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RATIONAL USE OF FRESH WATER AS A GUARANTEE OF AGRIBUSINESS DEVELOPMENT IN THE CONTEXT OF THE EXACERBATED CLIMATE CRISIS

Introduction. *The global problem of the 21st century is general planetary climate change whose direct consequences are significant warming as well as increasing water shortage and desertification of territories, which together has a merciless impact on agriculture and, subsequently, on the development of agricultural business.*

Problem Statement. *The rational use of fresh water and water supply for agribusiness in arid, dry, and very dry regions of Ukraine, as well as the determination of the priority vectors of its adaptation to climate change, which ensure water and food security of future generations and the environment preservation are the problems to be discussed in this publication.*

Purpose. *The purpose of this research is determining the rational use of fresh water based on the study of foreign experience, the vectors of adaptation of agribusiness to climate change, and the strategy and tactics of its water supply in medium- and long-term horizons.*

Materials and Methods. *In the course of the research, we have used the following methods: the economic and mathematical modelling, while determining the dependence of water use for irrigation on the average monthly air temperature and the average monthly precipitation; forecasting, for determining the volume of water use for irrigation under the condition of modernization of irrigation technologies; the method of analogies, while studying*

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the foreign experience and the possibility of its implementation in domestic practice; monograph, for presenting the research results; abstract and logical methods, for generalizing and formulating conclusions.

Results. *The priority vectors of agribusiness adaptation to climate change in the regions of the steppe zone of Ukraine have been determined.*

Conclusions. *The study of foreign experience in the rational use of fresh water has enabled us to determine the priority vectors of adaptation of agribusiness to climate change, and hence the strategy and tactics of its water supply on medium- and long-time horizons.*

Keywords: agribusiness, fresh water, fresh water availability, and fresh water use.

The global problem of the 21st century is global climate changes whose direct consequences are significant warming, as well as deepening water shortage and desertification, which together have a merciless effect on agriculture and, therefore, on the development of agribusiness.

Both foreign and domestic researchers have been working for quite some time on the problem of the impact of climate change on water supply. Among foreign researchers, Peter Rogers deserves special attention. He is a professor at Harvard University (USA), a laureate of the Guggenheim Scholarship and the Twentieth Century Foundation, a senior consultant at the Global Water Partnership. Based on long-term research, he has proven the impact of climate change on freshwater resources and the effects of their scarcity on water and food security. Research works by Malin Falkenmark also deserve special attention. He is a professor at the Stockholm International Water Institute; has determined the minimum water needs for agricultural production by climate zone. Also, the research works by Rodney John Allam are worthy of mentioning. He is the Nobel Peace Prize Laureate, his research is focused on freshwater scarcity and ecology. Miguel Brandao, Associate Professor at the Royal Institute of Technology in Sweden, has been dealing with the study of water scarcity and food security for future generations; Solveig Kolberg and Julio Berbel have been focusing on measures for the rational use of water during irrigation and so on.

Full Members of the National Academy of Agrarian Sciences of Ukraine (hereinafter, the NAAS of Ukraine), Director of the Institute of Water Problems and Land Reclamation of the NAAS of Ukraine, Prof. Romashchenko has made a significant contribution to solving the problems of the impact of climate change on water supply and desertification, namely the rational use of water resources, land reclamation, protection of agricultural lands and rural settlements from the harmful effects of water.

The research works by Full Member of the NAAS of Ukraine, and the Academies of Agricultural Sciences of Russia and Italy, Honored Worker of Science and Technology of Ukraine, Prof. P.I. Kovalenko have gained international recognition in solving the issues of water supply. The works and achievements of Full Member of the NAAS of Ukraine, Honored Worker of Science and Technology of Ukraine, Director of the Institute of Irrigated Agriculture of the NAAS, Prof. R.A. Vozhehov, as well as of Ukrainian researchers M.V. Yatsiuk, A.P. Shatkovskyi, and others are of great importance for the development of laws and regulations in the area of water management and improvement of integrated water resources management based on the basin principle, etc.

Based on the domestic experience, the researchers have been trying to find ways to overcome the problems of water supply and desertification of the steppe zone of Ukraine, but with the intensification of warming, which has been observed in recent years, their efforts are not sufficient. At present, it is necessary to implement the world experience into domestic practice of water supply and researching in this field needs to be continued.

Mankind is accustomed to treating water as something permanent and habitual. However, with climate change, the issue of water scarcity has been becoming increasingly important, both in the world as a whole and in Ukraine in particular.

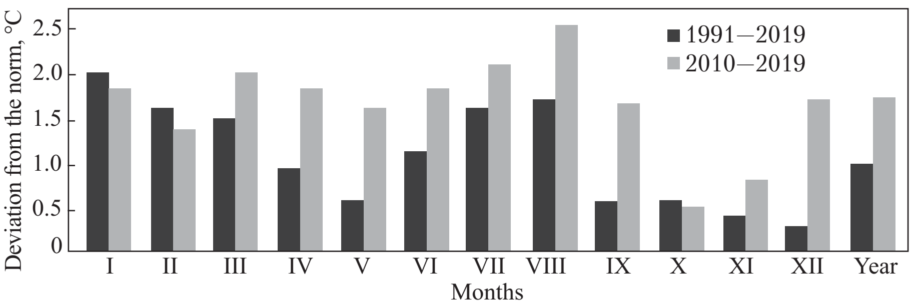

Fig. 1. Deviations of the average monthly air temperature in 1991—2019 and in 2010—2019 from the reference (1961—1990)
Source: [3, 14].

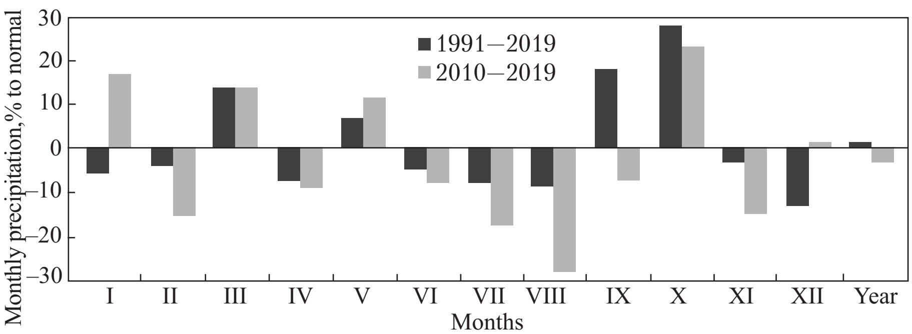

Fig. 2. Change in precipitations by months in 1991–2019 and in 2010–2019 as compared with the reference
Source: [3, 19].

According to the research data of the Institute of Water Problems and Land Reclamation of the NAS of Ukraine, the average air temperature in the country rises faster than on the planet as a whole. The recent observations have shown that the growth rate of the average temperature in Ukraine since 1991 is approximately +0.4 °C every 10 years [1, 5]. In addition, this process is constantly accelerating, i.e. each subsequent decade is warmer than the previous one. Thus, in 1991—2000, the average air temperature increased by 0.5 °C as compared with the same indicator for the previous decade; in 2001—2010, it grew by 1.2 °C, and, in 2011—2019, the growth reached 1.7 °C [2].

The largest increase in the temperature has been reported in summertime: in June and August, the deviation of air temperature from the reference was 1.8 and 2.6 °C, respe ctively. In wintertime, an increase in the air temperature is recorded in December and January, by 1.7 and 1.9 °C, respectively (Fig. 1).

During the period of instrumental observations in Ukraine, the number of days with a very high temperature (above + 30—35 °C), or in other words, the number of days with thermal stress, also increases. In the previous decade, on average, the number of such days in the southern regions ranged within 30—40 per year, and in the recent decade, it has grown to 50—65 days [4].

The nature of precipitation has also changed, as the number of heavy showers that often cause more harm than good after long dry periods has increased. Their seasonal and monthly values also have been redistributed. The most noticeable changes have been reported in autumn. In October, there is a significant increase in precipitation (over 20% of the reference). In summer, on the contrary, there is a significant scarcity of precipitations, in particular, in August, they account for up to 30% of the reference (in 1961—1991) (Fig. 2).

A rise the air temperature and uneven distribution of precipitations in the warm period of the year do not provide effective accumulation of moisture in the soil, cause an increase in the number and intensity of droughts, and thus contribute to the gradual desertification of territories [4]. In particular, the dynamics of the average monthly air temperature and the amount of precipitations during the vegetation period in the steppe zone of Ukraine for the last decade is characterized by the data of Table 1.

According to the forecast changes in the air temperature and precipitations, provided by the Covenant of Mayors for the adaptation to climate change, by 2030 the average annual air temperature will increase by 1.2—1.5 °C as compared with the current climate conditions, while the average monthly rainfall in the southern regions will reduce by 20% [4]. By 2050 (Fig. 3), the researchers predict an increase in the average annual temperature by 1.7 °C with a slight decrease (up to 10%) in the amount of precipitations, which testifies to the growing threat of desertification of the territories of Ukraine, especially, the southern regions.

A decrease in the average monthly rainfall during the vegetation period will encourage agribusiness to increase the use of water for irrigation, as it has been convincingly evidenced by the data of Table 2.

Thus, over the last decade, the water consumption has almost doubled in Odesa and Kherson Oblasts, and increased four times in Zaporizhia Oblast. Such a situation is primarily caused by an increase in water consumption per hectare of irrigated land, as the area of irrigated land has not expanded within the studied period (Table 3).

According to the results of the correlation and regression analysis of the dependence of water consumption for irrigation on the average month-

Table 1. **Dynamics of Indicators of Average Monthly Air Temperature and the Amount of Precipitations During the Vegetation Period in the Steppe Zone of Ukraine, in 2009—2018**

Indicators	Years									
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Average monthly air temperature, °C	16.92	17.60	17.50	19.38	17.54	17.44	17.38	17.65	17.98	19.04
Average monthly amount of precipitation, mm	51.32	53.57	39.84	43.39	39.03	47.54	39.19	48.96	34.12	28.90

Source: [5—14].

Table 2. **Use of Water for Irrigation in the Steppe Zone of Ukraine, in 2009–2018, million m³**

Region	Years									
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Dnipropetrovsk Oblast	15	16	19	26	20	19	21	20	23	28
Donetsk Oblast	16	16	13	13	11	5	6	6	5	12
Zaporizhia Oblast	37	32	35	53	63	66	67	86	113	154
Kirovohrad Oblast	2	2	2	2	1	1	1	2	1	3
Luhansk Oblast	4	4	4	4	4	0	—	—	—	1
Mykolaiv Oblast	34	25	33	47	47	38	42	51	55	31
Odesa Oblast	71	71	85	84	89	86	111	103	108	139
Kherson Oblast	687	695	878	944	989	984	961	914	1203	1174
Total for the steppe zone	866	861	1069	1173	1224	1199	1209	1182	1508	1542

Source: [5—14].

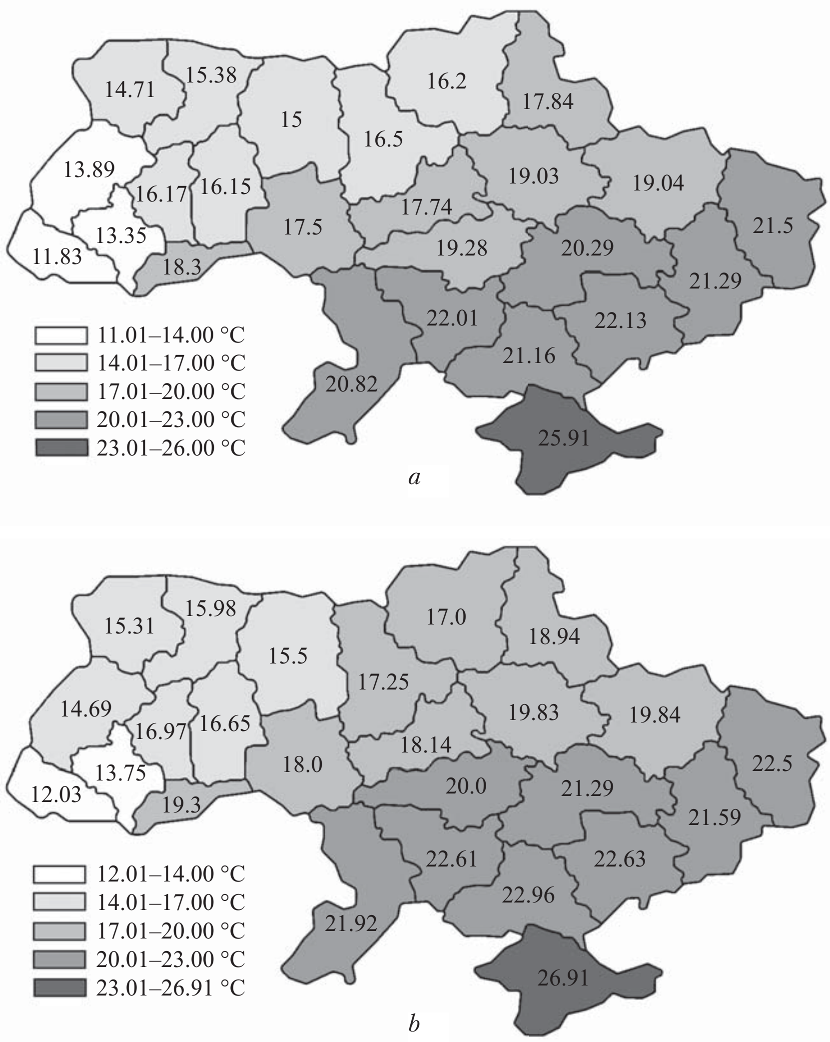

Fig. 3. Forecast of the territorial distribution of the average air temperature during the vegetation period for 2025 (*a*) and for 2050 (*b*)
Source: [15, 111].

ly air temperature and the average monthly rainfall in the steppe zone during the vegetation period, the multifactorial nonlinear dependence has been calculated as

$$V = -160.30 + 9.65\, t^{1.33} + 36983.81/d, \quad (1)$$

where V is the amount of water used for irrigation, million tons, t is average monthly air temperature in the steppe zone during the vegetation period, °C, d is average monthly precipitation in the steppe zone during the vegetation period, mm.

Dependence (1) of the growth of water consumption for irrigation on the change in the average monthly air temperature and the amount of precipitations in the steppe zone during the vegetation period is inversely proportional. A minus sign in front of the free member indicates that there is no need for irrigation if there are sufficient precipitations.

The obtained coefficient of determination for model (1) is $R^2 = 0.76$, i.e. quite close to 1, which indicates a sufficient density between variables.

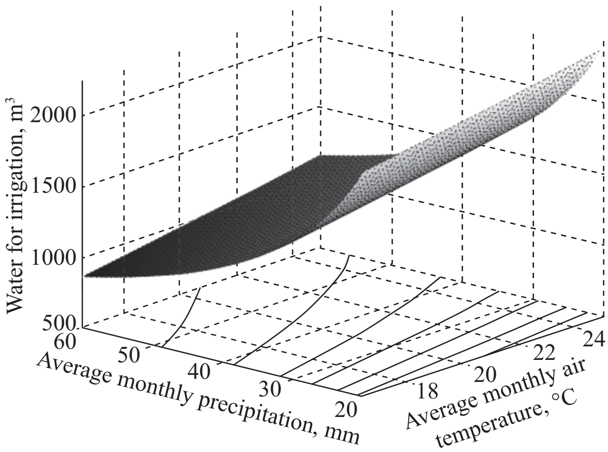

Fig. 4. The surface of the dependence of water consumption for irrigation on average monthly air temperature and precipitations in the steppe zone during the vegetation period
Source: authors' results.

The calculated Fisher's coefficient based on the sample data is 11.02, the critical value of the Fisher coefficient is F_{cr} = 4.74 for degrees of freedom $k_1 = 7$, $k_2 = 2$, the significance level $\alpha = 0.05$.

Comparing with Fisher's criterion $F > F_{cr}$ has shown that with a probability of 95%, the proposed mathematical model is adequate and acceptable for the implementation of predictive calculations.

According to the forecast calculations, in 2050, in the steppe zone, provided during the vegetation period, the average monthly air temperature increases to 22.68 °C and the average monthly rainfall amounts to 21.18 mm, with a probability of 95%, the water consumption for irrigation will come to 2199.27 million m³.

Multifactor nonlinear dependence (1) is shown in Fig. 4.

Currently, about 3 million ha agricultural land in the steppe regions belongs the zone with a critical deficit of moisture. Therefore, in order to have guaranteed yields, it is necessary to restore irrigation on an area of almost 1.2 million ha in the upcoming years., in particular, in the areas around reservoirs, large main canals with existing pumping stations and other inter-farm systems. This provides an additional gross production of grain crops of about 8 million tons per year, industrial crops of 3.5 million tons per year, and vegetables of 11 million tons per year, totally worth almost UAH 135 billion annually, according to the Institute of Water Problems and Land Reclamation estimates. Meanwhile, according to the EBRD, Ukraine's losses from a low level of irrigation development amount to over USD 1.5 billion annually [2].

In most cases, the infrastructure for irrigation systems requires large investments. Only the restoration or modernization of the existing systems (together with the purchase of irrigation equipment) requires an investment of USD 0.12—0.23 per 1 m² of communications [2].

Table 3. **Area of Irrigated Land in 2009—2018, ha**

Region	Years									
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Dnipropetrovsk Oblast	224.2	224.2	224.2	224.2	199.4	198.7	198.7	198.7	198.7	198.7
Donetsk Oblast	158.9	156.3	152.4	131.7	123.0	122.1	121.8	122.1	122.3	122.3
Zaporizhia Oblast	263.4	261.1	257.3	252.3	240.0	240.3	240.5	240.5	240.7	240.7
Kirovohrad Oblast	52.8	52.4	51.7	51.3	40.7	40.7	40.7	40.7	40.7	40.7
Luhansk Oblast	90.6	89.6	88.3	87.2	62.6	60.5	52.2	52.8	53.6	54.1
Mykolayiv Oblast	193.9	193.5	193.1	192.9	189.9	189.8	190.3	190.3	190.3	190.3
Odesa Oblast	246.2	236.7	232.8	228.4	226.9	227.3	226.8	226.8	226.8	226.9
Kherson Oblast	470.8	468.1	464.4	461.9	424.5	425.1	425.8	426.1	426.5	426.8
Total for the steppe zone	1700.8	1681.9	1664.2	1629.9	1507	1504.5	1496.8	1498	1499.6	1500.5

Source: [5—14].

The regression dependence is used by analogy with the Cobb-Douglas production function in order to determine the relationship between the amount of consumed water for irrigation and capital investment in agriculture, the area of agricultural land, and the gross output.

The Cobb-Douglas production function reflects the existing relationship between the output and the combination of factors used to achieve it. Production is considered the transformation of some products into others, in the process of which from a set of simple things comes something that is more complex in nature.

The Cobb-Douglas function $Q = a_0 \cdot L^{a_1} K^{a_2}$, as accepted in neoclassical the ories, has the two factors of production: labor and capital [16]. In fact, the parameters of the production function also depend on the characteristics of industry. Various existing models differ in how accurate they consider the real status of affairs. The most complex ones are the modern multifactor models. They take into account land, entrepreneurial skills, and information factors [17].

Having smoothed the initial statistical data for the period 2009—2018 on the steppe zone of Ukraine, shown in Table 4, we do the correlation and regression analysis, as a result of which the multifactor nonlinear dependence has been built:

$$Y = \ln 19.247\, I^{0.052} \cdot V^{0.114} \cdot 0.927^{S}, \qquad (2)$$

where Y is gross output of agricultural production (at constant prices of 2010), UAH million, I is capital investment in agriculture, UAH million, V is water consumption for irrigation, million tons, and S is the area of agricultural land, thousand ha.

The coefficients of multifactor nonlinear regression (2) after the initial linearization by logarithm have been found by the generalized least squares method in the matrix form.

The obtained coefficient of determination for this model is $R^2 = 0.73$, i.e. close to one, which indicates a sufficient density between variables. The calculated Fisher's coefficient based on the sample data is $F = 5.31$, the critical value of Fisher's coefficient is $F_{cr} = 4.76$ for degrees of freedom $k_1 = 6$, $k_2 = 3$, significance level $\alpha = 0.05$. Comparing with Fisher's criterion $F > F_{cr}$ has shown that with a probability of 95% we may assume that the proposed mathematical model is adequate to the statistics and suitable for the implementation of predictive calculations.

The capital investment in agriculture and the expected volume of gross agricultural output in

Table 4. **Dynamics of Water Consumption for Irrigation in the Steppe Zone and the Factors Influencing its Changes in 2009—2018**

Year	Capital investment in agriculture, UAH million, including the steppe zone	Water consumption for irrigation, million m^3 including the steppe zone	The area of agricultural land, thousand ha, including the steppe zone	Gross output of agricultural products, UAH million, including the steppe zone
2009	2555.44	866	15382.6	63704.02
2010	4291.67	861	15087.9	68010.5
2011	6185.4	1069	15076.3	73780.9
2012	5925.8	1173	15082.3	68043.5
2013	6991.6	1224	15060.9	81665.3
2014	6946.1	1200	15046.9	80724.8
2015	9289.9	1210	15055.7	77600.7
2016	19733.1	1183	15069.8	82305.7
2017	22089.7	1509	15073.2	79265.1
2018	19266.1	1542	15076.1	80842.5

Source: [5—14, 18—27].

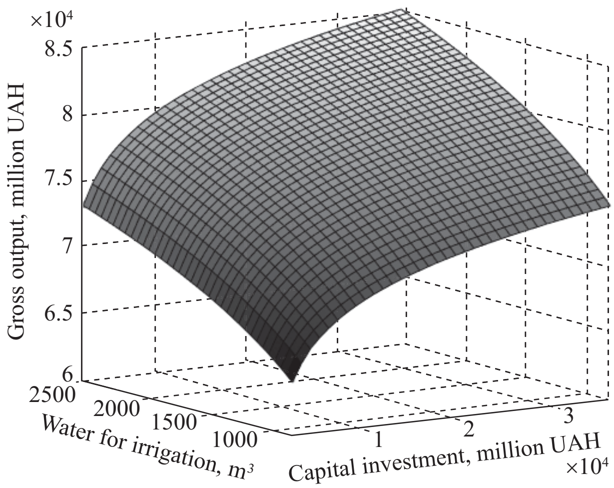

Fig. 5. The surface of the dependence of gross agricultural output on capital investment and water consumption for irrigation
Source: authors' results.

2050 have been estimated at UAH 30.000 million and UAH 86,816.88 million, respectively; the water consumption for irrigation with a probability of 95% will reach 2.200 million tons (Fig. 5).

The dependence of water consumption for irrigation and gross production of agricultural products is built for a fixed forecast capital investment in agriculture of UAH 30.000 million and an area of agricultural land of 15090 thousand ha (Fig. 6).

The reliable zone for this regression is constructed for significance level $\alpha = 0.05$, the critical value of the Student's coefficient is equal to $t_{cr} = 2.447$.

That is, for the forecast gross agricultural output, the confidence interval at $p = 95\%$ is $85376.88 \le Y_{pr} \le 88256.89$.

Having analyzed the future needs of agribusiness in fresh water, we conclude that the current needs already exceed its availability, and there is no reason to hope that the situation will improve by itself. Therefore, the government and authorities at all levels shall identify the priority vectors of agribusinesses adaptation to climate change, which would ensure water safety in the steppe zone of Ukraine both today and in the future.

When determining the strategy and tactics of the rational use of fresh water and water supply, foreign experience should not be avoided, on the contrary, it should be studied quite thoroughly in terms of environment friendliness, i.e. the possibility of preserving the environment and meeting the interests of future generations in water and food security.

Therefore, we focus on the study of the main vectors of rational consumption of fresh water currently used in foreign practice. They are all closely interconnected and form a single system for adapting agribusiness to climate change. We briefly describe each of them to determine the feasibility of their implementation (based on the existing natural potential of the region) in the Southern and South-Eastern regions of Ukraine.

Primary importance in addressing the issues of the adaptation of agribusiness to climate change in both foreign and domestic practice is undoubtedly given to innovation and modernization of technologies, namely the drip irrigation and the micro-irrigation technologies. Such technologies of Israeli companies have gained global recognition by Israeli companies *Netafim*, *CropX*, *Saturas*, *Manna*, and *SupPlant*, American company *Rain Bird* and others. Thanks to digital forecasting, they allow accurate and timely nutrition of the root system of plants by soil moisture sensors.

In fact, in this case, irrigation starts as plants need it, as soon as the sensors begin to receive signals about wet content going below the programmed level [2].

Drip irrigation has been introduced in Ukraine for over 15 years. However, during this time the area under drip irrigation has expanded over nothing but 75 thousand ha. Such systems make it possible to supply water to each plant, without evaporation losses, and just at the time when the plant needs it. They allow saving up to 30% of water and shifting to modern underground drip irrigation (the placement of system of polymeric pipelines to a depth of about 40 cm) [2].

However, the further spread of drip irrigation and micro-irrigation in the steppe zone of Ukraine requires significant investment and, unless new technologies have been introduced, it is possible only through a gradual transition from the use of the existing irrigation systems (those that have not lost their resource) and a simultaneous introduction of the cutting-edge technologies for rational use of water and ecological safety.

Saltwater desalination is also a very important factor in addressing the issues of the adaptation of agribusiness to climate change in foreign practice. According to the analysis of data on water desalination [27] made in 2019, in the world, there are almost 16.000 desalination plants that produce 95 million m of fresh water daily. 48% of this water is produced in North Africa and in the Middle East, 18.4% in East Asia, 11.9% in North America and 9.2% in Europe as a whole, including 5.7% in Spain [28].

Ukraine whose southern borders are washed by the Black and Azov Seas, also has the opportunity to get an additional source of fresh water through desalination, however, for making decision on its implementation and scaling it is necessary to take into account its advantages and disadvantages. Undoubtedly, the fresh water supply to agribusiness in this way will partially solve the issue of irrigation in the southern region of Ukraine, but before we talk about the feasibility of its introduction, let us focus on its consequences. At first glance, desalination seems to be an ideal way to supply fresh water, but the reverse osmosis process used in water desalination plants requires from 3 to 4 kW/h energy per 1 m^2 fresh water, which in comparison with the technologies for the purification of dirty river or ground water leads to three times higher CO_2 emissions, which is extremely dangerous for the atmosphere [30].

Brine emissions as a result of desalination of water that returns to the environment, mostly in sea reservoirs, are also very dangerous. They lead to increasing salinity, rising coastal water temperature, reducing amount of oxygen that is necessary for marine organism respiration, and hence to forming the so-called “dead zones” in the waters.

The introduction of water desalination is not expedient unless it is done by the TSSE (temperature swing solvent extraction) technology developed by the School of Engineering and Applied Sciences of Columbia University [31], which provides for solvent extraction without the use of membranes and phase transitions, i.e. the implementation of desalination with zero discharge of liquid, without water evaporation and condensation.

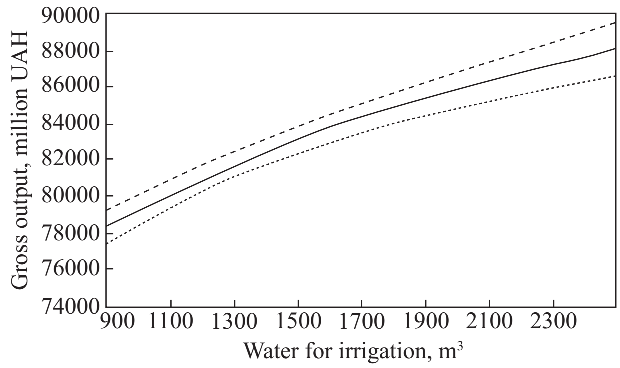

Fig. 6. The confidence zone of the regression of gross agricultural production
Source: authors' results.

This technology is cost-effective and is not accompanied by severe consequences for the environment, in addition, it saves a lot of energy, and therefore is not so influencing the cost of agricultural products. In addition, the introduced water desalination technologies based on reverse osmosis systems, which are now widespread in Singapore, Qatar, Israel, and other advanced economies, are highly energy-intensive and therefore can only be used with available sources of electricity. A distinctive feature of the TSSE technology is a relatively low energy consumption. The required amount of energy may be generated by geothermal and solar power plants that currently have been becoming widespread in Ukraine.

The experience of China, Saudi Arabia, Qatar, the UAE, the Republic of Yemen, Oman, Mexico, and other countries in addressing the issues of the adaptation of agribusiness to climate change deserves special attention. They have been trying to solve the problem of water scarcity due to underground mining, the volume of which, according to the data of geological services, has almost tripled in the last 20 years and led to the exhaustion of a large aquifer, the natural renewal of which takes more than 30 years. The debilitating treatment of groundwater sources has led to 4 cm sediment per year in some parts of Beijing, and up to 8 cm in Shanghai, Mexico City, and some cities in California [32].

The projected groundwater resources of Ukraine currently amount to 61.689.2 thousand m³/day, but they are unevenly distributed among regions, because of differences in geological, structural, physical, and geographical conditions. The vast majority of them are concentrated in the northern and western regions of Ukraine, while the resources of the southern region are limited, as shown in Table 5 [33].

The level of exploration of the projected groundwater resources in the southern and south-eastern regions of Ukraine is currently almost 42% and the level of development slightly exceeds 5.6% of the total projected groundwater resources in the steppe zone of the country. Thus, despite a significant difference in the distribution of groundwater by regions, their projected resources are sufficient to provide agribusiness with water for irrigation.

We believe that the experience of foreign countries in the use of water from the air is equally interesting for Ukraine in the water supply of agribusiness. In particular, according to the Tal-Ya Water Technologies of Israeli developers, the water supply of plants involves the collection of dew from the air with the help of reusable plastic trays. Each plant or tree is surrounded by square toothed trays made of recycled plastic that does not contain polyethylene, with UV filters and the addition of limestone. Dew is collected on both surfaces of the Tal-Ya tray when the temperature changes in the evening and during the night. The dew and condensate run down directly to the roots. When it rains, the trays increase the efficiency of every water millimeter 27 times. In addition, the trays block the sun and protect the plants from extreme temperature changes [34].

In Arizona and California, underground reservoirs or "water banks" are often used to collect rainwater and to protect it from evaporation.

The experience of using the so-called "grey water" (the reuse of domestic non-fecal effluents) is also noteworthy in terms of addressing the adaptation of agribusiness to climate change. The ever-increasing consumption of water for conventional urban flush toilets may be reduced if we use devices that do not require water or consume it in small quantities.

With this technology, urine is sent for the use in agriculture, and the other substances are converted into organic compost. The devices operate based on the same principle as a garden compost heap. With the help of aerobic microorganisms, they break down feces into a nontoxic mass that is rich in plant nutrients and may be used as fertilizer.

Table 5. **Projected Groundwater Resources of Ukraine and Their Production in 2018 by Administrative Regions**

Administrative unit	Projected resources, thousand m³/day	Exploration of projected resources, %	Extraction from projected resources, thousand m³/day	Development, %	Unused, thousand m³/day
Dnipropetrovsk Oblast	1092.6	65	100.3	9	992.2
Donetsk Oblast	2464	44	278.7	11	2185.2
Zaporizhia Oblast	1550.7	20	81.5	5	1469.1
Kirovohrad Oblast	404.6	56	52.7	13	351.8
Luhansk Oblast	4790	40	125.9	3	4664.0
Mykolaiv Oblast	441.6	23	41.2	9	400.3
Odesa Oblast	736.7	66	73.4	10	663.2
Kherson Oblast	4970.8	19	170.7	3	4800.0
Total for the steppe zone	16451	41.6	924.8	5.6	15526.1

Source: [33].

The technology can be used in a completely safe way, even in very densely populated urban areas, as shown by the example of the Gebers Housing Project in the suburbs of Stockholm [35].

Providing countries that suffer from water scarcity with "virtual water" is also worthy of consideration. It provides for the provision of arid regions with food that reduces the need to spend water on their cultivation. Delivery of such products to the place of consumption is equivalent to the delivery of water [35], but produces less impact on the environment. Currently, the largest areas to be irrigated in the southern region of Ukraine are chernozems (over 60% of the total area of agricultural land in the region) that are the most fertile among other soils, but more vulnerable and sensitive to external influences.

Therefore, interference with the soil system, in particular by irrigation, can disrupt the soil formation processes and lead to a decrease in their fertility. In addition, according to DSTU (Government Standard of Ukraine) 2730: 2015 [36] irrigation water shall be used for irrigation of chernozems that meets the requirements of class 1; if it is impossible to provide irrigation water of a certain quality, decisions should be made based on economically substantiated and environmentally limited production of agricultural products. In this case, food security should be addressed by means of "virtual water."

Recognizing the importance of the impact of climate change and the complexity of water supply to agribusiness, some countries have decided to abandon the cultivation of moisture-loving crops. Thus, in Saudi Arabia, in 2017, the Ministry of Nature, Water Resources, and Agriculture made decision to ban the cultivation of moisture-loving crops (including alfalfa, barley, corn, sorghum, etc.), which forced farmers to focus on growing salt-resistant varieties of potatoes and other vegetables that are easily cultivated in sandy soil and give good yields in hot climate.

Understanding the need for new varieties of crops suitable for cultivation in climate change conditions, foreign countries have invested significant capital in new varieties of plants. Thus, the Israeli seed producer *OriGene Seeds* has bred a pumpkin family that includes melons, cucumbers, zucchini, and pumpkins, which can be grown in hot climates. *Equinom* has developed several varieties of hardy varieties of barley, corn, soybeans, etc., resistant to drought and disease.

As for Ukraine, a significant contribution to the breeding of new highly efficient plant varieties suitable for cultivation in the steppe zone of Ukraine has been made by researchers of the NAAS of Ukraine. The varieties newly bred by them currently account for more than 72% of all varieties of Ukrainian breeding.

Considering the experience of foreign countries in addressing the adaptation of agribusiness to climate change, we shall mention the management of hydro-meteorological processes, the introduction of which has been currently intensified in China. The scale of China's weather modification infrastructure is impressive. In 2018, more than 500 special burners developed by the China Aerospace Science and Technology Corporation (CASC) were installed to generate clouds for silver iodide irrigation on the mountain slopes in the Tibetan Autonomous Region, which has led to an increase in precipitations up to 10 billion m^3 in the surrounding regions. Information about the costs of such measures remains secret.

However, according to unofficial data, the cost of similar measures in 2017 in the south-western provinces of China amounted to about USD 176 million [37]. The Chinese government has decided to solve the problem of water and food security in this way, but the neighboring countries are concerned about a disruption of hydro-meteorological processes and a harm to the environment. Therefore, the experience of China in addressing the adaptation of agribusiness to climate change through the management of hydro-meteorological processes should be considered more environment friendly than it was before.

In addition, in China and in other countries in South Asia, water supply to farmers has become widespread due to the construction of dikes and dams. At first glance, the solution is quite simple, but in the case of rivers flowing through the territories of several countries, solving the problem in this way leads to significant and sometimes even military conflicts.

For example, China that suffers from problems with fresh water has built 10 dams on Brahmaputra. Eighteen dams are still under construction, which means a further reduction in the amount of water for India and Bangladesh. Thailand, Laos, Vietnam, and Cambodia are dissatisfied with China's actions over the construction of dams in the upper Mekong.

All of them blame each other for the water problems, especially Laos that has been building dams following the Chinese example. For a long time, there was a threat of a military conflict between Egypt and Ethiopia due to the construction of the Hidaseu HPP in the upper reaches of the Blue Nile [32].

Ukraine is no exception. Currently, in the southern regions of Ukraine, according to the warning of U.S. analysts, there is a threat of conflict with the annexed Crimea over the North Crimean canal with fresh water. At the same time, the military conflict in the South-East of the country remains unresolved, which has vulnerable consequences for the irrigation of agricultural land and for Ukraine's agribusiness in general.

It should be emphasized that the government activities in foreign countries in solving the problems with water supply to agribusiness are not limited to investing capital in innovation, modernization of irrigation systems, plant breeding, etc., but also provide a number of measures to support and to encourage farmers to introduce innovative irrigation technologies. In particular, in Saudi Arabia, Cyprus, Israel, and other countries, subsidies have dramatically changed the attitude of agribusiness to irrigation methods and encouraged farmers to use new water-saving and environmentally safe technologies.

Having analyzed the Project of Adaptation Strategy to Climate Change in Agriculture, Forestry and Fisheries of Ukraine until 2030 [38], its purpose and objectives, we make sure that none of the vectors of its implementation aims at rational water consumption, the conservation of fresh water and the introduction of environmentally safe irrigation technologies. The issues of strengthening control over the use of terrestrial and ground freshwater, as well as the modification of the mechanism for water use rent payments, which we consider inadmissible, have not been duly addressed.

These problems are urgent, and therefore the following vectors need to be recognized as the priority ones in terms of the Strategy for irrigation and drainage in the steppe zone of Ukraine for the period up to 2030 and the Strategy for the adaptation of agriculture, forestry, and fisheries in the steppe zone of Ukraine to climate change until 2030:

- strengthening the institutional capacity of public authorities in taking effective actions and systemic measures for the rational use of fresh water by agribusiness;
- digitalizing the monitoring of the use of fresh water by agribusiness and improving the awareness of stakeholders on the impact of climate change on water supply to territories;
- coordinating efforts of the amalgamated territorial communities, their strategies and development plans in accordance with the policy of agribusiness adaptation to climate change;
- ensuring government support for the CSA (Climate-Smart Agriculture) implementation by amalgamated territorial communities;
- strengthening the control and establishing the limitations on the use of fresh water by agribusiness;
- developing and implementing an effective mechanism for the taxation of rent payment for the fresh water use by agribusiness entities;
- taking measures to raise awareness of business and the public on the rational fresh water use by agribusiness and the climate change impact on water supply to territories.

The proposals are justified by the need to intensify actions for the rational use of fresh water by agribusiness in the steppe zone of Ukraine, to ensure water and food security for the future generations, as well as to preserve the environment.

REFERENCES

1. Ivanyuta, S. P., Kolomiets, O. O., Malinovskaya, O. A., Yakushenko, L. M. (2020). *Climate change: consequences and adaptation measures: analyst*. Kyiv [in Ukrainian].
2. Dykalenko, M. (2018). In Ukraine, more and more regions where without irrigation agribusiness is impossible. URL: http://naas.gov.ua/newsall/newsukraine/?ELEMENT_ID=4304 [in Ukrainian] (Last accessed: 07.12.2020).
3. Adamenko, T. (2019). Climate change and agriculture in Ukraine: what farmers should know: URL: https://mepr.gov.ua/files/docs/Zmina_klimaty/2020/pdf [in Ukrainian] (Last accessed: 07.12.2020)..
4. Agreement of mayors on adaptation to climate change. URL: http://misto-em.org.ua/wp-content/uploads/2019/04/1_Adaptatsiya-do-zmin-klimatu.pdf [in Ukrainian] (Last accessed: 07.12.2020).
5. Environment of Ukraine for 2009. (2010). Statistical collection. Kiev. State Statistics Service of Ukraine. URL: http://www.ukrstat.gov.ua/druk/publicat/Arhiv_u/07 [in Ukrainian] (Last accessed: 07.12.2020).
6. The environment of Ukraine in 2010. (2011). Statistical collection. Kiev. State Statistics Service of Ukraine. URL: http://www.ukrstat.gov.ua/druk/publicat/Arhiv_u/07 [in Ukrainian] (Last accessed: 07.12.2020).
7. Environment of Ukraine for 2011. (2012). Statistical collection. Kiev. State Statistics Service of Ukraine. URL: http://www.ukrstat.gov.ua/druk/publicat/Arhiv_u/07 [in Ukrainian] (Last accessed: 07.12.2020).
8. The environment of Ukraine in 2012. (2013). Statistical collection. Kiev. State Statistics Service of Ukraine. URL: http://www.ukrstat.gov.ua/druk/publicat/Arhiv_u/07 [in Ukrainian] (Last accessed: 07.12.2020).
9. The environment of Ukraine in 2013. (2014). Statistical collection. Kiev. State Statistics Service of Ukraine. URL: http://www.ukrstat.gov.ua/druk/publicat/Arhiv_u/07 [in Ukrainian] (Last accessed: 07.12.2020).
10. Environment of Ukraine for 2014. (2015). Statistical collection. Kiev. State Statistics Service of Ukraine. URL: http://www.ukrstat.gov.ua/druk/publicat/Arhiv_u/07 [in Ukrainian] (Last accessed: 07.12.2020).
11. Environment of Ukraine for 2015. (2016). Statistical collection. Kiev. State Statistics Service of Ukraine. URL: http://www.ukrstat.gov.ua/druk/publicat/Arhiv_u/07 [in Ukrainian] (Last accessed: 08.12.2020).
12. Environment of Ukraine for 2016. (2017). Statistical collection. Kiev. State Statistics Service of Ukraine. URL: http://www.ukrstat.gov.ua/druk/publicat/kat_u/2017 [in Ukrainian] (Last accessed: 08.12.2020).
13. Environment of Ukraine for 2017. (2018) Statistical collection. Kiev. State Statistics Service of Ukraine. URL: http://www.ukrstat.gov.ua/druk/publicat/kat_u/2018 [in Ukrainian] (Last accessed: 08.12.2020).
14. Environment of Ukraine for 2018. (2019) Statistical collection. Kiev. State Statistics Service of Ukraine. URL: http://www.ukrstat.gov.ua/druk/publicat/kat_u/2019 [in Ukrainian] (Last accessed: 09.12.2020).
15. Tarariko, O. G., Sirotenko, O. V., Ilyenko, T. V., Kuchma, T. L., Tarariko, O. G., Sirotenko, O. V., Ilyenko, T. V., Kuchma, T. L. (2013). Predictive assessment of the impact of climate change on grain yields and their gross harvest in Ukraine using space information. *Ecological safety of coastal and shelf zones and integrated use of shelf resources*. 27, 106-116. [in Ukrainian].
16. Greene, W. H. (2018). *Econometric Analysis*, 8th Edition, Stern School of Business, New York University.
17. Zhang, Q., Dong, W., Wen, Ch., Tong, Li T. (2020). Study on factors affecting corn yield based on the Cobb-Douglas production function. *Agricultural Water Management*, 228, 105869, https:/doi.org/10.1016/j.agwat.2019.105869.
18. Agriculture of Ukraine 2009. (2010). Statistical collection. Kiev: State Statistics Service of Ukraine. URL: http://www.ukrstat.gov.ua/druk/publicat/ [in Ukrainian] (Last accessed: 10.12.2020).
19. Agriculture of Ukraine 2010. (2011). Statistical collection. Kiev: State Statistics Service of Ukraine. URL: http://www.ukrstat.gov.ua/druk/publicat/ [in Ukrainian] (Last accessed: 10.12.2020).
20. Agriculture of Ukraine 2011. (2012). Statistical collection. Kiev: State Statistics Service of Ukraine. URL: http://www.ukrstat.gov.ua/druk/publicat/ [in Ukrainian] (Last accessed: 10.12.2020).
21. Agriculture of Ukraine 2012. (2013).Statistical collection. Kiev: State Statistics Service of Ukraine. URL: http://www.ukrstat.gov.ua/druk/publicat/ [in Ukrainian] (Last accessed: 10.12.2020).
22. Agriculture of Ukraine 2013. (2014). Statistical collection. Kiev: State Statistics Service of Ukraine. URL: http://www.ukrstat.gov.ua/druk/publicat/ [in Ukrainian] (Last accessed: 10.12.2020).
23. Agriculture of Ukraine 2014. (2015). Statistical collection. Kiev: State Statistics Service of Ukraine. URL: http://www.ukrstat.gov.ua/druk/publicat/ [in Ukrainian] (Last accessed: 10.12.2020).
24. Agriculture of Ukraine 2015. (2016). Statistical collection. Kiev: State Statistics Service of Ukraine. URL: http://www.ukrstat.gov.ua/druk/publicat/ [in Ukrainian] (Last accessed: 10.12.2020).
25. Agriculture of Ukraine 2016. (2017). Statistical collection. Kiev: State Statistics Service of Ukraine. URL: http://www.ukrstat.gov.ua/druk/publicat/ [in Ukrainian] (Last accessed: 10.12.2020).
26. Agriculture of Ukraine 2017. (2018). Statistical collection. Kiev: State Statistics Service of Ukraine. URL: http://www.ukrstat.gov.ua/druk/publicat/ [in Ukrainian] (Last accessed: 10.12.2020).

27. Agriculture of Ukraine 2018. (2019). Statistical collection. Kiev: State Statistics Service of Ukraine. URL: http://www.ukrstat.gov.ua/druk/publicat/ [in Ukrainian] (Last accessed: 10.12.2020).
28. Edward, J., Manzoor, Q., van Vliet, M. T. H., Smakhtin, V., Seong-mu, Kang. (2019). The state of desalination and brine production: A global outlook. *Science of the Total Environment*, 1343—1356.
29. Kuzminchuk, A. (2020). Desalination of sea water. URL: https://ecosoft.ua/en/blog/opresnenie-morskoy-vody/ (Last accessed: 08.12.2020).
30. Goncharenko, R. (2011). Desalination of water: good or evil? URL: www.dw.com.uk/salting-water-good-or-vil/a-15314969 (Last accessed: 08.12.2020).
31. Boo, Ch., Billinge, I.H., Chen, Xi, Shah, K.M., Yip, N. Yi. (2020). Zero Liquid Discharge of Ultrahigh-Salinity Brines with Temperature Swing Solvent Extraction *Environ. Sci. Technol.*, 54(14), 9124—9131. https://doi.org/10.1021/acs.est.0c02555
32. Zablotsky, V. (2020). Wars of the XXI century - wars for water. Water may soon become more important than oil or gas. URL: https://defence- ua.com/army_and_ war/vijni_za_vodu-2234.html (Last accessed: 08.12.2020).
33. Groundwater: resources, use, quality. State Service of Geology and Subsoil of Ukraine. URL: https://www.geo.gov.ua/groundwater-archive (Last accessed: 10.12.2020)
34. Abigail, Klein Leichman. (2019). TOP 12 destinations where Israel helps to feed the world. URL: https://kurkul.com/spetsproekty/583-top-12-napryamkiv-de-izrayil-dopomagaye-nagoduvati-svit (Last accessed: 10.12.2020).
35. Shukh, S. (2018). Before the lack of fresh water. URL: https://cleanwater.org.ua/pered-faktom-nestachi-prisnoji-vody/ (Last accessed: 10.12.2020).
36. DSTU 2730: 2015. Environmental Protection. Quality of natural water for irrigation. Agronomic criteria. URL: https://budstandart.ua/normativ-document.html?id_doc=62381 (Last accessed: 08.12.2020).
37. Treasurer, P. (2020). China is suspected of creating its climate weapons. https://itechua.com/technologies/127169 (Last accessed: 10.12.2020)
38. Project of Adaptation Strategy to Climate Change in Agriculture, Forestry and Fisheries of Ukraine until 2030. URL: https://www.uahhg.org.ua/wp-content/uploads/2019/08/ (Last accessed: 10.12.2020).

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РАЦІОНАЛЬНЕ ВИКОРИСТАННЯ ПРІСНИХ ВОД ЯК ЗАПОРУКА РОЗВИТКУ АГРОБІЗНЕСУ В УМОВАХ ЗАГОСТРЕННЯ КЛІМАТИЧНОЇ КРИЗИ

Вступ. Глобальною проблемою XXI століття є загальнопланетарні кліматичні зміни, прямими наслідками яких є суттєве потепління, збільшення дефіциту водозабезпечення та опустелення територій, що в сукупності нещадно впливає на землеробство, а отже, і на розвиток аграрного бізнесу.

Проблематика. Раціональне використання прісних вод та водозабезпечення агробізнесу у посушливих, сухих і дуже сухих регіонах України, боротьба з опустеленням територій та забезпечення інтересів прийдешніх поколінь у водній і продовольчій безпеці та збереженні довкілля.

Мета. Визначення на підставі вивчення зарубіжного досвіду раціонального використання прісної води й боротьби з опустеленням, векторів адаптації агробізнесу до кліматичних змін, а отже, і стратегії та тактики його водозабезпечення на середньо- та довгочасових горизонтах.

Матеріали й методи. В процесі дослідження використано методи: економіко-математичного моделювання — при визначенні залежності обсягів використання води на зрошення від середньомісячної температури повітря та середньомісячної кількості опадів; прогнозування — при визначені обсягів води на зрошення за умови модернізації технологій зрошення; аналогій — при вивченні зарубіжного досвіду та можливості його імплементації у вітчизняну практику, монографічний — при викладенні результатів дослідження; абстрактно-логічний — при узагальненні й формулюванні висновків.

Результати. Визначено вектори раціонального використання прісної води та шляхи боротьби з опустеленням в регіонах степової зони України.

Висновки. Вивчення зарубіжного досвіду раціонального використання прісної води та боротьби з опустеленням дозволило визначитися з векторами адаптації агробізнесу до кліматичних змін, а отже, й зі стратегію та тактикою його водозабезпечення на середньо- та довгострокових горизонтах.

Ключові слова: агробізнес, прісна вода, доступність прісної води, використання прісної води, опустелення територій.