

GEOSPATIAL MODELING OF DIRECTIONS FOR THE DEVELOPMENT AND IMPLEMENTATION OF THE LAND ADMINISTRATION SYSTEM AT THE REGIONAL LEVEL

Andrii BIELIATYNSKYI¹, Kostiantyn MAMONOV², Volodymyr GRYANYK³, *, Olena KANIVETS⁴, Lyudmyla KOVALENKO⁵

¹ School of Civil Engineering, North Minzu University, 204 Wenchang Road, Yinchuan, NingXia, P.R. China

² Department of Land Administration and Geoinformation Systems O. M. Beketov National University of Urban Economy in Kharkiv, 17, Chornoglazivska Street, Kharkiv, Ukraine.

³ Pridneprovskaya State Academy of construction and architecture, 24A Chernyshevsky Str., Dnipro, Ukraine

⁴ Sumy National Agrarian University, 160 Herasyma Kondratieva Street, Sumy, Ukraine

⁵ Department of Higher Mathematics, O. M. Beketov National University of Urban Economy in Kharkiv, 17, Chornoglazivska Street, Kharkiv, Ukraine

* corresponding author: volodymyr_gryanyk@sci-academy.cc

Abstract

The article is devoted to researching the topical issue of the development and implementation of a modern land administration system as a direction of land relations, considering the development of geo-information systems, mathematical modeling tools and international experience. For the implementation of the land administration system, it is proposed to ensure the comprehensive application of the distribution or determination of the right to land; intensification of the processes of determining boundaries between areas; increase in the level of informatization of land relations; ensuring transparency of procedures regulating land transactions, including sale, lease; resolution of uncertainty or dispute resolution regarding land rights and boundaries; use of modern tools and implementation of land planning, control and monitoring processes; ensuring land assessment and taxation procedures; active public involvement and bureaucratic transparency; increasing level of visualization of land management elements; increasing the effectiveness of land restriction management, etc.

Keywords:

land administration principles;
graph theory;
category theory;
category theory;
land use.

1 Introduction

In today's ambiguous conditions of the transformation of land relations, the formation of an effective system of land relations, considering international experience and meeting the needs of society, is an urgent issue. The duration of the land reform in Ukraine led to the existence of a significant number of legislative and regulatory acts in the field of land relations. However, it is almost impossible to transform land relations without adequate changes in their legal regulation. It was determined that the adopted legal acts adopted by the state authorities may be inconsistent with the current land legislation or contain contradictory provisions. The imperfection of the activities of some individual legislative bodies creates problematic aspects that reduce the effectiveness of regulatory and legal support and land use at the regional level.

Disadvantages and problems of land use are revealed by comparing existing domestic regulations and international experience (Table 1) [1].

Table 1. The results of a comparative analysis of domestic and international experience in the formation and implementation of land relations (developed by the author)

No.	International experience	Domestic practice
1	Land legislation is systematic and clearly related to legislative acts in other spheres of life	The legislation of Ukraine in the field of land relations is not complete,
2	International requirements for land relations between society and the state are clearly controlled	holistic and has certain contradictions
3	Elected bodies at all levels are an effective link of the state policy system	Modern land relations in Ukraine within the boundaries of land use and land ownership are not sufficiently regulated at the legislative level
4	The system of formation and implementation of the state land policy is effectively integrated into the national management system	Local self-government bodies are not efficient enough due to the irrational distribution of functions and powers between them and state administrations, as well as due to pressure from the state authorities and lack of resources
5	The information support system is complete, detailed, accessible and convenient	State and regional programs and activity plans in the spheres of industry, energy, and urban planning do not always agree with the norms of land use, urban planning, and environmental regulations, and sometimes violate these norms
6	Land management bodies are covered by effective and transparent control and audit systems	The elements of the cadastral and registration systems have been developed, meet international standards and practical needs, but have not yet been fully implemented due to the complexity and lack of independence of bodies that have an impact on land management processes

As can be seen from the Table 1 in fact, none of the recommended requirements in land use practice is fully implemented and has certain problematic aspects. The state domestic land policy does not fully meet European and global criteria and requirements for effective management of land resources. Identified problematic aspects of the formation and implementation of land relations at the regional level. First, there is insufficient control over legislation, which is evidenced by a significant number of violations during the adoption of laws and insufficient time for their consideration by specialists and society before approval. Secondly, the implementation of laws in practice makes it difficult for some public services to fail to fulfill their obligations. Thirdly, corruption in land relations, as evidenced by the official reports of the anti-corruption bureau. Fourthly, failure to perform soil protection works and lack of comprehensive land protection measures in practice. Fifth, the lack of comprehensive computer support aimed at organizing the administration of land relations using modern IT technologies, the need for which is presented in the Decree of the Cabinet of Ministers of Ukraine "On approval of the Procedure for information interaction between cadastres and information systems".

Existing scientific research substantiates approaches to the development and improvement of the modern system of land administration (hereinafter – LA), [2-13]. The works of scientists also discuss the issue of determining LA substantiation of functions and factors of its formation and implementation, peculiarities of its application for regulation of various spheres of economy, including food security. However, at a low level, cause and effect relationships between the factors of LA, its influence on the general criteria for the development of regions and the state are influenced. In this context, it is proposed to use mathematical modeling tools to solve the complex issue.

To achieve effective land use, it is necessary to implement a whole set of actions. It is advisable to use not only a quantitative approach in solving land management tasks, but also a qualitative one to increase its efficiency. All this should lead to effective land legislation [14, 15].

In the system of land management management, the formation and use of quantitative basis by applying the methods and models of mathematical and geospatial modeling is of particular importance for making informed decisions. In addition, the use of the presented tools provides an opportunity to build a monitoring system of distribution, use, development of land resources as functions of LA.

The importance of using mathematical tools in the system of land relations and the peculiarity of its use is determined by the development of authors [16, 17]. In addition, it is established that the low level of influence of land relations indicator on the general criterion of regional development (the index of gross regional product) (the coefficient of determination is 0.005). This indicates the need to rethink approaches to the formation of the land management system, the introduction of elements of LA, the

construction of theoretical platform and regulatory support, the creation of a quantitative basis for decision-making based on mathematical and geoinformation modelling results.

To correct the problems, the state is taking steps that can change the perception of land management. One of such solutions is digitization of land management. In the presented research, directions for the formation and implementation of land management are analysed and modelled in synergy with the principles of LA, which allows to single out problematic aspects and propose ways to solve them.

2 Literature review

2.1. Principles of LA

The main three dimensions of sustainable development of land management are distinguished: economic, ecological, and social. From an economic point of view, the economic essence of land management, its socio-economic content, which characterizes the impact on the overall gross regional product, is revealed. To do this, it is necessary to outline objective economic laws, establish the forms and regularities of their manifestation in the organization of the territory of land ownership and land use, evaluate their impact on land management, and as a result, create conditions in which the implementation of land relations will bring maximum profit. The importance of land management in the economic mechanism of land relations regulation is growing. Therefore, it is necessary to improve the methods of economic substantiation and assessment of the effectiveness of land management decisions, to determine the most effective ways of forming sustainable land use at the regional level. This, in turn, will lead to the determination of ways to increase the capitalization of land management in the presented process [18].

The development of land management is closely related to land transformations, an integral part of which are ecological processes. The development of ecologically safe land use is based on three principles:

- land suitability for maintaining balance in ecosystems,
- land suitability for population's livelihood,
- the suitability of land for economic use, as well as the protection of land from the catastrophic consequences of its use, i. e. ecologically safe use of land by:
 - ensuring the ecological and economic condition of land resources for a long time,
 - predicting opportunities for both present and future generations regarding land use,
 - positive impact within certain territories on land use processes,
 - preventing the occurrence of irreversible processes that lead to a violation of the quality of land resources and, indirectly, through food products, will affect people's lives and health,
 - determination of a complex of land use indicators at the regional level.

Preservation of the integrity and sustainability of land use development in conditions of only qualitative changes is possible only with the integration of ecological, economic, and social interests of people. The biggest problem in land use is related to the fact that the level of ecosystem development is differentiated. Ecosystems with infertile lands have a significant capacity reserve (territorial and demographic) and are characterized by a tendency of quantitative demographic growth. However, next to them there are ecosystems with fertile lands, the reserve of both territorial and demographic capacity has been exhausted. The initial stage of the development of natural ecosystems is the dominance of economic interests over ecological ones, the final stage of the development of intensively used ecosystems is the superiority of ecological interests over economic ones.

The main goal of sustainable land reclamation is not only to achieve a state of equilibrium between ecological and economic interests, but also to limit the quantitative growth of population parameters, man-made load, etc. in the ecosystem with further maintenance (fluctuation) in the range of sustainability [19]. Along with this, man-made processes are determined to ensure the development of land management: the construction of power grids, gas pipelines, sewers, roads, and many other infrastructure elements. The presented processes form a balancing exercise of rights for these large-scale infrastructure projects, regardless of whether they are provided by public or private agencies, to implement effective land use from an administrative and legal perspective. For this, it is necessary to realize the importance of information about land and its processing for different groups of stakeholders. The importance of integrated land information for the sustainable development of land relations at all levels is increasing [20, 21, 22].

Modern land management is being transformed in the context of forming a synergistic system with other spheres of production and human life. Land management should turn into a new, more modern tool that should cover and optimize all processes related to land use. In this context, the toolkit of LA deserves attention. LA is characterized by discussions on the development of disciplinary ties and improving the response of stakeholders to the most complex problems [23, 24]. For the successful implementation of the LA system, its institutions must be stable, transparent, and free from corruption. Uncontrolled use of land resources leads to massive over-regulation of land-related activities and the emergence of contradictory legislative acts [25].

Despite the uniqueness of local LA systems and the various difficulties that may arise, it is possible to develop an effective process. The Ten Principles of Land Management provide a framework for designers, developers and managers dealing with land use to assist them in making decisions about the local system. In general, these principles are written to facilitate the creation and reform of the LA system, reflecting a modern philosophy in the field of development and optimization of the use of assets and resources to ensure sustainable development. Their versatility lies in the fact that countries at different stages of development can use them depending on technical and professional capabilities, improving LA through appropriately developed process and tools. These principles reflect a comprehensive approach to LA, focused on the principles of sustainable development, which constitute a key strategy for any national system, regardless of the specific country that implements them [26]. Below is a description and functionality of these principles to understand the practical meaning of each of them. LA systems create a basis for the implementation of land use strategies and policies, contributing to sustainable development. This infrastructure includes institutional arrangements, legal frameworks, processes, standards, land information, management and distribution systems, and the necessary technologies. It is intended to support the effective distribution of land resources, development of land markets, conducting assessments, control of use and protection of interests in land matters.

Land management paradigm is a conceptual basis for understanding and implementing innovations in LA systems. This paradigm is a set of principles and practices that define land management as an independent discipline. These principles and practices are related to the four key functions of LA systems: land ownership, land assessment, land use and land management, as well as their interaction. These functions determine the efficiency of the land market and the efficiency of land use management. The term "land" encompasses the natural and built environment, including both land and water resources.

2.2. Comprehensive frameworks for effective land administration systems

LA systems interact with the overall social and institutional structure of each country, including citizens in this unique process. This encompasses effective governance, capacity building, institutional progress, social interaction, and a focus on the needs of users, not just providers. Land management systems must be revised to better meet the needs of citizens, governments, and businesses. Interaction with society and people's perception of the land is a key aspect. Achieving this goal requires effective management when making and implementing decisions. This requires the development of the necessary skills in individuals, organizations, and society in general for effective and sustainable performance of functions. LA systems establish a framework for conceptualizing rights, constraints, and responsibilities related to politics, place, and society. Rights, restrictions, and obligations must be tailored to the individual needs of each country or jurisdiction and balanced across different levels of government, from local to national. Rights usually involve aspects of ownership and possession, while restrictions usually regulate the use and activities on the land. Responsibilities are more related to social and ethical obligations or concern environmental sustainability and the rational use of resources.

The cadastre serves as the basis for LA systems, ensuring spatial integrity and unique identification of each piece of land. Most cadastres guarantee ownership through the registration of land rights in the relevant register. A cadastre can be seen as a detailed cartographic representation of how a community divides its territory into functional parts, often defined as parcels. Spatial integrity within the cadastre is usually supported by a cadastral map, which is periodically updated using cadastral surveys. Ideally, a cadastre should cover all types of land in each jurisdiction, including public, private, communal, and open land. The unique identification of land plots establishes a link between the cadastral map and the land register, which is the basis for LA systems and land information, especially in digital and geocoded format. LA systems are dynamic covers four aspects. First, it involves transformations that reflect the ongoing development of the relationship between people and the earth.

This process can occur due to economic, social and environmental influences. Secondly, the development of information and communication technologies and globalization, as well as their impact on the structure and functioning of land resource management systems, are considered. A third aspect concerns the dynamic nature of information in land management systems, such as changes in the ownership, valuation, use and distribution of land parcels through their subdivision. The fourth aspect involves changes in the use of land information.

2.3 Optimizing land administration systems for sustainable development

LA systems include a complex of processes that regulate changes. The main processes cover the transfer of rights to land, changes in its status, creation and distribution of interests, evaluation, and development of land. These processes, including actors and their responsibilities, explain how land management systems function, serving as a basis for comparison and improvement. While institutions, laws, technologies, or aspects of land management systems, such as land ownership, a land registry, a particular piece of legislation or a cadastral survey technology, are important, the processes act as a basic element for an overall understanding of how these systems work. Technology opens new opportunities for increasing the efficiency of LA systems and for using spatial opportunities in the field of land issues. The potential of technologies is revealed much earlier than the ability of institutions to respond to these opportunities. The technology contributes to the improvement of the processes of collection, storage, management, and distribution of land information. At the same time, the development of information and communication technologies opens opportunities for spatial resolution of land issues, using space or place as a key organizer of human life.

Effective and efficient LA systems aimed at sustainable development require the use of spatial data infrastructure. This infrastructure is an enabling platform that enables interaction between people and information. It promotes the combination of natural (mainly topographic) and man-made (in particular, land or cadastral) environmental data as a prerequisite for sustainable development. Spatial data infrastructure also allows the integration of land information at different levels, from local to national. Successful LA systems are measured by their ability to manage and dispose of land efficiently, effectively and at low costs. The success of LA systems is not determined by the complexity of the legal framework or the sophistication of technological solutions. Success lies in the adoption of appropriate laws, institutions, processes and technologies designed for the specific needs of a country or jurisdiction [26]. In the future, by introducing these principles into the land processes of Ukraine, it will be possible to get rid of most of the existing problems, including corruption.

3 Materials and methods

This study is based on the ten principles of land administration (LA), which serve as foundational elements in the development of modern LA systems. To analyze and display the connections and logical sequences between these principles and elements of LA, we propose utilizing the mathematical frameworks of graph theory and category theory. This approach allows for a comprehensive representation of the LA system, emphasizing its complexity and interrelated components. These mathematical tools enable the logical, structured representation of the LA system, informed by theoretical provisions and international practices [27, 28, 29, 30].

Data formation and separation of factors of LA was carried out based on generalization of theoretical provisions and international experience of its implementation in developed systems. In this context, international documents and development should be noted [26, 31, 32, 33].

Fig. 1 presents the principles in the form of vertices of a disconnected graph, as the foundation of a full-fledged LA system.

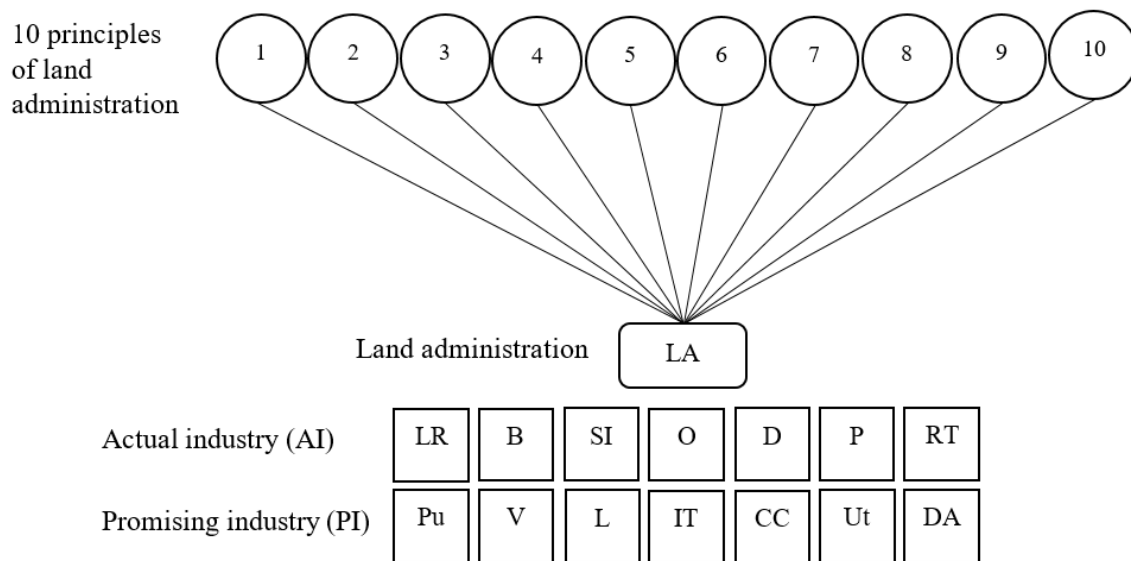


Fig. 1.: Conceptual model of land management principles.

3.1. Categorization of land administration processes

The principles of land administration (from 1 to 10) are represented numerically and form the basis for the LA system, shown in Table 1. Each number corresponds to a specific principle, and all the graph edges are directed towards the "ground administration" (LA), signifying the interconnectedness of the principles in forming the overall system.

Currently, land administration at the regional level in Ukraine is underdeveloped. It faces unique challenges that hinder its optimization. The study identifies several key industry impacts (AI) affecting land administration practices:

1. Procedures, distribution, or determination of land rights (LR).
2. Determination of boundaries between sections (B).
3. Storage of land rights information (SI).
4. Procedures regulating transactions with land, including sale, lease (O).
5. Resolution of uncertainties or disputes regarding land rights and boundaries (D).
6. Tools and processes for land planning, control, and monitoring (R).
7. Land valuation and taxation (RT) procedures.

At the same time, with the implementation of the principles of land administration, in addition to the optimization of existing processes, new opportunities appear in the form of promising industries (PI):

1. Public involvement procedures and bureaucratic transparency (Pu).
2. Visualization of land management elements (V).
3. Management of land restrictions (L).
4. Information technologies and technologies of land management (IT).
5. Control and regulation of productivity, profits obtained from the land (SS).
6. Support for the management of communal services and the provision of services (electricity, drainage, sewage, communications) (Ut).
7. Sustainable development accounting (DA).

3.2. Graph theory and category theory applications

The graph makes it possible to determine the level of structuring of the administration system and the impact of principles on development prospects. Category theory methods are used to detail the further analysis. Each of the principles of LA characterizes the complexity and complexity of the process, which should lead to certain positive results in the LA system. The presented principles are a set of elements that ensure the functioning of the LA system. At the same time, each principle can be represented as an independent system with a set of elements and functions that ensure the fulfilment

of these LA functions. Essentially, in category theory, these are categories that can appear in the form of the object class "Ob(LA)" and the morphism class "Mor(LA)" of the LA land administration category. The actual industry "Ob(AI)" of land administration in Ukraine and the prospective industry "Ob(PI)" can be presented as a class of objects of the LA category. The resulting formalized elements can be presented in the form of a commutative diagram (Fig. 2).

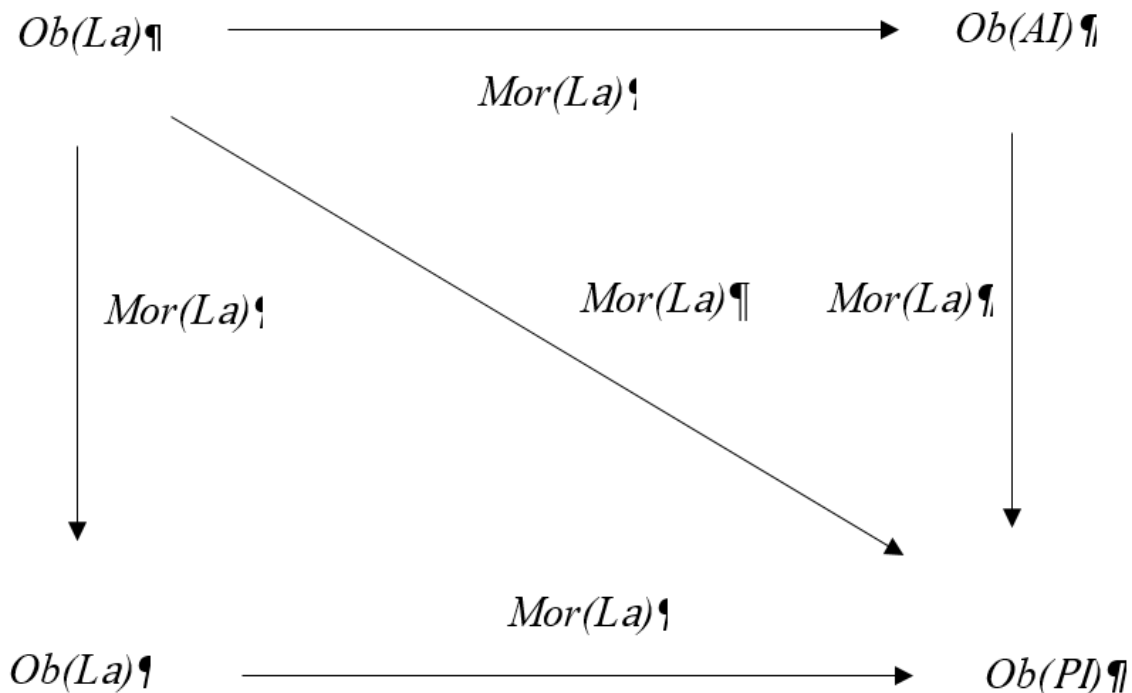


Fig. 2.: Commutative diagram of land administration category.

The resulting commutative diagram characterizes the relationships and influence on:

- implementation of new principles of PI land administration from the point of view of introducing them into the existing land management system of Ukraine at the regional level, considering that some of these AI principles are part of the system. It is necessary to implement these principles in such a way that they are embedded in the existing system, taking into account the laws and traditional aspects of the functioning of the land management system;
- ensuring or optimizing existing processes in the field of LA in Ukraine, that is, the implementation of the principles of LA is characterized not by the fact of their implementation, but by the functioning of the system ensuring these principles and their interaction;
- the formation of new processes in the field of LA in Ukraine, which arise as a result of the introduction of the principles of LA into the existing system, which provide new connections and dependencies;
- ensuring the functioning of LA based-on principles to achieve synergy between all existing and new elements and processes of the LA system.

4 Results

It should be noted that to form a quantitative basis for effective decision-making in the LA system, cause-and-effect relationships between the presented factors are determined by mathematical modelling methods [30, 34, 35, 36].

Thus, directions for mathematical modelling of LA factors by regions of Ukraine are proposed, based on the obtained commutative diagram (Figure 2), considering the assumption that only one of the four points characterized by this commutative diagram is considered. Namely, the implementation of

new principles of LA from the point of view of their introduction into the existing land management system of Ukraine [37]:

- formation of information and analytical support for modelling;
- selection of LA factors that have the greatest influence;
- determination of quantitative parameters of LA factors by methods of expert analysis;
- construction of a model of the general indicator of LA;
- determination of the general indicator of land administration;
- building a model of the influence of the general indicator of LA on the index of gross regional product;
- definition of criteria for the adequacy of mathematical models;
- interpretation of established cause-and-effect relationships between LA factors.

A numerical experiment was conducted on the formation of information and analytical support for modelling, which is carried out based on the parameters and factors defined in Figure 1 and will characterize the quantitative impact of the principles of land administration. The selection of factors is characterized using expert methods based on points (from 0 to 10 - depending on their importance), the results of which are presented in Tables 2, 3 and 4.

It should be noted that experts are defined for the implementation of the expert assessment method by the following criteria:

- participation in expert assessments;
- the number of projects implemented in the field of land relations;
- availability of vocational education;
- availability of scientist, title;
- experience of functioning in the field of land relations;
- experience in the system of distribution and use of land resources;

The level and possibilities of application of modern technologies in the field of land relations.

Table 2 presents expert scores for criteria that characterize the principles of LA that are already implemented in practice in Ukraine, and Table 3 presents expert scores for criteria that may be in the future.

Table 2. Selection of land administration factors affecting the generalizing criterion now (AI), resp. unit (developed by the authors).

Experts (Ei)	LR	B	SI	O	D	P	RT
E1	6	2	3	2	3	7	3
E2	7	3	2	2	3	6	4
E3	7	2	2	2	2	6	4
E4	6	2	2	2	2	6	4
E5	6	2	2	2	2	8	4
E6	6	3	2	2	3	8	3
E7	7	3	3	3	3	7	4
E8	7	3	2	2	2	7	4
E9	6	3	2	2	2	6	4
E10	6	3	2	2	2	7	3
E11	7	2	2	2	3	7	4
E12	6	3	2	2	3	8	4
E13	6	3	3	3	3	7	4
E14	7	2	3	2	3	7	3
E15	6	2	2	2	2	6	4
Average value	6,4	2,533	2,267	2,133	2,533	6,867	3,733

Next, the selection of factors affecting the generalizing prospective criterion (PI) is carried out, relative to (Table 3).

Table 3. Selection of land administration factors affecting the generalizing prospective criterion (PI), resp. unit (developed by the authors).

Experts (Ei)	Pu	V	L	IT	CC	Ut	DA
E1	3	2	2	5	3	1	5
E2	4	2	1	5	3	2	5
E3	4	2	1	6	2	2	5
E4	4	2	2	7	2	1	6
E5	5	3	1	7	2	2	5
E6	4	3	1	6	3	2	5
E7	4	2	2	6	3	3	5
E8	4	2	2	6	2	2	5
E9	3	3	2	7	2	2	6
E10	4	2	3	5	2	2	5
E11	4	2	2	5	3	3	5
E12	3	3	1	5	3	2	4
E13	4	1	1	5	3	2	5
E14	4	2	2	6	3	2	5
E15	3	2	2	7	2	2	5
Average value	3,8	2,2	1,667	5,867	2,533	2,0	5,067

As a result of the study, the selection of factors affecting the generalizing criteria (AI) and (PI) is carried out when the criterion (PI) is implemented. This is since each new implemented principle affects the LA system, considering the improvement or deterioration of the functioning of existing industries during the implementation of promising industries, where each factor (PI) is characterized by the possibility and relevance of its implementation in Ukraine. So, the change in AI factors under the influence of the RI criterion is presented in the Table 4.

Table 4: Indicators of changes in land administration factors affecting the generalizing prospective criterion (AI) relative to the criterion (PI), resp. unit (developed by the authors).

AI	PI							Average value
Factors	Pu	V	L	IT	CC	Ut	DA	
LR	5,045	2,367	0,298	5,286	0,004	1,869	2,46	2,476
B	1,95	2,98	0,597	5,309	0,056	0,468	2,569	1,99
SI	1,27	2,398	2,298	5,352	0,099	1,365	2,698	2,211
O	3,128	2,998	2,98	6,368	1,296	1,265	2,579	2,945
D	4,386	2,458	3,245	6,295	1,396	1,024	2,564	3,052
P	2,108	2,298	0,195	5,297	1,386	1,105	2,197	2,083
RT	0,26	2,398	3,658	5,208	1,386	1,385	2,975	2,467

In addition, the factors of LA affecting the generalizing criterion (AI) are singled out, considering their changes (Table 5).

Models (1) and (2) were constructed considering the results of factor evaluation. The first model (basic) characterizes the cause-and-effect relationships between the generalized indicators of the regions with the principles of administration, which are already implemented in practice according to the data in Table 2. The second model (transformed) shows the results of determining the generalized indicators by region, considering the principles of administration that have already been implemented and will be implemented in the future, considering their synergistic impact, which is presented in Tables 3 and 5.

Table 5: Land administration factors affecting the generalizing criterion (AI) considering their changes, resp. unit (developed by the authors).

Experts (Ei)	LR	B		SI	O	D	P	RT
E1	8,476	3,99		5,211	4,945	6,053	9,084	5,467
E2	9,476	4,99		4,211	4,945	6,053	8,084	6,467
E3	9,476	3,99		4,211	4,945	5,053	8,084	6,467
E4	8,476	3,99		4,211	4,945	5,053	8,084	6,467
E5	8,476	3,99		4,211	4,945	5,053	10,084	6,467
E6	8,476	4,99		4,211	4,945	6,053	10,084	5,467
E7	9,476	4,99		5,211	5,945	6,053	9,084	6,467
E8	9,476	4,99		4,211	4,945	5,053	9,084	6,467
E9	8,476	4,99		4,211	4,945	5,053	8,084	6,467
E10	8,476	4,99		4,211	4,945	5,053	9,084	5,467
E11	9,476	3,99		4,211	4,945	6,053	9,084	6,467
E12	8,476	4,99		4,211	4,945	6,053	10,084	6,467
E13	8,476	4,99		5,211	5,945	6,053	9,084	6,467
E14	9,476	3,99		5,211	4,945	6,053	9,084	5,467
E15	8,476	3,99		4,211	4,945	5,053	8,084	6,467
	Average value	8,876	4,523	4,478	5,078	5,586	8,95	6,2

The basic model for determining general indicators by LA region is as follows:

$$LA = (k_1 \cdot AI) \cdot k_{r_i}, \quad (1)$$

k_1 – the weighting factor characterizing the influence of the criterion "AI" on the generalizing indicator "LA", resp. unit;

k_{r_i} – the regional coefficient, which considers the peculiarities of the formation and use of land at the regional level, resp. unit.

The presented coefficient is determined according to the author's method based on theoretical and methodological developments [38, 39, 40].

The transformed model for determining the generalized indicators of LA by regions of Ukraine, considering the influence of the principles of administration that have already been implemented and will be implemented in the future:

$$LA = (k_1 \cdot AI + k_2 \cdot PI) \cdot k'_{r_i}, \quad (2)$$

k_1 – the weighting factor characterizing the influence of the criterion "AI" on the generalizing indicator "LA", resp. unit;

k_2 – the weighting factor characterizing the influence of the "PI" criterion on the generalizing indicator "LA", resp. unit;

k'_{r_i} – prospective regional coefficient of peculiarities of land formation and use, which considers modern directions of implementation and realization of land administration, resp. unit - the results of the calculation of the general indicator of LA according to the basic model are presented in the Table 6.

The results of the assessment of the general indicator of LA by regions of Ukraine showed its low or insignificant development in most regions. Along with this, there are significant opportunities for the introduction of LA in the Dnipropetrovsk, Kyiv, and Lviv regions.

The results of the assessment of the general indicator of LA according to the transformation model by region are presented in the Table 7.

Table 6. Results of the calculation of the general indicator of LA according to the basic model, resp. unit (developed by the author).

Regions	Indicator value
Vinnitsia	3,887
Volynskyi	2,551
Dnipropetrovsk	5,345
Donetsk	1,093
Zhytomyrskyi	3,037
Transcarpathian	2,672
Zaporozhye	1,458
Ivano-Frankivsk	3,158
Kyivskyi	6,802
Kirovohradskyi	2,551
Luhansk	0,121
Lviv	5,709
Mykolaivskyi	1,944
Odesa	2,915
Poltava	3,28
Rivne	3,037
Sumy	2,672
Ternopilskyi	3,523
Kharkiv	3,158
Khersonskyi	1,093
Khmelnitskyi	3,158
Cherkasy	2,915
Chernivtsi	2,794
Chernihivskyi	2,672

The model of the influence of the transformational generalizing indicator of land administration on the gross regional product index (I_{GRP}) is presented in Fig. 3.

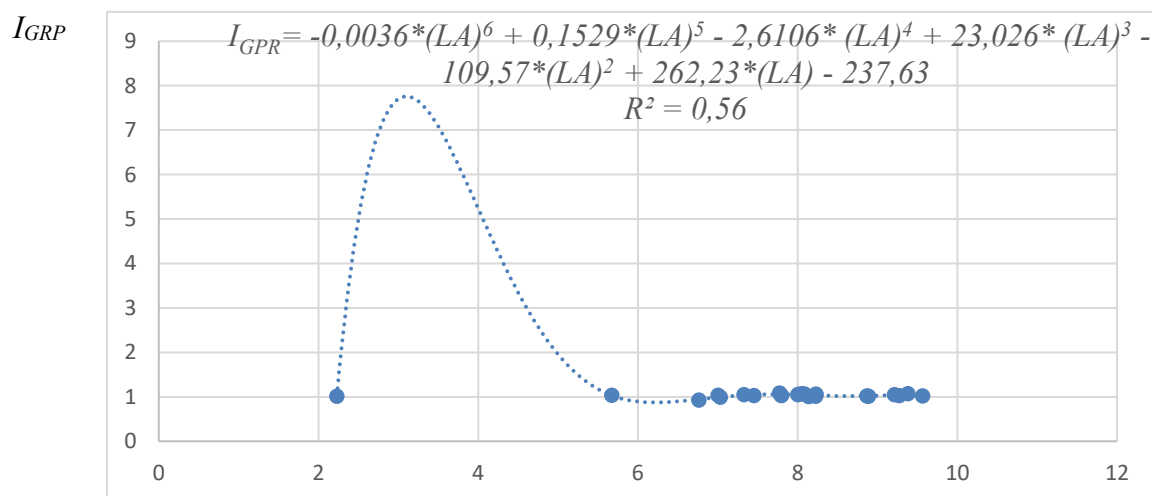


Fig. 3: The model of the influence of the transformational generalizing indicator of land administration on the gross regional product index, resp. unit.

Table 7. Results of the calculation of the general indicator of LA according to the transformation model, resp. unit (developed by the author).

Regions	Indicator value
Vinnitsia	8,226
Volynskyi	6,763
Dnipropetrovsk	9,271
Donetsk	5,672
Zhytomyrskyi	9,211
Transcarpathian	8,866
Zaporozhye	7,329
Ivano-Frankivsk	8,227
Kyivskyi	9,565
Kirovohradskyi	8,228
Luhansk	2,228
Lviv	9,381
Mykolaivskyi	7,773
Odesa	8,085
Poltava	8,139
Rivne	7,452
Sumy	7,032
Ternopilskyi	8,054
Kharkiv	8,889
Khersonskyi	7,002
Khmelnitskyi	8,012
Cherkasy	8,002
Chernivtsi	7,794
Chernihivskyi	7,799

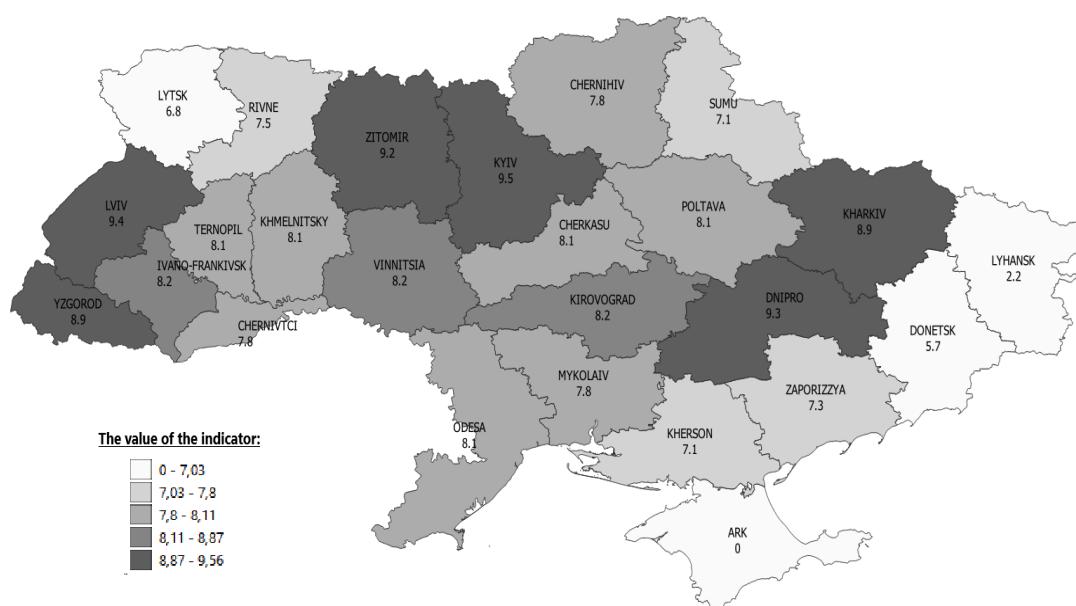


Fig. 4: Geoinformation map of the transformational generalizing indicator of land administration by region, reflecting the prospects for its development.

The criteria of the adequacy of the mathematical model testify to the completeness and reliability of the established relationships (Fisher's F-test and Student's t-test), the absence of autocorrelation of the residuals (the Durbin-Watson criterion), homoscedasticity (the criterion of the homogeneity of the distribution of the residuals of the model). Multicollinearity testing was not performed because a one-factor model was built [41, 42].

The geo-informational map of the transformative generalizing indicator of LA by region, which reflects the prospects for its development, is presented in Fig. 4.

5 Conclusion

Based on the results of the research, an analysis of scientific publications characterizing the state of land relations in Ukraine was carried out, the main shortcomings of land management were identified. Analyzed works on the development of modern land administration, considering international experience. It was determined that the formation and application of LA is influenced by factors and principles that ensure the functioning of the system of land relations. Using mathematical methods of formalization, mathematical logic, graph theory and category theory, a conceptual model of the principles of land management was developed, which characterizes the possible influence on the development of LA in Ukraine, and a commutative diagram of LA category was developed, which comprehensively reflects the processes of implementation and development of LA in Ukraine.

The provisions of scientific developments characterizing the practical directions of applying the theory of categories at the level of LA objects are analyzed. The defined principles of LA influence the formation of regional development processes. A low level of influence of LA processes on the factor of regional development has been established, which requires a rethinking of approaches to the development of measures and implementation of the LA system, considering the influence of relevant factors. To implement the LA system, it is proposed to ensure the comprehensive application of the procedure, distribution or determination of the right to land; intensification of the processes of determining boundaries between areas; increase in the level of informatization of land relations; ensuring transparency of procedures regulating land transactions, including sale, lease; resolution of uncertainty or dispute resolution regarding land rights and boundaries; use of modern tools and implementation of land planning, control and monitoring processes; ensuring land assessment and taxation procedures; active public involvement and bureaucratic transparency; increase in the level of visualization of land management elements; increasing the effectiveness of land restriction management; ensuring control and regulation of productivity, profits obtained from the land; support for the management of communal services and the provision of services (electricity, drainage, sewage, communications); ensuring sustainable development.

The results of mathematical modelling of the influence of the transformed indicator of LA on the gross regional product index showed the need to increase the factors of LA due to the application of modern foreign experience, methods and models of increasing the efficiency of land use at the regional level, the possibility of implementing a multi-purpose cadastral system, modern practice of formation, use, assessment and development of land based on relevant principles. In addition, the development and application of monitoring procedures using geographic information systems at the regional level is of particular importance. Geoinformation maps of LA indicators by region were built, which made it possible to monitor the implementation of land relations, considering the directions and perspectives of the implementation and implementation of elements of land administration.

Compared to existing scientific developments, which discusses certain issues of use of geoinformation systems and mathematical modelling to ensure the management of land relations, the presented research proposes a comprehensive approach to the formation of a quantitative basis of decision -making, which is built using geospatial modelling tools. It combines the directions of determining the factors of management of land relations, methods and models of mathematical modelling, tools of geoinformation technologies, which allowed to offer a modern system of distribution, use and development of land.

Acknowledgments

This research project was supported by funding from the Science and Technology Department of Ningxia, the Scientific Research Fund of North Minzu University (No. 2020KYQD40).

References

- [1] ROHAN, M.B. - JEROME, D. - ERYADI, M. - KIRSIKKA, R.: Land Administration As-A-Service: Relevance, Applications, and Models. *Land*, Vol. 12, Iss. 241, 2023, pp. 1-19.
- [2] ADAM, A.G.: Systematic review of the changing land to people relationship and coevolution of land administration. *HELIYON*, Vol. 9(10), 2023, doi: <http://dx.doi.org/10.1016/j.heliyon.2023.e20637>
- [3] ADAMS, M. - SIBANDA, S. - TURNER, S.: Land tenure reform and rural livelihoods in southern Africa. *Natural Resource Perspectives*. February, № 39, 1999, pp. 1-15.
- [4] AKINGBADE, A., - NAVARRA, D., - ZEVENBERGEN, J. - GEORGIADOU, Y.: The impact of electronic land administration on urban housing development: The case study of the Federal Capital Territory of Nigeria. *Habitat International*. № 36(2), 2012, pp. 324–332, doi: [10.1016/j.habitatint.2011.10.008](http://dx.doi.org/10.1016/j.habitatint.2011.10.008)
- [5] BURNS, T. - GRANT, C. - NETTLE, K. - BRITS, A.M. - DALRYMPLE, K.: Land Administration Reform: Indicators of Success and Future Challenges. Land Equity International Pty Ltd, Wollongong, Australia, 2006, URL: <http://www.landequity.com.au>
- [6] BURNS, A.F. - RAJABIFARD, A. - SHOJAEI, D.: Undertaking land administration reform: Is there a better way? *Land Use Policy*. Vol. 132, 2023, doi: <http://dx.doi.org/10.1016/j.landusepol.2023.106824>.
- [7] ÇAĞDAŞ, V. - STUBKJÆR, E.: A SKOS vocabulary for Linked Land Administration: Cadastre and Land Administration Thesaurus. *Land Use Policy*. Vol. 49, 2015. Pp. 668-679, doi: <http://dx.doi.org/10.1016/j.landusepol.2014.12.017>
- [8] DALE, P. - MCLAUGHLIN, J.: Land administration. Oxford: Oxford University Press, 1999.
- [9] ENEMARK, S.: Understanding the Land Management Paradigm. In FIG Commission 7 Symposium on Innovative Technologies for Land Administration. Madison, Wisconsin: International Federation of Surveyors, 2005, URL: https://www.fig.net/organisation/council/council_2007-2010/council_members/enemark_papers/madison_2005.pdf
- [10] HULL, S.A. - KINGWILL, R. - FOKANE, T.: An Introduction to Land Administration. Cape Town: LandNNEs, 2020, doi: <http://dx.doi.org/10.13140/RG.2.2.29539.17442>
- [11] ROCKSON, G. - BENNETT, R. - GROENENDIJK, L.: Land administration for food security: A research synthesis. *Land Use Policy*. Vol. 32, 2013, pp. 337–342. doi: <http://dx.doi.org/10.1016/j.landusepol.2012.11.005>
- [12] WILLIAMSON, I. - ENEMARK, S. - WALLACE, J. - RAJABIFARD, A.: Land administration for sustainable development. Redlands, California: Esri Press, 2010.
- [13] ZEVENBERGEN, J. - AUGUSTINUS, C. - ANTONIO, D. - BENNETT, R.M.: Pro-poor land administration: Principles for recording the land rights of the underrepresented. *Land Use Policy*. Vol. 31, 2013, pp. 595–604. doi: <http://dx.doi.org/10.1016/j.landusepol.2012.09.005>
- [14] HOSSAIN, M.A. - FERDOUS, N. - FERDOUS, E.: Crisis-driven disruptions in global waste management: Impacts, challenges and policy responses amid COVID-19, Russia-Ukraine war, climate change, and colossal food waste. *Environmental Challenges*, Vol. 14, 2024, pp. 1-14.
- [15] GANZ, K. - MORALES-MOLINO, C. - GOBET, E. - KIOSAK, D. - KOTOVA, N. - LEEUWEN, J. - MAKHORTYKH, S. - SCHWORER, C. - TINNER, W.: Holocene vegetation dynamics in southern Ukraine under changing land use and climate. *Review of Palaeobotany and Palynology*, Vol. 321, 2024, pp. 1-17.
- [16] MAMONOV, K. – VYATKIN, R. – SHTERNDOCK, E. – SHTERNDOCK, A.: Methods of mathematical modeling for assessment of the level of land use of objects of the nature and preserve fund of the regions. *The scientific heritage*. № 128, 2023, Pp. 28-32.
- [17] ANTHONY, M. – BIGGS, N.: Mathematics for Economics and Finance: Methods and Modelling. Cambridge University Press, 2021. 407 p.
- [18] TRETIAK, A. - TRETIAK, V. - HETMANCHYK, I. - HUNKO, L.: Concept and essence of land economics and land management in Ukraine. *Agrosvit*, Vol. 11, 2021, pp. 3-10.
- [19] BUDZYAK, O.: Conceptual basis of the strategic development of eco-friendly land management. *Economist*, Vol. 5, 2015, pp. 54–56.
- [20] CHEHREH BARGH, F.J. - RAJABIFARD, A. - ATAZADEH, B. - STEUDLER, D.: Identifying global parameters for advancing Land Administration Systems. *Land Use Policy*, Vol. 136, 2024, pp. 1-14.
- [21] STÖCKER, C. - BENNETT, R. - KOEVA, M. - NEX, F. - ZEVENBERGEN, J.: Scaling up UAVs for land administration: Towards the plateau of productivity. *Land Use Policy*, Vol. 114, 2022, pp. 1-14.

- [22] XU, S. - EHLERS, M.: Automatic detection of urban vacant land: An open-source approach for sustainable cities. *Computers, Environment and Urban Systems*, Vol. 91, 2022, pp. 1-12.
- [23] OKEMBO, C. - LEMMEN, C. - KURIA, D. - ZEVENBERGEN, J.: Developing an adapted land administration domain model profile for Kenya. *Land Use Policy*, Vol. 117, 2022, pp. 1-10.
- [24] ACHAMYELEH, G.A.: Systematic review of the changing land to people relationship and co-evolution of land administration. *Heliyon*, Vol. 9, Iss. 10, 2023, pp. 1-14.
- [25] ANTHONY, F.B. - ABBAS, R. - DAVOOD, S.: Undertaking land administration reform: Is there a better way? *Land Use Policy*, Vol. 131, 2023, pp. 1-14.
- [26] WILLIAMSON, I. - ENEMARK, S. - WALLACE, J. - RAJABIFARD, A.: *Land Administration for Sustainable Development*. Esri Press, 2009.
- [27] ORMANDJIEVA, O. - BENTAHAR, J. - HUANG, J. - KUANG, H.: Modelling multi-agent systems with category theory. *Procedia Computer Science*, Vol. 52, 2015, pp. 538-545.
- [28] KUKHSR, M.A.: Models of computer support for making decisions on the land relations system in Ukraine. O. M. Beketov National University of Urban Economy, 2018.
- [29] KUKHSR, M.A.: Conceptual models of decision support in multi-level administration systems. *Visnyk of Vinnytsia Polytechnical Institute*, Vol. 3, 2020, pp. 51-56.
- [30] MAMONOV, K. - KUKHAR, M. - SHTERNDOCK, E. - KAMCHATNA, S.: Standardization of geodetic data for determination of boundaries of natural reserve areas. *E3S Web of Conferences*, Vol. 452, 2023, pp. 1-13, doi: [10.1051/e3sconf/202345203001](https://doi.org/10.1051/e3sconf/202345203001).
- [31] Land administration guidelines with Special Reference to Countries in Transition. United Nations Economic Commission for Europe. 1996, 112 p., URL: <https://digitallibrary.un.org/record/216105?v=pdf>
- [32] Land administration in the UNECE region. Development trends and main principles. United Nations Economic Commission for Europe. 2005, 112 p., URL: http://users.ntua.gr/cpotsiou/books/2_2.pdf
- [33] WILLIAMSON, I.P. - GRANT, D.M.: United Nations-FIG Bathurst Declaration on Land Administration for Sustainable Development: Development and Impact. 1999, 12 p., URL: <https://rest.neptune-prod.its.unimelb.edu.au/server/api/core/bitstreams/31935407-947b-5787-bf63-0f126dcf1c8f/content>
- [34] MAMONOV, K.: Methodological approach to the integral assessment of the regional lands use territorial development. *Geodesy and Cartography*, Vol. 4, Iss. 3, 2019, pp. 110-115.
- [35] MAMONOV, K. - GRYTSKOV, E. - VELYCHKO, V. - HAIDENKO, S. - PRASOL, V. - ABOLHACANZAD, A.: Econometric modeling of investment attractiveness of enterprises. *Ukrainian Metrological Journal*, Vol. 6, Iss. 4, 2020, pp. 57-63, doi: [10.30525/2256-0742/2020-6-4-56-65](https://doi.org/10.30525/2256-0742/2020-6-4-56-65).
- [36] MAMONOV, K. - VELYCHKO, V. - GRYTSKOV, E. - ZUBAREV, D.: Econometric modeling of the level of stakeholder interaction at construction enterprises. *Ukrainian Metrological Journal*, Vol. 2, 2020, pp. 72-77.
- [37] MAMONOV, K. - VELYCHKO, V. - HOLOVACHOV, V. - KOVALENKO, L.: Theoretical and methodological provisions regarding the development and implementation of an integral method for assessing the level of information support of the multipurpose real estate cadastre at the regional level. *Ukrainian Metrological Journal*, Iss. 2, 2023, pp. 40-51, doi: [10.24027/2306-7039.2.2023.286728](https://doi.org/10.24027/2306-7039.2.2023.286728)
- [38] MAMONOV, K. - BIELIATYNSKYI, A. - GOI, V. - KOVALENKO, L. - HAIDENKO, S.: Economic and mathematical modeling of the development of construction enterprises, taking into account the peculiarities of the formation of intelligent economic system. *Road and Bridges Collection of Scientific Papers. Section: Economy. Management*, Iss. 28, 2023, pp. 38-46, doi: [10.36100/dorogimosti2023.28.038](https://doi.org/10.36100/dorogimosti2023.28.038)
- [39] BIELIATYNSKYI, A. - MINGMING, W. - CHANG, L. - MAMONOV, K. - DYMCHENKO, O.: Formation of the intellectual systems for the territorial development of land administration in the coastal regions. *Journal of Environmental Engineering and Landscape Management*, Vol. 30, Iss. 3, 2022, pp. 424-432, doi: [10.3846/jeelm.2022.17632](https://doi.org/10.3846/jeelm.2022.17632).
- [40] MAMONOV, K. - WEN, M. - ZHOU, C.: Deep Neural Network for Predicting Changing Market Demands in the Energy Sector for a Sustainable Economy. *Energies*, Vol. 16, Iss. 5, 2023, p. 2407, doi: [10.3390/en16052407](https://doi.org/10.3390/en16052407).
- [41] WAHEED, M. - ASMAEL, N.: Assessment of the Numerical Behavior of Remolded and Undisturbed Clayey Soil. 2024. *Civil and Environmental Engineering*, Vol. 20, Iss. 2, 2024, pp. 742-753, doi: 10.2478/cee-2024-0056.
- [42] WIJAYA, M.F. et al.: Physical and Mechanical Properties of Fly Ash-Bottom Ash Geopolymer Mixtures on Expansive Clay Soil Stabilization as a Subgrade Material. 2024. *Civil and Environmental Engineering*, Vol. 20, Iss. 2, 2024, pp. 890-904, doi:10.2478/cee-2024-0065.