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CURRENT STATE OF IRRIGATION IN THE KHERSON STEPPE ZONE OF UKRAINE AND IN KUJAWSKO-POMORSKIE PROVINCE IN POLAND

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Abstract. In various regions of the world you will find areas with low precipitation and high water deficits in soil in terms of field plant production. Examples of such areas are the Kherson region in Ukraine and the Kujawsko-Pomorskie province, especially the Kujawy region, in Poland. The Kakhovka Irrigation System in the Kherson region of Ukraine is the largest irrigation system in Europe. In 2015 it facilitated irrigating about 220 thousand ha. of farmland. Some limitation in the use of that system for enhancing soil productivity comes from the water quality. In the Kujawsko-Pomorskie province, Poland, which covers about 1 mln ha. of agricultural land, direct irrigation is performed on about 12 thousand ha. An improvement in soil moisture is seen through increasing water retention in the habitat by limiting water outflow.

Key words: agricultural land, drainage, irrigation, precipitation deficits, water

INTRODUCTION

Water, both precipitation and irrigation, is the key agroecosystem productivity factor. Its deficit in soil or an unfavourable precipitation distribution during the vegetation period in terms of crops requirements limits their yields and deteriorates their quality [Dzieżyc *et al.* 1990, Stępień 2009, Podsiadło and Jaroszewska 2013]. The problem of soil and agricultural droughts concerns many regions in Europe and throughout the world. [Dai *et al.* 2004]. Such regions occur e.g. in Ukraine [Skakun *et al.* 2016] and Poland [Łabędzki 2004]. In the Ukrainian steppe zone crops are cultivated

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in the conditions of insufficient natural humidification. The main factor which limits their yields is lack of water. Thus, highly productive cultivation can be achieved in the Ukrainian steppe zone only if additional artificial irrigation is provided, this is especially true for such water-demanding crops as soybeans, maize, corn silage, etc. So irrigation should be considered as a factor promoting significant increase of agricultural productivity and decreasing its dependence on adverse climatic conditions [Morozov *et al.* 2003].

The Kujawsko-Pomorskie province is one of the largest agricultural regions in Poland, where many valuable crops are grown, such as winter wheat, oilseed rape, sugar beet, vegetables and herbs. The region is affected by unfavourable pluviothermic conditions. According to Bąk and Łabędzki [2008], every second year meteorological droughts and frequently also agricultural droughts occur. Droughts coincide with high air and soil temperatures, very high insolation and a negative climatic water balance [Łabędzki 2007]. In the years 2005-2006 drought generated high field plant production losses. Yields on grasslands were 40-100% lower, and cereal yields – 15-60% lower. The reduction in rape, potato, sugar beet and vegetables yields were as high [Kaca *et al.* 2011].

Highlighting the problem of water deficits in field plant production and the current scale and potential of irrigating various deficit areas in Europe calls for sharing knowledge and acquiring applicable solutions.

It was assumed that in areas with high rainfall shortage for field crop production in the two countries of Central and Eastern Europe, Ukraine and Poland, that there would be different possibilities for the irrigation of agricultural soils.

The aim of the present publication is to compare the condition and the possibilities of irrigation in these two areas that are essential in terms of field plant production, while showing unfavourable precipitation conditions.

MATERIAL AND METHODS

The scientific elaboration includes regions with high rainfall shortage, the Kherson region in Ukraine and the Kujawsko-Pomorskie province in Poland. On the basis of the scientific literature, administrative and economic information, and statistical data the condition and the possibility of irrigation of agricultural soils was evaluated. The paper shows the range of operation, and the degree of restriction on the use of the Kakhovka irrigation system in Ukraine. The paper also presents environmental and economic conditions of drainage and irrigation in the Kujawsko-Pomorskie region in Poland.

RESEARCH OBJECTS AND CONDITIONS

Kakhovka irrigation system is the biggest in Ukraine and in Europe. The land surface within the system is flat, divided by gullies and temporary streams. The topsoil is represented mainly by southern black earth and dark–chestnut soils in combination with alkaline soils. The average groundwater level in the northern part of the Kakhovka irrigated area is about 20-40 m, while in the southern part it is about 3-4 m from the surface. The source of irrigation water is the Kakhovka reservoir. Water is supplied to the Kakhovka main canal by the main pumping station. The system is provided with

a closed internal network, highly efficient sprinkling machines, automatic water distribution and irrigation, while its design parameters ensure high efficiency and effective land use. All connected farmlands are irrigated using machine water-lifting according to a two-stage scheme. The first lifting is executed by the main pumping station, while the second lifting is performed by farm pumps that take water from the main canal and water distributors and provide the supply head within each closed irrigation system that is necessary for operating sprinkling machines. Additional water lifting from the main canal is performed only for supplying water to two distribution canals: P-1 and P-1-1. The Kakhovka irrigation system is provided with regulatory constructions. The inter-farm irrigation system is designed as a number of canals with anti-filtration devices in the form of ground concrete-film screens. Drainage, surface and released waters are drained by water discharge canals (their total length being 1609 km) into accumulating ponds and reservoirs, which are used for fish farming. The main pumping station of the Kakhovka irrigation system supplies water to other irrigation systems as well: to Priazovskaya, Sirogozskaya, Genichesk, Kalanchak, North-Crimean canal etc. The Kakhovka irrigation system operation is based on automatic control using local automation of the farm network, tail water cascade control, electric and hydraulic automation and telemechanics, which ensure complete work scheduling and, consequently, the ability to control the system by computers. The system implements a number of environmental measures: planting forest belts along the canals, maintaining optimum air and water-salt regime by means of drainage and anti-filtration solutions [Morozov *et al.* 2003].

The Kujawsko-Pomorskie province is located in the north-central part of Poland. The area of agricultural land is more than 1 mln ha, which accounts for 57% of the province. Arable land accounts for 51%, and grasslands for 6% of the area. Soils vary a lot; from the best ones for plant production to very light. Cambisols and Podzols dominate. In the region of Kujawy, the southern part of the province, very fertile Phaeozems are found. At the same time it is the region with the lowest precipitation in Poland [Atlas klimatu Polski 2005] and the highest precipitation deficits for plants [Dzieżyc *et al.* 1990]. The highest precipitation deficit and the highest water deficits in soils occur in the włocławski, radziejowski, aleksandrowski, inowrocławski, mogileński and żniński counties.

Data from the Kherson regional center for Hydrometeorology – Ukraine (2015) and from Research Station of the Faculty of Agriculture and Biotechnology in Mochełek near Bydgoszcz – Poland (1949-2015) indicate that these are regions with a very low precipitation (Table 1). In the first case the average annual precipitation is about 500 mm, of which 300 mm falls in the period from April to September during the intensive growing season for crops. In the vicinity of Bydgoszcz, the capital of the Kujawsko--Pomorskie province, the total precipitation is arround 460 mm, while from April--September it is below 300 mm. For good growth of field crops annual rainfall should be about 100 - 200 mm higher. In those regions irrigation is indispensable to enhance plant productivity.

Table 1. Precipitation (mm) in the areas of research

Month	Kherson region (Ukraine) 2015	Kujawsko-Pomorskie province, district Bydgoszcz (Poland) Average for 1949-2015
January	39.8	25.2
February	47.4	19.4
March	53.8	24.6
April	65.5	27.4
May	86.9	44.0
June	38.3	54.7
July	104.6	73.6
August	12.1	53.3
September	4.6	41.2
October	18.6	32.1
November	44.2	32.8
December	2.1	32.3
Sum for the year	517.9	–
Average yearly sum	–	460.6

Volume of irrigation

An essential characteristic of the Kakhovka irrigation system operation is the irrigation area and quality. It is the actual volume of irrigation that testifies to the system technical state, its provision with sprinkling machines, availability or lack of electric power, fuel and lubricants and the economic interest of farms in the effective use of irrigated lands. It is through the irrigation quantity and quality that the technological function of irrigation systems is implemented: supplying irrigation water to plants in accordance with water consumption standards that ensure optimum plant growth conditions during the whole vegetation period and maximum yields in a particular field with irrigated crop rotation and the maximum amount of agricultural products in all irrigated fields [Romashchenko and Baluk 2000]. Out of the total area covered by the Kakhovka irrigation system only 83.3% was irrigated in 2015. It should be noted that in some areas mobile irrigation is sometimes used, which can lead to apparent anomalies between the average (over several years) and actual (2015) irrigation values (Table 2).

Table 2. State of irrigation on the Kakhovka system

Region	Average area available for irrigation per year ha	Actually (2015) irrigated area ha	Water supply thousands of m^3	Rate of water $m^3 \cdot ha^{-1}$
Velikolepetikha	6590	2360	2701	1144
Verhnerogachik	2709	0	0	0
Genichesk	28294	21900	45051	2057
Gornostaivka	16721	17290	66854	3867
Ivanivka	19767	15330	50873	3319
Kakhovka	59426	64700	112384	1737
Nizhnesirogozy	2829	1820	6131	3369
Novotroitsk	72730	53530	119152	2226
Chaplinka	50330	38200	122070	3196
Nova Kakhovka	2910	3450	4300	1246
Total	262306	218580	529516	2423

The system of regularly irrigated fields on the Kakhovka irrigation area can be clearly seen from the circular shape produced by the centre pivot systems that dispense the water. This is shown on satellite photographs (Fig. 1).

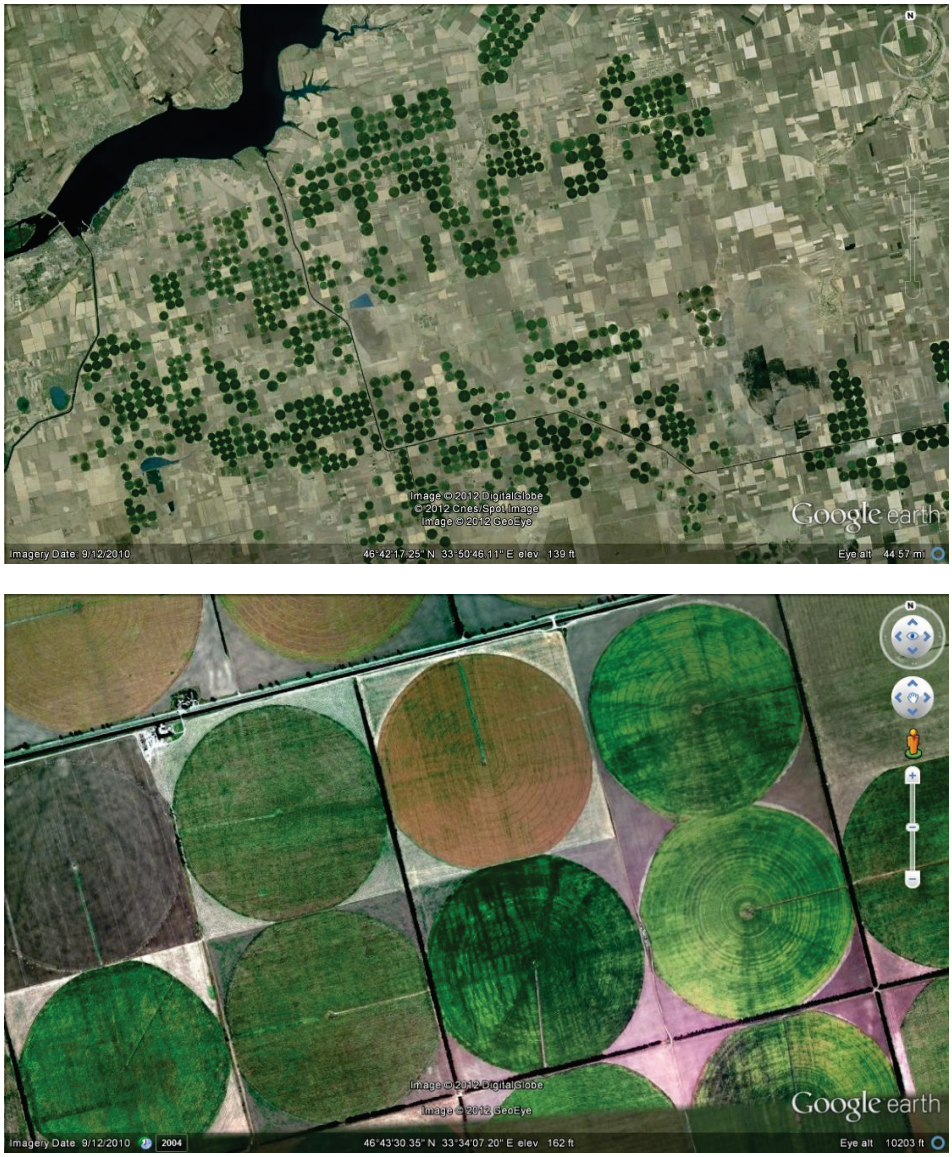

Fig. 1. Aerial photography of the irrigated fields on the Kakhovka irrigation area (source: http://bestplacesofworld.com/node/43)

Of no less importance than the quantity is the irrigation quality, which means compliance with science-based irrigation routines, that is, watering at the optimum time in compliance with ecologically and economically reasonable standards [Romashchenko

and Baluk 2000]. The actual quality of irrigation is characterized by the water supply and irrigation standards for various regions of the Kakhovka irrigation system. At present there are two opposite trends.

The first trend is towards reducing the amount of irrigation water used (Velikolepetikha, Kakhovka districts and Nova Kakhovka),which testifies to the inability of the irrigation system to provide the necessary amounts of water corresponding to the actual moisture deficit for various crops.

The second trend is towards providing irrigation rates that exceed ecologically sound and economically feasible ones. Especially high irrigation rates were registered in Gornostaivka, Nizhnesirogozy, Ivanivka and Chaplinka districts.

Analysis of the data confirms a significant deviation in the actual volume of water supplied and, consequently, irrigation regimes that indicate both overwatering and insufficient watering. Both trends can lead to losses of essential crops. The situation with irrigation quality becomes even more complicated because users have virtually no opportunity to use the methods of operational planning. Without providing farms with operational and reliable information on irrigation optimal timing and rates it is impossible to solve the problem of effective use of the irrigated land. The degree of use of the irrigation system in the Kherson region over the last 25 years is shown in Table 3.

Table 3. Actual irrigation use in the Kherson region, Ukraine

Year	Possibilities of irrigation thousands of ha	Irrigated area thousands of ha	Utilization %
1980	185.0	171.6	92.8
1990	267.9	259.1	96.7
2000	275.8	156.2	56.6
2001	262.7	71.8	27.3
2005	261.7	184.5	70.5
2010	262.3	199.2	76.0
2011	262.2	200.6	76.5
2012	262.2	201.3	76.8
2013	262.2	203.9	77.8
2015	262.3	218.6	83.3

In Poland the key method of irrigation and drainage is water-removing drainage. It is justified even in the regions with low precipitation. It allows for growing winter crops and early sowing of spring crops, with no risk of high losses generated by stagnating water in land depressions and landlocked places. The shortcoming of the irrigation and drainage system is, however, a lack of the possibility of its application for water-damming and for use for irrigation in periods with low precipitation. In the Kujawsko--Pomorskie province in 2013 the land drainage system was available in 44.0% of agricultural land. However, the direct possibility of irrigation was available only for 5.44% of grasslands and 0.44% of arable land (Table 4). Sprinkler irrigation was possible in an area of 4.5 thousand ha, however, that area is increasing. The biggest problem is not very easily accessible surface water sources for irrigation. Especially in the southern part of the province, with its fertile black soils, there are no rivers, lakes or large ponds. The building of deep wells is expensive and the water from these sources is primarily used for irrigation of vegetables and crops with high profitability. For small fields with valuable vegetable plants, flowers and some orchards drip irrigation is also used. This method of plant irrigation enables effective use of limited water resources.

Table 4. State of the drainage and irrigation of agricultural land in the Kujawsko-Pomorskie province [GUS 2014]

Agricultural land	Area, ha	% of agricultural land in the province
Drainage agricultural land, including:	462600	44.0
– arable land	390200	43.2
– meadows and pastures	72400	50.5
Irrigation agricultural land, including:	11800	1.12
– arable land	4000	0.44
– meadows and pastures	7800	5.44

According to Kujawsko-Pomorski Zarząd Melioracji i Urządzeń Wodnych [KPZMiUW 2015], the best method of counteracting the unfavourable effects of water deficit in agriculture over large areas is, after irrigation, mostly through increasing retention. To do so, small storage reservoirs and structures limiting the outflow of water from fields and irrigation and drainage systems must be built and used to collect water after winter and periods of high precipitation. According to Kaca and Wołowicz [2014] one of the strategic plans in the Kujawsko-Pomorskie province is the development of the Lower Vistula Program and the building of the second dam and a water reservoir. An intervention in this area should contribute to the development of irrigation systems in order to improve the efficiency of farming in Kujawy.

IRRIGATION WATER QUALITY

The main source of irrigation water in the Kherson region are the Kakhovka reservoir, the rivers Dnieper and Ingulets, the Dnieper delta and groundwater. The water from the Kakhovka reservoir is delivered to the Kakhovka main canal and the network of inter-farm distribution canals. Apart from water source, the quality of irrigation water is influenced by a number of factors: weather conditions, the original quality of water in irrigation sources, canal design features and operation regime. According to its design, the Kakhovka main canal is controlled, lined and permanently filled, its distribution canals operate in the seasonal filling mode, except for their main sections. Water is analyzed and the basis for the evaluation of water quality for irrigation is the State standard of Ukraine [State Standard of Ukraine 1994]. The water quality in the main canal and in the distribution ones is similar to that of the Kakhovka reservoir, but is characterized by higher pH due to low rate of water flow in the canal, permanent filling, high temperatures in summer, abundance of weeds and reduced oxygen content. Irrigation water mineralization within the period of the research varied between 0.30 – 0.39 $g \cdot dm^{-3}$. As to its hydrochemical composition the water is mainly hydrocarbonate, calcic, with a high content of magnesium (Table 5).

Table 5. Chemical composition of Kakhovka irrigation system water

Source	Date	pH	Total mineralization, $g \cdot dm^{-3}$	Ionic composition, $mg\text{-}equ \cdot dm^{-3}$						
				CO_3^{2-}	HCO_3^-	SO_4^{2-}	Cl^-	Ca^{2+}	Mg^{2+}	Na^+
Reservoir	20.05.2013	7.8	0.39	0.0	3.60	0.76	0.84	2.72	1.28	1.20
	10.05.2014	8.3	0.34	0.24	2.80	0.85	0.72	2.92	0.78	0.91
	12.05.2015	8.4	0.36	0.40	3.04	0.80	0.84	1.76	1.88	1.44
Irrigation system, system of canals	22.05.2013	8.4	0.39	0.0	2.88	1.68	0.96	2.20	1.80	1.52
	15.05.2014	8.5	0.30	0.16	2.48	0.98	0.68	1.56	1.84	0.90
	12.05.2015	8.6	0.34	0.24	2.88	0.74	0.88	1.96	1.72	1.06

In Poland, in the Kujawsko-Pomorskie province, the key source of water for irrigation are low-retention water intakes, watercourses, lakes and underground water. The quality of water from those sources, in general, does not limit their use for agricultural purposes. Examples of water quality from the Kruszyński Canal, which is used for irrigation, are presented in Table 6 [Rolbiecki 2013]. On the basis of most of the physical and chemical indicators it can be said that the water had features of I, II and III quality classifications, according to the normative indicators identified by the Minister of Environmental Protection [Rozporządzenie... 2004].

Table 6. Selected indicators of water quality in the Kruszyński Canal

Parameter	Value measured	The value for the quality class*				
		I	II	III	IV	V
pH	6.94	6.5-8.5	6.0-8.5	6.0-9.0	5.5-9.0	< 5.5 > 9.0
Conductivity, $\mu S \cdot cm^{-1}$	840	500	1000	1500	2000	>2000
Total suspensions, $mg \cdot dm^{-3}$	60	15	25	50	100	>100
Nitrate nitrogen, $mg \cdot dm^{-3}$	3.5	2.5	5	10	20	>20
Phosphates, $mg \cdot dm^{-3}$	0.1	0.2	0.4	0.7	1.0	>1.0

* Rozporządzenie Ministra Ochrony Środowiska z dnia 11 lutego 2004 (Dz.U. 2004 nr 32, poz. 284)

In accordance with its agronomic performance the water of the Kakhovka irrigation system is considered only partially suitable for irrigation due to the risk of soil alkalescence (Table 7). Other negative processes that may manifest on irrigated lands, including the risk of secondary salinity. Currently, it is not a big a problem, but the quality of the water in the river varies over time. Thermodynamic parameters describe the real systems formed by the interaction of irrigation water on the soils based on the thermodynamic principle. They depend on indicators of activity of the ions in irrigation waters and soil solution. This assessment has been based on an evaluation of water quality for irrigation [State Standard of Ukraine 1994].

Table 7. Risk factors (area in ha.) for soil degradation on the Kakhovka irrigation area

Region	Total area	Risk of				
		salinization	alkalescence	alkalinization	toxic effects	thermodynamic
Velikolepetikha	2360	0	2360	0	0	0
Verhnerogachik	0	0	0	0	0	0
Genichesk	21900	0	21900	0	0	0
Gornostaivka	17290	0	17290	0	0	0
Ivanovka	15330	0	15330	0	0	0
Kakhovka	64700	0	64700	0	0	0
Nizhneserogozy	1820	0	1820	0	0	0
Novotroitsk	53530	0	53530	0	0	0
Chaplinka	38200	0	38200	0	0	0
Nova Kakhovka	3450	0	3450	0	0	0
Total	218580	0	218580	0	0	0

To improve water quality and prevent its negative effect on soil fertility in the Kherson region it is recommend:

1. Farms, individual land users and land owners should not irrigate the lands with water unsuitable for irrigation; water of such quality should be improved using chemical meliorants (gypsum, phosphor-gypsum).
2. To avoid irrigated land alkalinization, chemical melioration should be performed (adding gypsum, phosphor-gypsum, ground limestone to soils).
3. Fields should be watered at night in order to reduce the effect of pH value and soda on soils and plants (increase in the alkalinity of the water in the summer period, changes in indicators of carbonate – calcium balance) and increase the efficiency of irrigation.
4. Irrigation standards, irrigation regimes, methods of irrigating various crops should be dependant on water quality and soil properties, besides, they must be aimed at saving water and protecting soils.
5. In order to provide the required irrigation water quality with regard to alkalescence and alkalization risks as well as toxic effects on plants, a set of measures should be carried out: seasonally filled canals should be carefully cleaned from sediment and plant debris in the off-season; during the irrigation season the rate of water flow that is critical for phytoplankton life should be observed.

CONCLUSIONS

1. In the Kherson region, Ukraine has the biggest irrigated system in Europe. In 2015 out of the total area covered by the Kakhovka irrigation system, about 220 thousand ha. was irrigated. This was 83.3% of the available area and was the largest area in 15 years. The aim should be to maximize the use of this irrigation system.

2. The water of the Kakhovka irrigation system is considered only partially suitable for irrigation due to the risk of soil alkalescence.

3. In Poland, in the Kujawsko-Pomorskie province, no such big irrigation structures and systems exist. At present about 5% of meadows and pasture and 0.5% of arable land are irrigated.

4. The potential strategies to improve water conditions in the agricultural areas of the Kujawsko-Pomorskie province consist of adjustments to the flow of the lower Vistula, including the building of dams and water reservoir, the development of small water retention ponds, restricting the water outflow from the areas of agricultural land and an expansion of irrigation systems.

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AKTUALNY STAN NAWODNIEŃ NA OBSZARZE STEPU UKRAIŃSKIEGO I W WOJEWÓDZTWIE KUJAWSKO-POMORSKIM W POLSCE

Streszczenie. W różnych regionach świata występują obszary o małej ilości opadów i dużych niedoborach wody w glebie dla polowej produkcji roślinnej. Przykładem takich obszarów jest region Kherson na Ukrainie i województwo kujawsko-pomorskie, a zwłaszcza Kujawy – w Polsce. Na Ukrainie w regionie Kherson znajduje się największy system nawadniający w Europie – Kakhovka. W 2015 roku pozwolił on na nawodnienie około 220 tys. ha użytków rolnych. Pewnym ograniczeniem wykorzystania tego systemu do zwiększania produktywności gleb jest jakość wody. W województwie kujawsko-pomorskim w Polsce, obejmującym około 1 mln ha użytków rolnych, bezpośrednie nawadnianie wykonywane jest na powierzchni około 12 tys. ha. Poprawy uwilgotnienia gleb upatruje się w zwiększeniu retencji wody w siedlisku poprzez ograniczenie jej odpływu.

Słowa kluczowe: deficyt opadów, melioracje wodne, użytki rolne, woda

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