifested in LCC composite's result. It is need to be mentioned that several indicators of this method evaluated a static condition. The timeseries based assessment must be integrated in the further development of this method because of landscape processes spatio-temporal evaluation (González-García et al., 2020). Remote sensing based evaluation provide better opportunities for this assessment. Moreover, through this evaluation subsystem could be strongly support (Wellmann et al., 2020) the territorial planning or also static data based evluation. However, it is required some special knowledge about remote sensing and vegetation indexes. To sum, our research's approach also emphasise the changing of classical territorial planning practice. Because of role of nature (De Groot et al., 2002; Westman, 1977) sustainability and nature focused palnning systems must be applied for sustainable landscape management (H. & P., 2015; Klaučo et al., 2015). We offer a solution for a developed spatial planning process: (i) first step is the LCC based evaluation of the given territory; (ii) LCC map and its proposed land use plan comparison with socio-economic needs and plans; (iii) LCC assessment of planned elements and suggest one or more developed land use plans; (iv) further spatial planning steps like more participatory planning, strategy and program development, monitoring system planning. This research's presented LCC method can be used in the spatial planning practice as the first evaluation step. Moreover, the iterative useing of this method can support the versions of the final spatial plan. However, fully or partly application of this LCC method shall be also suitable for other types of strategical planning depend on that aims. On one hand, our method efficiently applicable because of it's based on existed data based evaluation, have inner weightening and multi-step system., Furthermore, it's based on previously tested methods, it focuses the assessment of main landscape elements. Moreover, LSe and LLo based

LCC map and proposed land use map can be a good basis for the further territorial planning processes. On the other hand, the integration of landscape processes' evaluation and socio-economic factors (maybe as weightening factors) in this method needs further research. Among other things climate change approach should also be applied in these future researches in the framework of our method. The application of other remote sensing based vegetation indexes as LSe LLo indicators and alternative databases are also need more researches. Finally, the weightening of composites and its calssification method, and indicators of weighted spatial structure evaluation also a developable point and need more research.

CONCLUSION

Traditional spatial planning models need to be developed to suggest better prepeared solutions for the 21st century's challenges through the spatial plans as higher scaled regulators of human activities. We proposed a possible planning process, what need to be splitted substeps for stakeholders. This approach based on sustainable space and resource management.

This research's method proposes an applicable basic landscape evaluation system what combines remote sensing based evaluation in additon to basic existed national and international data based assessment. In case of study area five focus areas were delimited by the results. These focus areas should be the primary land-use planning areas. The main elements of landscape were evaluated for the more overall assessment. Moreover, the used databases are free to use. The composites can efficiently aggregate the indicators' results. The LSe, LLo, LCC composites' relation can determine the more loadable, maximum loaded, over loaded areas and focus areas. However, it has some developable element such as the weightening of indicators, the evaluated factors, composites' calculation or splitting. These elements need more researches for a more advanced method of the landscape evaluation. LCC approach could support the spatial planning because it not only examine the sensitivity but also load in overall. The landscape sensitivity must be simultaneous evaluated with landscape load by result aggregation and claster analysis (LCC). Finally, we argue that landscape suitability assessment should be integrated in the spatial planning process and LCC assessment because of resource management and potential useability for human activities.

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