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SERVICES OF SURFACE WATER ECOSYSTEMS IN RELATIONS TO WATER USAGE FOR IRRIGATION OF AGRICULTURAL LAND

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ABSTRACT: One of the areas using the supply function of surface water ecosystems is agriculture. In the case of a lack of a sufficient amount of water for plants, it is necessary to supplement this amount through irrigation of agricultural land i.e. using the ecosystem service – water collection.
The aim of this article is to determine the surface water ecosystem services connected to water collection for irrigation of agricultural land in the area of Podlaskie voivodship and to present a method for estimating the requirements for such services as a tool for water management within municipalities.

KEY WORDS: surface waters, agriculture, irrigation, estimation

JEL: Q56

Introduction

One of the areas using the supply function of surface water ecosystems is agriculture. Agriculture is a significant user of water in Europe. Its water usage constitutes approximately 24% of the total water usage. This percentage varies significantly from country to country and in some parts of southern Europe is as high as 80% (Water resources across Europe, 2009). In countries of northern Europe water usage in agriculture is significantly lower, although it still can reach over 30% of total water usage in some areas.

The amount of water used for irrigation depends on factors such as:

- climate;
- type of crops;
- type of soil;
- water quality;
- methods of cultivation (http://ec.europa.eu).

In the case of a lack of the required amount of water for plants, it is necessary to supplement this amount through irrigation of agricultural land i.e. using the services provided by surface water ecosystems – water collection.

The aim of this article is to determine the surface water ecosystem services connected to water collection for irrigation of agricultural land in the area of Podlaskie voivodship and to present a method for estimating the requirements for such services as a tool for water management within municipalities.

Water collection for agricultural irrigation as an ecosystem service

The benefits, which people obtain from ecosystems, such as water, wood, food or climate regulation, are called ecosystem services. Currently, these are divided into four groups: provisioning services, regulating services, supporting services and cultural services (MEA, 2005).

Services of surface water ecosystems can be analysed in each of the four presented categories presented above (Ecosystems and Human Well-being, 2005). The most important one, from the point of view of people is the provisioning function.

Access to water at a given time and place, taking into account the quality and quantity of water, is also an ecosystem service. Its meaning for agriculture is obvious. Every agricultural activity requires fresh water, including cultivation (Aylward, Bandyopadhyay, Belausteguigotia, 2005).

Access to water for agroecosystems depends mainly from factors such as: infiltration and flow as well as water retention in soil and it is connected with

other types of ecosystem services. In many cases it is necessary to supplement the water requirements of agriculture through collection of surface waters or extraction of groundwater ('blue water'). In some parts of the world 80% of water used by agriculture comes from rainfall stored as soil moisture ('green water') (Molden, 2007). The division of green waters in Poland (133.8 billion m^3) in an annual scaleis following (Mioduszewski, 2008):

- agricultural land – 65.0 billion m^3,
- forests – 50.0 billion m^3,
- other – 18.8 billion m^3.

Food production consumes large amounts of water and it is estimated that to fulfil the daily food needs of a single person over 1300 m^3 of water is used (Mioduszewski, Szymczak, Kowalewski, 2011).

The forecasted climate changes, including changes in rainfall, can lead to increased risk of draught or flood. An increase in temperature will result in an increased requirement for water (IPCC, 2007).

Apart from the size of ecosystem services, which in the case of water collection for irrigation in agriculture is expressed in volume units (m^3), the financial value of such ecosystem services is also estimated. The performer estimations can be used as a tool in ecosystem management policies (Polasky, 2008).

Real water markets are rare, and the value of the services of aquatic ecosystems for agriculture were usually only partially taken into account in the conducted estimations. The majority of farmers, who collect surface waters, do not pay for this service. Estimations for water requirements in agriculture are often based on production data. The value of water is then estimated based on the increase in agricultural production for a unit of collected water (Mendelsohn, Olmstead, 2009).

Irrigation of agricultural land as a service of surface water ecosystems in the Podlaskie voivodship

Agricultural land in Podlaskie voivodship take up 1078017 ha, which is approximately 53% of the voivodship's area (Rocznik Statystyczny Rolnictwa, 2015). It is an area of potential irrigation i.e. there is a need for the services of the surface water ecosystems. The service can be presented in relations to the amount of collected water in volume units, and in relations to water usage, which is the area which was irrigated.

Water collection for agricultural irrigation in the Podlaskie voivodship in 2006 within the districts is presented in figure 1.

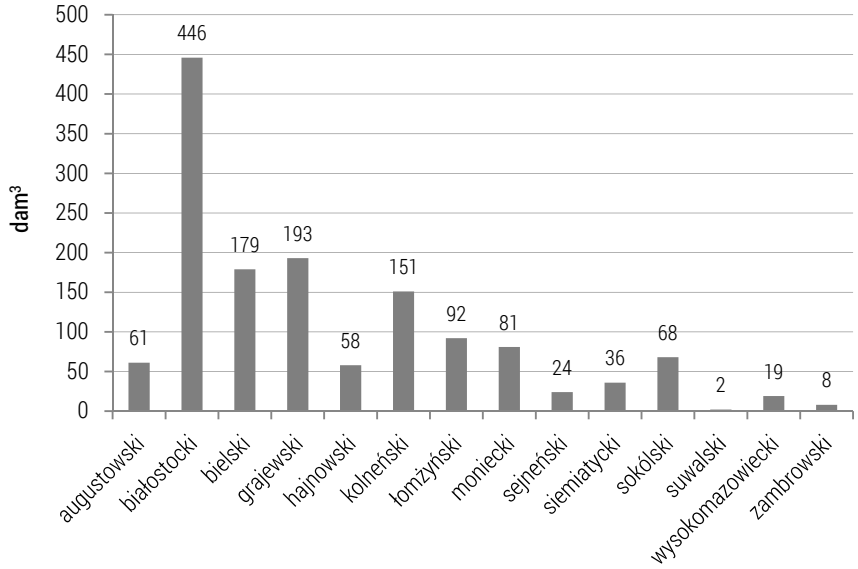

Figure 1. Services of surface water ecosystems in relations to water collection for agricultural land irrigation in Podlaskie voivodship in 2006

Source: author's own work based on (*Program nawodnień rolniczych województwa podlaskiego na lata 2007–2013*, 2008).

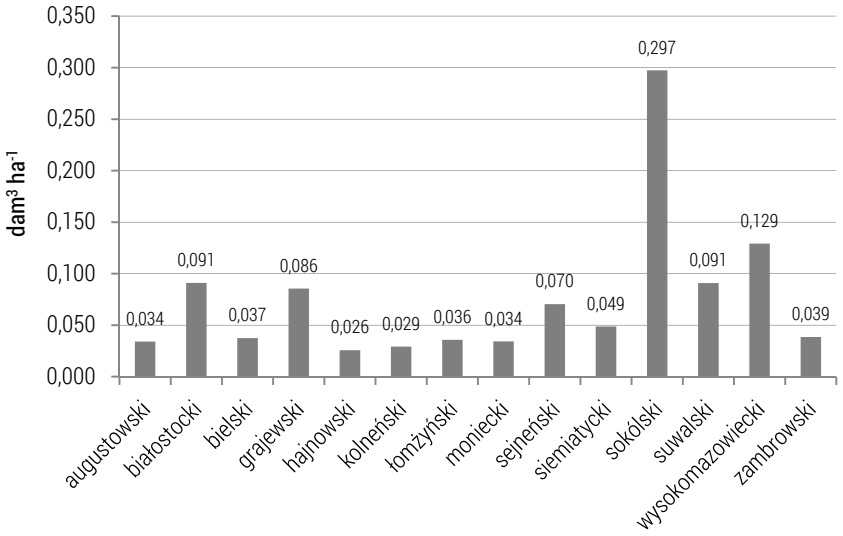

Figure 2. Unit rates of the usage of water collection services for irrigation in the Podlaskie voivodship in 2006

Source: author's own work based on (*Program nawodnień rolniczych województwa podlaskiego na lata 2007–2013*, 2008).

In total 1418 dam^3 of surface water was collected for agricultural irrigation in the Podlaskie voivodship in 2006. This water was used to irrigate 27757.8 ha of agricultural land.

Unit usage of water for irrigation was within the range of approximately 0.03 dam^3·ha^{-1} to 0.3 dam^3·ha^{-1} (figure 2).

The analysis of the amount of water collected for irrigation was conducted by the Voivodship Board of Land Amelioration and Water Facilities in Bialystok for the *Agricultural irrigation plan for the Podlaskie voivodship in years 2007–2013*. Currently, the amount of water collection is not determined. However, the size of the irrigated area is recorded.

The size of the irrigated area in the last 10 years is presented in figure 3.

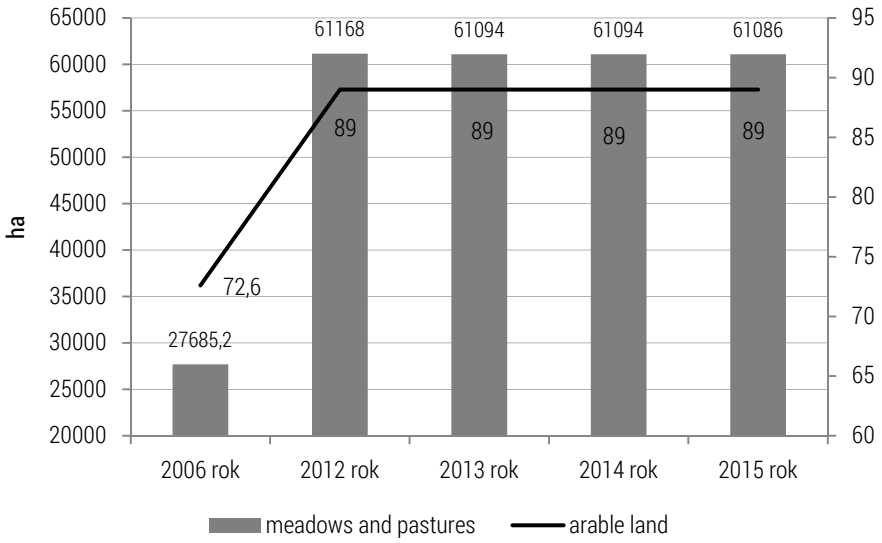

Figure 3. Size of irrigated agricultural land in the Podlaskie voivodship in 2006-2015

Source: author's own work based on data from the Voivodship Board of Land Amelioration and Water Facilitiesin Bialystok.

As seen from the data presented in figure 3, within the last 4 years the size of irrigated land in the Podlaskie voivodship was at a similar level ofapproximately 61100 ha.

The size of irrigated land in individual districts in 2006 and 2015 is shown in table 2.

Table 2. Area of agricultural land and grassland irrigated in the Podlaskie voivodship in 2006 and 2015

District	Arable land		Grasslands	
	2006	2015	2006	2015
	Area [ha]			
Augustowski		1790		6464
Białostocki		4895.8		10037
Bielski		4782.4	1	5518
Grajewski		2256		5326
Hajnowski		2252.3		3024
Kolneński	55.6	5112.5	55	7257
Łomżyński	17	2 549.60	21	3430
Moniecki		2361.2	12	4804
Sejneński		341		347
Siemiatycki		739.3		2045
Sokólski		228.6		5421
Suwalski		22		91
Wysokomazowiecki		147		1695
Zambrowski		207.5		5630
Total	72.6	27685.2	89	61089

Source: data from the Voivodship Board of Land Amelioration and Water Facilities in Bialystok.

In the Podlaskie voivodship water was used mainly to irrigate grasslands. In 2006 only in the koleński and łomżyński districts agricultural land was also irrigated. In the kolneński district this was approximately 1.1%, and in the łomżyński district approximately 0.67% of the total irrigated area in the given district. In 2015 in the kolneński district the area of irrigated agricultural land increased by 0.6 ha, and in the lomżyński district by 4 ha. Agricultural land irrigation also took place in the bielski and moniecki districts.

Access of agricultural cultivations to a required amount of water is directly linked to the size of harvest, which are a testimony to the quality of the service. Figures 4 and 5 show the size of harvest in dry years in irrigated and not irrigated fields. The analyses were conducted by the Voivodship Board of Land Amelioration and Water Facilities in Bialystok for two districts: the kolneński and łomżyński districts.

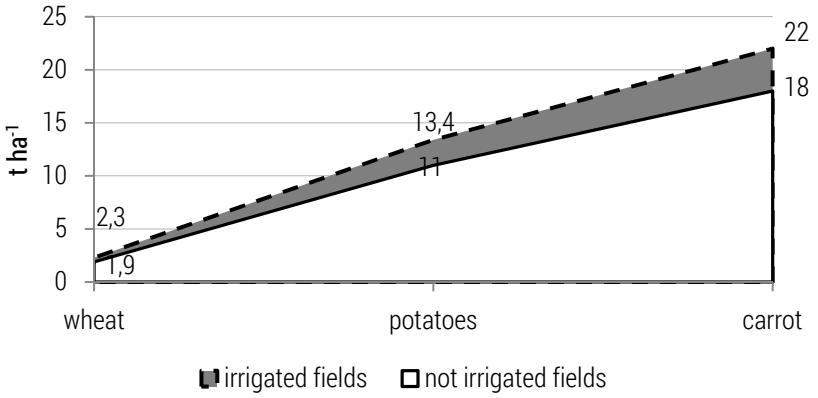

Figure 4. Harvest of chosen plants in irrigated and not irrigated fields in the kolneński district

Source: author's own work based on (*Program nawodnień rolniczych województwa podlaskiego na lata 2007–2013*, 2008).

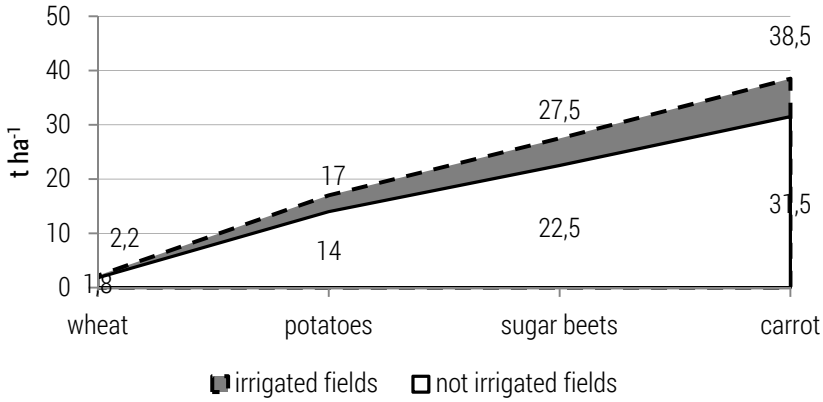

Figure 5. Harvest of chosen plants in irrigated and not irrigated fields in the łomżyński district

Source: author's own work based on (*Program nawodnień rolniczych województwa podlaskiego na lata 2007–2013*, 2008).

In both districts there was a visible increase of harvest in irrigated fields by approximately 21–22% in relations to harvest from not irrigated fields.

Method of determining the requirement for the services of surface water ecosystems in relations to water collection for agricultural land irrigation

The presented method is a simplified way of determining the water requirements for any given agricultural area, which may be supplied by the services of surface water ecosystems. It may be a tool used in water management policies of districts connected with the implementation of investments in irrigation of agricultural land.

Unit requirement for the service of surface water collection for irrigation in agriculture may be calculated using the following equation:

$$ES_j = (P_{opt} - P_r) \cdot 10, \quad (1)$$

where:

ES_j – unit rate of the requirement for the water collection service for irrigation of a given cultivation, $m^3 \cdot ha^{-1}$;
P_{opt} – optimum rainfall, mm;
P_r – actual rainfall, mm;
10 – conversion of mm to $m^3 \cdot ha^{-1}$

Based on this equation (1) the amount of water for optimal hydration of plants can be determined. Above this level the harvest will not increase, what is more it can begin to decrease. The maximum value of ES_j will be equal to the value of P_{opt}. The minimum value will equal 0, which means that the sum of actual rainfall fully provides for the water needs of plants and there is no need to use the services of surface water ecosystems.

The P_r values are available based on research conducted at the Institute of Meteorology and Water Management (IMiGW). The P_{opt} values can be obtained from literature (Dzieżyc, 1989). They were designed for individual plants and take into account soil and meteorological conditions. The P_{opt} for selected plants according to Klatt after Dzieżyc are shown in table 1.

In the case of soils other than moderately firm and other monthly average temperatures, the rates shown in table 2 can be used to determine the amount of optimal rainfall.

Table 1. Optimal rainfall for selected cultivated plants for moderately firm soil according to Klatt after Dzieżyc

Plant	Monthly rainfall in mm					
	IV	V	VI	VII	VIII	IX
	Average monthly temperature [0C]					
	8	13	16	18		
Spring wheat	45	65	70	60		
Summer barley	50	60	70	45		
Oat	50	65	75	60		
Sugar beet	50	50	60	90	90	60
Early potato	50	60	80	60		
Late potato		50	60	80	70	
Corn		50	60	70	65	50

Source: (Borówczak, 2009).

Table 2. Conversion rates for different types of soil and average monthly temperatures

Specification	Rate
Light soil	1.25
Heavy soil	0.85
Peat soil	1.00
Muck soil	1.25
Rainfall increase for every10C of temperature increase	5 mm

Source: author's own work based on (Borówczak, 2009).

The total requirement for the service of water collection for irrigation of the land for which the identification of the requirement for the service of water collection for irrigation of agricultural land is being calculated, can be obtained using the following equation:

$$ES = \sum_{j=1}^{n}(ES_j \cdot A_j), \quad (2)$$

where:

ES – total requirement for the service of surface water ecosystem related to water collection for irrigation of a given area, m^3;
ES_j – as above;
n – number of cultivation in a given area;
A_j – area occupied by a given cultivation, ha.

The presented method enables the estimation of the requirement for the water collection service for irrigation of the analysed agricultural area expressed in primary units i.e. in m^3.

Assessment of the value of the surface water ecosystem services in relations to water collection for irrigation of agricultural land

It is often difficult to put a price on ecosystem services, as they do not function within a typical products and services market.

In Poland, according to article 294 of the Environment protection law bill, the collection of surface waters for agricultural irrigation is free of charge (Prawo ochrony środowiska, 2001). It can be said that the water itself is free. This does not mean, however, that the service of the surface water ecosystems in relations to water collection for irrigation of agricultural land is not connected to any cost. The whole of the service, apart from the water, comprises of the following costs:

- design documentation for the system of water collection and distribution;
- costs of procedures to obtain permits for water collection (permit required by the Water Law Act, article 122) (Prawo wodne, 2001);
- costs of constructing the technical systems for water collection and distribution;
- usage and maintenance costs of water collection and distribution systems.

The value of water can be estimated based on the value of the benefits resulting from water usage. The value of the collected water can be estimated based on the increase in harvest, resulting from the additional water being delivered to the area.

The increase in harvest from a given area can be determined using the following equation, based on the dependencies designed by Żarski and others (*Żarski, 2013)*.

$$I_j = ES_j \cdot A_j \cdot k_j, \quad (3)$$

where:

I_j – increase of harvest of a given type of cultivation caused by the irrigation of the entire area, kg;

ES_j – unit rate of the requirement for water collection service for irrigation of a given type of cultivation, $m^3 \cdot ha^{-1}$;

k – harvest increase per m^3 of water delivered to 1 ha of the cultivated area, $kg \cdot m^{-3} \cdot ha^{-1}$;

A_j – cultivated area size, ha.

The value of k can be obtained from literature. Table 3 contains the rates designed at the University of Science and Technology in Bydgoszcz.

Table 3. Rate of harvest increase caused by irrigation for a selected plant type

Cultivated plant	k $kg \cdot m^{-3} \cdot ha^{-1}$
Spring wheat	192
Summer barley	195
Oat	163
Sugar beet	1147
Early potato	1350
Late potato	1380
Corn	280

Source: author's own work based on (Rzekanowski, Żarski, Rolbiecki, 2009).

Primary units such as kilograms of harvest can be easily converted to a monetary estimation. The value of agricultural products is determined by their purchase prices. As such, the value of the service of surface water ecosystems as water collection for irrigation of agricultural land can be determined from the following equation:

$$V_j = I_j \cdot p_j, \tag{4}$$

where:
V_j – value of the service of surface water ecosystems as water collection for irrigation in agriculture for a given type of cultivation, PLN;
I_j – increase in harvest of a given type of cultivation resulting from irrigation, kg;
p – purchase price for a given type of cultivation, PLN/kg.

The value of ecosystem services in relations to the value of collected water for irrigation of a given area of land can be established from the following equation:

$$V = \sum_{j=1}^{n} V_j, \tag{5}$$

where:
V – value of the service of surface water ecosystems as water collection in agriculture for an area for which the service is being identified, PLN;
V_j – value of water collection for a given cultivation, PLN;
n – amount of plants grown in the given area.

The services of surface water ecosystems as water collection for irrigation of agricultural land can be determined by estimating the benefits resulting from the use of such service.

Summary

The amount of water used for irrigation in agriculture is connected to the geographical location of the irrigated area. On a worldwide scale water collection for agriculture is 69% of the total amount of collected water. Agriculture is, therefore, the largest recipient of the service of surface water ecosystems in this field. Water collection for industrial purposes amounts to 19% and for living purposes – 12% (http://www.fao.org). This is why the possibilities for being more economical with the use of water resources should be sought in agriculture.It is thought that saving 1% of water used around the world for food production can mean a 2-3 dm^3 saving on water per person, which is the amount of drinking water a single person needs (Rijsberman, 2006).

Surface water collected for irrigation of agricultural land in Poland is free of environmental charges. However, this situation can change, as the Polish government aims to introduce the rule of refunding of costs of water services, including the cost of collecting surface water and extracting ground water (http://legislacja.gov.pl). This rule is one of the basic ones included in the water framework Directive (Directive 2000/60/EC).

From the point of view of surface water ecosystem protection it is important to determine the actual water collection amount in agriculture. This may be an important information for the districts on the direction of water usage in agriculture. Apart from monitoring of the current water usage, district policy of agricultural land irrigation is important. It is here, that the method for estimating the water requirements can be useful as a tool for shaping the future decisions concerning irrigation investments within districts.

Acknowledgements

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