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DETERMINING THE IMPACT OF VIRTUAL WATER SCARCITY RISK ON THE GLOBAL FOOD CRISIS 2022 AS A RESULT OF HOSTILITIES

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The object of this study is the process that forms conceptual foundations for managing the impact of virtual water deficiency risks on the global food crisis. The main idea of the study focuses on determining the consequences of the global food crisis in the world under the influence of a significant reduction in virtual water exports from Ukraine to agri-food markets.

It is determined that most likely, in the context of the replacement of Ukrainian exports of grain and agricultural products as a result of Russian aggression in Ukraine, the countries of the world will resort to new ways of obtaining effective imports of virtual water from other countries. The study proved that rapid structural changes in the economies of the countries of the world and the reorientation of their national economies towards the development of the agricultural sector under modern conditions of global uncertainty would inevitably lead to certain consequences. Namely, either to the fall in the growth rate of national economies, or to the state of the "bifurcation explosion" with the subsequent dispersion of possible states of development.

The proposed scientific and methodological approach to assessing the sustainability of the systemic development of the territory over time for water-intensive regions makes it possible to take calculated decisions at the national level regarding the scale and prospects for the development of economic activities in the state.

The described theoretical and methodological foundations of the interdependence of water and food security and the developed fundamental provisions of the economies of countries under the conditions of the global food crisis and the risk of a shortage of virtual water will create the following opportunities. Specifically, they enable state authorities to assess the depth of the specified crisis in the world and its consequences for all countries in 2022–2023. Such an understanding creates the conditions for making effective decisions on the volume of import of virtual water in a particular country

Keywords: food crisis, virtual water, sustainable development, agricultural sector, military aggression

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1. Introduction

The war in Ukraine, which began in February 2022, had an incredible impact on world energy markets. But now, humanity is facing an even deeper crisis: food shortages. The military invasion of Ukraine has already led to the closure of ports and the suspension of trade operations, which will have a significant impact on the export of grain and sunflower oil from Ukraine for many months. To protect their food supplies, countries began to turn to the policy of trade protectionism, one of the factors that sharply exacerbated the financial crisis in the world in 2007–2008. After the russian invasion, a number of countries, such as Indonesia, Hungary, Serbia, Egypt, and others immediately imposed new restrictions on the export of oil and grain, as bread prices had already begun to rise.

In particular, 45 African and least developed countries import at least one third of their wheat from Ukraine; 18 of these countries import at least 50 %. These include Burkina Faso, Egypt, the Democratic Republic of the Congo, Lebanon, Libya, Somalia, Sudan, and Yemen.

Egypt receives about 8 % of wheat from Ukraine and is one of the largest importers of wheat in the world. Lebanon imports 66 % of wheat from Ukraine and is currently suffering from a lack of food. Similarly, more than 65 % of the population of Syria needs humanitarian assistance [1]. In Yemen, about 89 % of the population already live under conditions of extreme lack of food [2].

The war in Ukraine has an impact outside the country, namely on developing countries, where fears of famine are exacerbated. The global food system has been threatened because russia's invasion of Ukraine poses great risks to the effective functioning of one of the world's largest breadbaskets.

The agricultural sector of Ukraine is one of the largest in the world. Ukraine's food system and global supply chain in the world are under threat because russia started the war at a vital time for fieldwork. The disruption of food exports caused by the military invasion of Ukraine exposes global food markets to increased risks of declining availability, unmet import demand, and higher international food prices.

Such a factor as a significant decrease in the flow of exports of "virtual water" from Ukraine due to the impossibility of additional production of agricultural products under the conditions of the war in Ukraine deserves extraordinary attention.

Agricultural production is one of the most water-intensive economic activities in the world. Not all countries have sufficient water potential to carry out water-intensive activities in their territories, including the cultivation of agricultural products.

Scientific research on this topic is important because it is most likely that in the context of the replacement of Ukrainian agricultural exports as a result of Russian aggression, the countries of the world will resort to new ways to obtain effective imports of virtual water from other countries.

In practice, due to the increase in the cost of water resources and the rise in the cost of virtual water flows, prices for wheat and food will increase significantly in addition to other inflationary factors.

2. Literature review and problem statement

Over the past decades, the concepts of food security, energy security, and access to natural resources have been widely discussed.

Using the example of water resources, it was recognized that the shortage of fresh water poses both a direct and indirect threat to security. This is due to the fact that, on the one hand, as a result of this deficit, a dangerous situation develops, and on the other hand, it threatens with potential conflicts.

Scientists around the world point out that insufficient water supply in the country is already a serious problem for the economic development of many countries, and the water crisis in the future will be the greatest danger to humanity. Thus, it is pointed out the increased negative impact of virtual water flows on the formation of water shortages in China [3], and China's agriculture has been identified as a high-risk sector [4]. But these studies do not take into account and do not determine the interdependence of water and food security, which is now an extremely relevant issue. For the most part, the research data focuses on exploring sustainable water management solutions in China. Finally, the political consequences of long-term sustainable water management in China, Mexico, Brazil, and Australia are predicted [5]. The study provides insight into China's water footprint and the trade in virtual water using three specific types of water: green, blue, and gray. It was concluded that organizational relations, resource provision, and the relationship between supply and demand can play a key role in China's global virtual water footprint network, rather than geographical location. Such conclusions indicate the actualization of the issue of food security, although the study itself is not aimed at this problem.

With the growing water shortage in a number of countries, recently various ways have been developed to minimize water consumption, in particular, by importing water-intensive products, both agricultural and industrial, including energy. Minimizing water consumption through the import of water-intensive products is explained by the concept of "virtual water" by J. Allan, which has already received sufficient publicity [6]. On the one hand, «virtual water» is defined as the volume of water that was actually used to produce the product, depending on the production conditions, including the place and time of production and the efficiency of water use. On the other hand, "virtual water" is considered from the position of the importing country of "virtual water", which gives a determination of the amount of water that would be necessary for the production of the product in that place where the product is needed. This definition is especially important for calculating the volume of water that was saved when importing a product instead of its own production.

Returning to agricultural production, following this concept, it may take two to three times more water to produce one kilogram of grain in an arid country than to produce the same amount in a humid country.

For arid countries, the import of virtual water (primarily in the form of agricultural products, which accounts for up to 70 % of water consumption) can be a good means of reducing domestic demand for water and, thus, mitigating domestic water deficits.

Therefore, the structure of trade in agricultural products should be modified based on the characteristics of the virtual water flow. The authors of [7] note that for countries that do not have stable economic development and, at the same time, have a shortage of water, the export of crops with high water consumption should be under control. At the same time, the study does not take into account the consequences of the impact of virtual water shortage risks on the global food crisis. But this study focuses on studying the driving factors behind the virtual water trade to ensure food security.

There is already considerable concern in Africa about the trade in virtual water, which plays a key role in the management of water resources and the sustainability of food security in the region. Given the growing tensions over virtual water imports, some African countries are currently reviewing international agricultural trade policies and water conservation policies [8]. The purpose of such actions is to promote a more balanced ecosystem and to avoid the food security crisis as much as possible. This study, again, considers the problem of ensuring food security, which actualizes our desire to shape the economic situation of countries in the context of the global food crisis and the risk of a shortage of virtual water.

The decline in the flow of virtual water exports from Ukraine in the world raises a number of important questions. The cost of exporting virtual waters on average in Ukraine is quite low and attractive to the world due to the presence of fertile black soil lands. Such lands make it possible, at minimal cost, including water resources, to obtain sufficiently large yields, provided that there is a dry year with sufficient rainfall per year. On other types of land, the use of water resources can significantly increase. This will lead to an increase in the cost of water-intensive agricultural products due to the cost of the entire cycle of use of the water resource (climatic conditions and the level of machinery and technology, etc.).

Therefore, for most countries, two questions will arise. The first is whether to increase the level of use of water resources in one's country, which will affect the country's water security and indirectly national security and send the country for some time to the zone of "evolutionary impasse". The second is whether to resort to new ways of obtaining imports of virtual water from other countries on the market. It should be understood that if a new virtual water exporter is found, an increase in the cost of water-intensive products is possible.

The research results covered in [9] indicate that Ukraine is characterized by significant volumes of virtual water formation. According to [9] estimates, the total export of virtual water is recorded at the level of 19.5 billion m^3, which exceeds the basic volumes of water use in the country as a whole. These results are confirmed in [10], which indicates an even greater total export of virtual water from Ukraine at the level of 25.3 billion m^3. That is, Ukraine forms significant volumes of flows of virtual water exports in the world. These studies formed the basis for the formation of a scientific and methodological approach to assessing the sustainability of the systemic development of the territory over time for water-intensive regions, which is proposed in this article.

Previous studies [11, 12] considered the hypothesis that the water supply of territories does not determine the specialization of the regions of Ukraine in the export/import of water-intensive products due to the existence of land resources (chernozems). But with a decrease in the water supply of the territories of Ukraine, upon reaching a certain limit, the need to increase the net import of virtual water into the country will increase.

The opinion that upon reaching a certain limit of water supply of the territory will increase the need to increase the net import of virtual water into the country is determined by many scientists of the world. Large farms in Thailand apply appropriate rice production management methods, with which they can maintain rice yields and reduce the use of water resources [13]. This approach is a vivid example of the use of water-efficient technologies. The issue of determining the limit of water shortage remains unresolved, but this issue is a global problem that many successors are working on. Another scientific paper notes that the increase in virtual water exports increases the burden on local water resources in China [14]. This situation is typical for other regions of the world.

Evaluation of virtual water flows in Iran using a multi-regional analysis of input data showed that with the development of the agricultural complex, the country began to need to increase the net import of virtual water [15]. This is confirmed by previous studies [11, 12], which state that with a decrease in the water supply of the territories of Ukraine, upon reaching a certain limit, the need for an increase in net imports of virtual water into the country will increase. Diagnostics of water safety and constancy of the horticultural model of Almeria was performed, which indicated the same results [16]. A similar conclusion was made in the study of the sustainability of agricultural sector development in eastern Australia under uncertain future climatic and economic conditions [17]. An improved model of system dynamics was developed to assess the regional water shortage in terms of virtual water [18]. The proposed model can effectively assess the regional water shortage, and the need to take comprehensive measures to alleviate water shortages with prioritization in accordance with socio-economic and environmental indicators. In studies [19, 20], in which data on African and Asian countries are analyzed, it is argued that for most countries the degree of water supply is a significant factor that affects international trade. So, the country begins to show a demand for imports of grain, the production of which is one of the most water-intensive types of economic activity, which confirms the inexhaustibility and relevance of the proposed study.

Also, according to the results of research [7], the regression model, which is built on the example of China's grain trade data, shows that GDP is positively correlated with the virtual flow of water. At the same time, water resources, arable land, geographical remoteness of the land resource were negative factors that prevented the virtual import of water.

The theoretical information described above, based on the results of the study of sources [3–20], gives reason to recognize that there are unresolved issues related to the assessment of the stability of the systemic development of the territory over time, taking into account water intensity. The lack of such knowledge makes it impossible to take informed decisions regarding the prospects for the development of state territories.

The theoretical and methodological foundations of the interdependence of water and food security and the fundamental provisions of the economy of countries under critical conditions of today also need to be improved. Such conditions can be recognized as a global food crisis and the risk of a shortage of virtual water. Such an understanding creates the conditions for making effective decisions on the volume of virtual water imports in one's country.

All this gives grounds to argue that it is expedient to conduct a study on determining the impact of the risks of virtual water shortage on the global food crisis as a result of hostilities in Ukraine.

3. The aim and objectives of the study

The purpose of this study is to determine the vector and consequences of the global food crisis in the world under the influence of a significant reduction in virtual water exports from Ukraine to agri-food markets as a result of russian aggression in Ukraine. The acquired knowledge will help in making effective management decisions on the scale and prospects for the development of economic activities in the state and the number of imports of virtual water in one's country.

To accomplish the aim, the following tasks have been set:

– to determine and describe the structural organization of the system and the stability of the systemic development of the region over time from the standpoint of water use by type of economic activity;

– to establish the peculiarities of interdependence of water and food security, which significantly deepens the global food crisis and is based on the risk of a shortage of virtual water;

– to determine the fundamental position of the economies of countries in the context of the global food crisis and the risk of a shortage of virtual water.

4. Materials and research methods

4. 1. Object and hypothesis of research

The object of this study is the process that forms conceptual foundations for managing the impact of virtual water shortage risks on the global food crisis. The study is based on the logical assumption that the economic development of the country is limited by the presence of the water potential of the territory, and the lack of sufficient water resources pushes countries to use the import of virtual water.

The hypothesis is considered that the formation of structural changes in the economies of the world and the reorientation of their national economies in the direction of the development of the agricultural sector under modern conditions will inevitably lead to global consequences. Namely, they will either lead to a drop in the growth rate of national economies, or to a state of "bifurcation explosion" followed by dispersion of possible states of economic development. The terms of such changes are determined by globalization of water problems, improper use of water-efficient technologies, and military aggression in Ukraine.

4. 2. Methods

Traditional and special research methods were used. Historical and logical – to analyze the share of world trade of Ukraine in agri-food markets and the formation of export-import of virtual water to Ukraine and the world as a whole. Methods of theoretical generalization, analysis, and synthesis – to specify that agricultural production is one of the most water-intensive types of economic activity in the world. And also, to actualize the fact that not all countries have sufficient water potential to implement on their own territories of water-intensive activity. Statistical analysis – to estimate the content of virtual water in some selected products for a number of selected countries. Econometric methods – to draw a logical conclusion that the lack of sufficient water resources pushes the country to use innovative water-efficient technologies and industries, as well as the use of virtual water imports in one's country. Synergistic approach, based on the tools of measure of order and chaos – to assess the capacity of the regional system for self-development and proximity to the new technological structure.

4. 3. Materials

While people in Ukraine are in a desperate position and dying from war, in other countries people are dying of starvation, as a result of the bombing of the world breadbasket – Ukraine. In addition, hostilities are accompanied by the blocking of its ports and cargoes with wheat and sunflower oil, as well as other agricultural goods; destruction of granaries and illegal export of agricultural products from the territory of Ukraine to the territory of russia.

Currently, as a result of the war in Ukraine, world prices for food and fertilizers are growing. After the russian invasion in February 2022, The New York Times predicted that wheat prices would rise by 21 percent, barley by 33 percent, and some fertilizers by 40 percent in 2022–2023 [21] .

Data from the US Department of Agriculture (USDA) indicate that food and beverage price inflation in 2022 was growing at the fastest pace in 40 years [22]. The USDA predicts that livestock prices on farms will rise by 12.5–15.5 % in 2022–2023. It is expected that wholesale prices for beef will increase by 4–7 %.

The increase in prices for agricultural products will continue throughout 2023, as energy and transport routes will change. It is predicted that wholesale prices for poultry meat will increase by 9–12 %, and for wholesale dairy – by 7–10 % in 2022 –2023 [22].

Prices for soybeans on farms will increase by 8.5–11.5 % in 2022–2023, and prices for fats and oils can rise by 27–30 %. Now it is predicted to increase fruit prices at the farm level by 12.5–15.5 %, and for vegetables at the farm level – by 6–9 %. Wheat prices are likely to rise by 20–23.0 %, and wholesale prices for wheat flour will increase by 12–15 % in 2022–2023 [22].

In several European countries, a number of potential options for replacing russian energy supplies to Europe are being considered, which could reduce price increases while maintaining pressure on the russian economy. The cost of fuel for transportation, production, and packaging of food products is one of the main reasons for the rise in prices worldwide [23].

In the spring of 2022, British egg farmers faced an unprecedented increase in their value. The growth occurred at the level of 30 % on some farms, as a result of which many farms are on the verge of bankruptcy, and hundreds of farms have a real danger of curtailment [24].

Since British farmers lose money on every egg produced, after the russian invasion of Ukraine many decided to stop production so as not to lose their farms. Such actions lead to a decrease in the number of chickens in the UK and increased pressure on supply [24].

Sunflower oil is among the agricultural goods that are becoming increasingly difficult to obtain due to the Russian invasion of Ukraine. Most sunflower oil in the UK comes from Ukraine, food companies report that sunflower oil reserves are limited and are likely to run out, and some businesses are already experiencing serious difficulties. This situation has already led to the fact that some food manufacturers urgently replace sunflower oil with refined rapeseed oil.

At the same time, given the serious impact of the war in Ukraine on the food security of Ukrainians, the European Parliament emphasizes the need for a powerful long-term humanitarian food assistance for Ukraine both from the EU and from around the world [25].

The war in Ukraine will continue to lead to higher food prices and shortages of major crops in parts of Central Asia, the Middle East, and North Africa. About 25 African countries imported wheat from Ukraine and russia for Rs 82 billion between 2018 and 2020 [1].

Ukraine and russia are among the five largest exporters of wheat. This indicates that the crisis may increase inflationary pressures in the food chain (Fig. 1). According to the Food and Agriculture Organization of the United Nations (FAO), in 2020 russia produced 86 million tons of grain, second only to China and India [26]. At the same time, it should be noted that both China and India consume the lion's share of their production in the domestic market, which makes russia the largest exporter of wheat by a significant margin.

Fig. 1. Countries that are the largest wheat exporters in the world in 2020
Source: compiled by authors using data from [27]

In general, Ukraine and russia account for 53 % of world trade in sunflower oil and seeds and 27 % of wheat; the countries are global exporters in agri-food markets [26] (Fig. 2).

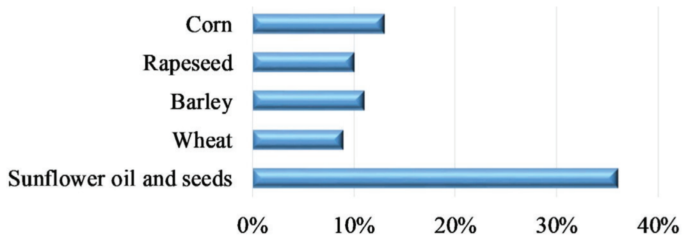


Fig. 2. The share of Ukraine's world trade for selected goods on agri-food markets in 2020, %
Source: compiled by authors using data from [27]

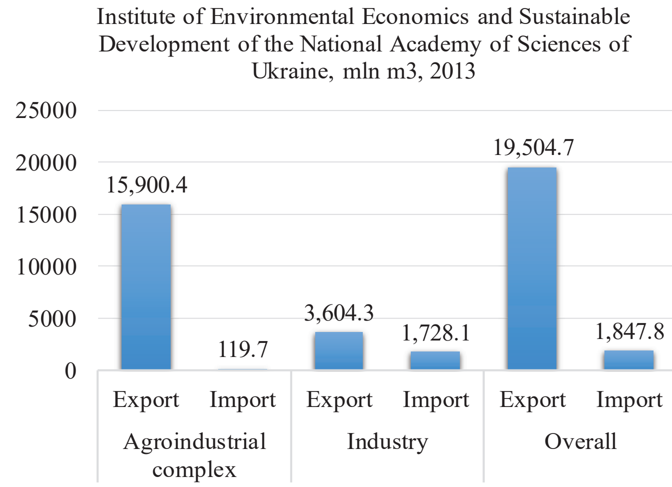
As already mentioned, due to the production of agricultural goods, Ukraine forms significant volumes of flows of virtual water exports in the world. According to estimates of the Institute of Environmental Economics and Sustainable Development of the National Academy of Sciences of Ukraine, the cost of virtual water for the production of one ton of wheat is about 1000–1200 m^3/ton [9]. At the same time, the export of virtual water in the agro-industrial complex is recorded at the level of 15.9 billion m^3. According to European researchers, the total export of virtual water from Ukraine is at the level of 25.3 billion m^3 (Fig. 3).

The world's leading studies on this issue [10] indicate the following streams of virtual water associated with the production of agricultural products (Table 1). Table 1 shows that according to available data, only a few countries can fully replace the reduction in virtual water flows associated with agricultural products from Ukraine without rising prices due to the cost of water resources: the Netherlands, China, Japan, and the USA. Also influential world grain exporters are Canada and Australia. It should be noted that these countries have the world's largest reserves of water resources, along with the United States. This enables these countries to develop water-intensive types of production, including agricultural production.

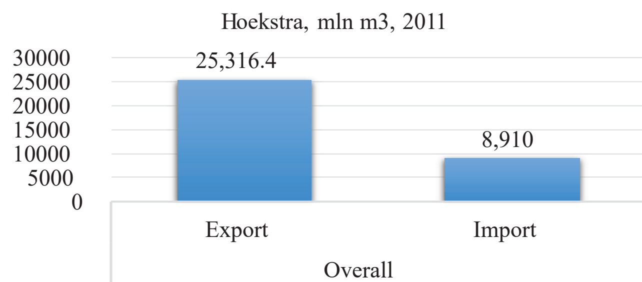
The Netherlands, China, Japan are not the world's influential grain exporters, and this, in the overwhelming majority, happens for two reasons, either there is an insufficient amount of high-quality land resource, or water per unit population.

In previous studies on regional water management dependence [29], a scientific and methodological approach to assessing the level of needs of regional socio-economic systems of Ukraine in water resources was developed and applied, based on the application of the index of regional water management dependence. The index of regional water management dependence is the ratio of the total use of fresh water in the region to the volume of existing river flow of this region (water potential). This index was calculated on the basis of data on the use of fresh water by the regions of Ukraine over the past 10 years (Table 2).

The use of the index of regional water management dependence (I_{RWD}) has made it possible to determine the gradation of regions according to the degree of regional water management. Dependence of the «deficit» type indicates that more than 100 % of the water supply of the territory is used in the region. Such use is possible only through significant infrastructure schemes for the redistribution of water resources between regions for economic activity. With the «high» dependence of the region, from 71 to 100 % of the water supply of the territory is used, which is critical in the operation of the water resource to ensure its timely restoration according to environmental parameters. The use of water resources, which exceeds 70 % of the flow, is a critical limit, leading to a radical violation of the state of water systems.



a



b

Fig. 3. Export-import of virtual water in Ukraine according to various estimates, million m^3: *a* — Export-import of virtual water in Ukraine according to the estimates of the Institute of Environmental Economics and Sustainable Development of the National Academy of Sciences of Ukraine, million m^3; *b* — Export-import of virtual water in Ukraine according to Hoekstra A., million m^3
Source: compiled by authors using data from [9, 10]

Table 1

Average virtual water content in some selected products for a number of selected countries, m^3/tonne [28]

Products	Netherlands	China	Japan	United States	Mexico	Australia	Brazil	India	Russia	Italy	Indonesia
Wheat	619	690	734	849	1,066	1,588	1,616	1,654	2,375	2,421	–
Corn	408	801	1,493	489	1,744	744	1,180	1,937	1,397	530	1,285
Barley	718	848	697	702	2,120	1,425	1,373	1,966	2,359	1,822	–

Table 2

Assessment of the level of needs of the regions of Ukraine in water resources

Regions of Ukraine on a classification basis			The value of the index of regional water management dependence (I_{RWD})
Characteristics of water management dependence	Low	Other areas	I_{RWD}: 0–0.5
	Average	Does not have this category of dependence	I_{RWD}: 0.51–0.7
	High	Kyiv Oblast and the city of Kyiv, Odesa Oblast, ARC, and the city of Sevastopol	I_{RWD}: 0.71–1.0
	Deficit	Kherson, Dnipropetrovsk, Donetsk, Zaporizhia Oblasts	I_{RWD}: 1.0 and >

Source: authors' calculations [29]

The conducted assessment shows that indeed the water supply of territories does not determine the specialization of the regions of Ukraine in the export/import of water-intensive products. Territories with high water risk (water management dependence) are simultaneously agrarian and are engaged in one of the most water-intensive types of economic activity (cereals, sunflower, etc.).

As already defined, Ukraine's resources are increasingly becoming a serious component of national security. Ukraine belongs to the least water-rich countries in Europe since the reserves of local resources of river flow for 1 person are about 1.0 thousand m^3 per year. In terms of regions, according to the UN methodology, sufficient river flow is formed only in 8 oblasts – Volyn, Zhytomyr, Zakarpattia, Ivano-Frankivsk, Lviv, Rivne, Sumy, and Chernihiv, which exceeds the critical value of 1.7 thousand m^3 per year for 1 person [29].

The proof that the water supply of territories does not determine the specialization of the regions of Ukraine in the export/import of water-intensive products is also the determined absence of a correlation between the factors of influence. There is no connection both between the production of grain and leguminous crops in the regions of Ukraine and the river flow (water potential) in them, and between the use of fresh water by region and the river flow in them (Table 3). For calculations, the method of correlation analysis was used – biserial correlation using the point biserial coefficient of Pearson correlation [11, 12].

The assessment of the level of needs of the regions of Ukraine in water resources indicates the existence of regions in which there is a water dependence "deficit". The simultaneous presence of the regions' dependence on water resources "deficit" and the lack of connection between the use of fresh water by region and the water supply of the regions makes it possible to draw a certain conclusion. Also, the lack of connection between the production of grain and leguminous crops in the regions of Ukraine and the water supply of the regions indicate the same conclusion. Consequently, Ukraine has a peak load on the use of water resources and, as a result, a peak load on the agricultural sector, which is the most water-intensive among other sectors of the economy.

It is clear that further economic growth is possible only through the introduction of innovative water-efficient technologies, closed-loop technologies in production, and the effective use of intersectoral externalities in the economy, including the import of virtual water into the country. That is, the development of the Ukrainian economy was not an exception to world development trends, and it was proved that upon reaching a certain limit of water supply of the territory, the need to increase the net import of virtual water into the country will increase.

In further studies, the influence of spatial economics on the development of regional systems under conditions of limited water resources was recognized and the dependence of the level of development of regions on the existing water potential of the territory was substantiated.

The study once again confirmed the opinions of world scientists on the existence of a relationship between the provision of countries with water resources and their trade specializations. Based on the use of correlation and regression analysis to establish the relationship between the GDP of countries and the availability of water resources in them, the following thesis was determined. The very presence of inland renewable water resources in the country does not have a significant impact on the formation of the country's GDP but the total volume of catchment per 1 person in the country already has a significant impact on GDP. That is, indeed, after reaching a certain threshold of water shortage, the country begins to present demand for grain imports, which increases with the decrease in water resources [12].

The regression equation is given as

$$GDP=-2{,}870.5+12{,}063\times X3, \tag{1}$$

where $X3$ is the total volume of catchment per 1 person, thousand m^3/year (source: authors' calculations [12]).

The indicator R^2 is given a qualitative estimate on the Cheddock scale – the bond strength is moderate/weak.

According to data from the US Department of Agriculture, wheat consumption in the world is steadily growing. And this is not always associated only with the growth of the population in the country (Fig. 4, 5).

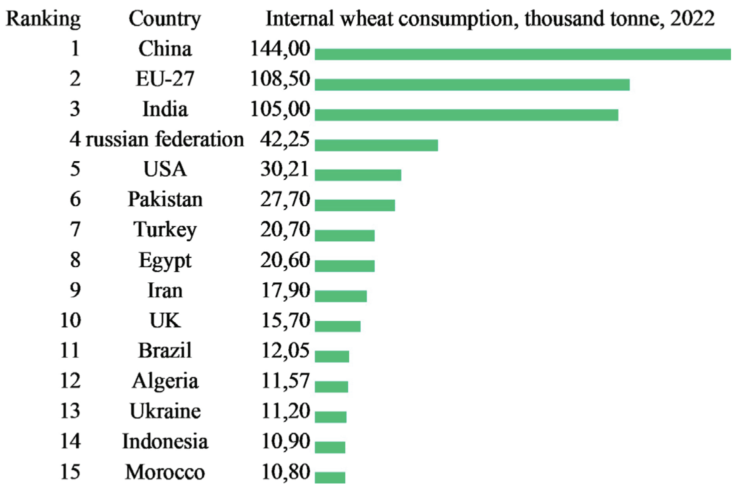
According to the US Department of Agriculture, the 15 largest wheat consumers in the world are China, EU-27 (countries of the European Union), India, the russian federation, the USA, Pakistan, Turkey, Egypt, Iran, Brazil, Algeria, Ukraine, Indonesia, Morocco [2] (Fig. 5).

Table 3

Calculation of the correlation between indicators using the biserial correlation method applying the point biserial coefficient of Pearson correlation

The relationship between the production of grain and leguminous crops by region and the river flow in them	Sample size: n=24, df=22. Dichotomous scale for Y: n_1=14, n_0=10
	S_x=1160,176. $\bar{x}=2{,}273.778$; $\bar{x}_1=2{,}223.507$; $\bar{x}_0=2{,}344.158$
	$r_{pb}=-0.0524$
	$\lvert t\rvert=0.24599$, no correlation
The relationship between the use of fresh water by region and the river flow in them	Sample size: n=24, df=22. Dichotomous scale for Y: n_1=14, n_0=10
	S_x=459.14. $\bar{x}=368.70$; $\bar{x}_1=222.66$; $\bar{x}_0=573.16$
	$r_{pb}=-0.3844$
	$\lvert t\rvert=1.9533$, no correlation

Source: authors' calculations [11, 12]



a

Country	Population, people, 2020
China	1 394 016 000
India	1 326 093 184
USA	332 639 104
Indonesia	267 026 368
Pakistan	233 500 640
Nigeria	214 028 304
Brazil	211 715 968
Bangladesh	162 650 848
russian federation	141 722 208
Mexico	128 649 568
Japan	125 507 472
Philippines	109 180 816
Ethiopia	108 113 152
Egypt	104 124 440
Democratic Republic of the Congo	101 780 264

b

Fig. 4. Countries with the highest domestic wheat consumption and the largest population as of 2022 and 2020: *a* – countries with the highest domestic consumption of wheat as of 2022, thousand t; *b* – countries with the largest population as of 2020, persons

Source: compiled by authors using data from [30]

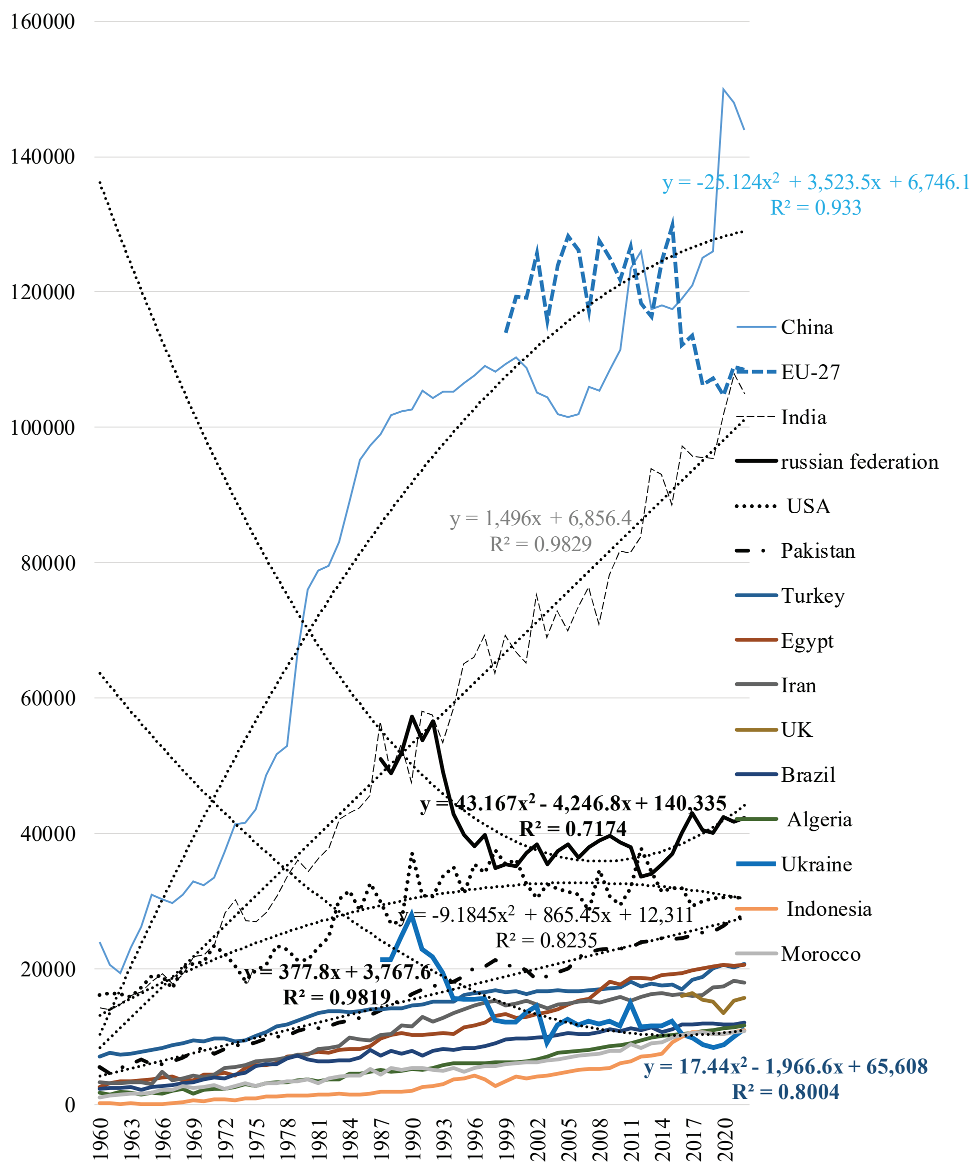


Fig. 5. Countries with the highest domestic consumption of wheat, 1960–2022, t

Source: compiled by authors using data from [2, 30]

But not all of these countries are densely populated and have a large and growing population. For example, the countries of the European Union are not densely populated, the same applies to Ukraine and Morocco, which are not among the first 15 countries with the largest populations in the world.

From Fig. 5 it is clear that China, India, Pakistan will continue to rapidly increase the consumption of wheat by the population, and this is mostly due to the increase in populations in these countries (Fig. 6). Wheat consumption in Turkey, Egypt, Iran, Brazil, Algeria, Indonesia, and Morocco will also increase.

After a decline in consumption in the Russian Federation and the United States, in 2020–2022, a tendency to increase wheat consumption is again predicted while the population of the russian federation decreases every year.

Domestic consumption of wheat in the USA, Ukraine, and EU-27 is decreasing. It should be noted that the population of the United States is steadily growing from year to year but is decreasing in Ukraine and EU-27.

Thus, it is clearly understood that the consumption of wheat in the world will continue to grow steadily, and therefore the need to increase the net import of virtual water into the country will also increase, and this is not always associated with the existing population of the country.

It has been analytically proven that a direct link between the growth of domestic consumption of wheat and the existing population does not always exist.

So, based on the facts obtained and the results of original research [29], the pattern of the "principle of globality of water problems" was derived and proved mathematically. Namely: "the axes (corridors) of the development of the territory, which determine, together with the poles of growth, the spatial framework of economic growth, in the light of globalization of water problems, are determined by the presence of the total amount of inland renewable water resources."

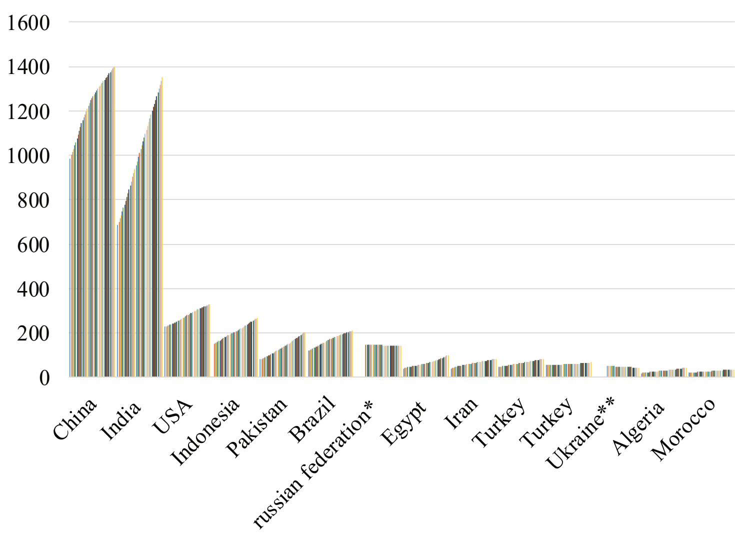


Fig. 6. The population of the world, 1980–2019, million people: * – population over 1989–2019, million people; ** – population over 1992–2019, million people

Source: compiled by authors using data from [31, 32]

The basics for obtaining a pattern were:

– assessment of the level of needs of regional socio-economic systems of Ukraine in water resources, based on the application of the index of regional water management dependence;

– lack of correlation between the production of grain and leguminous crops in the regions of Ukraine and their river flow (water potential);

– lack of correlation between the use of fresh water by region and their river flow;

– empirical comparison of economic growth with the presence of water potential of the territory.

It is clear that under such conditions, further economic growth is possible only through the introduction of innovative water-efficient technologies, closed-loop technologies, and the effective use of intersectoral externalities in the economy. Including the use of virtual water imports. That is, the development of the Ukrainian economy was no exception to world trends. It is proved that upon reaching a certain limit of water supply of the territory, the need to increase the net import of virtual water into the country will increase.

5. Results of investigating the impact of the risk of virtual water deficiency on the global food crisis

5. 1. Assessment of the structural organization of the system and the sustainability of the systemic development of the region over time from the standpoint of water use

Based on the described results of the specified studies, it is possible to make a logical assumption that the economic development of the countries of the world, nevertheless, is limited by the presence of the water potential of the territory and has an impact on the formation of the country's GDP. And the lack of sufficient water resources pushes the country to use innovative water-efficient technologies and industries, as well as the use of virtual water imports in one's country.

Otherwise, using water resources at the critical limit of recovery according to environmental parameters, countries can fall into the so-called zone of "impasse of the evolutionary corner". That is, countries may find themselves in a regulated economy with a lack of self-development, which under modern emergent conditions can lead to a gradual inhibition of the national economy.

Based on the above arguments, it is possible to assume that a decrease in the import of virtual water into the country can lead to several scenarios for the development of events:

1. A critical level of use of water resources in one's country, which will affect the water security of the country and indirectly national security and send the country for some time to the zone of "evolutionary impasse". This situation will make it impossible for the economy to approach the new technological structure due to the region's inability to self-development.

2. Search for new ways to get virtual water imports from other countries on the market. If a new exporter of virtual water is found, an increase in the cost of water-intensive products exported due to the higher cost of water resources in the exporting country is possible, which is caused by climatic conditions and the level of machinery and technology in a given country.

For the vast majority of countries, the second scenario will be more realistic.

We shall assess the region's capacity for self-development and proximity to the new technological structure on the example of the Kherson Oblast of Ukraine. This area is indicative from the point of view of national regulation of the structure of economic activity of the region. This is indicated by two factors, firstly, this region is the largest water consumer in Ukraine while it has the smallest own water potential of the region, and secondly, the region, in the overwhelming majority (almost 30 %), is engaged in agricultural activities (Table 4). This oblast has the characteristic of water management dependence "deficit", which means that the region uses more than 100 % of its own water supply of the territory, this is possible only due to the redistribution of water resources between regions. Almost the entire volume of production of vegetable crops falls on the Kherson Oblast, which is a very water-intensive production and the most water-intensive among the production of agricultural crops. The provision of the average long-term river flow per 1 person in the Kherson Oblast is 0.13 thousand m^3/year but, according to the UN methodology, the minimum river flow should be 1.7 thousand m^3 per year for 1 person. In terms of oblasts, according to the UN methodology, sufficient river flow is formed only in 8 oblasts – Volyn, Zhytomyr, Zakarpattia, Ivano-Frankivsk, Lviv, Rivne, Sumy, and Chernihiv, which exceeds the value of 1.7 thousand m^3 per year for 1 person.

Using the thesis that the production of major crops has the greatest impact on the formation of virtual water flows, the indicator of gross value added by type of economic activity can be considered a characteristic feature that describes the structural organization of the system and the sustainability of systemic development over time of regions from the standpoint of water efficiency.

Evaluation of the structural organization of the system will be carried out using the tools of a measure of order and a measure of chaos [34–36]. It is based on two information functions: additive negentropy (IΣ) and entropy of the reflection (S).

In economics, the concept of entropy explains the unpredictable development of the market. That is, the economic goal was not achieved due to the fact that the system turned out to be disordered, uninformative, etc. Entropy is a measure of the complexity of the system, a measure of chaos. The greater the entropy, the harder it is to understand the logic of this particular system.

Negentropy means a measure of the orderliness and organization of the system.

To describe the structural organization of the system, that is, the ratio of order and chaos in synergistic theory, the R-function of the following form is calculated [35, 36]:

$$R=\frac{I\Sigma}{S}. \quad (2)$$

The value of additive negentropy is calculated from the following formula [35, 36]:

$$I\Sigma=\frac{\sum m\log_2 m}{M}. \quad (3)$$

Table 4

Gross value added by type of economic activity in the Kherson Oblast, UAH million

Types of economic activity	2012	2013	2014	2015	2016	2017	2018	2019	2020	Specific share in 2020,%
Agriculture, forestry and fisheries	4,140	5,114	6,721	10,999	12,476	13,576	14,665	14,503	17,045	28.12
Mining and development of mines	37	56	24	63	92	81	101	138	146	0.24
Processing industry	2,216	2,110	2,290	2,850	4,124	5,035	5,345	5,487	6,140	10.13
Supply of electricity, gas, steam and air conditioning	378	385	426	622	834	922	1,481	1,933	2,709	4.47
Water supply; sewage, waste management	117	119	149	148	153	184	218	258	308	0.51
Construction	233	266	238	239	304	476	540	810	915	1.51
Wholesale and retail trade; repair of motor vehicles and motorcycles	2,077	2,202	2,383	2,861	3,203	4,328	5,290	6,052	6,173	10.19
Transport, warehousing, postal and courier activities	1,125	1,155	1,101	1,668	2,004	2,027	2,905	2,018	2,265	3.74
Temporary accommodation and catering	202	180	200	235	297	322	431	576	557	0.92
Information and telecommunications	202	213	265	388	500	655	795	1077	1381	2.28
Financial and insurance activities	436	467	467	724	773	917	1041	172	2635	4.35
Real estate transactions	1,329	1,614	1,705	2,040	2,518	3,051	3,960	4,762	5,075	8.37
Professional, scientific, and technical activities	238	229	242	309	387	495	644	816	832	1.37
Activities in the field of administrative and support services	147	159	185	181	248	305	353	451	501	0.83
Public administration and defense; compulsory social insurance	1,201	1,475	1,792	2,055	2,535	3,449	4,701	5,579	6,352	10.48
Education	1,670	1,797	1,770	2,017	2,106	3,265	3,950	4,251	4,550	7.51
Health care and social assistance	987	946	959	1,045	1,171	1,465	1,441	1,527	1,957	3.23
Arts, sports, entertainment, and recreation	173	203	185	187	208	269	376	451	488	0.81
Provision of other types of services	218	234	245	241	277	343	422	586	578	0.95
The average exchange rate of hryvnia to 1 US dollar at the end of the year, UAH (according to LLC "MinfinMedia")										
–	8.0970	8.2890	16.5290	24.0999	27.6000	28.1750	28.1500	24.6000	28.5000	–

Source: compiled by authors using data from [33]

The value of the entropy of the reflection is calculated from the following formula [35, 36]:

$$S = \log_2 M - \frac{\sum m \log_2 m}{M}, \tag{4}$$

where m is the value of the elements in each part;

M – the total number of elements of the system ($M=\Sigma m$).

Based on the ratios of information flows (entropy and negentropy), we calculate the R-function in accordance with the methodology. The value of the R-function indicates which of the information functions prevails in the structure of the system: chaos or order.

At the value of R-function=1, the functions of additive negentropy and entropy (order and chaos) are balanced, and the structural organization of the system is equilibrium, that is, synergistic.

For further characterization of the values of the R-function and their interpretation, it is necessary to calculate the intervals of permissible values of negentropy and entropy [35, 36]: S_{max}; S_{min}; $I\Sigma_{max}$; $I\Sigma_{min}$ (Table 5):

$$S_{max} = \log_2 N, \tag{5}$$

$$S_{min} = \log_2 M - \frac{M-N+1}{M}\log_2(M-N+1), \tag{6}$$

$$I\Sigma_{max} = \frac{M-N+1}{M}\log_2(M-N+1), \tag{7}$$

$$\Sigma_{min} = \log_2 M - \log_2 N, \tag{8}$$

where N is the number of components of the system.

Table 5

Calculation of the R-function on the characteristic basis "Gross value added by type of economic activity, million UAH" (and intervals of permissible values of negentropy and entropy) in the Kherson Oblast

Types of economic activity	2012	2013	2014	2015	2016	2017	2018	2019	2020
	$m\log_2 m$	$m\log_2 m$	$m\log_2 m$	$m\log_2 m$	$m\log_2 m$	$m\log_2 m$	$m\log_2 m$	$m\log_2 m$	$m\log_2 m$
Agriculture, forestry, and fisheries	49,743.82	63,005.69	85,453.89	147,662.51	169,759.28	186,381.79	202,964.91	200,490.40	239,602.60
Mining and development of quarries	192.75	325.21	1,10.04	376.57	600.17	513.53	672.48	980.98	1,049.71
Processing industry	24,628.05	23,300.79	25,558.99	32,708.73	49,528.53	61,919.30	66,192.34	68,158.43	77,265.90
Supply of electricity, gas, steam and air conditioning	3,236.53	3,306.66	3,720.99	5,772.64	8,093.06	9,080.43	15,598.42	21,101.84	30,892.20
Water supply; sewage, waste management	803.83	820.48	1,075.66	1,067.00	1,110.38	1,384.34	1,693.46	2,066.90	2,546.17
Construction	1,832.36	2,142.71	1,878.97	1,888.31	2,507.37	4,233.93	4,901.48	7,826.04	9,001.43
Wholesale and retail trade; repair of motor vehicles and motorcycles	22,889.13	24,452.33	26,733.84	32,850.87	37,299.60	52,280.01	65,432.29	76,032.46	77,728.91
Transport, warehousing, postal and courier activities	11,402.67	11,750.60	11,125.16	17,854.11	21,981.21	22,266.86	33,420.06	22,155.04	25,244.09
Temporary accommodation and catering	1,546.96	1,348.53	1,528.77	1,850.98	2,439.65	2,682.56	3,771.92	5,281.88	5,080.69
Information and telecommunications	1,546.96	1,647.49	2,133.21	3,336.77	4,482.89	6,127.75	7,659.67	10,848.41	14,405.90
Financial and insurance activities	3,822.93	4,141.02	4,141.02	6,877.89	7,416.41	9,023.99	10,434.73	18,511.28	29,943.05
Real estate transactions	13,789.87	17,199.47	18,304.12	22,428.48	28,448.52	35,315.53	47,327.09	58,179.03	62,469.15
Professional, scientific, and technical activities	1,878.97	1,795.18	1,916.36	2,555.88	3,326.73	4,430.89	6,009.11	7,892.70	8,070.77
Activities in the field of administrative and support services	1,058.35	1,162.75	1,393.31	1,357.47	1,972.64	2,517.06	2,987.62	3,976.46	4,493.30
Public administration and defense; compulsory social insurance	12,286.25	15,526.59	19,366.78	22,615.12	28,665.20	40,532.52	57,346.33	69,435.07	80,244.79
Education	17,878.41	19,428.04	19,097.47	22,142.62	23,250.85	38,111.91	47,193.17	51,239.80	55,290.01
Health care and social assistance	9,817.60	9,351.87	9,499.27	10,480.61	11,936.62	15,406.94	15,120.20	16,150.29	21,398.68
Arts, sports, entertainment and recreation	1,286.19	1,556.06	1,393.31	1,411.27	1,601.69	2,171.22	3,216.53	3,976.46	4,358.20
Provision of other types of services	1,693.46	1,841.67	1,944.48	1,907.01	2,247.51	2,888.77	3,680.30	5,388.13	5,303.11
R-function	3.0465	3.1513	3.3466	3.7187	3.7444	3.7178	3.6763	3.5693	3.6184
$I\Sigma$	10.59	10.79	11.07	11.68	11.89	12.08	12.24	12.26	12.45
S	3.48	3.42	3.31	3.14	3.17	3.25	3.33	3.43	3.44
Intervals of permissible entropy values									
S_{max}	4.248	4.248	4.248	4.248	4.248	4.248	4.248	4.248	4.248
S_{min}	0.0163	0.0149	0.0133	0.0101	0.0087	0.0073	0.0063	0.0058	0.0051
Intervals of permissible negentropy values									
$I\Sigma_{max}$	14.048	14.193	14.368	14.807	15.053	15.322	15.564	15.688	15.882
$I\Sigma_{min}$	9.816	9.960	10.134	10.569	10.814	11.081	11.322	11.446	11.639

Source: authors' calculations

With $R>1$, we have a predominance in the structure of the order system. From the calculations it can be seen that the value of entropy is within extreme limits. The value of entropy (measures of chaos) averages 3.25–3.48 with a maximum allowable value of 4.248, that is, it approaches its maximum threshold value.

The closer the entropy value approaches the maximum threshold, the greater the level of nonlinearity. Thus, an increase in the degree of uncertainty regarding the manifestations of events will lead to the inaccuracy of the characteristics and assessments of systems and, therefore, reduces the validity of management decisions made on their basis.

The value of negentropy is within the normal range. That is, with the existing values of entropy, the system is in the range of values more prone to the domination of uncertainty. But the value of negentropy, which is within the normal range, does not allow us to conclude that there is an irreversible domination of chaos over order. That is, the entire regional system for creating gross value added by type of economic activity, in accordance with the value of the R-function, is an orderly and tightly regulated process (we have the dominance of the order as a whole in the system). The results of the flow of information functions by type of economic activity in the Kherson Oblast clearly demonstrate the orderliness and stability of the system due to state intervention, that is, the development of only one type activity – agricultural production. Consequently, the stability of the system, in this case, depends on state intervention, and the system itself cannot be self-regulating.

5. 2. Features of the interdependence of water and food security, which are based on the risk of a shortage of virtual water

With an increase in the value of the R-function in 2012–2020, we also have an increase in the value of entropy. This means that when approaching the thresholds of entropy, in the economy of the region we can expect a “bifurcation explosion” and the subsequent scattering of possible states of development of the system. The ability to self-development is one of the fundamental properties of the system. That is, the system must be adaptive and come in such an interval of the value of the R-function where the domination of both order over chaos and chaos over order is mutually inverse. Therefore, there is reason to believe that orderly and chaotic systems are not stable, nor are they capable of self-development.

Thus, with the strengthening of state intervention in the economic complex of the Kherson Oblast, the territory, including the use of water resources of the regional system for management (agricultural production), there is an increase in the orderliness of the regional system. This leads to a delay in this system in the zone of “evolutionary impasse” and makes it impossible to move to the concept of self-organization and to a new technological structure.

It is necessary to clearly understand whether there is a need for such state intervention and economic conduct without the transition to self-organization of regional systems. Or, nevertheless, it is necessary to introduce mechanisms for regulating development based on market laws and the balance of centralized management with decentralized management. Centralized management of the economy in practice showed its insolvency and thus gave impetus to its improvement and development.

5. 3. Fundamental provisions of managing the country’s economy in the context of the global food crisis and the risk of a shortage of virtual water

The critical level of use of water resources in one’s country will push the countries of the world now, under the conditions of the russian-Ukrainian war, to use the import of virtual water in one’s country from other countries. Consequently, the scenario of plowing their territories or increasing their own acreage for most low-water countries is unlikely. The basis of this statement is that these countries will for some time be in the zone of “evolutionary impasse” and this will make it impossible for the country to approach the new technological structure due to the region’s inability to self-development.

Thus, it is mathematically proved that rapid structural changes in the economies of the countries of the world and the reorientation of their national economies towards the development of the agricultural sector under modern conditions will inevitably lead to global consequences. Namely, they will either lead to a drop in the growth rate of national economies, or to a state of “bifurcation explosion” followed by the dispersion of possible states of economic development. The conditions for change are the globalization of water problems, the lack of proper use of water-efficient technologies, and military aggression in Ukraine. Under the conditions of accelerated scientific and technological progress, the time factor plays an increasingly significant role in the formation of modern trends. Time in dynamics models is the main independent variable. It should be noted that dynamic models take into account the dependence of variables on time and the interdependence of variables over time. Also, the basis for taking into account the time factor in the analysis of economic processes is the process of the emergence, development, and manifestation of economic crises.

6. Discussion of the consequences of the global food crisis under the influence of a significant decline in virtual water exports from Ukraine

Africa, Europe, and India represent the largest importers of virtual water. A particularly urgent need to increase the import of virtual water is felt in Africa and India, as the availability of water for irrigation there decreases and the population increases over the course of a century.

According to FAO estimates, wheat stocks are quite limited in Canada and the United States, which currently makes it impossible to compensate for the gaps that have arisen in the supply of grain and sunflower oil and seeds for importers as a result of russia’s military invasion of Ukraine. Other grain suppliers include possible exports from Argentina, but it is likely to remain limited due to the government’s efforts to control domestic inflation. Another supplier is Australia but, according to FAO estimates, exports from this country reached the maximum throughput capacity in logistics [26].

We can assume, based on the forecasts of experts, that it is likely that Brazil and the United States will only partially satisfy the unfilled 14 million tons of corn exports from Ukraine in 2022–2023 [26]. Given the significant share of Ukraine’s exports on the world market of sunflower oil, failures in its supplies have significant consequences for the main importers of sunflower oil, namely for India, the European Union, China, the Islamic Republic of Iran, and Turkey.

The content of virtual water in wheat, corn, and barley in production in the United States is much lower, almost twice as much as in production in Brazil (Table 1). For example, the content of virtual water in wheat in the United States is 849 m^3/ton, and in Brazil – 1616 m^3/ton. In Ukraine, as noted, this value is 1,000–1,200 m^3/ton. The situation is the same for corn, in the USA – 489 m^3/ton, and in Brazil – 1,180 m^3/ton.

Thus, taking into account the fact that individual countries will not go for structural changes in their economies in the direction of building the agricultural sector, we can predict the next trend. The lack of Ukrainian exports of grain, sunflower oil, and other types of agricultural products in 2022 and 2023 will be compensated by, mostly, exports from countries such as the USA, Canada, Brazil, possibly Australia. Such influential exporters as France and Germany are predicted to cover the need for agricultural products only in European countries.

At the same time, only the value of US exports can compensate Ukrainian exports with a minimum level of inflation, only through logistics, the rising cost of energy carriers and fertilizers, and without the impact of rising costs of virtual water flows.

Since the content of virtual water in wheat in production in Brazil and Autralia is higher than in production in Ukraine, on average by 20–25 %, the projected rise in the price of wheat by 20–23 %, which was described above, is probably necessary to be added with another percentage. The rise in price will occur due to an increase in the cost of water resources, and this may lead to an increase in prices by another 10–12 %.

It is predicted that by 2100 China will be able to become the largest exporter of virtual water in the world due to trade in wheat products and agricultural goods [37]. That is, in the future, China will move from importer to exporter due to a decrease in population growth after 2030 and the introduction of water-efficient technologies, closed-loop technologies, and the use of intersectoral externalities. Reducing domestic needs will allow the use of all excess water resources to meet the international needs of agriculture. Regions in Africa will experience almost the opposite effect as the population grows rapidly over the course of a century, leading to increased demand for water resources.

Another major source of future virtual water exports is the United States through the production of corn, grain, and other types of agricultural products.

The impact of virtual water shortage risks on the global food crisis of 2022 as a result of hostilities in Ukraine is considered. But there are objective difficulties associated with determining the time and its duration when countries will find themselves in the zone of "evolutionary impasse" due to a drop in the growth rate of national economies, or a "bifurcation explosion". The reason for this is that there is a high level of nonlinearity, that is, an increase in the degree of uncertainty regarding the manifestations of events.

Within the framework of the study, a scientific and methodological approach to assessing the sustainability of systemic development over time is proposed on the characteristic basis of "gross value added by type of economic activity" for water-intensive regions. It is based on the use of the proposed charactryttic feature "gross value added by type of economic activity" for water-intensive regions, which is based on the large-scale formation of virtual water flows in the production of major crops. This approach makes it possible to describe the structural organization of the system and the sustainability of systemic development over time of regions from the standpoint of water use by type of economic activity. The knowledge gained is given by the ability to make calculated decisions at the national level regarding the scale and prospects for the development of economic activities in the state.

The theoretical and methodological foundations of the interdependence of water and food security are described, which significantly deepens the global food crisis. The basis of these principles is the risk of a shortage of virtual water**.**

The fundamental provisions of the economies of countries in the context of the global food crisis and the risk of a shortage of virtual water have been developed. The fundamental provisions made it possible to reflect the consequences of the structural restructuring of the economy, the transition to the zone of "evolutionary impasse", and the inability to approach the new technological structure, increasing the use of virtual water imports in one's country at the expense of other countries.

The proposed scientific and methodological approach, theoretical and methodological foundations of the interdependence of water and food security and the fundamental provisions of the economies of countries in the context of the global food crisis and the risk of a shortage of virtual water enable state authorities to assess the depth of the global food crisis in the world and its consequences for all countries of the world in 2022–2023. On this basis, it becomes possible to make decisions on the volume of import virtual water in one's country.

Usually, when investigating economic phenomena and processes, economic and mathematical methods are used in the form of regression multifactorial models. But the use of such methods is justified only under static conditions of the system. When trying to go beyond these limitations to describe phenomena under conditions of dynamic development and uncertainty, objective difficulties arise that are associated with limited mechanisms for describing phenomena in dynamics.

The proposed solutions are timely and most relevant and such that the conditions beyond which, in their application, will not be necessary to imagine. Only the ideal state of implementation of the concept of "economic interdependence" of the countries of the world can create conditions for the lack of relevance of these decisions.

The disadvantages of this study are that the paper does not reveal possible ways to overcome the global food crisis in the world and reduce the risks of a shortage of virtual water caused by russian aggression in Ukraine. In the future, to eliminate these gaps, further research should be directed to investigating these issues.

7. Conclusions

1. We have proposed a scientific and methodological approach to assessing the sustainability of systemic development over time on a characteristic basis, which is characterized by the use of the proposed charactryttic feature "gross value added by type of economic activity" for water-intensive regions. The basis of this approach is the large-scale formation of virtual water flows in the production of major crops. It is determined that with the strengthening of state intervention in the economic complex of the region, terri-

tory, including the use of water resources of the regional system for management (agricultural production), there is an increase in the orderliness of the regional system. Such intervention leads to a delay in this system in the zone of "evolutionary impasse" and makes it impossible to move to a new technological structure.

2. The proposed theoretical and methodological foundations of the interdependence of water and food security indicate that the critical level of use of water resources in the country will push the use of virtual water imports in one's country from other countries. The scenario of plowing their territories or increasing their acreage for most low-water countries is unlikely because it will create the need for structural restructuring of the economy. It is determined that the most likely scenario of development will be the second – "search for new ways to get imports of virtual water from other countries on the market". This is explained by the fact that the first scenario ("the critical level of use of water resources in one's country") requires a structural restructuring of the economy and a reorientation of the economy towards the development of the agricultural sector. This structural restructuring of the economy will lead to two options for the development of events: either it will lead to a drop in the growth rate of national economies and send the country for some time to the zone of "evolutionary impasse", or to the state of "bifurcation explosion" followed by the dispersion of possible states of economic development.

3. We have proven and, on the basis of the knowledge gained, developed the fundamental provisions of the economies of countries under the conditions of the global food crisis and the risk of a shortage of virtual water. The principal provisions are developed in the part that rapid structural changes in the economies of the countries of the world and the reorientation of their national economies towards the development of the agricultural sector under modern conditions will inevitably lead to global consequences. Namely, they will lead either to a drop in the growth rate of these national economies, or to a state of "bifurcation explosion" followed by the dispersion of possible states of economic development. These modern conditions are the globalization of water problems and the lack of proper use of water-efficient technologies, as well as military aggression in Ukraine.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

The data will be provided upon reasonable request.

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