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O. M. Motuzka,
PhD in Economics, Associate Professor,
Associate Professor of Department for Management,
Marketing and Public Administration,
National Academy of Statistics, Accounting and Audit,
E-mail: ommotuzka@nasoa.edu.ua
Researcher ID: K-6501-2018,
ORCID: https://orcid.org/0000-0001-9028-6994

A Statistical Study of Water Resource Accounting in Ukraine in the Conditions of Martial Law

The article contains results of a statistical study of water resource accounting in Ukraine in the conditions of martial law. The regulatory framework of water use is shown: constitutional principles and provisions of the Water Code of Ukraine, regulatory acts specifying accounting and monitoring schemes. A retrospective review of the evolution of the national water resource accounting system, from creation to transformation in the era of Ukraine's independence, and gradual transition to the basin principle of management, was made.

A description of the available water resources and their distribution across the Ukrainian territory is given, with underscoring the role of underground waters and water-shortage problems in southern and eastern regions of Ukraine. The operation of the water sector in the prewar period was analyzed, with outlining crucial changes occurring in the wartime. The dynamics of the total water intake, the structure of fresh water use by main economic sector, and the water discharge in surface water bodies was compared, enabling to reveal an express downward trend resulting from the ruining of infrastructures and stoppage of factories.

The challenges faced by the accounting system in the wartime were elaborated on: missing data, losses of data on the occupied territories, disrupted operation of hydrological posts, laboratories, regular observations. Special emphasis was placed on the consequences of the ruining of Kakhovka water reservoir, entailing the stoppage of irrigation, change in hydrological regimes, increasing environmental and humanitarian risks.

The official measures to eliminate the disastrous effects, especially capital investment in the renewal of sewage treatment plants, pumping stations, water pipes, and monitoring systems, are highlighted. The developments in statistical accounting of water resources in Ukraine were proposed: integration of satellite and GIS technologies, digitalization and creation of a single information system, consolidation of basin-based management, expansion of the regional observation networks, adaptation of techniques to emergency situations, and appropriate funding. Results of the study have practical value for public administration bodies, water-management organizations and the research community in the context of postwar recovery and water policy setting.

Key words: *water resources, statistical accounting of water resources, monitoring of water use, Kakhovka hydropower plant, Kakhovka water reservoir, basin principle of water resource management.*

Introduction. Water resources constitute a strategic national wealth of Ukraine, determining the environmental security, economic stability, and social welfare. The significance of water as a critical resource ever increased in time of the large-scale war going on since 2022. The warfare aggravated the shortage of fresh water and degraded its quality, with millions of people facing limited access to safe drinking water. Ruining of water supply and hydrotechnical facilities caused massive losses of water resources. The destroyed share of fresh water stocks in Ukraine (mainly due to the loss of Kakhovka water reservoir) since the beginning of the Russian aggression is estimated as one third of the total [1]. Thousands of water-sector infrastructures have been ruined [2]. As a consequence, millions of persons had no or limited access to safe water as early as in April 2022. Once the Kakhovka hydropower plant was blasted in June 2023, another 1,250,000 people (including 300,000 children) in southern Ukrainian regions were left without a sustainable water supply [3].

The martial law dramatically aggravated statistical aspects of water resource accounting. The conventional system of monitoring faced an array of challenges: missing data from occupied territories, accounting of many indicators complicated or suspended, degrading reliability of the official statistics. While the data from the State Statistics

Committee of Ukraine had not covered Crimea and Donbas since 2015, temporary occupied areas of other oblasts were lost for accounting in 2022. Amidst intensive warfare and massive ruining, data collection is fragmentary and delayed, with some business entities not reporting at all. Yet, the governance decision-making increasingly requires accurate accounting of water resources, pollutions, and population's demand for water.

The abovementioned poses a theoretical and practical problem of identifying the tendencies and vulnerabilities in the statistical accounting of water resources in Ukraine in the conditions of martial law (2022–2025); analyzing the dynamics of core water use indicators, assessing the impact of war on the accounting method and reliability of data; and outlining the areas for modernization of the monitoring system in the postwar period.

Sources and methods. This study is based on a wide range of sources: peer-reviewed research papers, international analytical reports, official statistical books of the State Statistics Service of Ukraine, normative and legal acts, proceedings of international organizations (e.g. FAO, World Bank, EU Water Data, UNICEF), dissertations, and satellite data from open sources.

The research methodology is based on analysis of normative and legal acts pertaining to the water sector, a retrospective review of the dynamics of water use in Ukraine, statistical analysis of the data from the State Statistics Service of Ukraine, regional analysis by basin principle and economic sector, and on using satellite images and remote sensing data, to identify spatial changes and confirm military effects.

Results and discussion. Water resources encompass all the water bodies within the country's territory: surface waters (rivers, lakes, water reservoirs, and ponds), underground waters, and internal marine waters. Article 13 of the Constitution of Ukraine specifies that lands, bowels, air, water and other natural resources within the territory of Ukraine constitute the objects with property right of the Ukrainian people [4]. According to the Water Code of Ukraine (enforced in 1995), all the waters constitute the property of the Ukrainian people and the basis for life and statehood [5]. The legislative acts place emphasis on the need for public management of waters and their monitoring, protection from pollution and depletion.

The official accounting of water resources in Ukraine supplies the data on quality, use, discharge, rational allocation, protection, and regeneration of waters. The amendments to the Water Code of Ukraine (2012) specify that the accounting is performed through reporting by water users, and the entity responsible for the accounting is the central government body charged with the water sector (the State Agency on Water Resources of Ukraine) [5].

The Regulations for water use accounting, specifying the rules and indicators for water intake, use, discharge, operation of circulation systems, wastewater treatment, were enforced in 2015. Water users submit an annual report by the form No 2ТП-vodhosp laying the basis of the cadaster [6]. The existing system is focused on rational use of water, planning of water-economy activities, and control over protection of water resources from pollution and depletion.

Water resource statistics in Ukraine dates from the soviet period, when the accounting was performed within the framework of the State Water Cadaster and the water sector was part of the planned and administrative economy. The water statistics system was transformed after 1991, with creating the Ukrainian State Agency on Water Resources, and the State Statistics Committee of Ukraine launching the yearbook "Environment of Ukraine" containing a separate section on water resources. 1990s and early 2000s saw a drastic reduction in water use resulting from economic slowdown and closure of many water-intensive factories. At early 1990s, the total estimated water intake in Ukraine was 26 km^3 per year, of which nearly 30% accounted for by agriculture, 53% by industry, and 18% by utility services. However, the structure of water use changed in 2000: amidst the reduction of the total water intake to ~19.2 km^3 per year the share of industry grew up to 70%, the share of agricultural sector fell down to 6%, and the share of utility water supply grew up to 24% [7, с. 4]. The subsequent dynamics confirms a downward trend, as by 2010 the water intake fell to 14.8 km^3 per year (not counting transit losses) [8, p. 40]. These figures were fluctuating in 2000–2013, but with an overall downward trajectory, which can be explained by the economic restructuring (industry recession and reduction of irrigated areas) and the growing efficiency of water resource utilization.

The official statistics has not counted the data on the temporary occupied Crimea and part of Donbas since 2014, which complicates comparisons with the previous period. As regards the controlled territory, the trend was downward, with the total water intake from natural sources fallen to 8,857 km^3 per year by 2021 [8, p. 40]. But the legislative framework was being improved by adopting several official programs ("Drinking Water of Ukraine", "Environmental Rehabilitation of the Dnieper Basin", etc.), harmonizing national monitoring standards with European ones (through legal adoption of the integrated management of water resources by the basin principle) [9, 10]. Yet, the implementation of many programs was incomplete due to chronic underfunding.

Consequently, by 2022 Ukraine had a legally established system for the official water accounting, elaborated in terms of reporting formats and regular

publication of aggregated data. But the beginning of the large-scale war caused unprecedented shocks in this system, and put into question the completeness and accuracy of further statistics.

The Ukrainian territory is divided into nine basin districts of the main rivers. The largest one, the Dnieper basin, covers nearly two thirds of the country's area. Dnieper is the principal water artery (which length within the Ukrainian borders is ~981 km) with the created cascade of six water reservoirs. In the west of Ukraine flows Dniester river (the third one in Ukraine by length); in the south, Ukraine borders the largest European river Danube via the Danube basin. An important river in the east is Siverski Donets, the largest tributary of Don river, which supplied water to Donbas. Across the center and the south flows Pivdenny Buh running to the Black Sea estuary. Small rivers of the Black Sea region and Crimea constitute separate basins [11]. Hence, the majority of Ukrainian rivers belong to the basins of Black and Azov seas, except for small tributaries of Vistula river in the west (the basin of the Baltic sea).

Apart from the river flow, large stocks of fresh water are concentrated in underground aquifers (Dnieper-Donets, Volyn-Podil, and other artesian basins). Underground waters are usually of higher quality, and less exposed to pollution; they account for nearly 20% of the total water supply in Ukraine. However, the natural regeneration of underground waters is limited in the south (steppe zone), with their quality degraded due to high mineralization and pollution with nitrates in agricultural areas [9]. Separate emphasis should be put on mineral waters (which deposits are found in the resorts of Zakarpattya, Mirhorod, Truskavets, etc.), as they are a valuable resource but their extraction is small compared with the total water use.

The distribution of water resources across the Ukrainian territory is extremely uneven. The overwhelming part of the river flow (nearly 70%) forms in the north-west (Polissia, Carpaty) and flows across the country to the Black sea [12, p. 69]. At the same time, southern and eastern regions are short of water, as the local flow here is small. By hygienic criterion, the most part of river basins in Ukraine are classified as polluted and very polluted [9]. The situation is the gravest in the basins of medium and lower Dnieper and its tributaries (Dnipropetrovsk, Zaporizhzhia, Mykolaiv, and Kherson oblasts), as these regions suffer from the shortage of good water, high technogenic burden, added now by destructions caused by the war. To supply water to the southern Ukraine, cross-basin canals had been built in the soviet times (Dnieper – Kryvyi Rih canal, Southern Crimean canal, Siverski Donets canal), but the war disrupted their operation (Southern Crimean canal was shut off in 2014–2022, and seized by Russia in 2022). The blasting of Kakhovka dam in 2023 left large irrigation systems in Kherson and Zaporizhzhia oblasts without a source of water, causing the risk of desertification in a large area of the Ukrainian south [13].

The estimated total resources of internal flow in Ukraine are ~50 km^3 per year (renewable), corresponding to only ~1200 m^3 of the annual supply per capita, which is one of the lowest in Europe (Ukraine ranks 37th among 50 European countries by water supply per capita) [1]. On top of it, the water supply greatly varies between urban and rural settlements: the centralized water supply covers 97% of the city residents and only 26% of the rural ones, with the rest of villagers forced to use wells or imported water, creating health-related risks [14]. Hence, Ukraine had been a country with a shortage of accessible high quality water resources even prior to the war, and this trouble heavily aggravated in 2022–2023.

The official water statistics show that the situation with water use in Ukraine became critical after the beginning of the large-scale invasion in 2022. While the water intake had gradually been down prior to 2021, the year of 2022 saw its unprecedented plummeting: the total water intake from natural sources fell by nearly twice: from 8.857 km^3 in 2021 to 4.883 km^3 y 2022 (Fig. 1, constructed by data from [8]). This drastic fall can be explained by the immediate impact of warfare: a large part of industrial factories and irrigation systems were stopped or got to occupied territories, with water intake facilities ruined.

As regards water use by category, its structure had stabilized in 2015, with nearly 63% accounted for by industry, 17% by utility services (individuals and utility facilities), 17% by agriculture (mostly irrigation), and the rest 3% by other needs (e.g. fishing counted separately after 2015). The total use of fresh water (without recirculation) amounted to 7.238 km^3 and 6.143 km^3 in 2020 and 2021 [8]. It means that Ukraine featured a sustained decline in water use and the persisting prevalence of industry in the structure of water use.

It should be noted that a large share of water in Ukraine has been traditionally reused in water recycling facilities. The amount of circulation water was 34,122 km^3 in 2021, being several fold higher than the primary water intake [8]. It gives evidence of intensive water recycling at industrial factories (basic metals and chemical industry), where water is reused many times in the production cycle. Hence, the burden on natural sources is weaker than it could have been, but still remains tangible.

The impact of the large-scale war on water use indicators proves to be drastic and clear: 2022 saw its essential decline in all the user categories. Figure 2 (constructed by data from [8]) shows a comparison of the fresh water use by economic sector in 2021

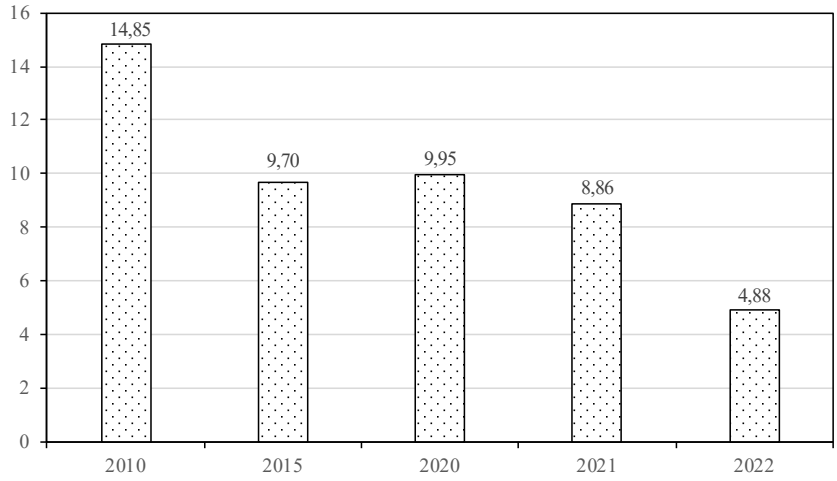

Fig. 1. The dynamics of the total water intake from natural water objects, Ukraine, 2010–2022, km³ per year

and 2022. The Ukrainian industry consumed only 2.397 km³ of water in 2022 against 4.047 km³ in 2021. It means that the industrial consumption of water reduced over a year by approx. 41%. This is explained by full stoppage or contraction of many factories in the warfare zone (metallurgical combines in Mariupol, chemical factories in the Ukrainian east, etc.), ruining of energy facilities, and forced idleness of factories.

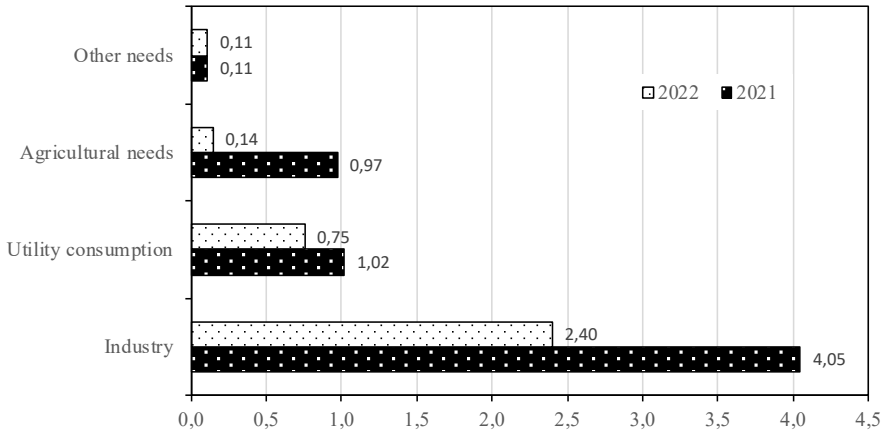

Fig. 2. Fresh water use by main economic sector, Ukraine, 2021 and 2022, km³ (not including the temporary occupied territories)

Utility water consumption (drinking and sanitary-hygienic) also markedly reduced: 0.753 km³ in 2022 against ~1.02 km³ in 2021 (by 26%). This was caused by massive migration of the population (with millions of residents fleeing abroad or to other regions), ruining of water supply networks in frontline cities (with part of residents being left without water), and water-saving measures taken in time of crisis.

But the most heavily hit sector was agriculture: the amount of water for irrigation fell from 0.97 km³ in 2021 to miserable 0,143 km³ in 2022, i.e. by 85%. It was caused by the loss of control over a major part of irrigated lands of the Ukrainian south (Kherson and Zaporizhzhia oblasts), occupation and subsequent drying of Kakhovka mainstream canal. In fact, the irrigation facilities in the Ukrainian south were shut down as early as in spring 2022, plummeting the water consumption in the agricultural sector. According to data from the Ukrainian Ministry for Agricultural Policy, while the area irrigated in 2018–2021 amounted to 500,000 hectares, the blasting of Kakhovka hydropower plant in 2023 caused its reduction to only 15,000 hectares in the same year of 2023. This entailed a disastrous decline in yields on irrigated lands (yields of vegetables and crops plummeted by 85% and 93%, respectfully) [15].

The warfare has notable effects for the discharged wastewater. The total water discharge in surface water bodies was 2.98 km³ in 2022 against 4.685 km³ in 2021 (Table 1, compiled by data from [8]). So, the discharges reduced by approx. 36%. Of these, the polluted reverse waters (the ones discharged without appropriate treatment) amounted to 0.374 km³ in 2022 against 0.542 km³ in 2021, i.e. the 31-percent reduction. These trends are expectable, as the less

water is consumed, the less discharges occur, especially from the industry. The share of untreated discharges slightly declined, although in absolute figures this improvement would be merely statistical due to the stoppage of the largest polluters. In 2022, when some chemical factories, power plants, municipal sewage treatment plants on the occupied territories were nearly at a standstill, they could not discharge wastewater. On the other hand, there were numerous cases of emergency discharges caused by shelling, with pollutants getting into water bodies. These unauthorized pollutions cannot be easily assessed in quantitative terms, as they tend to be overlooked by the official statistics.

Table 1

The discharges into surface waters, Ukraine, 2021–2022

(km^3)

Indicator	2021	2022	Absolute deviation 2022/2021 (+/–)	Standard deviation 2022/2021, %
Total, including:	4,685	2,980	–1,705	–36,39
– polluted reverse waters	0,542	0,374	–0,168	–31,00
– normatively cleaned waters	1,430	1,055	–0,375	–26,22
– normatively clean, without cleaning	2,713	1,551	–1,162	–42,83

It should be noted that the trends of 2022 persisted in 2023: by preliminary estimates, the water consumption remained low because of the ongoing warfare and partly unrestored infrastructures. Besides that, the blasting of Kakhovka hydropower plant in June 2023 further aggravated the situation with water intake in the south (as this source of water disappeared for Mykolaiv oblast, the city of Kryvyi Rih, etc.) [13]. The final official data for 2023 are now missing or partial, but selected regional reports show the ongoing decline in the water intake and problems with quality of water supply.

Ukraine had been gradually improving some environmental indicators, including fresh water, prior to the martial law. According to the Ukrainian Ministry of Health Protection, the share of drinking water samples not compliant with sanitary norms fell from 7–8% in 2019 to ~5,5% in 2020 [9, p. 4]. As soon as the war began, control over the water quality got complicated in many regions. Ruining of sewage treatment facilities, electricity disruptions and shortage of reagents increased the risks of microbiological pollution of tap water. Tests conducted in the liberated territories of Kherson oblast often revealed excessive content of nitrates and bacteria due to flooding, sewage spill, etc. [16].

The official water quality indicators of 2022–2023 are fragmentary. Some studies show that the water stress (the ratio of the total fresh water intake to the available resources) for Ukraine temporarily fell in 2022 to ~15% (relative to previous ~25–30%) [17]. It formally improves the SDG indicator 6.4.2 (water stress level), but this improvement is misleading, being caused by economic devastation rather than efficiency. At the same time, in many southern oblasts the stress dramatically increased, because the available resources virtually disappeared after the drying of Kakhovka water reservoir.

Basically, the war period is still marked by lack of consistent statistical data about the quality of water resources. There are ad hoc studies fixing local environmental consequences such as chemical pollution of rivers resulting from spilling of oil products, explosives or flooding of mines. As a full cycle of the official monitoring of waters in warfare zones was not conducted in 2022, many indicators could not be estimated due to missing data. Filling these gaps by retrospective estimates will pose a challenge in the postwar time.

The war revealed weaknesses in the Ukrainian water resource accounting system. Immediate consequences of warfare are ruining and seizures of facilities engaged in data collection and water resource management. The occupation and blasting of Kakhovka hydropower plant caused, apart from an environmental disaster, the loss of the network of hydrological stations and observations on the lower Dnieper. According to reported data, the following objects were fully or partially ruined as of the middle of 2023: 724 hydrotechnical structures, 38 water plants and 71 sewage pumping stations, more than 800 km of water networks, 32 water towers [3]. Apart from disruptions in water supply, it entails missing data on water supply, leakages and quality.

The temporary occupation of territories made impossible data collection therein. In 2022, the State Statistics Service of Ukraine did not obtain official information from business entities or administrative bodies located in occupied or warfare zones. Hence, the national indicators were estimated only for the controlled territory. As the water use is not counted in large industrial centers (the city of Mariupol, Zaporizhzhizia nuclear power plant, etc.), the totals for 2022 do not reflect the full picture, but only its fragment for which the data are available. After de-occupation, it will be necessary to make a retrospective

assessment of the wartime losses of water and water discharges in those territories.

Methodological constraints occur as well. The wartime statistics became more incomplete and inaccurate. Thus, due to disruptions of electricity and communications at the end of 2022, some water canals could not submit annual reports in timely manner, and the State Statistics Service of Ukraine was forced to publish the data for 2022 with delay and, probably, with partially estimated outputs. Experts observe that problems with the reliability of accounting had existed in times of peace, with some factories underrating data on water consumption, to reduce the fees [18]. As the control became even weaker in the chaos of war, substantial underreporting of the actual water use could be quite probable. As many computerized monitoring systems (meters on rivers or hydrological stations) were broken, data from them would be missing over the time of warfare.

Another problem is in discrepancies between national and international statistics. As Ukrainian agencies had no data for certain regions, international organizations (UN, UNISEF) attempted to assess the situation themselves. It could give rise to various figures. While a national report may inform that the residents in the controlled part of an oblast are supplied with water by 100 percent, UN data may count occupied communities where water supply is equal to zero, resulting in different total shares of access to water. These discrepancies need to be accounted for in analyses of figures for 2022–2023. Basically, it should be admitted that the official water monitoring system proved to be unprepared for operation in the conditions of war, because there were neither backup channels for data collection nor schemes for quick methodology updating.

Once Kakhovka water reservoir was blasted on June 6, 2023, the vast water body (18 km^3 of water) turned into ruin. It had colossal effects for the water statistics: plummeted figures of water intake in the south, stoppage of all the irrigation systems, and even changed hydrological regime of Dnieper. But the official accounting of these events is impracticable, as conventional reporting formats were designed in a way not allowing to predict such a scenario. Thus, data for 2023 fixed the zero intake by the canal of Kakhovka irrigation system, whereas in 2021 it had amounted to hundreds millions m^3. A correct accounting will require using special symbols indicating an emergency situation.

Figure 3 (by data from [13]) shows that the water sector infrastructure in the Ukrainian south was too heavily hit, as the canal networks dried up. It is not a mere economic or environmental blow, but also a challenge for the monitoring: it is necessary to track the degradation of these objects, to control the water quality in newly emerged marshes, and to count losses. As of 2025, efforts are being on to collect data on all the cases of environmental crimes committed by the Russian Federation, including ones on water bodies, but this information, being beyond the standard statistics, has been accumulated by the Ukrainian Ministry for Environmental Protection and Natural Resources and law enforcement bodies.

Hence, the war compromised the credibility and promptness of statistical accounting of water resources. By far, it has become obvious that the monitoring system is a critically important tool for assessing losses, planning renovation and preventing humanitarian crises caused by shortage of water. Water resources are being under the double blow: direct (physical destruction or pollution of water bodies) and indirect (changed regimes of water use, degradation of water management). Its implications are as follows:

Fig. 3. A satellite image of an area in lower Dnieper and North Crimean canal made on June 18, 2024, twelve days after the blasting of Kakhovka hydropower plant

1. Pollution of surface and underground waters. The warfare caused numerous cases of chemical and biological pollution of water reservoirs. A vast quantity of blasting ammunitions adds toxic substances to the environment: heavy metals, explosives (TNT, DNT, RDX), and products of fuel burning. They precipitate with rains in rivers and soils. In industrial areas, shelling caused accidents on sewage treatment plants, with raw sewage getting to water due to de-energizing of these plants. The gravest problem for Donbas is flooding of mines. The warfare caused the stoppage of water pumping from dozens of coalmines, with mining waters swelling and pouring into rivers. According to data for 2019, flooded mines of Donbas caused outpouring, in one year only, of nearly 760 mln m^3 polluted highly mineralized water containing ~2,5 mln tons of salts into Sivervki Donets river and Azov sea. The flooding of mines reached disastrous scales in 2022–2023, when not less than 49 mines on the occupied territory were left without pumping [3, p. 4]. Salty and heavy metals would inevitably seep into underground and surface waters, endangering drinking sources of Donetsk and Luhansk oblasts.

One cannot overlook the problem of probable radiation risks: one mine ("Yunkom" located in Donbas oblast) contains an underground chamber wherein a nuclear explosion was in 1979. This mine is being flooded now, raising concern that radionuclides can ingress into water aquifers [19]. This impact cannot be assessed without a meticulous monitoring that is impossible now.

2. Loss of drinking water and its humanitarian effects. Russian troops purposefully shell critical infrastructures, leaving people without water. According to UNICEF, nearly 1,500,000 Ukrainians did not have access to centralized water supply, with another 4,500,000 being exposed to the risk of being cut from it [9]. Cities like Mykolaiv lived out long months without centralized water supply after the damage of water pipes, when the residents had to stand in lines to water cisterns. Nearly 6,000,000 persons (15% of the population) did not have adequate access to safe water in April 2022 [3], which caused outbreaks of infectious deceases in some locations. Hence, the water crisis became part of the humanitarian crisis. According to UN, more than 4,000,000 persons have already been cut from clean drinking water due to the ruining of infrastructures [20].

3. Economic losses and the impact on agriculture. Dewatering of the southern steppes endangers the food security. Once Kakhovka water reservoir was lost, irrigation systems in the Ukrainian south stopped operating, which caused a dramatic decline in the output of vegetables and technical plants (sweetcorn, soy bean, etc.) and the consequent loss of several million tons of products. So, the southern vegetable growing and horticulture was thrown dozen years back. The farmers suffered colossal losses: only the direct lost revenue from the lost yield of vegetables amounted to 217,000,000 USD. If the irrigation is not restored, the annual long-term losses can reach 300,000,000 USD, and the total deserted area can increase by 45% [15]. In a broader sense, Ukraine risks to lose the position of a top food exporter.

The industry suffers along with the agriculture: water-intensive sectors (basic metals, power engineering) were forced to shrink the production process or to bear expenses on alternative sources of water. Thus, after the cooling of Zaporizhzhia nuclear power plant once the water reservoir had dried, temporary pumping stations had to be built for smaller water-cooling ponds.

4. Ecosystem effects. Ruining of water bodies and hydrological regimes has environmental effects: the receding Dnieper reservoirs endanger with massive death of fish, flowering of water, and siltation. The destruction of floodplains, shifts of riverbanks, or loss of spawning areas entail long-term environmental losses. According to preliminary estimates, the environmental rehabilitation in Ukraine will require 15 postwar years or longer, provided an intensive regeneration effort. More than 12,000 km^2 of nature reserve areas turned into a warfare zone, of which many are wetlands (for example, the flood caused by the blasting of Kakhovka nuclear power plan inundated the island of Jarylhach, which is a national park). The years-long efforts on protecting these ecosystems proved to vain [20].

Hence, the war provoked a multidimensional water crisis – from drinking water for people to the health of river ecosystems and the whole economy. This underscores critical importance of the water factor in the national security. Neither the normal community life nor the recovery of industry and agriculture will be feasible without sufficient and clean water supply.

As regards government support, the official policy on the water sector has refocused to disaster recovery and support of basic services since 2022: repair and modernization of sewage treatment facilities, pumping stations, and collectors; installing module units for sewage treatment and backup sources of water supply; re-laying of water pipes in ruined communities; implementing projects in reducing water losses, and introducing recirculation at factories; intensified monitoring of quality of surface and underground waters with documenting environmental losses. These are the activities recorded in two water-related items of the capital investment: (i) collection and treatment of sewage waters; and (ii) protection and rehabilitation of soils, underground and surface waters (Table 2, compiled by data from [21]).

Overall, the data show a dramatic fall due to the war in 2022, a partial recovery in 2023, and the top priority of sewage water treatment in 2024 (a growth in investment in sewage collection and treatment

Table 2

The capital investment in water sector (in actual prices)

(billion UAH)

Year	Collection and treatment of sewage waters	Protection and rehabilitation of underground surface waters	Total
2021	1,383	2,717	4,100
2022	0,743	0,993	1,736
2023	1,711	1,386	3,097
2024	1,916	1,014	2,930

against lower expenses for protection of underground and surface waters relative to 2021). The figures comply with the emphasis on renovation of critical water facilities and gradual return to reconstruction and nature-protection projects.

The elimination of war-related effects and preparation to potential future crises require consolidation of the water monitoring system in Ukraine. The development prospects in this field are given below:

1. *Integration of satellite and GIS technologies.* The wartime has shown that remote observation methods can partially replace terrestrial ones, when the latter are not accessible. For example, NASA analysts could promptly assess the scales of inundation and drying after the blasting of Kakhovka hydropower plant by Landsat and Planet images. Ukraine needs to introduce a regular satellite monitoring of waters, with outlining the areas of water bodies, water levels, and water color (as a quality indicator). Advanced GIS platforms enable for computerized processing of data obtained from remote probing, to produce statistical indicators (e.g. the volume of water reservoirs) in real time. This can be indispensable in emergency cases. Also, satellites will help control illegal water intakes or discharges, and reveal pollutions (such as oil spills). Ukrainian researchers and IT experts have already been involved in international projects of monitoring (CEOBS and others – maps of the ground water exposure to war-related pollutions) [22]. It is important to integrate these developments in the official statistics.

2. *Digitalization and a single database*. It is necessary to create a single information system for water resource accounting, where all the data (from official observations, water canals, basin administrations) will be accumulated in a centralized manner. Now these efforts are fragmented, with water-related information being a responsibility of more than twenty agencies. There is a need in data unification and exchange between them in online mode. A perfect fit would be a created public information platform with a country map displaying, in real time, water levels, quality, and consumption by region. This will enhance the transparence and credibility of statistics. Also, online reporting on water use should be introduced at factory level, to minimize the loss of time and errors of manual data insertion. Large water users must be obliged to have digital meters of water and sensors of discharge control, which data would automatically be transmitted to the database. Such modernization requires funds, but international partners (World Bank, EU) are keen to help in reconstructing the Ukrainian water sector [23].

3. *Harmonization with international standards.* In reconstructing the monitoring system, Ukraine should be guided by EU Water Framework Directive and other European standards. Ukraine has already been introducing the basin approach: there are nine basin councils; plans of river basin management for 2025–2030 are being elaborated [24]. These efforts should be continued, e.g. reference (target) indicators for each basin (on water quality and water use) be set, and monitoring by European methods be launched. Ukraine must officially estimate the indicator "water stress level", and submit it to international reports of UN. This is also true for the indicator of drinking water safety (SDG 6.1) that need to be measured even in the wartime (maybe, by sample methods), in order to see a real picture. European colleagues can help with laboratory equipment and training of staff. Integration to EU will demand obligatory reporting by Water Framework Directive on water quality, nitrates, ecosystems' performance, which, in its turn, stimulate improvements in the national statistics.

4. *Development of regional monitoring systems.* An observation network needs to be renewed and expanded at local level. According to experts, now in Ukraine there are nearly 400 stations for monitoring of surface water and the equal number of stations for underground waters, whereas in Israel (a country with a much smaller area) there are 11,000 borehole observations [18]. Computerized stations need to be installed on rivers, especially on the ones that had previously been warfare zones (to track the rehabilitation). Local laboratories should be created within communities, to check water quality at least by essential criteria (salinity, pollution with nitrates). A public monitoring can also be useful, with involving rank-and-file residents and environmental experts in sampling or reporting about cases of pollution. This will reinforce official data and enable a rapid response.

5. *Renewal and modernization of the accounting infrastructure*. This includes repair of hydrological

posts, installation of new sensors of water level, meters at pumping stations, creation of backup systems for charging and data transmission, in order to avoid data losses in case of accidents. Ruined objects should be reconstructed with installing advanced technologies of control. For example, when a new water pipe is built, it should be equipped with sensors transmitting data on flows and leakages to dispatchers. When a new sewage treatment plant is constructed, it should have inbuilt online monitoring of the runoff quality.

6. *Adaptation of statistics to wartime and postwar conditions*. It means that data collection techniques should be more flexible. Whenever a territory is inaccessible, one should have an assessment protocol (based on retrospective data, satellite images, etc.). Instructions should be elaborated on how to account for contingencies (like blasting of a dam) in reports, to avoid a skewed overall picture. Also, an accounting of war-related losses should be envisaged for the water sector, probably a separate section of statistics recording the number of ruined km of water pipes, the amount of water under-received by the population, the costs for reconstruction. This is possible to do as part of a special postwar official environmental monitoring, which is being planned now. An interactive map of damages in the water sector is being prepared with EU support, and these data should also be included in the official statistics reporting [23].

Hence, although the war hit the system for statistical accounting of water resources, it caused rediscovering of its significance. Water being a vitally important resource, its accounting cannot be of minor attention. By investing in the advanced monitoring and statistics of waters, Ukraine invests in its national security, economic resilience, and public health.

Conclusions and recommendations. Results of the study led to the following conclusions:

1. Water use in Ukraine shows a sustained downward trend, attributed to structural change in the economy and water-saving measures. The large-scale war precipitated this trend by drastically reducing the water consumption in key sectors.

2. The quality and accessibility of water resources dramatically worsened in the warfare zones. Millions of people were devoid of the centralized water supply, which increased the risks of deceases caused by consumption of poor-quality water. There was a massive pollution of ecosystems: flooded mines in Donbas, leakages of oil products, discharges of untreated sewage waters into rivers due to de-energizing of sewage treatment facilities, etc.

3. Statistical accounting of water resources in the wartime faced the problems of data incompleteness, breaks of time series, and degraded reliability. The official indicators for 2022–2023 do not show the situation in the occupied territories, often being based on rough estimates. The majority of data for 2023 and 2024 are missing at all, thus complicating the analysis. Yet, the reliable statistics became much more important, as an effective planning of the rehabilitation requires a perception of the actual scales of losses in water facilities and changes in water use.

4. The official policy needs to consider the water factor as a critical one. Water has direct impact on the food security (irrigation), power engineering (cooling of power plants), and sanitary well-being of the population. Therefore, investment in rebuilding and modernization of water supply and water monitoring systems must be a priority of the postwar reconstruction.

Below we are going to propose a list of measures to improve the accounting, monitoring, and management of water resources in Ukraine.

1. Renewal and modernization of the accounting infrastructure: reconstruct the ruined hydrometeorological stations, observation posts, water quality laboratories by equipping them with advanced technologies; install backup charging and communication systems for critical units (pumping, purification), in order to continue data recording in emergency cases; mount computerized recording devices (water consumption meters, sensors of water level, etc.) on new and existing hydrotechnical facilities.

2. Expansion of international cooperation: engage the assistance of EU and World Bank in the implementation of projects on smart monitoring of waters; adapt the European practices related with the implementation of Water Framework Directive (data exchange via EIONET, participation of Ukrainian specialists in international trainings); continue integrating in global initiatives like GEMI (monitoring of SDG 6) and AQUASTAT (FAO database on water) as a way to enhance the quality and comparability of the Ukrainian data.

3. Digitalization of the monitoring system: create a state information system "Water Resources of Ukraine", to accumulate the data from water users, public institutions and computerized field devices; ensure public online access to main indicators, which will encourage the responsible agencies to display updated data; develop software for processing big data arrays (Big Data, IoT) on the water sector, e.g., for forecasting the effects of ruining and risk assessment.

4. Using the basin approach and regional systems: consolidate water resource management at the level of river basins by giving them a broader autonomy and more techniques for monitoring within their respective areas; create in each basin a center for data collection and analysis, which would collaborate with communities; launch training programs for communities "Organizing local monitoring of wells, springs, and small rivers". This will help to quicker

reveal local problems (water pollution or shortage), and to respond in a targeted manner.

5. Adaptation of statistics to the conditions of war and reconstruction: develop, within the State Statistics Committee of Ukraine, methodical recommendations on accounting in the wartime and postwar period; envisage special symbols in tables for cases of missing data and indicators measuring war-related impacts (for example, "number of days without water supply in the year" by region, "share of irrigated lands that have lost a water source", etc.); supply statistical yearbooks with explanatory notes with a detailed description of how the war affected the indicators, so that data users could understand the context.

6. Financing and price policy: ensure the adequate financing of the water sector; make the cost of water cover the expenses for its accounting and protection; abandon, in a gradual manner, the practices of cross-subsidizing and dotation of tariffs in the industry, because when factories pay a fair price, they will be keen to invest in water saving and purification, whereas the government will receive funds for monitoring; establish targeted funds for elimination of environmental losses from the war, to finance projects on rehabilitation of water bodies.

This study shows that the large-scale war has caused dramatic change in the Ukrainian water sector – in water use indicators as well as in the possibilities of their accounting. Water resources have turned into a national security factor, as the stability of their supply determines the survival of cities and the economic development. Therefore, the state must address water resource management from a strategic perspective, by relying on credible data. Improving the accounting system is an investment that will pay back with the readiness to meet future challenges, new crises or climate change. Further research should be focused on the development and testing of methodological approaches to the statistical accounting and assessment of water resources under wartime and post-war challenges, taking into account data incompleteness, the basin-based management principle, and the integration of remote sensing and digital data sources.

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О. М. Мотузка,
кандидат економічних наук, доцент,
доцент кафедри менеджменту, маркетингу
та публічного управління,
Національна академія статистики, обліку та аудиту,
E-mail: ommotuzka@nasoa.edu.ua
Researcher ID: K-6501-2018,
ORCID: https://orcid.org/0000-0001-9028-6994

Статистичне дослідження обліку водних ресурсів України в умовах воєнного стану

Стаття присвячена статистичному дослідженню обліку водних ресурсів України в умовах воєнного стану. Висвітлено нормативно-законодавче регулювання у сфері водокористування, починаючи від конституційних засад, положень Водного кодексу України та підзаконних актів, які визначають механізми ведення обліку й моніторингу. Простежено історичні передумови становлення державної системи обліку водних ресурсів, її трансформацію після здобуття незалежності та поступовий перехід до басейнового принципу управління.

Охарактеризовано наявні водні ресурси та їхній розподіл територією країни, зважаючи на роль підземних вод і проблеми вододефіциту південних та східних регіонів. Проаналізовано особливості функціонування водогосподарського комплексу у довоєнний період та визначено ключові зміни, що відбулись у воєнний час. Порівняно динаміку загального забору води, структуру використання прісної води основними секторами економіки та обсяги скидання у поверхневі водні об'єкти, що дозволило виявити масштабні скорочення внаслідок руйнування інфраструктури та зупинки виробництв.

Розглянуто проблеми, з якими зіткнулася система обліку у воєнних умовах: неповнота статистики, втрати даних з окупованих територій, порушення роботи гідропостів та лабораторій, методичні обмеження. Особливу увагу приділено наслідкам руйнування Каховського водосховища, що спричинило припинення зрошення, зміни гідрологічних режимів, зростання екологічних і гуманітарних ризиків.

Висвітлено державні заходи з подолання наслідків, зокрема спрямування капітальних інвестицій на відновлення очисних споруд, насосних станцій, водоводів та систем моніторингу. Запропоновано напрями розвитку статистичного обліку водних ресурсів України: інтеграція супутникових і ГІС-технологій, цифровізація та створення єдиної інформаційної системи, посилення басейнового управління, розширення регіональних мереж спостережень, адаптація методик до надзвичайних умов і забезпечення належного фінансування. Результати дослідження мають практичну цінність для органів державного управління, водогосподарських організацій і наукової спільноти у контексті повоєнного відновлення та формування сучасної водної політики.

Ключові слова: *водні ресурси, статистичний облік, статистичне дослідження, облік водних ресурсів, моніторинг водокористування.*

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