IOP Conf. Series: Earth and Environmental Science **1474** (2025) 012014 doi:10.1088/1755-1315/1474/1/012014

Water supply ecosystem services of the former Kakhovka Reservoir

V Karamushka[1*], M Khoriev[1], O Huliaieva[2] and B Kuns[3]

[1] National University of Kyiv-Mohyla Academy, Kyiv, Ukraine
[2] Private Join Stock Company "Ukrhydroenergo", Vyshgorod, Ukraine
[3] University of Agricultural Sciences, Uppsala, Sweden

*E-mail: vkarama2011@gmail.com

Abstract. Kakhovka Reservoir (KR) on the Dnirpo River was one of the largest reservoirs in Europe. On the 6th of June 2023 at 02:50 AM the Kakhovka dam was demolished by RF military forces and as a result, by June 18-20 the Kakhovka Reservoir ceased to exist. In spite of its artificial origin, the KR supplied valuable ecosystem services (ESs) important for human being and natural aquatic and coastal ecosystems. The paper describes the key ESs of the Kakhovka Reservoir focusing attention on characteristic of the water-supply ES and its significance for the region. Supply of water for households and diverse sectors of the economy (provisioning ES) as well as providing water to ensure the functioning of natural ecosystems downstream of the KR were the most important ESs from the KR. Our estimates of the needs and analysis of actual volumes of water consumption from the KR by the population of the region (for drinking and economic needs), power generating stations (Kakhovka hydroelectric power station, Zaporizhzhya NPP and TPP), industrial enterprises, the agricultural sector (mainly for irrigation) show that in the absence of the Reservoir, the available resources of the Dnipro River cannot meet the needs of the region in water-supply ecosystem services as defined by the pre-war situation.

1. Introduction

Hydropower is one of the most dynamically developing energy sectors. As of 2019, 21,387 hydroelectric power plants were operating in Europe, and 8,785 additional plants were planned or under construction [1]. The vast majority of such stations belong to pumped-storage plants and are small in terms of power generation (0.1-10 MW). But small hydropower plants come with a large ecological impact because they are numerous, disrupt river continuity and form reservoirs, the surface area and water volumes of which can be very significant. In such artificial reservoirs, an ecosystem is formed with a certain set of universal and specific ecosystem services.

Today, many dams reach or exceed their designated operational lifetimes. Increasing sedimentation decreases the usefulness of dams. The greater knowledge and awareness of and concern about the ecological damage caused by dams accelerated the growing debate about dams removal. Moreover, the number of projects aimed at dams removal is growing. At the same time, most dam removal projects involve dams on smaller rivers or streams [2, 3].

Destruction of the Kakhovka dam and dewatering the reservoir was not planned by the Government of Ukraine and resulted from activity of the RF military forces in Ukraine [4]. This case stands out in the discussion about dam removal in several important ways. First, the Kakhovka HPP and reservoir would be one of the largest dams and reservoirs to be removed and dewatered, respectively, in modern history. Second, most discussion of dam removal envisages the peaceful and controlled removal of dams following stakeholder dialogue, environmental impact assessments, and democratic decisions. The Kakhovka reservoir and HPP were destroyed as part of military action with catastrophic consequences. Currently, the reservoir's area

IOP Conf. Series: Earth and Environmental Science **1474** (2025) 012014 doi:10.1088/1755-1315/1474/1/012014

separates the territory controlled by the Government of Ukraine and the territory occupied by the Russian Federation. In fact, it is a front line and access to it by civilians is critically limited.

Destruction of a reservoir actually means the destruction of the ecosystems within and otherwise connected to the reservoir, and therefore the loss of ecosystem services associated with it. The definition and evaluation of such services are important for making management decisions regarding the development of the region. In cases of dam removal, there is obviously a need to assess potential losses and find another source of ecosystem services to replace the lost ones.

There is no single methodology for evaluating ecosystem services. There are currently a significant number of approaches in use, and the number of dedicated publications is in the thousands [5, 6]. A dominating approach however involves the estimation of monetary value of ecosystem services. If we talk about natural or man-made ecosystems that are large in size and complex in structure, then the evaluations of their services are generalized [6]. The Kakhovka reservoir belongs to such systems. That is why the assessment of the lost ecosystem services of the Kakhovka reservoir is a complex and not a simple task, which many researchers have set themselves.

The purpose of this work is to identify the key ecosystem services supplied by the Kakhovka reservoir and to characterize the water supply system in the context of its importance for the region.

2. Study Area, Methods and Data Sources

2.1 Study Area

The study area covers the southern regions of Ukraine - Kherson, Zaporizhzhya and Dnipropetrovsk, where the Kakhovka reservoir is located and which used its water as the main source of drinking and household water supply. The Kakhovka HPP and reservoir were the sixth and southernmost in a series of hydroelectric power stations and reservoirs that were built on the Dnipro River, resulting in the formation of what is called the Dnipro cascade of reservoirs (Figure1). The Kakhovka HPP was created in the early 1950s and put into operation in 1956. Its full volume was 18,2 km^3 and its usable storage was 6,8 km^3. The area of the water surface, when a normal retaining water level was observed, was 2155 km^2. It was one of the largest reservoirs in Europe and in terms of volume, it was inferior only to the Kuibyshev (58 km^3), Volgograd (31.5 km^3), and Rybinsk (25.4 km^3) reservoirs, which were formed on the Volga River in RF. The length of the KR was 230 km and the maximum and average width was 25 and 9,3 km respectively. The maximum and average depth was 36 meters and 8,4 meters. The area of shallow waters, up to 1 meter, was 44 km^2, and up to 2 meters, 110 km^2 [7].

2.2 Methods and data source

A quantitative assessment of water resources and the extent of their use by various industries was the basis for the evaluation of the water-supply ES. For this purpose, the actual water balance of the Kakhovka reservoir from 1989 to 2021 (inflow = outflow) was analysed. The inflow to the Kakhovka reservoir consisted of surface inflow through the higher Dnipro HPP (Zaporizhzhia), water pumped into the reservoir from rivers blocked by dams; surface inflow of water from areas not covered by flow measurement (lateral inflow); atmospheric precipitation on the reservoir surface; as well as inflow into the reservoir from industrial and domestic wastewater. The outflow included water flowing through the Kakhovka HPP, intake

IOP Conf. Series: Earth and Environmental Science **1474** (2025) 012014 doi:10.1088/1755-1315/1474/1/012014

of water from the reservoir for irrigation, for drinking water systems, water losses from evaporation from the surface of the reservoir, and losses from one-way filtration (through soil) from the reservoir.

Figure 1. Kakhovka Reservoir on the map of Ukraine before the blowing up the Kakhovka dam. On the 6th of June 2023 at 02:50 AM the Kakhovka dam was demolished by RF military forces and as a result, by June 18-20, the Kakhovka Reservoir ceased to exist [4].

In this paper, we considered only actual data of water resources for municipal, agricultural, and commercial (industrial) use. Water balance data [8] were obtained from the State Water Agency of Ukraine.

3. Results and Discussions

3 .1 Scoping of the ecosystem services of the Kakhovka Reservoir

In a general sense, ecosystem services are defined as the benefits that people obtain from ecosystems [9] or the direct and indirect contributions of ecosystems to human well-being [10]. The Kakhovka Reservoir was a multipurpose reservoir with regulated flow. According to The Economics of Ecosystems and Biodiversity (TEEB) classification [5], ecosystem services of the KR can be presented as follows (table 1).

We removed from this list ecosystem services that do not apply to the Kakhovka Reservoir (in particular, 14 Pollination) and those that are unknown to us and require additional research (for example, 5 Medicinal resources, 12 Erosion prevention, 13 Maintenance of soil fertility and some others).

Reservoirs are integrated ecological systems [11], the components of which are the water environment and coastal natural complexes formed thanks to the hydrological system. With this approach, we can talk about such an ecosystem service as the use of raw materials. Such materials are thickets of reeds on a considerable length of the coastline of the Kakhovka Reservoir. Dried reeds are used as building material for roofs of houses or as fuel, though this use, which was never widespread, appears to be declining in recent years. Erosion of the banks during the formation of the reservoir in certain places contributed to the surfacing of rocks, mainly limestone, which were used for construction. The use of coastal limestone resources was however limited at local level.

The reservoir also regulated flow to prevent flooding, neutralized the flow of nutrients and pollutants, and prevented the spread of hazardous compounds, particularly heavy metals, by depositing them in bottom sediments. A significant volume of water and the area of the water surface increased air humidity and influenced the local climate. All these ESs belong to regulatory services with codes 7-11 and 15 (table 1).

Table 1. Ecosystem services of the Kakhovka Reservoir according to the TEEB classification [5].

Service Group	ES Code	Ecosystem Service
Provisioning	1	Food (fish, other aquatic bioresources)
	2	Water
	3	Raw materials
	4	Genetic resources
Regulating	7	Air quality regulation
	8	Climate regulation
	9	Moderation of extreme events
	10	Regulation of water flows
	11	Waste treatment
	15	Biological control
Habitat (supporting)	16	Maintenance of species' life cycles (incl. nursery service)
	17	Maintenance of genetic diversity
Cultural	18	Aesthetic information
	19	Opportunities for recreation and tourism
	20	Inspiration for culture, art and design
	21	Spiritual experience
	22	Information for cognitive development
	23	Existence and bequest 'values'

Water as a resource was used to generate electricity at the Kakhovka HPP (ES Code 2) and to support technological processes at the Zaporizhzhya NPP. In addition, the presence of an appropriate water level in the reservoir provided conditions for water transport.

The natural hydrological system of the reservoir was an environment for the existence and development of fish and other hydrobionts, and also supported the freshwater ecosystem of the Lower Dnipro from Kakhovka to the Black Sea (supporting ES, ES Codes 16, 17). The reservoir ecosystem was of great importance for tourism and recreation (ES Code 19), and also provided other socio-cultural ES (ES Code 18, 20-23).

However, hydrological ecosystem services were obviously key for the Kakhovka Reservoir - these are goods and services that ecosystems provide to people and which are related to various types of water use [11]. The availability of water is a necessary condition for the availability of this resource for municipal, agricultural and commercial (industrial) use (water-supply ES, ES Code 2). The volumes of water used by different water users can obviously serve as indirect evaluation indicators of water-supply ES.

3.2. Approach for assessing and valuing water-supply ecosystem services

Figure 2, A presents data on water consumption by the agricultural sector (irrigation), the energy sector (exclusively for the Zaporizhzhya NPP) and other water users (utility and production sectors together) for the period from 2010 to 2021. As can be seen from these data, at least during this period, the largest water user of the Kakhovka Reservoir was the agricultural sector. Note that the data on water consumption presented in the Figure 1 is for irrigation only,

IOP Conf. Series: Earth and Environmental Science **1474** (2025) 012014 doi:10.1088/1755-1315/1474/1/012014

and thus does not include the water consumption of livestock, etc. The total volume of water consumption by the agricultural sector will be larger.

Annual water consumption was different every year, depending on natural (climatic) and socio-economic factors. The use of water for nuclear energy needs was significantly less than the amount of water for irrigation with relatively minor fluctuation, while the use of water for municipal and commercial needs was slowly decreasing. The maximum amount of water withdrawal from the Kakhovka Reservoir was recorded in 2013, after which a sharp decline was observed. Since these changes are related to the use of water for irrigation (Figure 2, A), it can be assumed that such a reduction occurred as a result of the cessation of water supply to the North Crimean Canal after the annexation of Crimea by RF.

The seasonal dynamics of water consumption indicate intensive use of water for irrigation in the warm season, which reaches a maximum in August (Figure 2, C). But the volumes of water consumed in 2021 are significantly lower than in 2010. The maximum water consumption by the municipal and commercial sectors also falls in August, but the total water consumption by these sectors is about 20 times less than the use of water for irrigation and three times less than the volume of water used in the energy sector (Figure 2, B, C, D). Due to fluctuations in the volumes of water consumed in the nuclear power sector, we cannot claim that there are significant differences between 2010 and 2021, but the data do indicate that during January - April, that is, during the cold season, water intake for nuclear power was smaller than in other months (Figure 2, D).

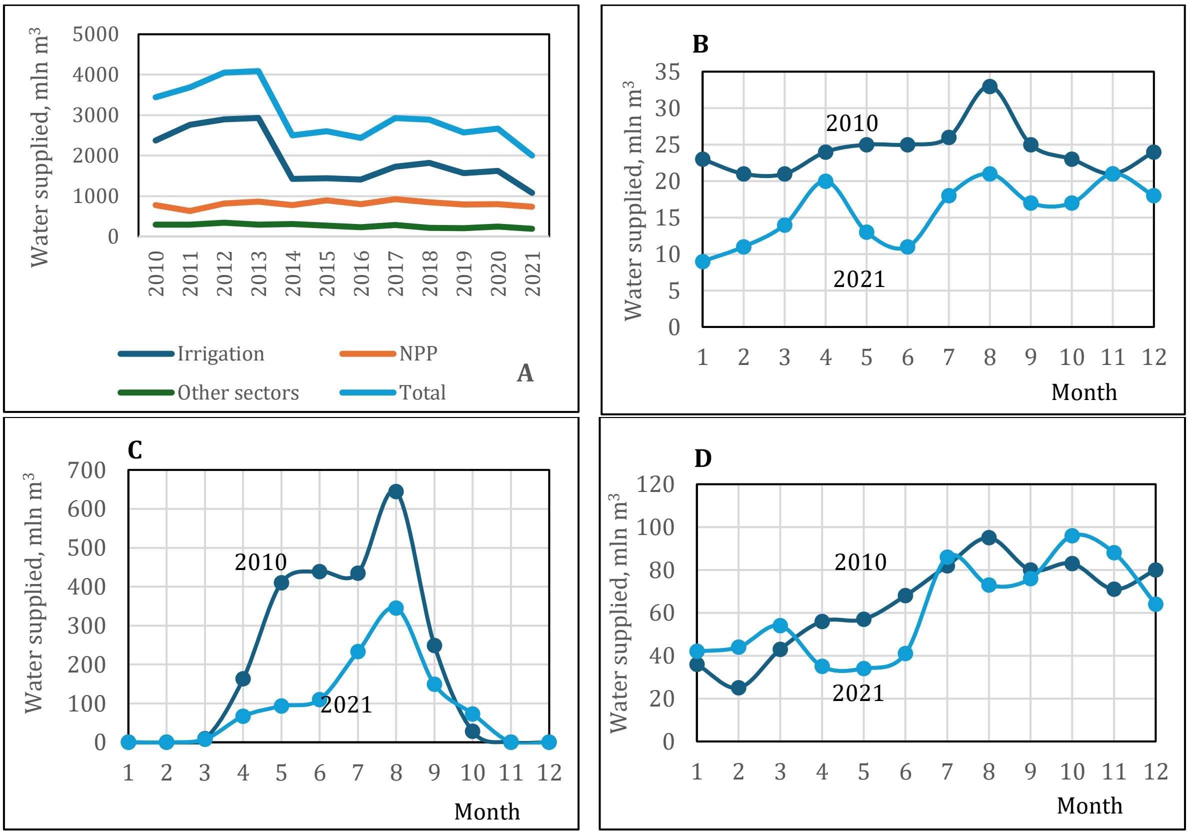

Figure 2. Annual (A) and monthly (B, C, D) dynamic of water supply from Kakhovka reservoir for municipal and commercial sectors (B), irrigation (C), and nuclear power generation (D).

The data can be used for the monetary evaluation of the provided ecosystem services – one possible indicator here would be the value of the water. In Ukraine, such an indicator would be reflected in taxes and rent for water use.

The applied approach for assessing the water supply ecosystem service of the Kakhovka Reservoir makes it possible to assess the volume of services provided, while the ecosystem has a much greater potential and other methodological approaches should be used for its assessment.

4. Conclusion

Assessments of ESs are of particular importance in the study of disturbed or lost ecosystems. These include, in particular, ecosystems of artificial reservoirs on rivers, formed due to the construction of dams and hydroelectric power plants. The KR on the Dnipro River, destroyed as a result of the explosion of the Kakhovka dam, provided ESs important for the environment, population and economy of the region. To evaluate these ESs, we used the volumes of services provided. The given data on the use of water by various sectors in the period 2010-2021 indicate a significant scale of use of such services. According to our estimates, in the absence of the KR, the flow rate of the current main channel of the Dnipro River does not make it possible to provide ESs in full capacity for water use in the region. That is, in low-water years, either there will be a shortage of water, or the quality of water ecosystems in the lower part of the Dnipro will be deteriorated. Such data are important for making a decision on the further development of the region. The key issue remains the question of rebuilding the Kakhovka dam or using the territory of the former reservoir for environmental and economic needs. An important argument for this will be the assessment of the needs in the water supply services and sources of their replacement. At the same time, it is necessary to assess the scale and significance of other ecosystem services of the former reservoir, which remains the subject of our further research.

5. References

[1] WWF 2019. WWF, RiverWatch, EuroNatur, GEOTA report: Hydropower pressure on European rivers: The story in numbers. 38 p.
ttps://wwfeu.awsassets.panda.org/downloads/hydropower_pressure_on_european_rivers_the_story_in_numbers_web.pdf

[2] O'Connor JE et al. 2015 *Science* 348(6234) 496–497. https://doi.org/10.1126/science.aaa9204

[3] Magilligan FJ et al. 2017 *Environ. Management* 59 982–994. DOI: 10.1007/s00267-017-0835-2

[4] Vyshnevskyi V et al. 2023 *Water International* 48(5) 631–647
https://doi.org/10.1080/02508060.2023.2247679

[5] De Groot R et al. 2020 *Update of global ecosystem service valuation database (ESVD).* FSD report No 2020-06 Wageningen, The Netherlands. 58 p. /
https://www.esvd.info/_files/ugd/53b4f9_c7518bbf3f884375828524c50773cff0.pdf

[6] Costanza R. et al. 1997 *Nature* 387 253–260.

[7] Baksheev E 2008 *Dnipro reservoirs and their economic effect: memories and reflections of a designer* K.: Dovira. 159 p.

[8] [SAWRU] State Agency of Water Resources of Ukraine 2019 *Water management balances of the main areas of river basins.* https://davr.gov.ua/vodogospodarski-balansi-osnovnih-rajoniv-richkovih-basejniv

[9] MEA 2005. Millennium ecosystem assessment. Ecosystems and Human Wellbeing: Synthesis. Island Press, Washington, DC.

[10] TEEB 2010. The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundation. Earthscan, London and Washington.

[11] Grizzetti B et al. 2016 *Environmental Science & Policy* **61** 194-203.
https://doi.org/10.1016/j.envsci.2016.04.008