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SPATIAL DIFFERENTIATION OF THE LEVEL OF ECOLOGICAL DEVELOPMENT OF POLISH VOIVODESHIP

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Purpose: The aim of the research is the evaluation of the ecological state of development based on statistical data from voivodeships in Poland.
Design/methodology/approach: The research uses selected methods of multivariate comparative analysis, in particular, linear ordering. The analysis of the differentiation of the level of ecological development by voivodeships in Poland made it possible to order the provinces according to the indicators that represent the state of the environmental situation. After the process of ordering, the process of grouping voivodeships was possible. The relevant calculations were made using QGIS and Statistica software.
Findings: The result of the analysis presents a tree main cluster with similar voivodeships according to ecological situation.
Practical implications: The presented methods enable continuous monitoring and control of progress in the implementation of the assumed ecological goals. Green development assessment methods can also help monitor progress towards the Sustainable Development Goals over time. This can help identify trends and patterns and provide feedback on the effectiveness of policies and programs. The results of the analyses may be a useful tool for monitoring and evaluating Poland's progress in achieving the assumed ecological goals of the European Union by 2030.
Originality/value: These studies are a very useful tool in identifying the ecological situation and directing administrative activities to the appropriate regions in the country.
Keywords: spatial analysis, sustainable development, classification.
Category of the paper: research paper**.**

1. Introduction

Economic development, which enables an increase in the quality of life in society, has a negative impact on the condition of the natural environment.

The level of environmental degradation is one of the most important aspects of sustainable development. The countries of the European Union show great commitment to the implementation of environmentally friendly initiatives and their protection. The presented article deals with the issue of measuring and monitoring the progress of countries or their regions in ecological activities. The authors of the article answer the question of how to measure and evaluate ecological development in a given administrative area. The level of ecological development is a multidimensional phenomenon; therefore, the article presents the chosen method of linear ordering for ranking voivodships in Poland according to the level of ecological development and then grouping voivodeships according to the degree of development. As a result of the research, it is possible to present the results on a map in spatial terms of the level of ecological development of the examined regions of Poland.

2. Literature review

The ecological aspects of the state of the natural environment are issues of the utmost importance for the development of society today and in the future. Progressive degradation of the environment should be stopped and subject to control and monitoring. In practice, there are many voluntary initiatives serving this purpose, and more and more environmental standards are being developed that put limits on further uncontrolled pollution of the environment (Ranosz et al., 2020). The popularization of this topic in the literature deepens the awareness of society about ecological issues, which has measurable benefits for caring for the condition of the environment. Environmental aspects are of great importance to today's society (Manowska et al., 2017), as they affect our health, well-being, and even the survival of our species. The Earth's climate is changing rapidly due to human activities such as the burning of fossil fuels, deforestation, and industrialization. Climate change leads to rising sea levels, extreme weather events, and the loss of biodiversity, which can have devastating effects on ecosystems and human communities (Bluszcz, Manowska, 2021). Environmental pollution, including air and water, can have harmful effects on human health (Bluszcz et al., 2023). Poor air quality can lead to respiratory problems, and contaminated water can cause diseases such as cholera and dysentery. Natural resources, such as water, soil, and minerals, are essential for human life and economic development. However, their availability is limited, and increasing demand for them could lead to their depletion, which could have serious consequences for future generations.

Biodiversity is important to the functioning of ecosystems, including the provision of food, clean air, and water. However, human activities such as deforestation, habitat destruction, and climate change are leading to biodiversity loss at an alarming rate. Environmental aspects are important to achieving sustainable development, which means meeting present needs without detracting from the ability of future generations to meet their needs. Sustainable development requires balancing economic, social, and environmental factors. In summary, environmental aspects are crucial to today's society because they affect our health, well-being, and the survival of our species. Protecting the environment is not only a moral obligation but also necessary to ensure a sustainable future for all. Environmental degradation is the dominant problem of today's generations. The idea of sustainable development implies that our generation should use natural resources in a sustainable manner to enable future generations to have access to them. The concept promotes a precautionary approach aimed at using natural resources efficiently today so that the natural process of ecosystem renewal can take place, thereby protecting sustainability for future generations.

In the literature, it is possible to find a great variety of methods for measuring the use of the environment (Jonek-Kowalska, 2022; Manowska, Nawrot, 2019; Burchart-Korol et al., 2014) and there is no one universal method. Among the very popular methods are multivariate analyses (Gajdzik, 2012; Kijewska, Bluszcz, 2016; 2017; Brodny, Tutak, 2020), which allow the evaluation of the problem under study on the basis of many diverse evaluation criteria.

Therefore, the subject of research in the article is the evaluation of the ecological state of development based on statistical data from voivodeships in Poland. The research uses selected methods of multivariate comparative analysis, in particular, linear ordering. The analysis of the differentiation of the level of ecological development by voivodeships in Poland made it possible to order the provinces according to the indicators that represent the state of the environmental situation. After the process of ordering, the process of grouping voivodeships was possible. The relevant calculations were made using QGIS and Statistica software. The analyses refer to statistical data from 2021, which were published on the webpage of the Central Statistical Office in Poland. The results of the analyses provide a useful tool for monitoring the state of the environment in the assumed time intervals, considering the selected evaluation criteria, as well as a very useful tool for monitoring situations in the spatial chart.

3. Methodology

This phenomenon Consumerism is a megatrend that characterizes today's times. This phenomenon significantly increases the consumption of natural resources and energy, which causes a dynamic trend of environmental pollution. To slow down the impact of the negative effects of consumerism on humans, there is a need for global environmental

awareness. Currently, the world has become one "ecological village," and as a result, decisions made in business entities or consumers' homes are now global, not just local (Mirski, 2017).

The Sustainable Development Goals (SDGs) are a set of 17 global goals adopted by the United Nations General Assembly in 2015 as part of the 2030 Agenda for Sustainable Development. The SDGs aim to end poverty, protect the planet, and ensure peace and prosperity for all people. The 17 SDGs are: No Poverty, Zero Hunger, Good Health and Well-being, Quality Education, Gender Equality, Clean Water and Sanitation, Affordable and Clean Energy, Decent Work and Economic Growth, Industry, Innovation and Infrastructure, Reduced Inequalities, Sustainable Cities and Communities, Responsible Consumption and Production, Climate Action, Life Below Water, Life on Land, Peace, Justice and Strong Institutions, Partnerships for the Goals. Each goal has specific targets and indicators to measure progress towards achieving the SDGs by 2030. The SDGs are interconnected and require collaboration and cooperation among all countries and stakeholders, including governments, civil society, the private sector, and individuals, to ensure a sustainable future for all (Nur Suhaili Mansor et al., 2014). Ecological development refers to the process of economic development that is environmentally sustainable and considers the impacts of economic activities on the natural environment. It is a concept that promotes economic growth while also ensuring that the natural environment is protected and preserved for future generations. Ecological development emphasizes the use of renewable resources, reducing waste and pollution, and implementing sustainable practices in industries such as agriculture, energy, and transportation. It also involves the protection of biodiversity, the preservation of ecosystems, and the reduction of greenhouse gas emissions to mitigate climate change. The concept of ecological development is closely related to the idea of sustainable development, which recognizes that economic growth must be balanced with social and environmental considerations. It seeks to promote a more harmonious relationship between economic activities and the natural environment by prioritizing the protection of natural resources and the health of ecosystems. Ecological development requires a shift in the way we think about economic growth and development, and it requires the cooperation of governments, businesses, and individuals to promote sustainable practices and protect the environment.

The article uses the methodology of linear ordering of objects, which are administrative units of Poland, into voivodships according to a synthetic measure describing the level of ecological development of a given voivodship in relation to others.

Multidimensional analysis is a method used to assess ecological development by considering multiple dimensions of ecological development. This approach recognizes that ecological development is a complex and multi-faceted issue and that progress towards sustainability must be evaluated across multiple dimensions and factors.

It should be noted that there is no one universal method for measuring the level of sustainable development or green development due to the limited access to data for selected areas and the wide range of potential variables describing specific aspects of the analysis.

Sustainable development covers a wide range of social, ecological, and economic aspects (Bluszcz, 2018; Mansor et al., 2019). The authors of this article will focus primarily on environmental aspects. The main aim of the article will be to measure and evaluate the ecological development situation. An example of the analysis will be the regions of Poland in terms of administration by voivodeships. The analysis was made on the basis of data available on the website of the Central Statistical Office of Poland, divided into voivodeships. Data on the ecological situation in terms of provinces in Poland were selected for analysis and included the following five diagnostic variables: emission of air pollutants in thousand tones particulates, emission of air pollutants in thousand tones gases (excluding carbon dioxide), industrial and municipal wastewater requiring treatment total in hm^3, waste generated (during the year, excluding municipal waste) total in thousand tones, area of special nature value under legal protection per capita in m^2. The comparative analysis was carried out in several stages:

- selection of variables for analysis,
- division of selected variables into stimulants and destimulants,
- normalization process of the selected variables,
- aggregation process of a result into a synthetic indicator,
- linear ordering according to the level of ecological development indicators,
- division into similar groups of voivodeships in Poland according to ecological situation,
- data mapping in the QGIS program according to the level of ecological development of the provinces of Poland.
- interpretation of the results and final conclusions from the analysis.

4. Results

The first stage of the analysis was the selection of diagnostic variables for analysis.

Characteristics of voivodeships according to the ecological situation can be carried out according to various evaluation criteria. The choice of evaluation criteria for this article was dictated by the availability of statistical data published on the website of the Central Statistical Office in the system for each voivodeship. The second process of dividing variables into stimulants and destimulants is based on a substantive assessment of the variable's impact on the ecological situation. As a result of the interpretation of the variables, one variable was indicated as having a positive impact on the ecological situation and was assessed as a stimulant. The final division of variables is presented in Table 1.

Table 1.
A set of diagnostic variables

	variables	type of variable
1	emission of air pollutants in thousand tones particulates,	destimulant
2	emission of air pollutants in thousand tones gases (excluding carbon dioxide)	destimulant
3	industrial and municipal wastewater requiring treatment total in hm3	destimulant
4	waste generated (during the year, excluding municipal waste) total in thousand tones	destimulant
5	area of special nature value under legal protection per capita in m^2	stimulant

Source: own elaboration based on website of the Central Statistical Office in Poland https://stat.gov.pl/

Normalization process

The available statistical data have different units, so in order to start the process of comparing variables, a normalization process should be carried out, which is used to bring the data to one measurement scale. The data normalization process is carried out according to formulas (Strahl, 1984):

-for destimulants (D):

$$\boldsymbol{z_{ij} = \frac{\min_i\{x_{ij}\}}{x_{ij}}\ x_{ij} \neq 0,} \tag{1}$$

- for stimulants (S):

$$z_{ij} = \frac{x_{ij}}{\max_i\{x_{ij}\}}\ \max_i\{x_{ij}\} \neq 0 \tag{2}$$

where:

x_{ij} - the value of the diagnostic variable

Z_{ij} - the normalized value of x_{ij}

The matrix of the data normalized in accordance with the formulas (1) and (2) is presented in the table 2.

Table 2.
A set of normalized diagnostic variables

	Variable X1	Variable X2	Variable X13	Variable X4	Variable X5
malopolskie	0.41667	0.124595	0.159574	0.142073	0.294718
slaskie	0.11628	0.013354	0.103781	0.022000	0.076233
wielkopolskie	0.33333	0.252459	0.204978	0.189556	0.315022
zachodniopomorskie	0.33333	0.432584	0.385675	0.121904	0.370578
lubuskie	0.83333	0.987179	1	1	0.651844
dolnoslaskie	0.35714	0.259259	0.22412	0.017447	0.160563
opolskie	0.41667	0.179487	0.675241	0.516923	0.333458
kujawsko-pomorskie	0.26316	0.262799	0.307918	0.399177	0.352516
warmińsko-mazurskie	0.83333	0.740385	0.810811	0.540333	1
pomorskie	0.71429	0.455621	0.306569	0.334721	0.320752
lodzkie	0.31250	0.067367	0.433884	0.079528	0.183483
swietokrzyskie	0.38462	0.115616	0.526316	0.119965	0.781141
lubelskie	0.41667	0.48125	0.546164	0.112312	0.342053
podkarpackie	0.55556	0.647059	0.551181	0.845770	0.472845
podlaskie	1	1	0.985915	0.685634	0.682362
mazowieckie	0.25000	0.120313	0.148305	0.097139	0.533508

Source: own elaboration.

After a normalization, aggregation was introduced. The values $\max_i\{x_{ij}\}$, $\min_i\{x_{ij}\}$ used for the normalization specify the coordinates of the so-called model object with optimum values of the examined diagnostic variables. The normalized data have undergone the process of aggregation by means of the calculation of the value Zi (i = 1, …, m) of the synthetic variable Z (indicator of an ecological situation). The following multidimensional object with the standardized coordinates: Q0 = [z01 z02 … z0k].

Where the coordinates of the model object z0j (j = 1, …, k) take the form of

$$z_{0j} = \begin{cases} \max_i\{z_{ij}\} \ dla\ j \in S \\ \min_i\{z_{ij}\} \ dla\ j \in D \end{cases} \tag{3}$$

At the same time {X}={S}∪{D} (the sum of the sets of all stimulants and destimulants is the set of all the diagnostic variables). Where S means a set of stimulants and D – a set of destimulants for normalized variables of the observation matrix X. where (i = 1, …, m; j = 1, …, k). the value of the diagnostic variable j in the object i (province). In this way, all diagnostic variables are treated as equally important when constructing the synthetic measure of development. For the assessment of the ecological situation of voivodships of Poland the synthetic measure calculated in accordance with the formula was used (Strahl, 1984):

$$z_i = 1 - \frac{d_{io}}{d_o}\ (i = 1, \dots, m) \tag{4}$$

d_{io} – the distance between the object Qi (i = 1, …, m) and the hypothetical (abstract) model object Q0 calculated in accordance with the formula:

$$d_{io} = \left[\sum_{j=1}^{k}\left(z_{ij} - z_{oj}\right)^2\right]^{0,5}\ (i = 1, \dots, m) \tag{5}$$

The Euclidean distance d_{io} constructed this way was used to compare the level of ecological situation of the examined objects (voivodships). The interpretation of the scale d_{io} is as follows: the smaller the value of the distance d_{io} the higher the level of development has been achieved by a given object (voivodships).

The value do is expressed by means of the formula:

$$d_o = \overline{d_o} + 2s_o \tag{6}$$

where:

$$\overline{d_o} = \frac{1}{m}\sum_{i=1}^{m} d_{io} \tag{7}$$

$$s_0 = \left[\frac{1}{m}\sum_{i=1}^{m}\left(d_{io} - \overline{d_0}\right)^2\right]^{0,5} \tag{8}$$

The next stage of the research is ordering object. The ranking of voivodships in Poland in accordance with the synthetic ecological indicator has been presented in table 3.

Table 3.
The ranking in accordance with the synthetic ecological indicator

	synthetic ecological indicator
lubuskie	0.8384
podlaskie	0.8130
warminsko-mazurskie	0.7553
podkarpackie	0.6200
pomorskie	0.4446
opolskie	0.4393
lubelskie	0.4031
swietokrzyskie	0.3785
zachodniopomorskie	0.3641
kujawsko-pomorskie	0.3593
wielkopolskie	0.3049
malopolskie	0.2699
mazowieckie	0.2641
lodzkie	0.2544
dolnoslaskie	0.2477
slaskie	0.1258

Source: own elaboration.

The result of the analysis is, among others, a ranking of voivodships according to the level of ecological development and based on a synthetic indicator. Based on the analysis, it can be concluded that the voivodeships with the highest level of the indicator are characterized by the best condition of the natural environment in the country. In 2021, the voivodship with the highest rate is Lubuskie (0.8384), and the lowest is Slaskie (0.1258).

The next stage of the analysis was to group voivodeships and present the results on a spatial map. The division into similar groups of objects was made using the Ward method for the square of the Euclidean distance. The results of the analysis are presented in the tree diagram in Figure 1, which shows the result of the analysis from the Statistica program. The spatial presentation on the map was made in the QGIS program.

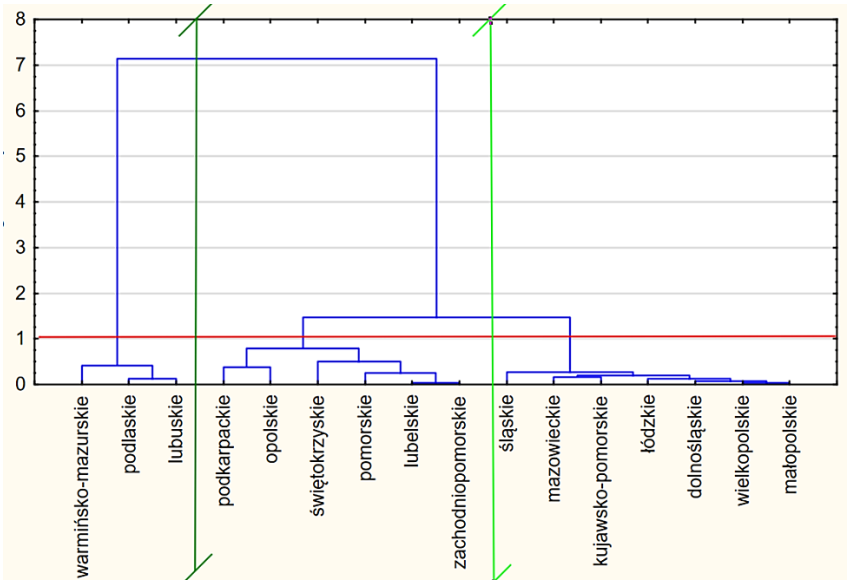

Figure 1. Selection of groups of voivodeships with a similar level of ecological development.

Source: own elaboration.

The first group consists of voivodeships with the best ecological situation: lubuskie, podlaskie, and warmińsko-mazarskie. The second group of similar voivodeships are: podkarpackie, opolskie, świętokrzyskie, pomorskie, lubelskie, and zachodniopomorskie. The third group of voivodships with a relatively unfavorable ecological situation are: śląskie, mazowieckie, kujawsko-pomorskie, łódzkie, dolnoślaskie, wielkopolskie, and małopolskie.

The results of the analysis indicated three groups of voivodeships, which were presented on the map in the QGIS program (fig. 2).

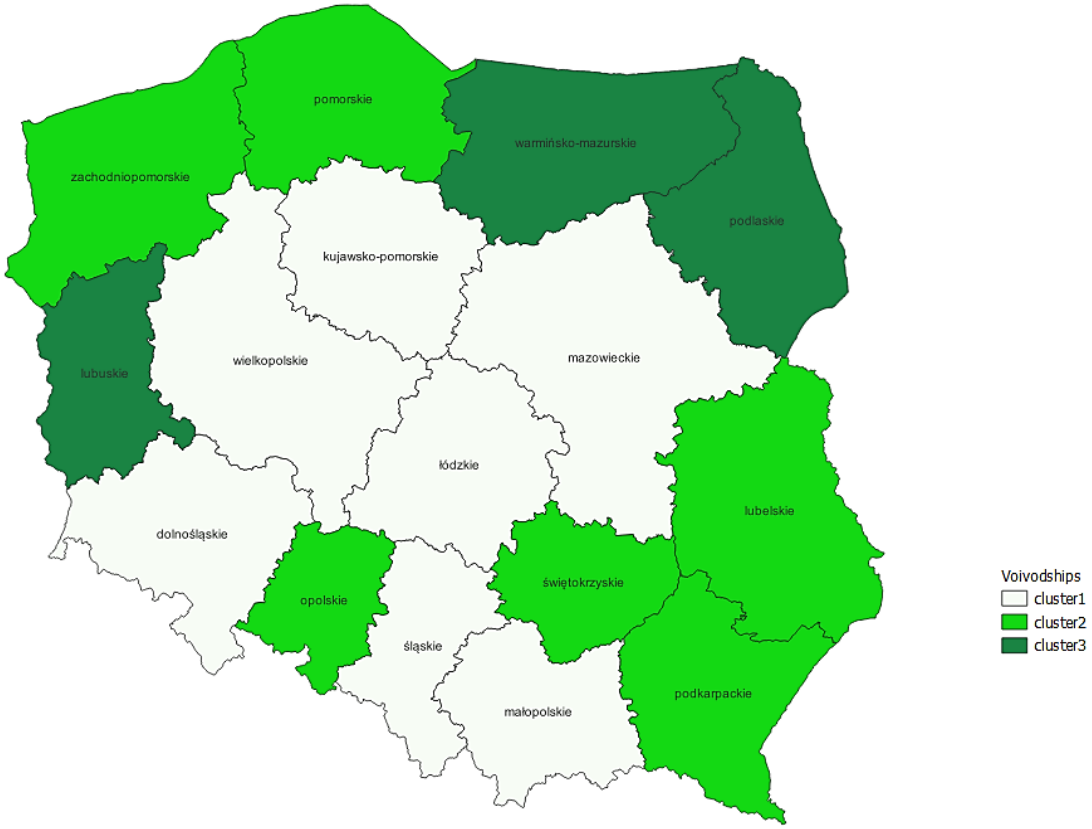

Figure 2. Selection of groups of voivodeships with a similar level of ecological development.
Source: own elaboration.

Figure 2 presents the tree main cluster with similar voivodeships according to ecological situation. The green color shows the most ecological voivodeships, and the white color on the map shows the voivodeships with the most unfavorable ecological situation. These studies are a very useful tool in identifying the ecological situation and directing administrative activities to the appropriate regions in the country. The results of the analyses may be a useful tool for monitoring and evaluating Poland's progress in achieving the assumed ecological goals of the European Union by 2030.

5. Discussion

The degradation of the natural environment requires constant monitoring and control. Therefore, there is a need to measure the condition of the natural environment with appropriate methods and tools.

The article addresses the important issue of answering the question of how to effectively measure and monitor the progress and effects of actions taken by national institutions to improve the ecological situation of voivodships.

The implementation of the sustainable development goals requires the implementation of adequate methods of measuring progress in achieving the assumed goals.

The article presents one of the many methods of multidimensional comparative analysis, which is perfect for assessing phenomena described by many diagnostic variables. The presented solution is not ideal or the best solution because the quality of the obtained results depends primarily on the quality of the available statistical data. Many phenomena or aspects related to sustainable development can be described by various variables but accessing them can be difficult. Therefore, the authors, using the available statistical data for each voivodeship, present the popular methodology as a model that can be successfully used in practice to assess the level of ecological development of the surveyed areas in the country as well as in other European Union countries.

6. Conclusions

The article presents an example of multidimensional analysis and linear ordering, which can be used in practice to control the ecological situation for any area. The article uses the assessment of the level of ecological development for voivodeships in Poland for data from 2021. Monitoring may apply to any selected time intervals for which relevant statistical data are known. These methods are a very valuable tool for several reasons such as: identify areas for improvement: green development assessment methods can help identify areas where improvements are needed, such as reducing carbon emissions, improving air and water quality, and protecting biodiversity. This information can be used to develop targeted regional or global policies and strategic programs to address these challenges. The presented methods enable continuous monitoring and control of progress in the implementation of the assumed ecological goals. Green development assessment methods can also help monitor progress towards the Sustainable Development Goals over time. This can help identify trends and patterns and provide feedback on the effectiveness of policies and programs.

An innovative aspect of the article is the presentation of the results of the statistical analysis and the grouping carried out into sets of voivodships similar in terms of ecological situation, and the presentation of these results in spatial terms. A clear presentation of the studied phenomena on spatial charts is currently a rapidly developing trend that is conditioned by the dynamic development of the functionality of the QGIS software.

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