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EFFECT OF LINEAR INVESTMENT ON NATURE AND LANDSCAPE – A CASE STUDY

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Abstract. The effect of road location on natural and landscape elements is presented in this paper. Special care was focused on nature conservation areas located along three proposed road variants. Landscape metrics as a supplemental tool for selection of the most environmentally friendly road variant were here examined. The matrix method was used to analyse the potential negative effect of the road on the nature and landscape. Landscape metrics were found to be a very useful supplemental tool to evaluate the potential negative effect of the planned road on the environment. Moreover, based on our study we can also clearly relate this element to the effect on nature conservation elements. One of the most important features is the possibility to calculate certain metrics based on existing land use information without the need for field analyses, as well as obtaining specific values, which may be more objective than visual landscape assessment.

Keywords: road, environment, impact, landscape metrics, nature protection, environmental impact assessment.

Introduction

Construction of a road is a huge scale investment connected with positive and negative effects. Positive effects include social-economic aspects, such as improvement of transport safety, drivers' comfort, shortening the time and costs of travelling and economic activation of surrounding areas. Negative effects are mainly connected with the effect on the environment (Bohatkiewicz, 2008; Forman, 2000; Dmochowski, Dmochowska, & Biedugnis, 2015; Jaeger, Schwarz-von Raumer, Esswein, Müller, & Schmidt-Lüttmann, 2007; Lin, 2015; Nematollahi, Fakheran, & Soffianian, 2017; Rogula-Kozłowska, Rogula-Kopiec, Klejnowski, & Błaszczyk, 2013).

An effect on the environment can involve many aspects and scales – from specific plant and animal species, through the water and soil environment, to the total ecosystem (Hawbaker & Radeloff, 2004; Liu et al., 2008; Schweitzer, 2005). Transport infrastructure development is one of the main causes of habitat fragmentation and land use deformation. Roads influence the landscape mainly through changes of existing elements in particular zones near the road area and through the creation of a new pattern of landscape (Liu et al., 2008), which is characterized by a decreased number of patches and their higher isolation, together with increased length of their edges. Usually, the common shape of a certain patch is more complex (McGarigal, Romme, Crist, & Roworth, 2001), although it can also be simpler (Saunders, Mislivets, Chen, & Cleland, 2002). As a consequence, decreased stability and resistance to landscape changes can be observed (Richling & Solon, 2011), and in turn losses of valuable habitats, decrease of biodiversity and creation of ecological barriers can be noted (Hawbaker & Radeloff, 2004; Rico, Kindlmann, & Sedlácek, 2007; Sanderson et al., 2002). However, the same road can affect creation of new habitats and migration corridors for many valuable species of plant and animals (Karlson & Mörtberg, 2015).

A special aspect of a road's effect is the impact on nature conservation areas (Albers, Ando, Bu, & Wing, 2012; Garriga et al., 2012). Hence, it is highly recommended to project several road locations as alternative variants, to indicate the possibility to avoid protected areas or at least limit the negative effect on such areas (Kiczyńska &

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Weigle, 2003). If it is not possible to locate a road far from protected areas, the range and character of influence is analysed, including such aspects as potential disturbance of the balance of distribution and density of key species, reduction of their population, potential reduction of key habitats, potential decrease of area diversity and area fragmentation (Bohatkiewicz, 2008; Lenart, 2002).

One of the basic environmental management tools to avoid negative effects of planned investments is environmental impact assessment (EIA). The most important features of EIA are complexity concerning causes and effects, the necessity to indicate several variants and the balance between local short-term usage of the environment and maintenance and increase of its long-term productivity. The most common methods used for EIA are the index method, matrix method and net method (Bohatkiewicz, 2008; Jay, Jones, Slinn, & Wood, 2007; Starzewska-Sikorska, 1994). In the case of road investment a popular approach is the "road-effect zone" method (Forman & Deblinger, 2000; Freudenberger et al., 2013; Liu et al., 2008; Su et al., 2014; Wu, Lin, Chiang, & Huang, 2014), as well as the use of landscape metrics together with statistical analysis (Cai, Wu, & Cheng, 2013; Liu et al., 2008; McGarigal & Marks, 1995; Roo-Zielińska, Solon, & Degórski, 2007; Saunders et al., 2002; Su et al., 2014; Wu et al., 2014).

The problem of the effect of a road on the landscape is not well studied (Nita & Myga-Piątek, 2012; Raszeja, 2002; Sas-Bojarska, 2007). The landscape is usually treated as a separate element of the environment and not related to others. Moreover, evaluation of the landscape is usually independently performed by experts and limited to description of the current status (Sas-Bojarska, 2006, 2007). The reason for this state is the common opinion about landscape assessment as totally subjective and difficult to verify, as well as lack of guidance and good practices of valorisation of changes in the landscape during environmental impact assessment procedures (Giedych, 2016; Łowicki, 2015; Sas-Bojarska, 2006).

The Polish road infrastructure has been transformed dramatically since the beginning of the 21st century. Approximately 975 km of highways were built in 2007–2016, 1 274 km of express roads and 73 city rings. Concerning assumptions of the National Road Building Programme for 2014–2023, another 2 750 km of highways and express roads will be built in the near future. Moreover, this will be accompanied by city rings and other road investments (Program Budowy Dróg…, 2017).

The aim of the present study was to evaluate the potential effect of a road on natural and landscape elements. The investigations were based on the potential northern ring road of Poznań city, Poland. Special care has been focused on nature conservation areas located along three proposed road variants. Moreover, as landscape analysis is usually omitted in road investments, here we also paid special attention to validate potential effects for these aspects and to indicate potential problems. Landscape metrics as a supplementary tool for selection of the most environmentally friendly road variant were here examined.

1. Material and methods

The Polish Law of 03.10.2008 on the provision of information on the environment and its protection, public participation in environmental protection and on environmental impact assessments (Journal of Laws of 2008 No. 199 item 1227) was implemented in Polish law as a consequence of the following European Directives: 2011/92/EU of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment and its 2014/52/EU of 16 April 2014 amendment; 2001/42/EC of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment and 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. Under those laws three alternative variants for the planned investment are proposed in this paper. Three of them resolve the given problem with construction of a new road, while the last one is based on avoidance of the undertaking and on further exploitation of the existing national road No. 5.

During designation of particular potential road variants the following assumptions have been made: maintenance of highway technical parameters, omitting the water reservoirs, limitation of disturbance of nature conservation areas, maintaining optimal distance between the road and built-up areas. Additionally a prognosis of road traffic has been evaluated for all analysed variants. This was based on the General Road Traffic Measurement from 2015 (GDDKiA, 2016) for existing roads which would be released thanks to the planned road. The prognosis was made for three time horizons: the present year (2017), the potential year of finishing the investment (2025), and 10 years after completion (2035).

For proper analysis of the effect on natural aspects, the following elements were addressed: influence on and conflict with existing nature conservation areas and ecological corridors.

Effect on the landscape was analysed with the aid of four landscape metrics: edge density (ED), patch density (PD), Shannon diversity index (SHDI) and Simpson's evenness index (SIEI). These parameters were calculated for each variant in buffer zones measuring 100 m, 200 m, 500 m and 1000 m from the road axis. Landscape metrics were calculated with the aid of Fragstats 4.2 software based on Corine Land Cover 2012.

The last phase included the accumulative effect of the potential northern Poznań ring road on natural and landscape aspects. For this purpose a matrix method was applied. The Leopold matrix was applied in the scale from –1 to 4, where significance of influence is as follows: –1 – positive influence, 0 – lack of impact, 1 – very weak, 2 – weak, 3 – medium, 4 – very high. The analysis was performed for all investigated variants combined together (in columns and rows) and all types of impacts of the investment with analysed environmental elements. The sum of points for each analysed variant revealed the most favourable environmental variant.

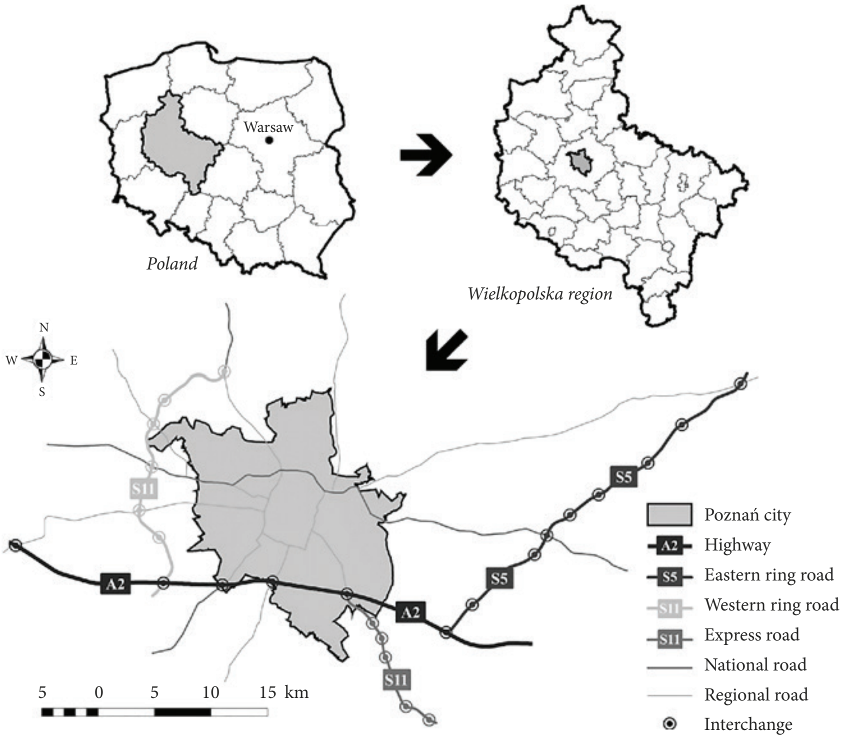

Figure 1. Road system in Poznań city (source: own study based on data from The Central Office of Geodesy and Cartography)

The investigations were conducted for the Poznań city northern ring road. The city is located in the central-western part of Poland. There are ring roads around the city, excluding the northern part (Figure 1).

2. Results and discussion

2.1. Characteristics of proposed investment

Three alternative ring road variants are here proposed for further environmental analysis – V1, V2 and V3 – as well as the variant "do nothing". In the last case existing roads were investigated with predicted future road traffic. Variants V1 and V2 are conducted in new locations omitting Poznań city from the north side, while variant V3 has been designated based on the old road No. 5.

Variant V1 would have a length of 47.169 km. Land use in the buffer of 1000 m is dominated by arable land (61.8%), as well as forestry and semi-natural areas (31.1%).

Variant V2 has a length of 50.957 km. Land use is dominated by arable area (64.0%) and forests and semi-natural areas (32.4%).

Variant V3 predicts the location of the ring road at the existing road and its adaptation to future traffic requirements. This variant location is similar to the variant "do nothing" and the length of the road is 35.628 km. The land use structure is also dominated by artable areas (59.4%), while forests and semi-natural areas cover 18.9% of the buffer zone. Urban areas cover 19.5%, which requires decommissioning of some buildings on the route of variant 3 (Figure 2). All proposed variants are planned according to the requirements of the national law (Journal of Laws of 1999 No. 43, item 430).

Based on the present road structure in the area of planned ring road the proposed road would take some of the traffic from regional roads. The prognosis of the road traffic has been based on the present traffic on existing roads. The mean daily car traffic is at the level of 14 524 cars, with the highest number of passenger cars (11 766) (Table 1).

It is predicted that the number of cars will increase in the future. The mean annual traffic for 2017 was assessed at the level of 15 914 vehicles, which is an increase of 9.6% in comparison to 2015. In 2025 the number of vehicles is predicted to be 19 663, which is about 35.4% more than in 2015. In 2035 the number of cars will reach 25 106 (which is about 72.9% in comparison to 2015) (Table 2).

2.2. Analysis of environmental impact on nature

The area through which the proposed highway passes is rich in nature conservation areas. There are nine Natura 2000 network areas of habitats and three of bird areas, three landscape parks, 15 nature reserves and 8 landscape protected areas (Figure 2).

All proposed variants would cross some nature conservation areas, but the greatest effect would be noted for variants V1 and V2. Variant V1 would go through two landscape parks, one Natura 2000 habitat area and one landscape protected area. The length of VI crossing nature conservation areas would be 23.038 km (48.8% of the total length). Variant V2 would cross one landscape park, one Natura 2000 bird area, one landscape protected area and two Natura 2000 habitat areas. The length of V2 crossing nature conservation areas would be 15.390 km (30.2% of the total length). Variant V3 and variant 0 would cross only one landscape park for the length of 6.157 km (17.3% of total length) (Table 3).

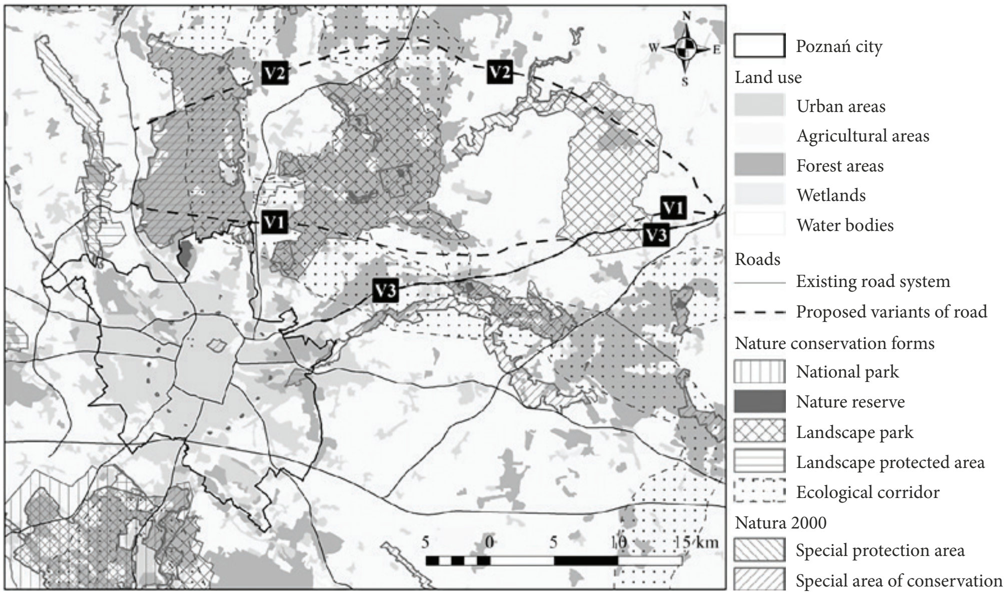

Figure 2. Location of proposed variants in relations to nature conservation areas (source: own study based on Corine Land Cover 2012 and data from The General Directorate for Environmental Protection)

Table 1. Number of vehicles at analysed roads and proposed northern Poznań ring road (source: own studies based on GDDKiA, 2016)

Vehicle structure	Existing regional road No. 187	Existing regional road No. 196	Existing regional road No. 197	Vehicles traffic at proposed Poznań northern ring road	
	Number of vehicles			Number of vehicles	Percentage (%)
Motorcycles	56	134	22	127	0.9
Passenger cars	4092	13 585	1934	11 766	81.0
Delivery vans	431	1 252	220	1141	7.9
Lorries	529	1 485	215	1337	9.2
Buses	21	217	17	153	1.1
Total	5129	16 673	2408	14 524	100.0

Table 2. Number of vehicles at northern Poznań ring in 2017 and prognosis for 2025 and 2035

Vehicles structure	Number of vehicles		
	year 2017	year 2025	year 2035
Motorcycles	127	127	127
Passenger cars	12 983	16 256	21 013
Delivery vans	1186	1303	1449
Lorries	1465	1824	2364
Buses	153	153	153
Total	15 914	19 663	25 106

There is also the central-northern Ecological Corridor located in this area (Figure 2). All of the analysed variants would cross this area. Variant V1 would cross the ecological corridor for the length of 15.882 km, variant V2 13.260 km, and variant V3 and "0" for the length of 9.625 km.

The area of the potential ring road passes through areas rich in protected sites and ecological corridors. Hence, there is no possibility to locate any variant without impacting on protected areas, and in the case of developing the existing road it almost impossible to perform. The analysed protected areas and ecological corridors also play an important role as migration pathways of several animal species. The proposed investment may make animal migration difficult or even impossible and cause deaths as a consequence of car accidents. It is also indirectly connected with fragmentation of ecosystems and degradation of habitats, as well as deterioration of conditions as a result of emission of pollution and noise (Bohatkiewicz, 2008; Forman & Alexander, 1998; Forman & Deblinger, 2000; Garriga et al., 2012; Kiczyńska & Weigle, 2003; Saunders et al., 2002). One of the simplest ways to allow migration of animals is construction of animal crossings (Jędrzejewski et al., 2006). It is significantly difficult to reduce the indirect effect of the road on fauna and flora. Several investigations indicate many influencing factors (Forman & Alexander, 1998; Forman & Deblinger, 2000; Garriga et al., 2012; Saunders et al., 2002).

Table 3. Collisions of proposed ring road variants with nature conservation forms

Nature conservation forms	Range of collision	
	Length of section [km]	Percentage [%]
Variant V1		
Landscape park	13.154	27.9
Natura 2000 – Special area of conservation	9.884	20.9
Landscape protected area	7.023	14.9
Total length of collision	23.038	48.8
Variant V2		
Landscape park	7.960	15.6
Natura 2000 – Special protection area	0.666	1.3
Natura 2000 – Special area of conservation	7.165	14.1
Landscape protected area	5.763	11.3
Total length of collision	15.390	30.2
Variant V3 and variant "0"		
Landscape park	6.157	17.3
Total length of collision	6.157	17.3

2.3. Assessment of impact on the landscape

The planned investment area is varied in regard to landscape structure, which affects the diversity of landscape metrics for analysed variants.

The landscape structure in variant V1 is characterised by patches with concentrated and regular shapes, which is revealed by the lowest value of edge density (ED). Patch density (PD) is also the lowest, but does not vary in comparison to other variants. The landscape is the most varied in comparison to the other variants, which is confirmed by Shannon's diversity index (SHDI). Values of Simpson's evenness index (SIEI) indicate unequal proportions between areas of certain patches.

In the case of variant V2, despite similar patch density (PD) as in the other variants, a higher mean value of edge density (ED) characterizes the less cohesive and regular shape of particular patches. Variant V is located mainly in arable and forest areas; hence it is less varied, dominated by two types of land use (the lowest levels of SHDI and SIEI).

Variant V3 and variant "0" are characterized by high landscape diversity. Especially areas located near to the road are diverse in terms of the shape and number of patches (mainly areas with dispersed and irregular built-up areas). Distribution of patches is unequal and mainly associated with the distance to the road, but the proportions between types of patches are similar.

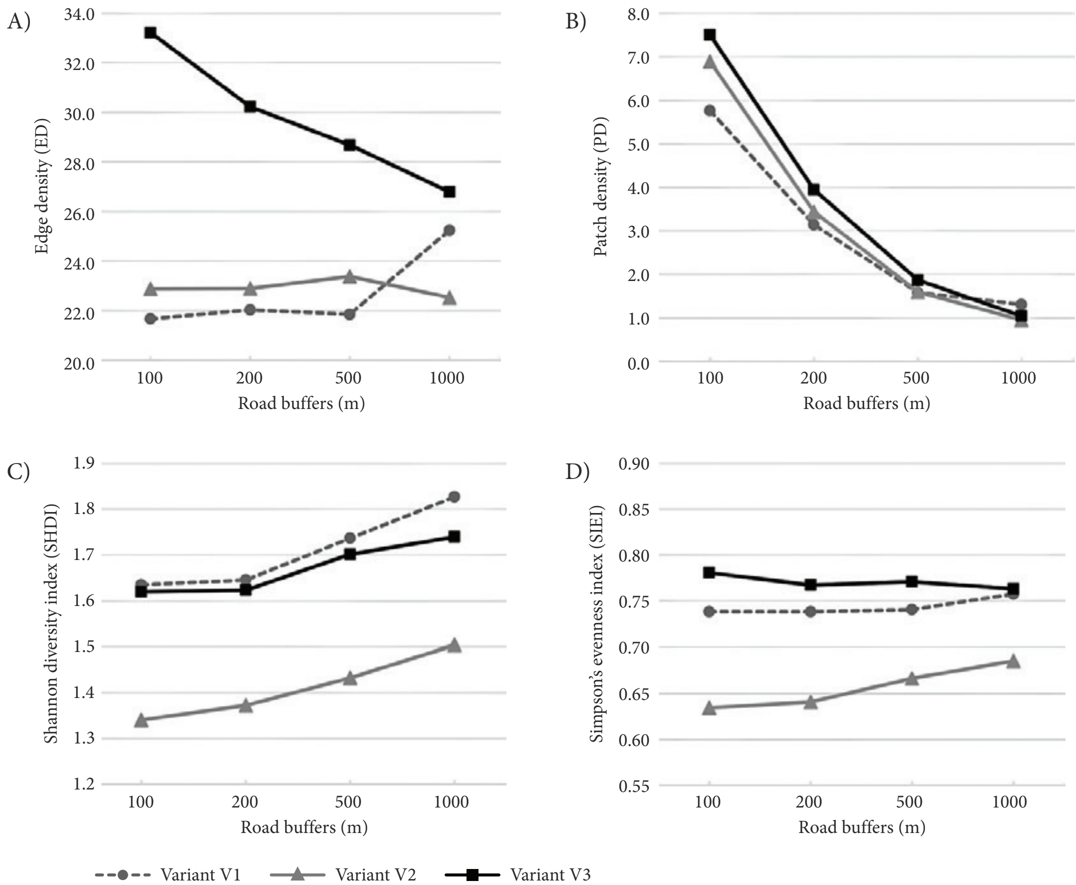

Figure 3. Landscape metrics: edge density (A), patch density (B), Shannon diversity index (C), Simpson's evenness index (D) (source: own study)

Patch density decreases in relation to the distance from the road in all analysed variants. Together with the distance from the road there are new types of land use, and the landscape becomes more varied. However, the area proportions of various types of patches are similar in a particular variant and are independent from the distance from the road (Figure 3).

Development of road transport can cause many deleterious effects on the environment, including the landscape. The landscape in areas located in the way of the proposed ring road is diverse. The most valuable areas were found on the route of variant V1. There are dispersed areas that are mostly less resistant to secondary deformations caused by the proposed investment (Richling & Solon, 2011). The highest landscape diversity was noted in areas on the routes of variants V1 and V3. For all variants the patch density increased together with the distance from the road. Similar observations were also previously noted (Liu et al., 2008; Su et al., 2014; Wu et al., 2014). According to Liu et al., (2008) and Su et al. (2014), Shannon's diversity index decreased together with the distance from the road, whereas in our investigations the opposite tendency was observed, which is connected with the appearance of new forms of land use and increase of its diversity.

2.4. Accumulative environmental assessment of planned investment with the matrix method

The simplified matrix method was used to analyse the impacts of selected variants of the northern ring road of Poznań city. The analysis was performed for all variants summarized together (in columns and rows) concerning effects of location of the road for analysed environment elements (Table 4).

Table 4. Accumulative matrix of effect (source: own study)

Parameters	Variant V1	Variant V2	Variant V3	"do nothing" variant
Land occupation by the planned road	4	4	1	0
Change of land use	2	1	4	0
Vehicle transport	–1	–1	–1	4
Collision with nature conservation areas	3	2	1	1
Collision with ecological corridors	3	1	2	2
Landscape structure	3	2	1	1
Landscape diversity	4	1	4	2
TOTAL	18	10	16	10

Accumulative matrix analysis with selected parameters revealed that the largest negative effect (18 points) would be noted for variant V1. The most positive variant from an ecological point of view would be variants V2 and "0" (10 points). The most affected elements influencing total value were land occupied by the road and effect on landscape diversity. In the case of variant "0" the largest effect was noted for vehicle transport, as this road is not adjusted to the predicted future number of vehicles. This in turn may cause a negative effect on road safety and travel comfort. In our opinion the best solution for the proposed road would be variant V2.

Conclusions

Four variants of the road ring were here proposed; three variants were based on a certain location, while the last one was based on a "do nothing" approach. All variants were analysed in regard to the impact on protected areas and the landscape. Considering the predicted traffic it was concluded that the most environmentally friendly would be variant V2.

Landscape metrics are a very useful supplemental tool to analyse the potential negative effect on the environment. Moreover, based on our study we can also clearly relate this element to the effect on nature conservation elements.

One of the most important features is the possibility to calculate certain metrics based on existing land use information, as well as obtaining particular values, which can be more objective than visual landscape assessment.

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Contribution

K. B., M. L. and J. S. conceived of the presented idea; M. L. and J. S. developed the theory and performed the computations; J. K. and A. A. verified the analytical methods; M. L. wrote the manuscript with support from K. B.; K. B. and J. K. helped supervise the manuscript; All authors discussed the results and contributed to the final manuscript.

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