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GEO-ENVIRONMENTAL INDICATORS IN STRATEGIC ENVIRONMENTAL ASSESSMENT

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Abstract. It is obligatory for European Union member states to conduct the Strategic Environmental Assessment (SEA) in order to implement the principles of environmental protection and development into the framework of strategic documents and development policies. As practice shows, SEAs are often performed in a descriptive, subjective manner which makes it difficult to perform a final evaluation of development variants. The use of environmental indicators which allow for the quantification of states, processes and phenomena may help make SEA more objective.

The aim of this article is to attempt at implementing environmental indicators into the SEA procedure. A matrix of environmental indicators taking into account environmental quality indicators and anthropogenic pressure indicators has been formulated as part of the research. The ArcGIS software with the CommunityViz platform was used for the analyses. The proposed concept and established model for the evaluation of the environmental consequences of the planning document is a contribution to the debate on issues related to SEA methodology and the use of the GIS-based approach in SEA.

Key words: environmental indicators, Strategic Environmental Assessment (SEA), environmental management

INTRODUCTION

European Union legal regulations establish the framework for the functioning of the Strategic Environmental Assessment (SEA) [Boroń 2007, Fonseca et al. 2017]. According to guidelines of the International Association for Impact Assessment, SEA is

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a management tool used for the purpose of achieving sustainable development through identification, prediction, evaluation and the limiting of possible biophysical, social and other types of consequences of planned developmental actions and decisions [Shepherd and Ortolano 1996, IAIA 1999, Abdel Wahaab 2003]. This involves strategies, plans, programmes or polices [Partidário 1996, Chaker et al. 2006, Victor and Agamuthu 2014, De Montis et al. 2014, Yousefi et al. 2015]. The SEA for strategic and planning documentation should be used to analyse the impact of a planned policy on each environmental component [Bednarek 2012]. These include: human beings, the fauna, the flora, water, air, the climate, the landscape, material goods and cultural heritage, as well as the interactions between the components [Dyrektywa… 2011]. It is also stressed that an evaluation involving SEA should make references to analyses of various alternative development scenarios [Bai and Xu 2008].

According to the conclusions from the 2012 SEA Effectiveness Review Report prepared by the Irish Environmental Protection Agency, the weakest stages of the SEA include effective monitoring of plan effects, as well as the effective consideration of alternatives, and—as a result of this—informed decicion-making [EPA 2012]. Integrating the evaluations performed by various experts and formulated using various methods is a considerable methodological challenge [Sánchez and Silva-Sánchez 2008, Łatuszyńska and Strulak-Wójcikiewicz 2014]. Practice shows that these analyses are usually conducted in a descriptive manner. They provide answers for a series of questions formulated by the person responsible for the SEA themselves or questions included on preexisting lists [Kistowski 2002]. This technique, referred to as the descriptive-verbal technique is classified as a method of qualitative evaluation, for which one alternative is the quantitative evaluation method [Bednarek 2012].

Quantitative evaluation allows for a more objective and parameterised SEA for the impact of implementing planning documents, using the point-rank or the number-sum techniques. The point-rank technique is based on performing the SEA with the use of symbols (e.g. numbers, letters, conventional characters, hatching or colour markings on maps) marking the rank of the evaluated component. The number-sum technique marks each value using numbers in a so-called continuous multi-range scale. These values are then subject to arithmetic operations, which produces a synthetic value from each elementary value [Bednarek 2012]. The matrix technique is most commonly used for this, as it allows the identification of conflicts between spatial policy aims and environmental protection. These analyses, however, include a certain degree of subjectivity and are often unable to represent spatial-temporal aspects [González et al. 2011]. So far, practice shows that the spatial dimension of relations was often ignored or concealed in the entire decision process [Antunes et al. 2001].

The current direction of research taken by specialists in the SEA field is to make use of environmental indicators, which allows for objectivising the evaluation process and comparing the results achieved for different alternative variants. The environment which allows for their implementation is the Geographic Information Systems (GIS). By using GIS in research, one can create and transform environmental indicators based on various databases. The GIS-based approach in SEA may serve as an answer to problems faced by the European Union regarding the effective implementation of this procedure. Using this sort of approach is postulated by scientists, yet part of the research only involves the possibilities for using it, without testing their functionality in practice [Sojka i in. 2014].

GEO-ENVIRONMENTAL INDICATORS

One of the fundamental elements of SEA is the identification, analysis and evaluation of the existing state of the environment, as well as determining its potential alterations resulting from a lack of implementing a project document [Bednarek 2012]. One of the problems making evaluation more difficult is the vaguely general character of the description of planned activities. This makes it impossible to perform an objective evaluation of the impact of the analysed documents on the environment. One solution to this problem might be to use indicators of the state of the environment evaluating the possible impact of the realisation of strategic documents on the natural environment [Kistowski 2002].

Examples of indices for the state of the environment proposed for use in strategic evaluations of environmental impact might be classified into three groups of indicators: (1) indicators for the resources/values, e.g. the size of surface water resources, the size of groundwater resources, the quality of agricultural production space, the attractiveness of the natural environment for recreation, forestation rate; (2) anthropogenic pressure indicators, e.g. household electric energy use, gas emission to the atmosphere from particularly harmful sources, water consumption for purposes of state economy, the number of sewage discharged to surface waters and groundwater, the amount of industrial and communal waste; (3) indicators for the quality of the environment, e.g. the quality of atmospheric air, the quality of surface waters, the share of land requiring recultivation, anthropogenic transformations of the vegetation.

The indicators are to complement the evaluation process and the monitoring of spatial management [Kistowski 2002]. There are more proposals and divisions of indicators used to verify the occurring changes [PAN 2012, Fogel 2005]. There is however a common element to each of the elaborations. Each of them stresses the important role of the GIS, indispensable in creating, analysing and modifying the existing environmental indices. These tools are becoming increasingly significant in the evaluation of environmental landscape changes, sustainable development or environmental management. The role of GIS systems is also highlighted as especially useful on the stage of collection and preparation of data required for the process of estimating environmental indices [Strulak-Wójcikiewicz and Łatuszyńska 2014]. However, not every environmental indicator will be directly dependent on spatial features. Some of them may be calculated exclusively on the basis of statistical data. Despite of this, part of the environmental indicators are closely related to spatial features (surface or structure). This group has been defined by the authors as the geo-environmental indicators group, consisting of change monitoring tools suggested in the below proposal of a methodological complementation of the SEA procedure.

AIM OF THE RESEARCH, MATERIALS AND METHODS

The aim of the article is to verify the hypothesis regarding the possibility of implementing environmental indicators in the SEA procedure for the planning document. The indicators used for the purpose of this research have been classified into two groups: environmental quality indicators and anthropogenic pressure indicators. The principles behind calculating each indicator have been represented further in this study.

The research described in the article is universal in character, yet in order to verify the hypothesis regarding the possibility of using environmental indicators for evaluating planning documents in practice, the established quantitative evaluation model has been tested on an example planning document. The test document was a Local Spatial Development Plan for an area located in the vicinity of the Centralna, Polna and Chińska streets in Wrocław, an area of 97 ha. It needs to be stressed that the model is universal in character and may be used to evaluate every planning document as long as information such as intended terrain use and the estimated built-up density is available.

With regard to spatial data the study makes use of information regarding the current use of terrain and land cover (European Environmental Agency data – the Urban Atlas) as well as planned future management (the Master Plan for the area located in the vicinity of the Centralna, Polna and Chińska streets in Wrocław). The following types of statistical data has been used:

- information regarding the minimum levels of biologically active area;
- data regarding the annual average rainfall;
- indices for surface runoff determined for each form of land cover [Bzymek and Jarosińska 2012];
- the scope of emission using the example of roads [Kula et al. 2008];
- data regarding annual water consumption per one resident;
- data regarding the annual amount of discharged sewage per one resident;
- data regarding the annual amount of waste from households per 1 resident.

The AcGIS software served as the environment for the analyses, after extending its functionality with the use of the CommunityViz platform. The suggested tool may be an innovative supplement for standard methods used in SEA. It has been assumed that the used instrument will allow to perform the analysis and evaluation of the influence of various spatial development variants on elements of the natural environment, such as impact on water, soil and air. Four scenarios have been created in the article: (1) Base Scenario—resulting from the provisions of the Master Plan; (2) Scenario No. 2—the same terrain use as in the Base Scenario with an increase in population density by 5%; (3) Scenario No. 3—a variant representing minimal changes in spatial management in comparison to the Base Scenario, with an increase in population density by 10%; (4) Scenario No. 4—a variant assuming the realisation of the provisions of the plan exclusively in the northern part, with an increase in population density by 15% (Fig. 1).

Each land development variant has been subjected to an indicator-based evaluation with regard to its potential impact on the environment. The following environment quality indicators have been established as part of research:

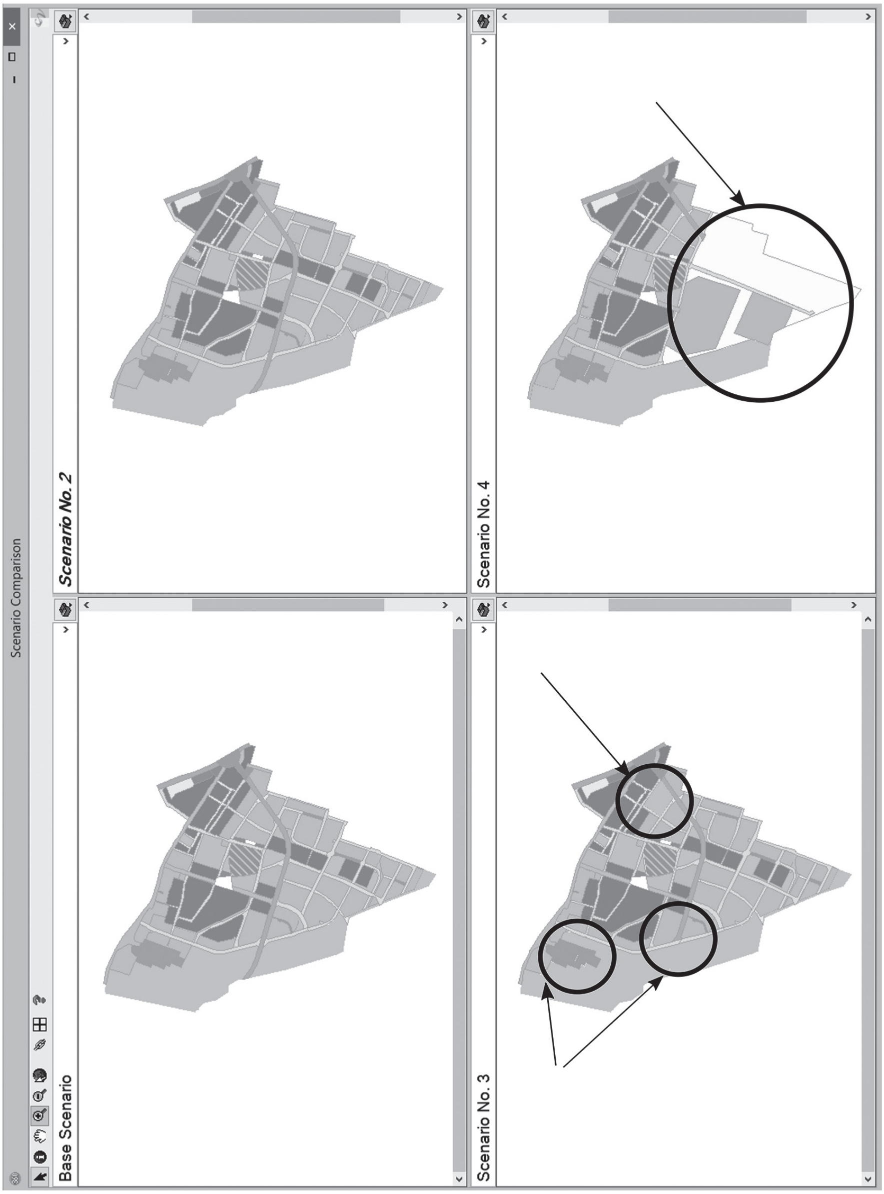


Fig. 1. Land development scenarios
Ryc. 1. Scenariusze zagospodarowania terenu

1.1. the biologically active area indicator – estimated on the basis of the total area of each of the areas and the minimal levels of biologically active area determined for them (expressed in %), in accordance with the following formula:

$$I_{BA_a} = \sum \frac{A_i \cdot B_{A_a \min}}{100\%}$$

where:

I_{BAa} – the minimum biologically active area index,
A_i – the area of the *i*-th terrain,
$B_{Aa\min}$ – the minimum biologically active area level for *i*-th terrain specified in the Master Plan;

1.2. annual average surface runoff index, measured as a quotient of the area of a given unit, annual average rainfall (for Wrocław – 0.522 m) and the runoff indicator determined for each form of land use as expressed in the following formula:

$$I_{RO} = \sum A_i \cdot RO_i \cdot R_{AA}$$

where:

I_{RO} – the annual surface runoff index,
A_i – the area of the *i*-th terrain,
RO_i – the runoff indicator for the i-th land use type,
R_{AA} – the average annual rainfall for Wrocław.

Runoff indicators are assumed on the basis of literature depending on the type and character of the watershed. The type of development and land (such as agricultural land, forests) is also taken into account [Królikowski and Królikowska 2009], along with terrain slopes (i.e. 0.5%, 1.0%, 2.5%, 5.0%, 7.5%, 10.0% slopes) [Bzymek and Jarosińska 2012]. About 40% of the studied area includes terrain slopes less than or equal to 0.5%, with the next 20% being less than 1%. Due to the above, the values of the runoff ratios for land use forms have been assumed based on the values established for types of development and land with 0.5 terrain slopes, i.e. (Table 1):

1.1. The indicator for the scope of dust emission from automobile tiers – the buffer zone surrounding roads vulnerable to accumulation of rubber dust in the soil from automobile exploitation (calculated in two variants: minimum reach of 15 metres and maximum reach of 45 metres) (Fig. 2);
1.2. The indicator for the scope of dioxane emission – the buffer zone surrounding roads vulnerable to accumulation of dioxanes in the soil emitted during automobile exploitation (calculated in two variants: minimum reach of 10 metres and maximum reach of 50 metres);
1.3. The indicator for the scope of vegetation destruction caused by salt – the buffer zone surrounding roads vulnerable to vegetation degradation due to using road salt for maintaining open roads during winter (calculated in two variants: minimum reach of 15 metres and maximum reach of 90 metres).

The minimum and maximum affected area for the 1.3,1.4 and 1.5 indicators have been assumed based on external research [Kula et al. 2008].

Table 1. Runoff indicators determined for each land use form
Tabela 1. Wskaźniki spływu powierzchniowego dla poszczególnych form użytkowania terenu

Land use form	Runoff indicator
Rural	0.05
Green areas	0.1
Low density housing, services	0.6
Road	0.7
High density housing	0.8

Source: own elaboration based on Bzymek and Jarosińska 2012

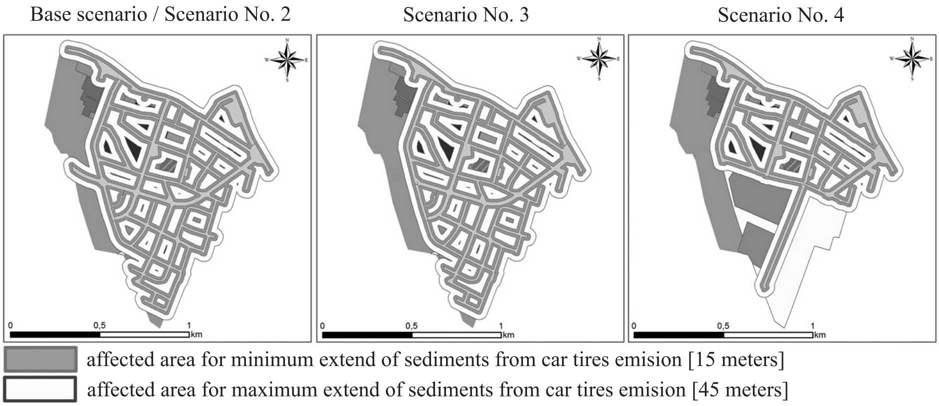


Fig. 2. Delineated affected areas for the minimum and maximum scope of dust emission from automobile tiers
Rys. 2. Wytyczone powierzchnie oddziaływania dla minimalnych oraz maksymalnych zasięgów emisji osadów z opon samochodowych

The second group of indicators included anthropogenic pressure indices resulting from the population density of the test area:

2.1. The indicator for annual water consumption in residential areas, taking into account the area of the housing development, population density and annual water consumption per resident, as expressed in the formula:

$$Iwc = \sum \left(A_i \cdot P_D \cdot Iwc_a \right)$$

where:

Iwc – the annual water consumption index for residential areas,
A_i – the area of the i-th residential terrain,
P_D – is the average population density of land use plan area,
Iwc_a – is the annual water consumption per capita index.

2.2. The indicator for annual discharged sewage in residential areas, taking into account the area of the housing development, population density and annual production of waste per resident, as expressed in the formula:

$$I_{SD} = \sum \left(A_i \cdot P_D \cdot I_{SD_a}\right)$$

where:

I_{SD} – the annual quantity of discharged sewage in the residential area,
A_i – the area of the *i*-th residential terrain,
P_D – the average population density of land use plan area,
I_{SDa} – the average annual rate of sewage discharge per capita index.

2.3. The indicator for the amount of produced communal waste in residential areas, taking into account the area of the housing development, population density and annual production of communal waste per resident, as expressed in the formula:

$$I_{LW} = \sum \left(A_i \cdot P_D \cdot I_{LW_a}\right)$$

where:

I_{LW} – the annual quantity of residential area landfilled waste index,
A_i – the area of the *i*-th residential terrain,
P_D – the average population density of land use plan area,
I_{LW_a} – the average annual quantity of landfilled waste per capita index.

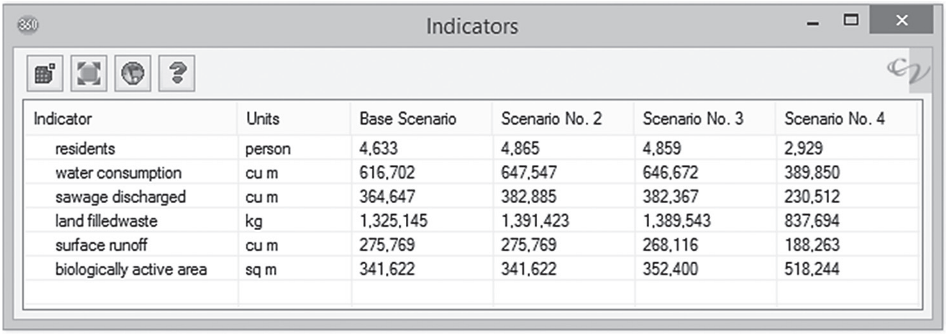
The use of statistical and spatial data allows for the calculation of approximate environmental impact related to the implementation of the objectives of each planning document containing this type of information. This solution may serve as an element of a decision support system in the process of spatial planning and urban management.

RESULTS

Establishing the variants served the purpose of representing the functionality of the concept of using geo-environmental indicators in SEA. The results for each scenario detailed below indicate that even minimal changes in development or alterations in population density in residential areas are automatically taken into account and analysed The indicators used in the research have been entered into the system in accordance with the formulas described in an earlier chapter. After their calculation is complete the system's dialogue window automatically informs the user of the value of each indicator in each scenario (Image 3). Such an arrangement of data provides the user with a quantified, and thus objectivised approach to variant evaluation for each development vision.

Geo-environmental indicator results can easily be saved as spread sheets, which allows for their further processing and visualisation in SEA reports. The achieved results should serve as a starting point in deliberations regarding the acceptable impact level of planned activities on existing environmental resources. Potential influence should be confronted with available environmental resources. The geo-environmental indicator values for the test area have been represented below (Table 2).

The aim of this comparative analysis is not to arbitrarily assume which of the proposed land development variants is the most beneficial. The variants involve different populations for the test area and various built-up area. The impact on the environment will be different with each implemented scenario. The idea behind the above analysis was to present the possibility of comparing different visions for development, based on the knowledge of approximate values and their impact in the decision process.



Indicator	Units	Base Scenario	Scenario No. 2	Scenario No. 3	Scenario No. 4
residents	person	4,633	4,865	4,859	2,929
water consumption	cu m	616,702	647,547	646,672	389,850
sawage discharged	cu m	364,647	382,885	382,367	230,512
land filledwaste	kg	1,325,145	1,391,423	1,389,543	837,694
surface runoff	cu m	275,769	275,769	268,116	188,263
biologically active area	sq m	341,622	341,622	352,400	518,244

Fig. 3. The values of established indicators for each spatial development scenario
Ryc. 3. Wartości wskaźników dla poszczególnych scenariuszy zagospodarowania przestrzennego

Table 2. Geo-environmental indicator values
Tabela 2. Wartości wskaźników geo-środowiskowych

Scenario name	Population density	Number of residents	Environmental quality indicators					Anthropogenic pressure indicators		
			1.1.	1.2.	1.3.*	1.4.*	1.4.*	2.1.	2.2.	2.3.
Base Scenario	9697	4633	34	276	$\frac{31}{73}$	$\frac{22}{77}$	$\frac{31}{99}$	617	365	1325
Scenario No. 2	10182	4865	34	276	$\frac{31}{73}$	$\frac{22}{77}$	$\frac{31}{99}$	648	383	1391
Scenario No. 3	10667	4859	35	268	$\frac{31}{72}$	$\frac{21}{75}$	$\frac{31}{97}$	647	382	1390
Scenario No. 4	11152	2929	52	188	$\frac{20}{51}$	$\frac{14}{54}$	$\frac{20}{76}$	390	231	838

* The values of indicators 1.3, 1.4, 1.5 have been represented using two values, taking into account the minimum and maximum area of influence (ha). The upper part of the cell for each given type of emission in a scenario represents the minimal value, with the lower part being the maximum area.

* Wartości wskaźników 1.3, 1.4, 1.5 przedstawione zostały za pomocą dwóch wartości, dla każdego rodzaju emisji w każdym ze scenariuszy, przedstawiają minimalne i maksymalne powierzchnie oddziaływania (ha). Wartość minimalną reprezentuje górna część komórki dla danego rodzaju emisji w danym scenariuszu, wartość dolna - maksymalną powierzchnię.

The results of the geo-environmental indicator calculation show that the Base Scenario and Scenario No. 2 represent the most unfavourable impact with regard to environmental quality indicators. In the case of anthropogenic pressure indicators Scenario No. 2 and

Scenario no. 3 involve the most unfavourable impact. In both indicator groups Scenario No. 4 is characterised by the least unfavourable impact. It is, however, noteworthy that Scenario No. 4 assumes a much smaller number of residents in the area. Not every indicator has an adequately, proportionally lower environmental impact. A smaller number of residents in the analysed area may involve the need to delineate additional terrain for residential purposes, which will also have its negative impact on the environment. It is thus important to remember that the results of such calculations serve as a referential value and may help the decision-makers in answering the question whether a given development vision is realistic and whether the available environmental resources will prove sufficient to fulfill the needs of future users.

SUMMARY AND DISCUSSION

Both scientists [Kistowski 2002, González et al. 2011] as well as practitioners [EPA 2012] involved in matters related to the SEA procedure point that there exist certain problems related to its functioning. One of the basic problems in this respect is the poor objectivity of conducted evaluations and a lack of the option to easily compare different variants. The combination of the spatial approach with environmental indicators extends beyond previously utilised descriptive evaluations or evaluation techniques. The proposal of assuming a methodical approach to the problem, represented in this article, involves the quantification of the impact of spatial development on selected components of the environment using geo-environmental indicators. The verification of the proposed concept on a test area proved that the indicators are applicable in practice and extend beyond theoretical deliberations. The suggested methodical approach is possible to implement in the process of ensuring spatial information regarding the area and layout of future land development, as well as statistical data characterising the manner of development and the unit consumption of environmental resources.

The results achieved in this study form a quantified information regarding the quality of the environment and anthropogenic pressure of planned spatial development. It needs to be stressed that the attained values do not currently represent the full information on the adequacy of planned actions in a given area. The geo-environmental indicator values provide only the possibility to compare the proposed solutions and to determine the order of magnitude of potential impact.

The results of measurements with the use of the proposed indicators should thus be interpreted not as an answer to the question regarding which of the scenarios is properly suited to local determinants. The only outcome is an approximate accumulated effect of the planned activities, and the answer to the question of which of the variants is more beneficial taking into account specific components of the environment. The physical dimension of development changes, which can be attained using the proposed approach, can thus serve as a decision support system not only in the SEA but also in other analyses and elaborations created in the process of space management and planning.

One future direction for research which could help answer the question of whether a given development scenario is suited to local determinants should be based on confronting the capacity of the environment in regard to the planned use of available environmental resources. This type of approach will help determine whether a given scenario will lead to excessive exploitation, and thus degradation, of the natural environment through human actions. The suggested geo-environmental indicators are thus one of the components which can serve as a solution to contemporary problems present in the evaluation of the impact of plans and strategic documents on the environment. The results of this study are a manner of supporting the SEA procedure and a way to pursue effective environmental protection and development.

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WSKAŹNIKI GEO-ŚRODOWISKOWE W STRATEGICZNEJ OCENIE ODDZIAŁYWANIA NA ŚRODOWISKO

Streszczenie. Obowiązkiem państw członkowskich Unii Europejskiej jest przeprowadzenie Strategicznej oceny oddziaływania na środowisko (SOOŚ) w celu wdrożenia zasad ochrony i kształtowania środowiska w ramach dokumentów strategicznych i polityk rozwojowych. Jak pokazuje praktyka, SOOŚ są często wykonywane w sposób opisowy i subiektywny, co utrudnia przeprowadzenie ostatecznej oceny porównawczej alternatywnych wariantów rozwoju. Wykorzystanie wskaźników geo-środowiskowych, które pozwalają na kwantyfikację stanu środowiska, procesów transformacji i zjawisk zachodzących w przestrzeni, mogą przyczynić się do większej obiektywizacji SOOŚ.

Celem artykułu jest próba wdrożenia wskaźników geo-środowiskowych do procedury SOOŚ. W ramach badań opracowano matrycę wskaźników geo-środowiskowych uwzględniających wskaźniki jakości środowiska i wskaźniki presji antropogenicznej. Do analiz wykorzystano oprogramowanie ArcGIS z platformą CommunityViz. Zaproponowana koncepcja i opracowany model oceny skutków środowiskowych dokumentów planistycznych stanowi wkład w dyskusję na temat metodologii SOOŚ i wykorzystania środowiska GIS w SOOŚ.

Słowa kluczowe: wskaźniki środowiskowe, Strategiczna ocena odziaływania na środowisko (SOOŚ), zarządzanie środowiskiem

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