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SOME METHODOLOGICAL REMARKS CONCERNING OF KARST STUDIES FROM THE SYSTEM APPROACH PERSPECTIVE

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Abstract: A systemic approach in scientific research, including Earth and environmental sciences, has a fairly long history (over 50-70 years). It has demonstrated a high effectiveness in research, and its use is becoming more and more widespread. The article considers selected methodological issues that concern the systemic approach in the field of scientific knowledge about karst (karstology) and caves (speleology), such as: karst as a system-forming factor, holistic approaches in karst research, karst ecosystems and karst geosystem approaches, research methods of white box, grey box and black box testing. The authors suggest that the systemic approach is useful in karstology studies and should undoubtedly be used and developed.

Key words: system approach, karst, ecosystem, geosystem

НЯКОИ МЕТОДИЧЕСКИ БЕЛЕЖКИ ОТНОСНО КАРСТОВИТЕ ИЗСЛЕДВАНИЯ ОТ ПОЗИЦИЯТА НА СИСТЕМНИЯ ПОДХОД

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Резюме: Системният подход в научните изследвания, включително в науките за Земята и околната среда, има доста дълга история (над 50-70 години). Статията разглежда избрани методологични въпроси, които засягат системния анализ в областта на научните знания за карста (карстология) и пещерите (спелеология). Представени са 4 основни холистични подхода (фиг. 1): карстоцентричен (изследва развитието на карста под съвместното въздействие на редица фактори и условия на околната среда), екологи-

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чен (изследва прави и обратни връзки между карстовия обект и неговата околна среда), ландшафтно-системен подход (изследва трансформиращия ефект на карста и формирането на специфичен карстов ландшафт) и геосистемен (разглежда карстовия обект като система и изследва взаимодействията между нейните елементи). По-специално внимание е отделено на моделите на екосистемния и геосистемния подход (фиг. 2), които според авторите са най-ефективни в изследването на карста. Екосистемният подход е центричен – той изследва взаимоотношенията карстов обект – околна среда, но не засята връзките между елементите на екологичната система. При геосистемния подход всички елементи на карстовата система са еквивалентни (равнопоставени) и се изследват взаимоотношенията между тях. На базата на този подход е разработена оригинална методологическа пратформа ProKARSTerra (фиг. 3), прилагана при изследванията на карста в България. Тя успешно интегрира научните изследвания с управлението и бизнеса с карстови ресурси и с образованието и обучението за/чрез карста. В статията на примера на циркулацията на водата в карстовия масив са представени 3 концептуални модела за изследвания на карстовата система (фиг. 4): „черна кутия“ (вътрешната структура на системата не е достъпна и за нейното функциониране се съди по параметрите на потоците вещества и енергия на нейните входове и изходи), „сива кутия“ (част от вътрешната структура на системата е достъпна чрез спелеоложки проучвания и някои от взаимодействията в нея могат да бъдат частично изследвани) и „бяла кутия“ (цялата вътрешна структура на системата е достъпна чрез спелеоложки проникивания или геофизически методи, следователно трансформацията на потоците вещества и енергия, постъпващи в системата, могат да се проследят и изследват в обема на цялата система). Предвид спецификата на карстовите геосистеми, най-често изследователската ситуация в карста е „сива кутия“. Авторите са убедени, че системният подход е много ефективен при изследванията на карста и несъмнено трябва да се използва по-широко и да се развива. Карстовите геосистеми се отличават със сложността на своята структура и голямото разнообразие от процеси, протичащи в тях. Системният подход като концептуален инструмент за изучаване на сложни обекти и явления от реалността открива път за широко приложение на числените методи и моделирането. Освен това приложението на системния подход позволява да се разкриват и свойства, предизвикани от взаимодействията на елементите на карстовата система. Познаването на тези свойства е особено важно за изясняване на тенденциите в развитието и прогнозиране на промените с оглед планирането на определени дейности в карстовите територии, особено на фона на активните глобални промени.

Ключови думи: системен подход, карст, екосистема, геосистема

INTRODUCTION

The systemic approach as such in the natural sciences has been developing since the 1950s and originated in the biological sciences (L. Bertalanfi) and technical sciences (N. Winer). Its appearance reflects, among other things, the response of science to the rapidly progressing (as a result of the development of more and more detailed analytical methods) specialisation of scientific knowledge, and the accumulation of data at an increasingly faster pace (‘information explosion’), which has the negative effect of blurring or loss of the overall picture of the examined object, phenomenon or reality. This leads to the situation when we are more and more able to distinguish ‘trees’, but we “cannot see the forest for the trees”. The development of analytical methodology and its tools, on the one hand has allowed and continues to allow an increasingly deeper and more detailed knowledge of the studied phenomena or ob-

jects, however on the other hand it leads to the loss of understanding of their specific integral essence.

This research situation is very unfavourable in science and the emergence of systemic ideology was aimed at maintaining and creating (understanding) a comprehensive vision of the things studied. This was to be achieved through the concept of a 'system', which assumes that the examined objects (phenomena, areas, etc.) have specific overall properties (they are so-called systems) or can be presented and studied as systems (specific cognitive structures). For some time there was a discussion among naturalists about the objectivity of 'systems', i.e. whether they really exist or they are merely a research structure that serves specific cognitive purposes. After years of dispute, what was arrived at was the understanding that both views are correct since everything is contingent upon the definition of the system. The simplest definition assumes that the system is a "complex (set) of elements correlated in one way or another." With this formulation, the system criteria are satisfied by both real objects exhibiting features of the whole, or groups of objects connected in one way or another, as well as virtual system constructions, for the occurrence of which it is enough several elements between which a specified (any) type of relationship exists. On the other hand, attempts to classify systems, both real and virtual, depend on how precise and specified the general definition is (through introducing a set of "signs" of the system, etc.).

The concept of the system resulted in the emergence and development of so-called 'systemic approach', according to which phenomena or objects can be perceived and studied as systems, with the employment of specific research tools, including mathematical ones (system analysis). Apart from the general theory of systems, which is fairly fuzzy in terms of methodology, fragmentary theories of systems have been created, both within individual sciences and in separate cognitive configurations, basing on various mathematical and logistic platforms.

In Earth sciences, the systemic approach began to develop rapidly in the 1960s and 1970s, primarily in landscape science, geomorphology, and also in geology, hydrology, climatology and others. The key concept became the concept of "geosystem", which in each of the aforementioned (and other) sciences was treated (defined) in its own way.

What has been invariable in all the definitions is the understanding of the geosystem as a specific segment of reality (geographical, geological, hydrological, etc.) that has systemic properties (indications). Such a not very restrictive understanding conferred universality onto the concept of the geosystem, and also allowed utilising it in a fairly flexible way in various sciences of the Earth and the environment – according to the needs.

The key issue of using the concept of geosystem and systemic approach in one or another field of natural science is to isolate from the studied reality an object or phenomenon of a holistic nature, and thus – to study it as a system. At the same time, what poses the question is not the presence or absence of 'geosystems' in one studied natural reality or another, but the researcher's recognition of the systemic organisation of this reality, i.e. its structure, hierarchy, functioning, self-regulation, etc. Systems or geosystems are everywhere, therefore everything depends on the researcher – their ability to perceive or construct (conceptual) systems and the objectives of the study (analysis or data synthesis, for example).

Similarly, karst reality – karst areas and relief, caves, may and should be effectively perceived, represented and studied as systemic formations (karst geosystems). In this article, the authors do not intend to prove (since it requires no proof) or illustrate the systemic nature of the karst environment, but they want to make the reader familiar with several selected methodological aspects of the systemic approach in karstological and speleological research. In individual short paragraphs, reference is made to the systemic vision of karst and karst areas, the existing holistic approaches to studying karst areas, two basic visions of karst objects, i.e. ecosystemic and geosystemic, and three basic research scenarios of karst objects as systems. These aspects, of course, do not cover the subject completely, but show some options and possibilities of systemic perception and approach in karstological studies.

The questions raised in this review refer to the previous works by the authors devoted to issues of systemic approach in karstological research (Andreychouk, 2007, 2008, 2010, 2016, Andreychouk and Stefanov, 2008, 2006, 2017; Stefanov et al., 2009, 2012, 2019; Mikhova and Stefanov, 1993, 1995, 1999, 2000; Stefanov, 2013).

KARST AS A SYSTEM-FORMING FACTOR

Karst, both as a process and also as its environmental effects (consequences of its development, i.e. caves, karst areas and relief, karst dolines, depressions, etc.) have systemic features and can be successively studied as specific (in various respects) geosystems. The basic specificity of karst geosystems is that a decisive (systemic, integrating) role in their formation is played by the *karst process*, whose essence boils down to the dissolving effect of waters on the rocks within which these waters circulate.

Klimchouk and Andreychouk in their article "About the essence of karst" (2010) have proposed a systemic approach to the definition of karst, based on the ideas of synergetics and unbalanced thermodynamics of I. Prigogine concerning self-organization in systems and formation of dissipative structures. Karst is being examined from the angle of self-development of permeability structures in karst rocks in the course of interaction between water and rock (aquifer and massif, etc.). The essence of the development and evolution of karst is the staged self-organization of permeability structures (channel networks), manifesting itself in the initiation, concentrating and integrating of underground drainage, and the intensification of the water cycle in karst massif. Karst is defined as a *"water-circulation geosystem" within a certain part of the hydrolithosphere, whose formation and progressive evolution are characterized by self-organization of permeability structure together with formation of integrated systems of channels owing to the impact of a specific speleogenetic mechanism based on the positive feedback between water circulation and dissolution"*.

By definition, karst is a progressive evolution of a geosystem with a permeable rock vulnerable to dissolution, triggered by water circulation and speleogenetic mechanisms of self-organization of permeability. *Progressive evolution* is understood as a process of formation and development of new dissipative structures (increase of structural complexity of the system), whereas *regressive evolution* – as a process of their destruction and collapse (reduction of structural complexity). During the cycle of karst (karst megasystem) development the progressive evolutionary trend

over time gives way to the regressive one, but this process of formation (integration) and degradation (disintegration) of structures is stretched over time, overlapping and complex.

Karst, in its very essence, has a hydrological (hydrogeological) nature, since it pertains to the impact of water on rocks and occurs mainly underground. However, as it develops, *the process of dissolution* of rocks in conditions that are favorable for the development becomes transformed into *the karst process*, which, subsequently brings about a number of other processes that accompany it or are induced by it (erosion, collapse of the earth surface, landslides, etc.). Working together underground and on the surface, these processes shape the relief, and thus - the entire landscape whose components, both abiotic (rocks, water, air) and biotic (plants, animals) or anthropic (human), while adapting to each other create a specific and complex environmental system - *karst landscape* (Andreychouk, 2007, 2009, 2016).

The karst landscape is the most complex karstic geosystem with a specific spatial and functional structure (Andreychouk, 2009, 2016). Elements of the karst landscape, for example, karst depressions of various sizes, hillocks and towers, disappearing rivers, blind valleys and canyons, sinkholes, chasms (avens) and caves, springs, karst lakes etc., on the other hand also have systemic features and can be studied as separate systems with a specific structure and "behavior".

In karst, the main system-forming role is played by the circulation of waters in massifs of karst rocks. The water cycle combines elements, such as hydrological, climatic (precipitation), geological (rocks), geomorphological (sculpture), biotic (flora, fauna, soil) and others, into various types of systems, but the water cycle itself can also be an excellent subject of systemological research – however only in terms of the hydrology (water circulation).

HOLISTIC APPROACHES IN KARST STUDY

A *scientific approach* implies a certain comprehensive vision of reality and a relevant organization of the research process, which means that it is embedded not in the empirical (research aspect) but in the methodological (research methods determined by a certain vision) field of science. The term *approach* has a general scientific status and is universal, as a *comprehensive* or *systemic* approach, the *anthropic principle*, etc. As a rule, the approach is applied to thematic, spatial or historical aspects of the reality to be investigated, which has a relative wholeness, structurally and a complex organization, which requires the researcher to prepare an adequate cognitive structure. Therefore, the application of these or other approaches to research on karst is conditioned by regarding karst comprehensively, as a certain type of *organization*. This may be, for example, *the entire karst as a set of genetically and spatially related processes and phenomena*, *the karst environment* (a concrete karst area together with the human inhabitants), *the karst landscape, karst massif*, etc.

What kinds of comprehensive approaches have application to karst studies nowadays? According to the authors, in karstology four main approaches are currently used: the karstocentric, environmental, geosystemic and landscape-systemic approaches (Andreychouk, 2010, Klimchouk, Andreychouk, 2010) (Fig. 1).

The karstocentric approach represents a concrete version of the *centric* approach which implies regarding the studied reality (object, phenomenon, process, area) as a certain organization functioning in the conditions of a strict (genetic) dependence upon particular factors (Fig. 1-1). Within a given approach karst is considered as a derivative of the collective impact of a number of factors and environmental conditions, i.e., the presence of karst rocks, water circulating in the massif, rock fracturing, aggressiveness of water, drainage conditions, and many other, more specific ones (lithology and structure of karst rocks, amount of rainfall, water temperature, etc.) which affect the course of the karst process or the physiography of the karst area. "Classic" examples of this approach may be found, inter alia, in the Soviet karst literature of the "50-70s" of the last century (the publications of F. Savarenskiy, D. Sokolov, some works of G. Maximovich, V. Dublyanskiy, A. Chikishev, R. Tsykin, and many others). The works of these authors dealt with the issues of "conditions and factors of karst development". They discussed a spectrum of karst formation factors, which of the factors are more important (essential, crucial), and which are less important, etc. in relation to the central concept of karst, sometimes regardless of discrepancies in defining karst itself. This approach was manifested in the characteristics of the researches carried out on karst, in the structure of the monograph studies on karst of these or other areas, in the organisation of material in reference books (introductory chapters), etc. This approach also has application nowadays, especially in the case of comprehensive studies on karst in a particular area, as well as in works generalizing on karst.

The karst-environmental approach is another version of the centric approach, that is, it implies examining the relationship between the studied object and its surroundings (environment) (Fig. 1-2). This approach is currently employed on a large scale in geoecological studies (*ecological*/*ecocentric*/*ecosystemic* approach relationship of man and nature (*anthropocentric, anthropic*), etc., *i.e.* when examining the impact of the environment on the object (nature, man, organism, etc.), and vice versa the impact of the object on the surroundings. This approach has been carried out since the time of J. Cvijić on a large scale in karst studies primarily in terms of geographical research, where karst was considered as the environment of human life, including issues of *karst determinism*. This approach found wide application in the countries of the Mediterranean basin, where karst issues have always been associated with the issues of water and its exploitation. The karst-environmental approach (especially its opposite aspect – the impact of the industrial activities on karst) has revived over the past decades due to a growing economic impact of man on the karst environment (*technogenic, activated*, etc., karst) and the concomitant consequences that are sometimes disastrous, as in induced surface collapse, land subsidence, etc.

The karst-landscape approach is the special (karstic) case of *the landscape approach of the* Eastern-European school that views landscape as a particular territorial, processual and physiographic part of nature as a whole. The landscape approach suggests considering a given area in terms of its entirety whose physiographic specificity is determined by the particular spectrum of natural processes occurring within its boundaries which shape its appearance (volcanic processes – volcanic landscape, aeolian processes – desert landscape, karst processes – karst landscape, etc.). It has been also implied that the compactness of the internal interconnections of the components (bedrock, water, soil, climate, biota and others) in the landscape understood in

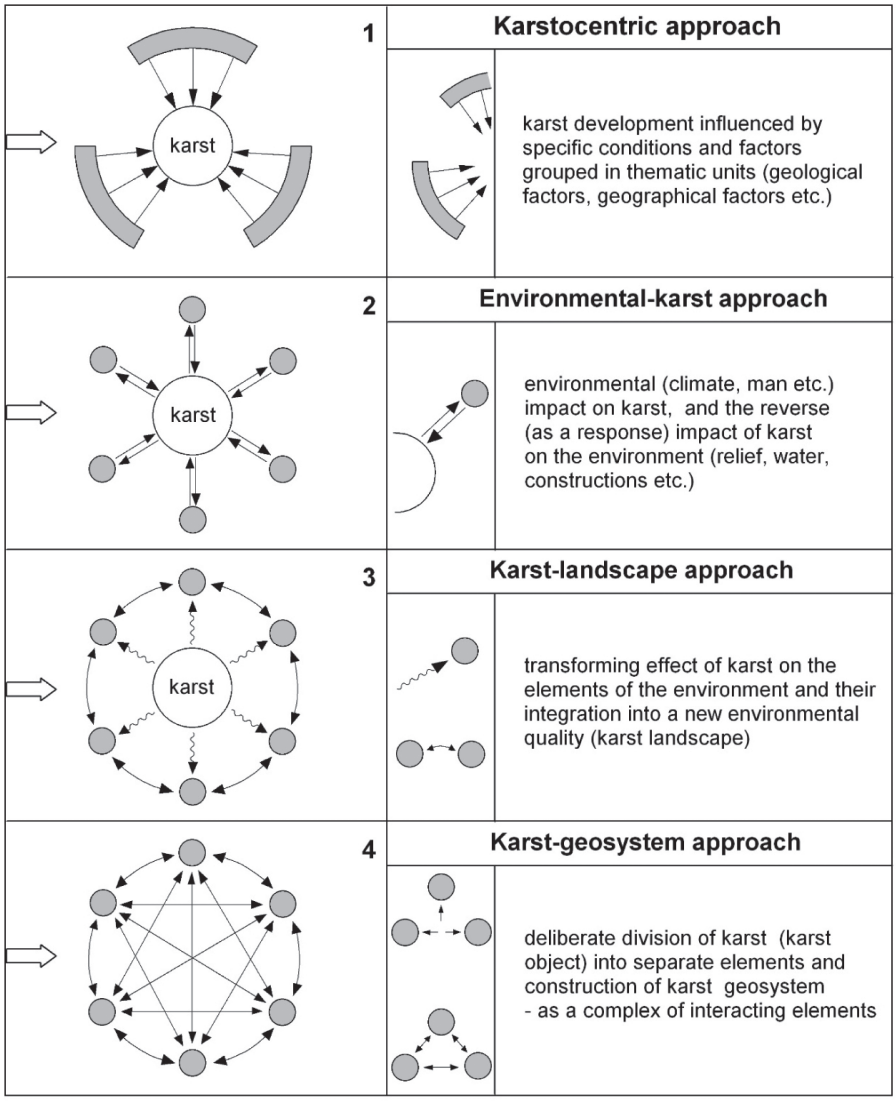

Fig. 1. Main comprehensive approaches to the karst study (Andreychouk, 2010)

such a way (Fig. 1-3), due to its characteristic processes is greater than of the external relations of the landscape, which is manifested, inter alia, in the specific physiognomy of the landscape area. It is also believed that the formation of a given genetic type of landscape is generally determined by the so-called "leading process or condition", which integrates and subordinates the activities of other processes, directs the development of landscape and determines its peculiarities. The role of such a condition or process may be played by climate (formation of polar, desert, etc. landscapes), tectonics (landscapes of rift valleys), erosion and landslide processes, etc. The presence of karst rocks and karst which over the course of development gradually subordinates

other processes and more and more considerably transforms the landscape to forming a specific (pathogenic, lithogenic) karst landscape can constitute such a leading or growth influencing factor.

The karst-landscape approach, as described above, is represented mostly in the works of researchers of the Eastern-European school of landscape science. These are the works of Gvozdiecki (1972, 1979), Chikishev (1982), Proskurnyak, Andreychouk, (1998, 1999) and one of the authors (Andreychouk, 2007; Andreychouk, Proskurnyak, 1993; Andreychouk, Voropaj, 1993; Voropaj, Andreychouk, 1985) and a number of other papers. This approach seems to be very useful to elucidate the evolution of karst areas (formation of the landscape), and explain the specifics of their natural environment. It is also advantageous when dealing with the issue of land use within karst areas and their protection.

The karst-geosystem approach is a special case of the *system approach*, which favours considering the object (phenomenon, area) as a system, an appropriate organization of the research process (algorithm research), and often also the application of appropriate numerical methods (system analysis, graph theory, and others) (Fig. 1-4). In the systemic approach the object is presented as a set of elements and relationships between them (structure), and the study itself focuses primarily on the issues of interactions between the elements, because it is just the interactions between the elements that determine the overall (emergent, system-derivatives) properties of the system.

Of course, these examples of comprehensive, as contrasted with partial, analytical, thematic, approaches to the research of karst are largely provisional. Their "methodological weight" is not equal, and they do not exclude other potential approaches. Nevertheless, in the author's opinion they allow determination of the "coordinates" for comprehensive scientific study of karst, revealing the systemic nature and specific organization of the karst terrains.

KARST ECOSYSTEM AND KARST GEOSYSTEM APPROACHES

Karst formations and areas of different types and sizes can be studied in a variety of ways - depending on the purpose of the study. The most important of them are two models / approaches, i.e. ecosystemic and geosystemic (Fig. 2).

The ecosystemic approach (environmental – in its broad, not only biological sense) consists in presenting the examined system as an interaction of an object and its environment, which may be represented by elements-factors affecting the object in one way or another. In this way, it is possible to study effectively, for example, cave dwelling organisms, the accumulation of stalactites and stalagmites in caves, the formation of the microclimate in caves, and ice forms in them, etc. In each of the aforementioned cases, the organism, stalactite, microclimate or ice infiltrations will constitute a 'crucial' element of the system (ecosystem), whereas the elements (factors) surrounding it will constitute the 'opposite' (environmental) element or group of elements. In ecosystem studies, the emphasis is on the crucial element whose essence (properties, dynamics, etc.) is to be explored. The internal structure of the central element is not usually studied, and neither it is broken down into parts, while the environmental element (subsystem) is segmented into more or less numerous structural elements-factors. As for the studied relationships between the system components, in

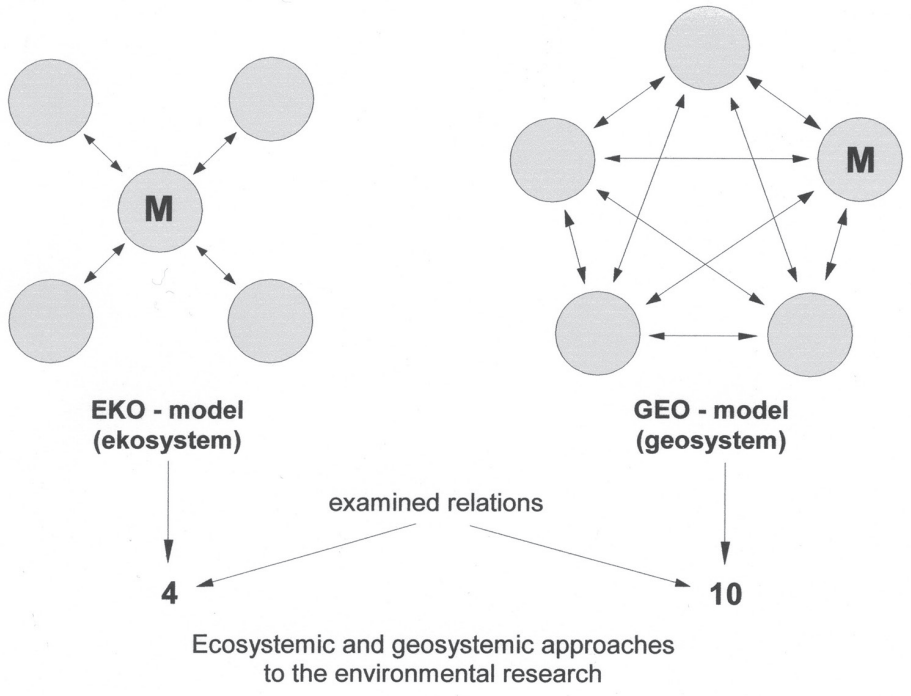

Fig. 2. Models of ecosystemic and geosystemic approach to the study subject (Andreychouk, 2008): M – element of "special attention"

the ecosystemic approach the researcher's attention is focused on the relationship(s) between the crucial element and the environment (environmental elements), whereas relationships (interactions) between the elements-components of the environment as such are not usually studied (Fig. 2).

The geosystem approach presents the studied system as a set of equivalent elements, wherein the element of 'special attention' is examined together with other elements of the system – as just 'one of them'. The aim of such a study is to learn about the relationships between all components of a separate system.

When using the ecological approach (the "centric" one) we examine only the relations of the type: "object – environment", from the geosystemic point of view we consider the relations between all the elements of environmental system. One can easily notice that although the number of the examined elements of both systems is the same (5) – in case of the ecosystemic approach we examine only 4 environmental relations, while in case of the geosystemic approach – we find 10 relations. Therefore, using the geosystemic methodology, we have a possibility of collecting more precise knowledge on the subject of our research, that is environment and man as a part of it. When incorporating the ecosystemic approach, such a precision is not possible.

The geosystem approach has been successfully applied since the end of the 20th century in Bulgaria, where karst is widespread (covering approximately a quarter of the country's territory) and is unique in its diversity. This makes it a kind of a natural

laboratory for testing the geosystem approach. Therefore, model karst geosystems were selected, representing the main types of karst (http://www.prokarstterra.bas.bg/lab/EN/methodology.html). After detailed interdisciplinary research, the precise boundaries, structure and functional relationships of geosystems were determined. The Experimental Laboratory of Karstology at the National Institute of Geophysics, Geodesy and Geography - the Bulgarian Academy of Sciences (NIGGG-BAS), has developed an original methodological platform called ProKARSTerra (fig. 3), based on the karst geosystem concept (http://www.prokarstterra.bas.bg/lab/EN/methodology.html). The main methodological "pillars" of the platform are the system analysis, the integrated monitoring (including stationary monitoring) and a specialized cadastre of karst geosystems. The monitoring also includes underground (cave) subsystems, for which an original model was developed (Speleo-MIKS, Stefanov, 2013). The specialized cadastre is based on GIS (Mikhova, Stefanov, 1993, 1995, 1999, 2000). Experience proves that the methodological platform of the geosystem approach to karst research successfully combines three important areas: research; management/ business and education/training as a basis for the sustainable development of karst territories in the context of growing global changes (Stefanov et al., 2019).

BLACK BOX, GREY BOX AND WHITE BOX STUDY SITUATIONS

Unfortunately, the systemic approach has not found wide enough application in karst studies. This is due to on the one hand, quite a narrow range of karst research compared with the overall natural studies, on the other hand, the lack of clearly for-

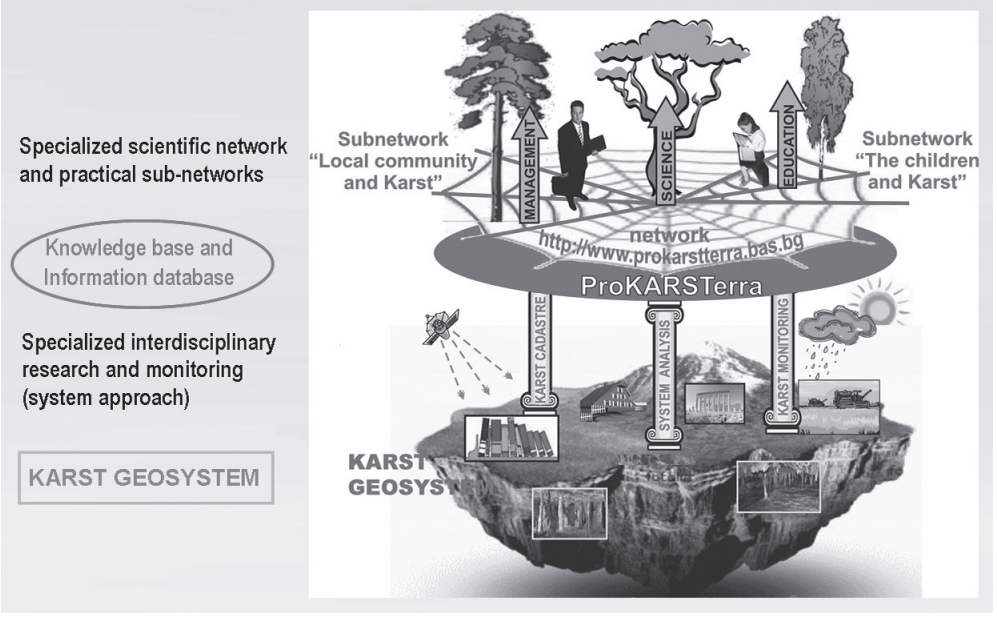

Fig. 3. Methodological Platform ProKARSTerra (Stefanov et al., 2012, 2013)

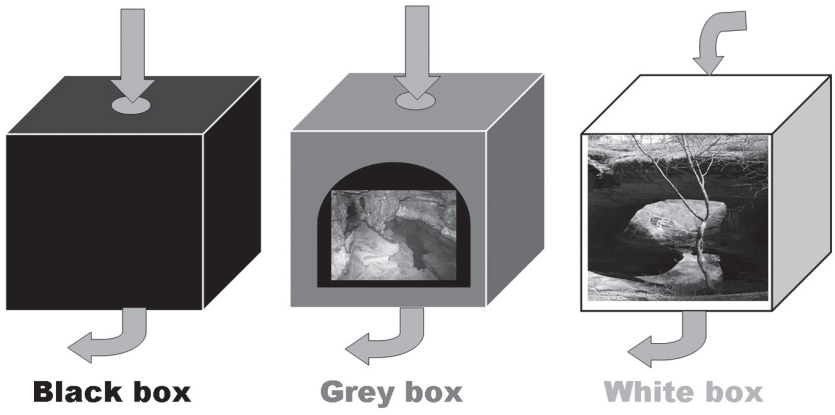

Fig. 4. Black box, grey box and white box study situations

mulated systemic concepts of karst (karst system visions). Speleological research into water circulation in karst massifs (karst systems performing the cycle: supply – transit – outflow) is an exception here. It establishes hydrological and other relationships between the objects (caves, springs) and areas, first of all. In the case of monitoring the flow of water, a "black box" or "gray box" testing situation takes place when the interior of the massif is inaccessible or only partly accessible: the internal structure of the karst system and the processes occurring within it are deduced based on the measured "input" and "output" parameters. In the situation when it is possible to follow the water circulation in the karst massif by cave exploration examining the links of the karst system inside from the input to the output, "white box" testing takes place (Fig .4).

CONCLUSION

The systemic approach may have a number of different "methodological configurations", and a variety of *research models* may be created by this approach. However, studying and presenting the material *as a system* remains invariant. This approach is no doubt very forward-looking in karst studies as caves, karst aquifer systems and areas (karst massifs, landscapes) are distinguished by the complexity of their structure and the large variety of processes occurring within them. The systemic approach is known for constituting a conceptual tool to study complex objects and phenomena of reality.

System studies (as well as the entire system methodology) have been finding wider and wider application for several decades in all fields of modern science, including the natural sciences – biology, ecology, and to a lesser degree, geology and geography. Despite many other merits of a cognitive nature, the systemic approach is advantageous also because it allows fairly easy formalisation of the studied object (functional connections of its elements), which paves the way for a wide application

of numerical methods and modelling. The systemic approach enables the most complete and appropriate examination of the object, since its application reveals not only the properties of the object, derived from the properties of its components (elements), but also properties induced by the interactions of the elements (structure-derivative properties, *i.e.* comprehensive, systemic). The latter are particularly vital when planning certain activities in the environment, in the landscape, as they allow for detection of trends in development and for forecasting changes. Therefore, general system visions and environmental studies are most forward-looking and effective methodology nowadays. This thesis applies undoubtedly also research on the karst and caves.

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REFERENCES

Andreychouk, V. 2007. Karst as geoecological factor. - Sosnowiec-Simferopol, 2007, pp.137. (Ru)

Andreychouk, V. 2008. Evolution of the geographical environment and contemporary geography. - In: Methodology of landscape research, Sosnowiec, 5-37.

Andreychouk, V. 2009. The system nature of karst landscape. - *Speleology and Karstology*, Simferopol, 2009, № 3, 47-59. (Ru)

Andreychouk, V. 2010. About the approaches to karst study. - *Speleology and Karstology,* Simferopol, 2010, № 4, 5-10. (Ru)

Andreychouk, V. 2016. The system nature of karst landscape and principles of protection resulting from it. - *Zeitschrift fűr Geomorphologie*, Vol. 60, Suppl. 2, 257-291.

Andreychouk, V. L. Voropai. 1993. Karst landscape as geosystem. - Problems of karst landscapes study, Perm, 1993, 37-52. (Ru)

Andreychouk, V., M. Proskurnyak. 1993. Problematic questions of karst landscape study. - Problems of karst landscapes study, Perm, 1993, 67-75. (Ru)

Andreychouk, V., **P. Stefanov.** 2006. Karst geosystems and principles of protection of karst territories. - GEOgraphy`21, 2006, №1, 5-11. (Bg)

Andreychouk, V., P. Stefanov. 2008. Principles of protection of karst areas. - Speleology and Karstology, 2008, № 1, 54-59. (Ru)

Andrejczuk, W., P. Stefanow. 2017. Podstawowe zasady ochrony krajobrazu krasowego i jaskiń. - Acta Geographica Silesiana, 11/1(25), WNoZ UŚ, Sosnowiec, 2017, 5–10. (in Polish)

Chikishev, A. 1975. Geographical conditions of karst development. - M: Moscow University Publish. House, 1975, pp.111. (Ru)

Chikishev, A.1979. Problems of karst study of Russian Plain. - M: Moscow University Publish. House, 1979, pp. 303. (Ru)

Ford, D., P. Williams. 1989. Karst geomorphology and hydrology. - Unvin Hyman. London, pp. 601.
Gvozdetskiy, N. 1954. Karst (2-nd ed.). - M: Geografgis, 1954, pp. 352. (Ru)
Gvozdetskiy, N. 1972. Problems of karst study and practice. M: Mysl, 1972, 391 pp. (Ru)
Gvozdetskiy, N. 1977. Karst landscapes and their rank related to karst types. - The question of general and regional karstology. M., 1977, 3-23. (Ru)
Gvozdetskiy, N. 1988. Karst landscapes. - M: Moscow University Publish. House, 1988, pp. 112. (Ru)
Klimchouk A., V. Andreychouk. 2010. About the essence of karst. Speleology and Karstology, 2010, № 5, 22-47. (Ru)
Mikhova, D., P. Stefanov. 1993. Design of an information system for modeling of karst geosystems – Problems of Geography, 2, 1993, 68-82. (Bg)
Mikhova, D., P. Stefanov. Cartographic modeling of natural systems with GIS (on the example of karst geosystem). - In: Sat. Reports "Geography '94", 1995, 68-76 (Bg).
Mikhova, D., P. Stefanov. 1999. Gis-based Modeling of Karst Geosystems. - In: Towards Digital Earh /Proceedings of the International Symposium on Digital Earth, Nov. 29 - Dec. 2, 1999, Beijing, China/ Science Press, 1999.
Mikhova, D., P. Stefanov. 2000. Use of Geographic Information Systems (GIS) in karst scientific and application research in Bulgaria. - In: Proceedings of the International scientific session "50 years Institute of Geography - BAS, Sofia, 2000, 147-155. (Bg)
Proskurnyak, M., V. Andreychouk. 1998. The structure of karstified landscapes. - Chernivtsy, 1998, pp. 88. (Ru)
Proskurnyak, M., V. Andreychouk. 1999. Landscape genesis and land use within the karstified areas. - Chernivtsy, 1999, pp.87. (Ru)
Sokolov, D. 1962. The main conditions of karst development. - M: Gosgeoltechizdat, 1962, pp. 321. (Ru)
Stefanov, P. 2013. The model "Speleo-MIKS Biserna". - In: Proceeding papers of the Second International Conference "Geografical Sciences and Education" (Shumen, 1-2 November 2013), Univ. ed. „Episkop Konstantin Preslavsky", Shumen, 2013, 34-48. (Bg)
Stefanov, P., M. Yordanova, D. Stefanova, D. Mikhova. 2009. A project for development of an experimental model for complex monitoring of protected karst territories. - In: Final Proc. Int. Conf. Management travních porostů krasových oblastí, Sept. 16-18, 2009, Chata Macoha, Czech Republic. MZLU - Brno, Czech Republic, 2009, 28-38.
Stefanov, P., M. Yordanova, D. Stefanova. 2012. ProKARSTerra – Bridges to the Future. - In: Collection of Abstracts of Papers from the International Scientific-Practical conference „Protected Karst Territories - Monitoring and Management" (16-24 September 2012, Shumen, Bulgaria). TerArt, Sofia, 2012, 8-9. (Bg)
Stefanov, P., V. Andreychouk, D. Stefanova. 2019. Geosystem approach as a basis for sustainable development of karst territories in the context of Global changes. - Plenary report of the International Scientific and Practical Conference „Protected Karts Territories - legislation, tourism, monitoring (ProKARSTerra`2019, 29 September – 2 October 2019, Sofia, Bulgaria) http://prokarstterra.bas.bg/forum2019.
Voropai, L., V. Andreychouk. 1985. The peculiarities of karst landscapes as geosystems. - Chernivtsy: Chernivtsy University Publishing House, 1985. pp. 81. (Ru)
http://www.prokarstterra.bas.bg/lab/EN/methodology.html
http://www.prokarstterra.bas.bg/lab/EN/base.html