Damian PANASIUK • Olena SUDUK • Rafał MIŁASZEWSKI •
Petro SKRYPCHUK

COMPARISON OF THE WATER FOOTPRINT IN POLAND AND UKRAINE

Damian **Panasiuk,** PhD – *Cardinal Stefan Wyszynski University in Warsaw*
Olena **Suduk,** PhD – *National University of Water and Environmental Engineering, Rivne, Ukraine*
Rafał **Miłaszewski,** Prof. – *Cardinal Stefan Wyszynski University in Warsaw*
Petro **Skrypchuk,** Prof. – *National University of Water and Environmental Engineering, Rivne, Ukraine*

Correspondence address:
Faculty of Biology and Environmental Sciences
Wóycickiego Street 1/3, Warsaw, 01-938, Poland
e-mail: d.panasiuk@uksw.edu.pl

ABSTRCT: The aim of the article is to compare the indices of water resources in Poland and Ukraine. The water footprint is an instrument which allows to link the consumption of water resources with the consumption of goods. The blue water footprint shows the consumption of water for production of goods, the green – the use of rainwater in agriculture and forestry and the gray – the amount of water necessary to assimilate pollution. Poland and Ukraine have different climates. The north-western part of Ukraine has a climate similar to Poland, i.e. moderate continental with an annual rainfall of 600 mm/yr. Southern Ukraine is a grassland plain with warm continental and marine climate and an annual rainfall of 300 mm/yr. This generates a greater need of water for Ukrainian agriculture. The green footprint of Ukraine (2302 m^3/cap/yr) is twice as high as that in Poland (1121 m^3/cap/yr). As a result, the total water footprint of Ukraine (2881 m^3/cap/yr) exceeds the total water footprint of Poland (1503 m^3/cap/yr). Analysis of "virtual water" indicates that the total net export of water from Ukraine is 282 m^3/cap/yr. At the same time, the net import of water to Poland amounts to 147 m^3/cap/yr.

KEY WORDS: blue water footprint, green water footprint, gray water footprint, virtual water, food

JEL: E21, Q18, Q25, Q27, Q56

Introduction

Water is an indispensable resource for human functioning. In Poland, opinions are expressed that it is a country with a water deficit and this condition will worsen as a result of climate change. Majewski (2013, p. 76) states that, according to water management standards, Poland has a water resources index on the critical borderline. This opinion results from the use of a simple river outflow index. The question is, whether in fact, Poland's current situation is so dramatic. The aim of article is compare Poland's water resources with those of Ukraine, its eastern neighbor.

Research methods

The conducted research based on literature studies and analysis of reports concerning water footprint and virtual water. Countries were chosen because of the scientific cooperation established between Cardinal Stefan Wyszyński University in Warsaw and National University of Water and Environmental Engineering in Rivne, Ukraine.

An overview of literature

Traditional indices of water resources exploitation The currently used indices of water resources exploitation include:

- volume of the annual river outflow,
- retention of the river outflow,
- structure and dynamics of water abstraction for main sectors of the national economy,
- water exploitation index (Miłaszewski, Panasiuk, 2018).

In the years 1951-2000, the average annual river outflow from Poland amounted to 62.4 billion m^3. In 2010-2016 it was 59.2 billion m^3 (GUS, 2017, p. 142). The country's disposable resources account for approximately 40% of the average resources, i.e. 25 billion m^3/yr, of which inviolable resources for ecosystems are estimated at 15 billion m^3/yr. Those which are available to the population and the economy amount to 10 billion m^3/yr (Miłaszewski, 2003, p. 9). Mountain and foothill areas as well as the Vistula and Odra river valleys are relatively rich in water. A deficit of water resources occurs in lowlands. Per capita, the river outflow from Poland is about 1600 m^3, which situates Poland in the twenty second position among the twenty three European Union countries with available data (Miłaszewski, 2016, p. 245).

In the case of Ukraine, the average annual river outflow is estimated at 170 billion m^3 (FAO, 2016), which means approximately 3800 m^3/cap. However, half of the country's water resources are concentrated in the Danube river, on a short stretch of the border with Romania. In contrast, water resources deficits occur in the basins of the lower Dnieper, Siverskyi Donets, Southern Bug and Inhulets rivers, in the Pryazovia region and in the Crimea (Skrypchuk, Suduk, 2014, p. 20).

Table 1 shows the basic data on water resources for these two countries.

Table 1. Long-term annual renewable water resources in Poland and Ukraine

	Poland	Ukraine
Area [km^2]	312 679	603 628
Population [cap]	38 612 000	44 824 000
Precipitation [mm/yr]	600	565
Precipitation [billion m^3/yr]	187.6	341.0
Surface water – produced internally [billion m^3/yr]	53.1	50.1
Surface water – entering the country [billion m^3/yr]	6.9	36.1
Surface water – flow in border rivers [billion m^3/yr[	0.0	84.1
Surface water – total renewable water resources [billion m^3/yr]	60.0	170.3
Surface water – total renewable water resources [m^3/cap/yr]	1 554	3 799
Total renewable water resources: surface + groundwater [billion m^3/yr]	60.5	175.3
Total renewable water resources: surface + groundwater [m^3/cap/yr]	1 567	3 911
Dependency ratio: participation of external surface and groundwater [%]	11.4	68.6

Source: FAO, 2016.

When applying the river outflow index, Poland is classified among countries with water stress (1000-1700 m^3/cap; Suduk, Fedyna, 2018, p. 63) and Ukraine is classified among countries with occasional or local water stress (1700-5000 m^3/cap; FAO, 2016). The average annual river outflow in Europe is higher and amounts to 4600 m^3/yr. This index depends on the size of rivers flowing from the territory of the country (medium-sized rivers in Poland) and therefore it must be treated with caution. It does not take into account the needs of water abstraction for agricultural irrigation. Throughout the world, 70% of absorbed water is consumed by agriculture and in Poland it amounts to less than 10% (Miłaszewski, Panasiuk, 2018).

The river outflow retention index is also used. In Poland, the capacity of water reservoirs is relatively small and amounts to 4 billion m^3. It thus constitutes approximately 6% of the average annual river runoff and does not protect against flooding or drought (Thier, 2017, p. 205). Ukraine has a total reservoir capacity of 56 billion m^3 and the cascade of six Dnieper water reservoirs alone accumulates 44 billion m^3 (FAO, 2016). Thus, the river flow retention in Ukraine is 33% and after deduction of the Danube waters it amounts up to 70%. There are, of course, ecological consequences of the total flooding of the Dnieper valley.

Water abstraction and its structure is another important index. In Poland, in 2016, out of the total water abstraction of 10.6 billion m^3, 71% was used by industry, 20% by municipalities and 9% by agriculture and forestry (GUS, 2017, p. 147). In Ukraine, in 2010, out of the total water abstraction of 14.8 billion m^3, 48% was used by industry, 30% by agriculture and 22% by municipalities (FAO, 2016). Since 2014, the data of the State Statistics Service of Ukraine are incomplete because they do not include the occupied territories of the Crimea and the Donbass. Per capita, water abstraction amounted to 275 m^3 in Poland and 330 m^3 in Ukraine.

Indices of river outflow and water abstraction considered separately do not properly reflect the problems of water management in a given country. Therefore, the water exploitation index was used to assess the use of water resources in the statistics of the European Union countries as well as the reports of the "*Millennium Development Goals*" (UN, 2015, p. 55). This is the ratio of the total annual water abstraction to the annual river outflow. An abundance of water occurs when its abstraction does not exceed 25% of the total available resources. However, the water exploitation index within 25-60% determines the level of water stress (Thier, 2016, pp. 59-60). For Poland, the index thus calculated is approximately 18%. Nevertheless, if we exclude from the calculation the return water abstraction for thermal energy purposes, then the index for Poland will decrease to 8% (Miłaszewski, 2016, p. 247). For Ukraine, the water exploitation index is 9%, but after deduction of river outflow in the Danube, it increases to 18%.

Table 2 shows the comparison of traditional index values for the two countries.

Water resources calculated as the average annual per capita river outflow are twice higher in Ukraine. However, after the deduction of the Danube waters they are close to the values for Poland. Ukraine has a multiple times larger river outflow retention and it additionally increases after drainage of the Danube waters. In Poland, the average per capita water consumption is slightly lower. However, the water exploitation index in both countries does not exceed 25% of the total resources and its value depends on the level of reverse water abstraction for thermal energy and border rivers outflow.

Table 2. Comparison of traditional water resources exploitation indices in Poland and Ukraine

Indicator	Poland	Ukraine
Annual river outflow [m^3/cap]	1600	3800
River flow retention [%]	6	33
Annual water absorption [m^3/cap]	275	330
Water exploitation index [%]	18	9

Source: author's own work.

Water footprint

The water footprint is an instrument which allows to link the consumption of water resources with the consumption of goods (Stępniewska, 2014, p. 321). It is a concept similar to the "carbon footprint", allowing to assess the volume of water needed for production of goods and services. The water footprint takes into account the source of the consumed water as well as the time of consumption. It also helps to assess the consequences of irrational use of water resources (Suduk, 2015, p. 133).

The blue water footprint shows the level of water consumption for production of goods. It is the water found in rivers, lakes, artificial reservoirs and underground layers (Majewski, 2012, p. 98). Such consumption refers to the loss of water in catchment areas, which is a result of evaporation, water inclusion in a product or the return of water to another catchment or the sea (Stępniewska, 2014, p. 322). This water footprint is associated with industrial production, domestic water supply, water consumption by farm animals and crop irrigation.

The green water footprint shows the use of water in agriculture and forestry. It refers to the consumption of rainwater, temporarily stored as soil moisture in the top soil layer which is particularly important in the cultivation of plants. This water does not run off or recharge groundwater (Hoekstra et al., 2011, p. 29-30). The green water footprint is associated with crop production and grazing.

In turn, gray water footprint shows the amount of water necessary to assimilate pollution in wastewater discharged to rivers and lakes. This water footprint is associated with industrial production, domestic water supply and water consumption by animals.

The highest water footprint is generated by the inhabitants of the United States, Greece, Malaysia, Italy and Thailand (2100-2500 m^3/cap/yr). Many of these countries are forced to import water to maintain water consumption on an unchanged level (Suduk, 2015, pp. 132-133). During the years of 1996-2005, the average global water footprint was 1385 m^3/cap/yr. About 92% of the overall water footprint is related to the consumption of agricultural products, i.e. crop production, grazing, animal water supply, 5% to the consumption of industrial goods, and 4% to domestic water use (Mekonnen, Hoekstra, 2011, p. 5).

Results of the research

Water footprint

Poland and Ukraine have diverse climates. The north-western part of Ukraine has a climate similar to Poland, i.e. moderate continental with an annual rainfall of 600 mm. Southern Ukraine is a grassland plain with warm continental and marine climate and an annual rainfall of 300 mm. This generates a greater need for water for Ukrainian agriculture.

Table 3 shows the green, blue and gray water footprints of these two countries.

Table 3. A comparison of the water footprint of national production in Poland and Ukraine in the years 1996-2005

Type of water footprint [million m^3/yr]	Poland	Ukraine
Water footprint of crop production	48 595	106 348
• green	40 857	98 614
• blue	108	2 573
• grey	7 630	5 161
Water footprint of grazing	2 452	4 562
• green	2 452	4 562
Water footprint of animal water supply	385	378
• blue	385	378
Water footprint of industrial production	5 240	13 280
• blue	638	664
• grey	4 603	12 616
Water footprint of domestic water supply	1 378	4 560
• blue	210	456
• grey	1 168	4 104

Type of water footprint [million m^3/yr]	Poland	Ukraine
TOTAL WATER FOOTPRINT	58 051	129 129
• green	43 310	103 177
• blue	1 341	4 071
• grey	13 400	21 881
Total water footprint per capita (m^3/cap/yr)	1 503	2 881
• green	1 121	2 302
• blue	35	91
• grey	347	488

Source: authors' own work based on Mekonnen, Hoekstra, 2011, Appendix I.

The green footprint of Ukraine (2302 m^3/cap/yr) is twice as high as that of Poland (1121 m^3/cap/yr). As a result, the total water footprint of Ukraine (2881 m^3/cap/yr) similarly exceeds the total water footprint of Poland (1503 m^3/cap/yr). Looking at various sectors of the economy, crop production is responsible for 84% of Poland's water footprint and for 83% of that of Ukraine and is followed in importance by industrial production (11-12%) and grazing (4-5%).

In Poland, the water footprint related to food consumption in 2009-2010 was estimated by Stępniewska (2014) to be 49 billion m^3/yr, or 1 271 m^3/cap/yr. The greatest contribution was made by meat consumption (724 m^3/cap/yr) and cereals (267 m^3/cap/yr). They were followed by imported coffee, tea and cocoa (82 m^3/cap/yr), vegetable oils (54 m^3/cap/yr) and vegetables (51 m^3/cap/yr).

Virtual water

The water footprint is closely related to the concept of virtual water. The content of virtual water in a product is defined as the amount of water used for all stages of production or contaminated in its course (Skrypchuk, Suduk, 2013, p. 248). It is a tool for describing virtual water flows exported due to the export of water-absorbent goods (Stępniewska, 2014, p. 321-322), see fig. 1. For example, a cup of coffee is about 140 liters of virtual water needed for growing coffee, its processing and preparation for consumption. On the other hand, 15 000 liters of water is needed to produce 1 kg of beef (Majewski, 2012, p. 99).

Figure 1. Virtual water imports into Europe

Source: Water footprint, 2018.

The largest share of virtual water flows between countries (76%) is related to international trade of crop products and the rest (12% each) is related to animal and industrial products trade (Hoekstra, Mekonnen, 2012, p. 2). Table 4 shows the volume of virtual water imports and exports in the two examined countries.

Table 4. Virtual water import and export in Poland and Ukraine in the years 1996-2005

Type of water footprint [million m³/yr]	Poland	Ukraine
VIRTUAL WATER IMPORT	18 803,9	8 910,0
Related to crop products	14 852,8	5 610,7
• green	11 501,5	4 585,8
• blue	2 229,6	677,3
• grey	1 121,7	347,6
Related to animal products	857,8	394,7
• green	715,6	349,3
• blue	77,5	26,1
• grey	64,7	19,3
Related to industrial products	3 093,3	2 904,6
• blue	223,1	154,6
• grey	2 870,2	2 750,0
WIRTUAL WATER EXPORT	11 471,2	25 316,4
Related to crop products	5 736,5	16 526,2

Type of water footprint [million m³/yr]	Poland	Ukraine
• green	3 946,3	15 289,2
• blue	909,0	545,6
• grey	881,2	691,4
Related to animal products	2 994,9	2 609,1
• green	2 569,4	2 303,6
• blue	230,3	227,5
• grey	195,2	78,0
Related to industrial products	2 739,8	6 181,1
• blue	268,6	292,5
• grey	2 471,2	5 888,6

Source: authors' own work based on Mekonnen, Hoekstra, 2011, Appendix II.

Table 5. Total virtual water flows in Poland and Ukraine in the years 1996-2005

Type of water footprint [million m³/yr]	Poland	Ukraine
Virtual water import	18 803,9	8 910,0
• green	12 217,1	4 935,1
• blue	2 530,1	858,1
• grey	4 056,7	3 116,9
Virtual water export	11 471,2	25 316,4
• green	6 515,7	17 592,8
• blue	1 407,9	1 065,7
• grey	3 547,7	6 658,0
Net virtual water import	7 332,7	-16 406,4
• green	5 701,4	-12 658,0
• blue	1 122,2	-207,6
• grey	509,0	-3 541,1
Net virtual water per capita (m³/cap/yr)	147,7	-282,4

Source: authors' own work based on Mekonnen, Hoekstra, 2011, Appendix II.

Virtual water import from Poland is more than twice as large as in the case of Ukraine. In Poland, as much as 79% of the virtual water import is related to crop production. In Ukraine, import of crop products accounts for only 63% of the virtual water import and import of industrial products amounts up to 33%. This is the effect of the import structure of these two countries among which Poland imports more food.

At the same time, export of virtual water from Poland is over two times smaller than from Ukraine. In Poland, 50% of virtual water export is related to crop products, 26% to animal products and 24% to industrial products. In Ukraine, as much as 65% of water export is related to crop products, 10% to animal products and also 24% to industrial products. Table 5 shows the balance of export and import of virtual water in these two countries.

Analysis of the “virtual water” indicates net export of water from Ukraine, i.e. 16.4 billion m^3/yr, or 282 m^3/cap/yr, while net import of water to Poland is 7.3 billion m^3/yr or 147 m^3/cap/yr. The main streams of virtual water are associated with green water, that is 77% of net imports in both Poland and Ukraine. Poland is a major producer of food, but imports 64% more water than it exports. In Ukraine, water export 3 times exceeds the water import.

Conclusions

The traditional indices of water resources exploitation may give the idea that Poland is a country with a water deficit (1600 m^3/cap) and Ukraine has two times larger water resources (3800 m^3/cap). However, this is the result of the size of rivers flowing through these countries. In the case of Poland, external resources account for only 11% of the total water resources. In Ukraine, the border waters of the Danube and tributaries from Belarus and Russia constitute as much as 69% of the total resources. Internal surface water resources are even greater for Poland (53 billion m^3/yr) than for Ukraine (50 billion m^3/yr). The annual per capita water absorption is more favorable for Poland and assessment of the water exploitation index depends on deduction of the return water abstraction for heat power engineering and boundary waters. Only retention of the river outflow is many times higher in Ukraine.

The size of the water footprint also indicates water deficits in Ukraine. The water footprint in Ukraine is two times higher than in Poland. Ukraine, which has grassland plains, exports more water than it imports. On the other hand, Poland with moderate precipitation throughout its territory imports more water than it exports. The authors recommend the use of modern indices of water resources such as water exploitation index, water footprint and virtual water instead basic indices used presently.

Contributions of the authors

Damian Panasiuk – 50% (concept of the paper, literature review, data acquisition, data analysis and interpretation, drafting the text).

Olena Suduk – 30% (concept of the paper, literature review, data acquisition, data analysis and interpretation).

Rafał Miłaszewski – 10% (concept of the paper, drafting the text).

Petro Skrypchuk – 10% (concept of the paper, literature review).

Literature

FAO (2016), *AQUASTAT. FAO's Information System for Water and Agriculture*, Food and Agriculture Organization of the United Nations, http://www.fao.org/nr/water/aquastat/main/index.stm [03-10-2018]

GUS (2017), *Ochrona środowiska 2017*, Główny Urząd Statystyczny, Warszawa

Hoekstra A.Y. et al. (2011), *The water footprint assessment manual. Setting the Global Standard*, Earthscan, London-Washington, p. 228

Hoekstra A.Y., Mekonnen M.M. (2012), *The water footprint of humanity*, "Proceedings of the National Academy of Sciences of the United States of America" Vol. 109 No. 9, p. 3232-3237

Majewski W. (2012), Światowy Dzień Wody 2012, „Gospodarka Wodna" No. 3, p. 97-100

Majewski W. (2013), *Jaka reforma gospodarki wodnej jest nam potrzebna?*, „Gospodarka Wodna" No. 2, p. 75-77

Mekonnen M.M., Hoekstra A.Y. (2011), *National water footprint accounts: the green, blue and grey water footprint of production and consumption,* Value of Water Research Report Series No. 50, UNESCO-IHE, Delft, the Netherlands

Miłaszewski R. (2003), *Ekonomika ochrony wód powierzchniowych*, Białystok, p. 258

Miłaszewski R. (2016), *Wykorzystanie zasobów wodnych w Polsce*, in: S. Czaja, A. Graczyk (eds), Ekonomia i środowisko. Księga jubileuszowa Profesora Bogusława Fiedora, Uniwersytet Ekonomiczny we Wrocławiu, p. 244-252

Miłaszewski R., Panasiuk D. (2018), *Wskaźniki oceny wykorzystania zasobów wodnych* (Indices of water resources exploitation), „Przedsiębiorczość i Zarządzanie" (in press)

Skrypchuk P.M., Suduk O.Y. (2013), *Vodnyy slid: balans, zbytky, ekologichna certyfikaciya* (Water footprint: balance, losses, ecological certification), in: O.V. Prokopenko (ed.), Ekonomichni problem stalovo rozvytku, Sumy State University, p. 248-249

Skrypchuk P.M., Suduk O.Y. (2014), *Osnovni aspekty formuvannya rynku vodnyh resursiv v Ukrayini* (Main aspects of forming the water resources market in Ukraine), "Ekonomist. Ukrayinskiy zhurnal" No. 1, p. 20-22

Suduk O.Y (2015), *Instytucyonalnaya sreda vodohozyaystvennovo sektora ekonomiki* (The institutional environment of water management sector), "International Journal of New Economics and Social Sciences" No. 1, p. 130-139

Suduk O.Y., Fedyna K.M. (2018), *Analiz ta vyznachennya indykatora vodnoho stresu v Ukrayini v umovah globalizacaciyi* (Analysis and determination of water stress indicator in Ukraine in conditions of globalization), “Zbalansowane pryrodokorystuvannya” No. 2, p. 62-66

Stępniewska M. (2014), *Ile wody naprawdę zużywamy? Ocena śladu wodnego Polaków związanego z konsumpcją żywności*, „Gospodarka Wodna” No. 9, p. 321-324

Thier A. (2016), *Gospodarcze i społeczne przyczyny oraz skutki deficytu zasobów wodnych* (The economic and social reasons and consequences of the water resources deficit), Biblioteka „Ekonomia i Środowisko” No. 36, Uniwersytet Ekonomiczny w Krakowie, p. 260

Thier A. (2017), *Kierunki wykorzystania zasobów wodnych w Polsce* (Trends in the use of water resources in Poland), „Gospodarka Wodna” No. 7, p. 203-207

UN (2015), *The Millennium Development Goals Report 2015*, New York, p. 72

Water footprint (2018), *Virtual water trade*, http://waterfootprint.org/en/water-footprint/national-water-footprint/virtual-water-trade/ [06-10-2018]