

Economy of Water: Case study on Water Intensive Region

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ABSTRACT

Water intensive production is a long-term challenge for economic, environmental and social issues of particular Post-Soviet states. Intensity of water consumption by economy and households differs among the geographical regions of former USSR territory that are located in continental, semiarid, arid and subarctic climate zones. The purpose of this paper is to analyze the regional inequalities of water consumption in one of the most water intensive economy after the Soviet Union brake up. To investigate the sustainability of water consumption through evaluation of economic, social and environmental factors, we select all data-available administrative regions of Ukraine. On the basis of selected criteria, we compute the integral sustainability indicator of each administrative region. The results indicate a high regional heterogeneity in water consumption efficiency in terms of economic, social and environmental dimensions of water resources usage.

Keywords: Water resources, scarcity, sustainability, integral criterion, cluster analysis

Mathematics Subject Classification: 62J12, 91B76

Journal of Economic Literature (JEL) Classification : Q01, Q53

1. INTRODUCTION

The growth of world economy and population has increased the use of natural resources and destruction of ecosystems. Such processes have led to determination of priority issues at the global scale. Suja and Boopathi (2015), for instance, showed that growing urbanization in the developing world is often positively liked with water and air pollution worsening the overall health conditions. One of the issues, therefore, is to ensure the sustainable development, and main conceptual principle of which, include a harmonious relationship between the natural environment and socio-economic development at different levels. A key factor for establishing a sustainable development is the availability of water resources, which became one of the most important types of resources necessary not only for global economic growth but also for the simple survival of mankind.

Remote regions suffering from lack of water resources understand that they are a source of international and regional instability as well. And the post-soviet space with several tensions on water resources is not an exception. Water disputes over Aral see, Amu Darya and Syn Darya rivers (Vinogradov 1996), water supply shortages in Donbas region or Crimean Peninsula are not the only cases of water intensive tensions in former USSR republics.

Socio-economic and environmental processes are relevant in targeted country as well. Ukraine, like the rest of the world, has its own development of the whole complex of advantages and problematic issues that are localized in the field of water resources. In comparison with other countries, Ukraine is considered as one of the least water-secure countries in Europe in terms of its reserves, still has its own regional peculiarities and lack of ecological innovations (Vovk et al. 2018). In the regional dimension, about half of administrative regions are below the national average. Nevertheless, the presence of a ramified network of water objects in its own territory, including natural and artificial water objects, determine the complex of water resources in the country. The balance of local river runoff is 52.4 km³ in average (Ministry of ecology and natural resources of Ukraine 2014). Using the river flow complicates its variability in time as the river runoff fluctuates 60-70% in the north and northeast to 80-90% in the south that is a part of semi-arid climate zone (Khvesyk 2012).

In this paper we investigate the economic, social and environmental aspects of water consumption. On other site we do not deal specifically with the technical aspect of water usage despite it is undoubtedly particular part of the investigated issue. It is important not only where water is taken, how it is distributed and how this affects economic and social development. It is important what technical means are used to exploit water resources, its delivery for industrial, energy, transport, agricultural or communal purposes. The purpose of this paper is to analyze the regional inequalities of water consumption in Ukraine as one of Post-Soviet water intensive economies. To investigate the sustainability of water consumption through evaluation of economic, social and environmental factors, we select all data-available administrative regions of Ukraine. Based on selected criteria, we compute the integral sustainability indicator of each administrative region. The results indicate a high regional heterogeneity in water consumption efficiency in terms of economic, social and environmental dimensions of water resources usage. Nevertheless, each of dimensional coefficients and integrated criteria shows a water consumption efficiency gap in selected administrative regions.

2. WATER SCARCITY AND STRESS EVALUATION

The literature on water management use notions of scarcity and stress to define a particular differentiation in availability of water resources. Authors distinguish several criteria in order to qualify whether an area is “water scarce”. It is important how people’s needs are defined, and environmental issues are included in the definition. Another aspect is whether these resources could be made available for consumers or does water scarce concept encompass the temporal and spatial scales (Rijsberman 2006).

Compared to scarcity, water stress is a more inclusive and broader concept. Scarcity is human driven – it is a function of the volume of human consumption relative to the volume of water resources in a given area. As such, an arid region with very little water, but no human water consumption would not be considered scarce but rather arid. Water scarcity is a physical, objective reality that could be measured

across regions and over time. The measurement of scarcity always includes two parts, one of which is the water resources (availability, quality, accessibility, pollution) and the second one is consumption. Water consumption and water withdrawals provide useful information that offers insight into relative water stress. This subjectivity presents itself in the water stress indicator created by Falkenmark, Lundqvist, Widstrand (1989), who proposed a threshold for scarcity and stress on the basis of total annual runoff available for human use (Brown, Matlock 2011).

One of the basic measures of water scarcity is Falkenmark indicator that is defined as total annual runoff available for consumption (Brown, Matlock 2011). There is evidence of water stress if the annual volume of water runoff per person is less than 1700 m³. Indicator below 1000 m³ per capita per year suggests that region or country possess water scarcity (Falkenmark, Lundqvist, Widstrand 1989). With annual runoff of 1147 m³ per capita, Ukraine for example, can be defined as water stress country.

The Falkenmark water stress indicator reflects only water reserves without taking into account real needs for water resources implicitly assuming that demand is uniquely determined by the quantity of population. Particular economic and social structures of different regions and countries are not considered here. A somewhat different approach was used in calculating water resources vulnerability index (Raskin et al. 1997) that is equal to the ratio of total annual withdrawals to available water resources (Brown, Matlock 2011). To some extent the vulnerability index reflects a change in the demand for water but at the same time the term “demand” is actually replaced by another definition of water usage or consumption. The actual volume of water consumption is neglected as part of water withdrawal is lost during the transportation, and, on the other hand, modern technologies of recycled water supply make it possible to reuse the water that is previously collected (Fridman 2012).

Brown and Matlock (2011), for instance, summarize five different approaches for water scarcity evaluation including indices based on human water requirements, water resources vulnerability indices, indices incorporating environmental water requirements and last but not least the life cycle assessment or water footprint. Aggregation of particular indexes varies and has its limitations, though aggregated and integrated indices poses simple numerical results that can be applied in order to run the ranging or comparative procedures across the cases. Sustainable water usage measurements include such indices as water poverty index, environmental performance index, water sustainability index (Russo, Alfredo, Fisher 2014), etc. Above-mentioned water sustainability indicators typically encompass few dimensions with contradictive features such as economy and environment. Water poverty index (Sullivan, Meigh, Giacomello 2003), for instance, is intended to reflect the five aspects of the local water supply, including reserves, access to water resources, socio-economic situation of the region, sectorial consumption, and environmental characteristics of water usage. This index is used to evaluate and make decisions concerning the assistance to water poor countries in order to modernize and improve their water supply and sanitation services. However, it should be noted that aggregated measurement does not always allow an adequate evaluation of the extent of water scarcity, since it does not incorporate the resource's and consumer's uneven distribution in particular region (Fridman 2012).

3. DATA AND METHODOLOGY

For a more complete understanding of the environmental and economic situation that has developed after the 26 years of independent economic activities of selected country we perform a brief analysis of the current state of water resources and the prospect of its further use based on the principles of sustainable development. To control for different factors of sustainable development a range of economic, social and environmental characteristics were chosen.

To analyze the impact of economic system on environment of particular regions scientific literature from the field of ecology of natural resources and ecological management distinguish different approaches (Endres, Querner 2004). The one individual problem is the development of integrated indicator of sustainable development that would simplify the characteristics of a particular situation that is part of a complex or system and which can be used to evaluate the level of sustainability of social and economic development. Indicators of sustainability represent the individual elements of information that reflect the state of the entire system or complex by which it is possible to better understand the complete picture of the current system and to investigate the direction it moves. Indicators of sustainable development can be perceived as a kind of criteria for determining the prospects for further development of the particular complex. The development of such a criterion is essential for decision-making and taking into account the environmental factor in the development of the region and the country as a whole. The issue of sustainable economic development and water consumption is especially relevant in the context of targeting the Sustainable Development Goals stated by international community.

To investigate the sustainability of water resources usage at the regional level we apply the modified integrated criterion of sustainable water consumption proposed by Vystavna and Grynenko (2007). Integral criterion helps to evaluate the social, economic and environmental problems of water usage and carry out a range procedure of selected regions according to the social, ecological and economic efficiency of water consumption. Integral criterion enables to identify the directions of environmental policy necessary to achieve sustainable water use as well. In addition to integral criterion of sustainable water consumption the few standard methods of mathematical and econometric analysis were used to achieve the purpose of the paper.

To compute the integral criterion for sustainable water consumption of selected administrative regions we apply following equation:

$$I_i = \sqrt[3]{\frac{P_i}{P_a} \times \frac{PC_a}{PC_i} \times \frac{DP_i}{DT_i}}, \quad (1)$$

where I_i represents integral criterion of sustainable water consumption in administrative region of selected country i , P_i equals the water productivity in region i , P_a represents the aggregated value of water productivity in targeted country. PC_a is water usage per capita in the whole country and PC_i equals water usage per capita in particular administrative region i . DP_i and DT_i equals the purified discharge water and total discharged water in selected region i respectively.

To assess the economic efficiency of water consumption (K_{eco}) we use the water productivity indicator that shows how many units of regional output is produced through the usage of one unit of water. In our case we apply dollar to cubic meter ratio dividing gross regional product and water usage in particular administrative region. Economic prosperity can be the cause of degradation of the regional environment as it leads to increased exploitation of local energy and water resources. Therefore, economically efficient use of water represents a system that produces more units of regional output with the same volume of water. Furthermore, for evaluation of the sustainability of water use in particular administrative region of selected country we need to control for environmental and social efficiency as well. Environmental effectiveness can be defined as the amount of water returned that is purified to environmentally safety standards. The amount of discharged water is crucial for our analysis due to a harmful impact on environment (Vasanthi and Kumar, 2019) and can be reflected in our criterion. Ecological criterion (K_{env}) is defined as the proportion of purified discharge water (DP_i) and total discharge water (DT_i). At last but not least we need to compute the social parameter of sustainable water consumption.

Social efficiency is a more complex indicator that is complicated both to measure and compute. Reflecting the sustainable water consumption this criterion deals with the minimization of water usage in order to meet the needs of society. Thereby, the volume of water use is inextricably linked to the demand for water. Same level of water consumption can be more or less socially effective at different levels of needs and distinct water demand depend on structure of the economy, water policy, climate and cultural features (Heinzmann 2006) etc. Obtaining quantitative data on water consumption at the regional and state levels is a rather complicated procedure. Likewise, these data cannot be highly reliable due to the subjectivity of the concept of demand. Nevertheless, to determine the social efficiency of water consumption (K_{soc}) we use the ratio of indicators such as average country value of water consumption per capita (PC_a) and water consumption per capita in particular administrative region (PC_i). All water consumption and discharged water data was obtained from annual national report of Ministry of ecology and natural resources of Ukraine (National environmental report of Ukraine, 2014). National environmental report does to include up-to-date data on Crimean Peninsula, so it was omitted in our analysis. Data on volumes of water consumption and discharge is represented in millions of cubic meters. Gross regional product (GRP) was collected from the regional statistics database of State statistic service of Ukraine. The transformation of gross regional product values was needed, as all data is available in national currency only. To convert GRP values the annual exchange rates available at the United Nations Conference on Trade and Development exchange rates database were used (UNCTAD 2017).

To understand the chosen methodology some additional explanation in computing overall integral criterion of sustainability is needed. Unlike the computing methodology proposed by Vystavna and Hrynenko (2007) a geometric mean of the three criteria is used. The use of a geometric mean in computing integral coefficient is critical. Use of a geometric mean ensures that poor performance in any dimension directly affects the overall criterion, hence allowing for imperfect substitutability is a beneficial change here.

In order to fulfill the main purpose of the paper we apply cluster analysis as well. According to Repkine (2012), cluster analysis is a multidimensional statistical procedure, which collects data on an object and then arranges objects into relatively homogeneous groups. Cluster analysis is applied to set up a large number of data into smaller groups or clusters. This statistical method is suitable for our investigation as it allows the grouping of selected administrative units in terms of their economic, social and environmental effectiveness of water consumption. Targeted clusters will encompass all values with the biggest similarity. Such a classification allows us to assess and understand the relationships between large amounts of data (Repkine 2012). Using cluster analysis, it is possible to set up the group of administrative regions in a smaller number of clusters that can be further investigated. As suggested by Gress (2014), to carry out cluster analysis we apply squared Euclidean distance and Ward's clustering method (Ward 1963, Repkine 2012).

4. RESULTS

The results of our calculations are presented in the Table 2. It shows the heterogeneity of the regions of Ukraine. We can emphasize the four groups of regions that represent extremes, and, at the same time, they are valuable for interpreting the results. Table 2 shows the available information for all regions of Ukraine.

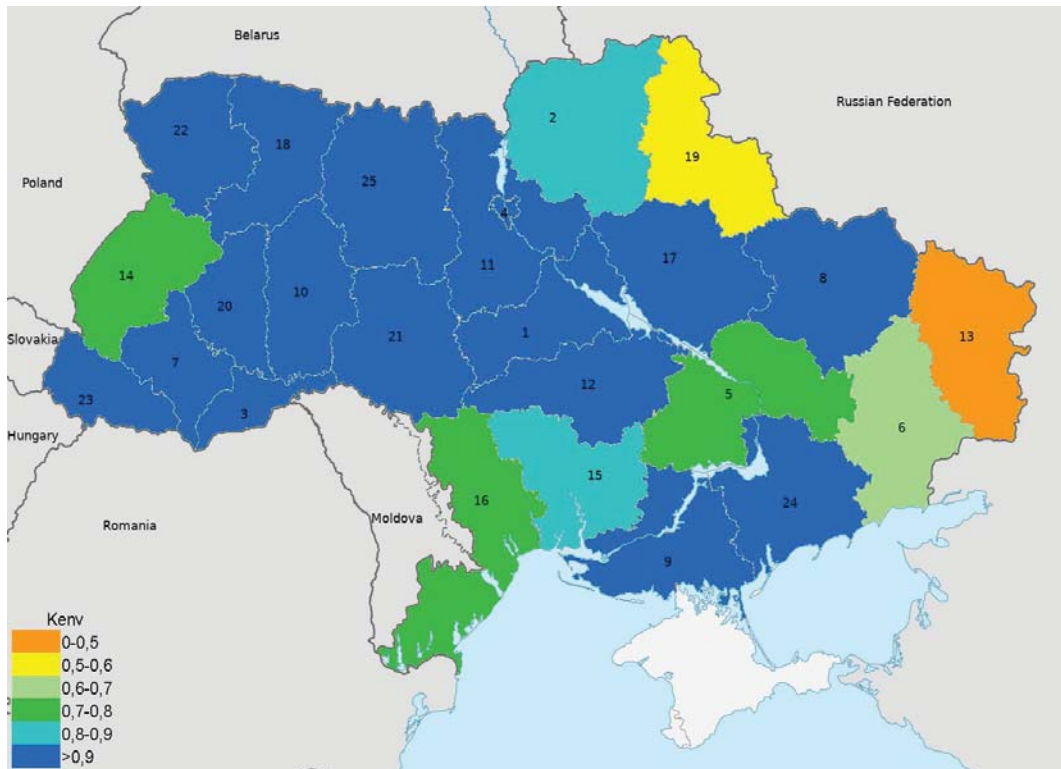
Table 2 – Final coefficients and integrated criteria of sustainability

	K _{eco}	K _{soc}	K _{env}	ICS
Cherkasy	0.958	1.153	0.970	1.023
Chernihiv	1.013	1.403	0.812	1.049
Chernivtsi	0.961	2.147	0.951	1.252
City of Kiev	3.288	0.982	0.991	1.474
Dnipropetrovsk	0.663	0.455	0.722	0.602
Donetsk	1.141	1.511	0.676	1.052
Ivano-Frankivsk	2.089	2.837	0.986	1.801
Kharkiv	1.596	1.669	0.963	1.369
Kherson	0.112	0.190	0.979	0.275
Khmelnyskyi	2.346	3.509	0.931	1.972
Kiev	0.503	0.404	0.997	0.587
Kirovohrad	1.579	1.990	0.956	1.443
Luhansk	1.843	4.817	0.434	1.568
Lviv	2.466	3.173	0.791	1.836
Mykolajiv	0.829	1.008	0.808	0.878
Odessa	1.412	1.669	0.757	1.213
Poltava	1.666	1.278	0.979	1.278
Rivne	0.858	1.282	0.938	1.010
Sumy	1.552	2.121	0.592	1.249
Ternopil	1.537	2.805	0.957	1.604
Vinnysa	2.042	2.764	0.983	1.770
Volyn	1.872	2.983	0.977	1.761
Zakarpattia	4.106	7.926	0.935	3.122
Zaporizhia	0.294	0.291	0.910	0.427
Zhytomyr	0.970	1.510	0.981	1.128

Source: processed by authors

The regional distribution of water usage, in the Table 2, shows the differences in overall amounts of water discharged into the environment (water discharge) and the extent of pollution (Discharged untreated and insufficiently treated). Water consumption in absolute numbers is concentrated (up to 65%) in a relatively few industrial or agrarian regions of Ukraine (Dnipropetrovsk, Donetsk, Zaporizhia, Kiev, and City of Kiev). The same applies for the main polluting regions (Dnipropetrovsk, Donetsk) where up to 65% of untreated and insufficiently treated water was discharged. The regional distribution of environmental footprint is represented on the map (Fig. 2) by K_{env} coefficient. The warmer are the colors the bigger is the relative amount of unpurified and insufficiently purified of total water discharged in a selected region.

Fig. 2 – Regional distribution of environmental coefficients



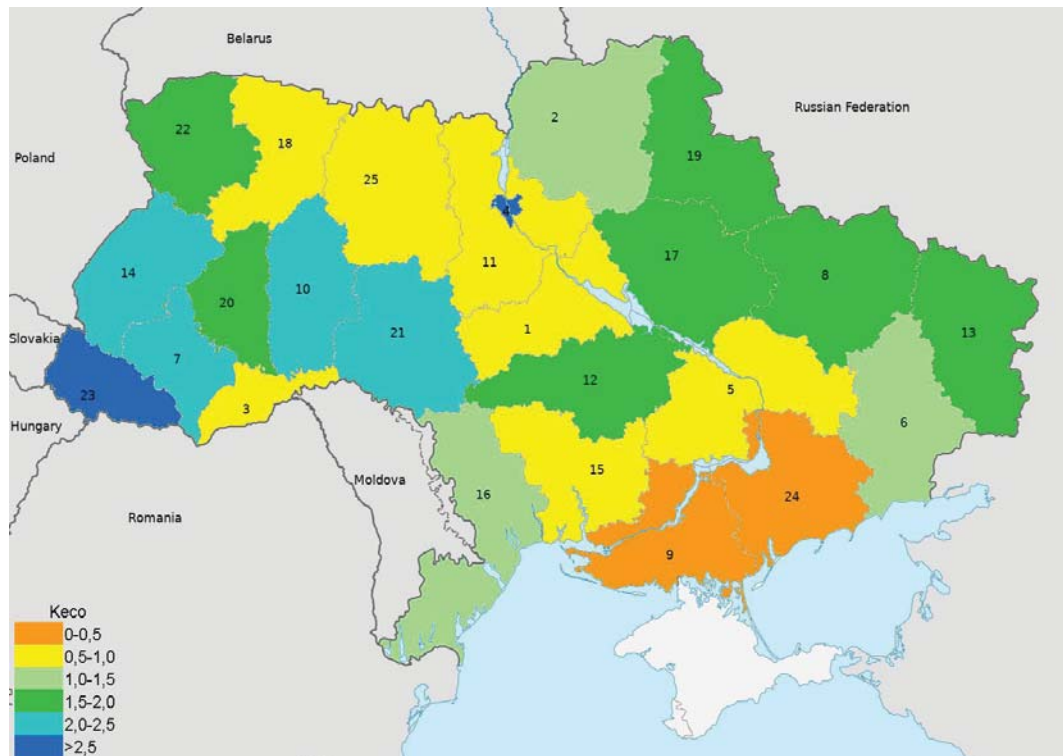
Note: 1 – Cherkasy, 2 – Chernihiv, 3 – Chernivtsi, 4 – City of Kiev, 5 – Dnipropetrovsk, 6 – Donetsk, 7 – Ivano-Frankivsk, 8 – Kharkiv, 9 – Kherson, 10 – Khmelnytskyi, 11 – Kiev, 12 – Kirovohrad, 13 – Luhansk, 14 – Lviv, 15 – Mykolaiv, 16 – Odessa, 17 – Poltava, 18 – Rivne, 19 – Sumy, 20 – Ternopil, 21 – Vinnytsa, 22 – Volyn, 23 – Zakarpattia, 24 – Zaporizhia, 25 – Zytomyr.

Source: processed by authors

The extreme readings (Fig. 2) are mostly concentrated in the southern part of the country in regions such as Odessa, Mykolaiv, Dnipropetrovsk, Donetsk and Luhansk. In the northern part, the worst environmental impact is in Sumy, Chernihiv and Lviv. Absolutely the worst environmental impact was in the Luhansk region (over 50% percent of the discharged water was unpurified or insufficiently purified).

The economic productivity coefficient (K_{eco}) allows the effectuation of a comparative analysis of the regions underlining the extremes. The coefficient K_{eco} , which is in the first column (Tab. 2), evaluates the economic efficiency of using water resources. The differences in the coefficient values are interpreted from top to bottom, the lower the value, the lower is the economic efficiency of a particular area. For example, extremes such as Kherson, Zaporizhia and Kiev, underline the regions in which the use of water resources is associated with a low regional product (up to 10 USD gross regional product from each consumed cubic meter of water). On the other side of this coefficient are regions such as Zakarpattia, the city of Kiev and the Lviv region, which also represent the extremes (values above 40 USD per m^3). Each value reflects the structure of the region's economy and its specificities; for example, the Kherson region has a low figure due to the extensive use of water for agriculture and the general low level of regional product. On the contrary, Kiev is the extreme due to the concentration of economic activity, the prevalence of the service sector, which gives higher values. The map from the Fig. 3 shows the distribution of economic productivity between regions, warmer colors represent relatively worse performing regions.

Fig. 3 – Regional distribution of economic coefficients



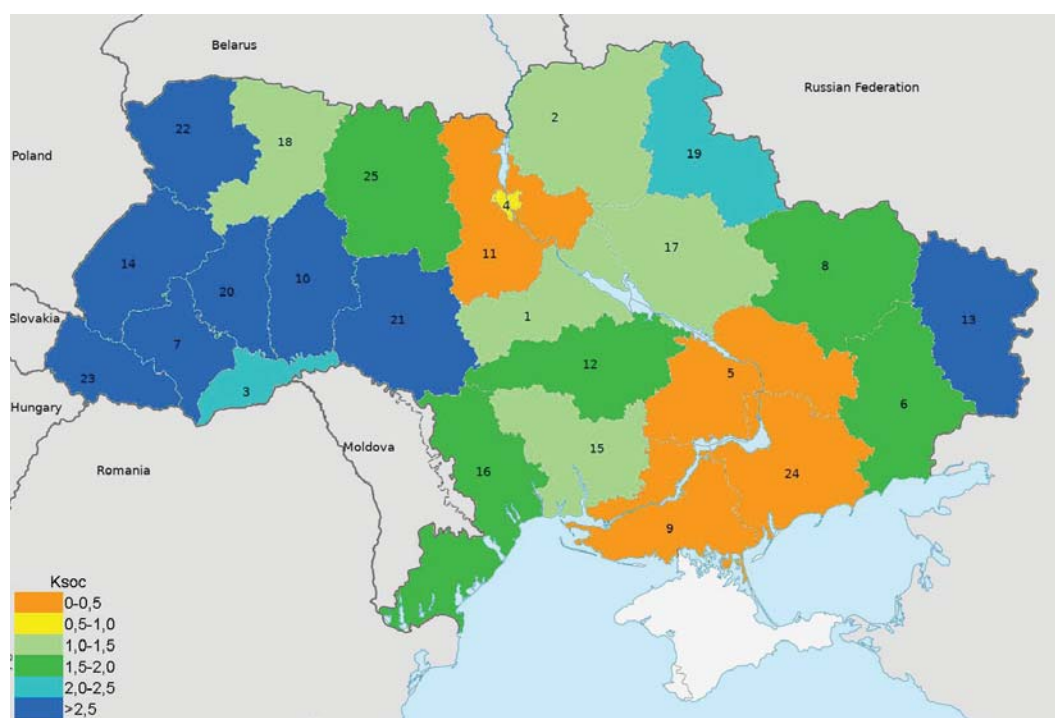
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Source: processed by authors

The water consumption per capita is also heterogeneous. In four regions of Ukraine (Dnipropetrovsk, Zaporizhia, Kiev, Kherson) the water usage per capita is two times higher than the Ukraine average. Kherson region has the extremes values of water usage per capita because it has vast agrarian irrigations systems. This is also the reason why Kherson does not discharge vast amounts of untreated and insufficiently treated water.

In accordance with the methodology stated in the section above, we made the calculations of disaggregated coefficients that allow us the comparison of the regions. The methodology allows the determination of extreme values and problematic regions for policy creation and addressing the critical cases of consumption of water resources. The coefficients are calculated so that their values have the same logic of interpretation (in our case the higher the value the better performance of a selected region for all three coefficients).

Fig. 4 – Regional distribution of social coefficients



Note: 1 – Cherkasy, 2 – Chernihiv, 3 – Chernivtsi, 4 – City of Kiev, 5 – Dnipropetrovsk, 6 – Donetsk, 7 – Ivano-Frankivsk, 8 – Kharkiv, 9 – Kherson, 10 – Khmelnytskyi, 11 – Kiev, 12 – Kirovohrad, 13 – Luhansk, 14 – Lviv, 15 – Mykolaiv, 16 – Odessa, 17 – Poltava, 18 – Rivne, 19 – Sumy, 20 – Ternopil, 21 – Vinnytsa, 22 – Volyn, 23 – Zakarpattia, 24 – Zaporizhia, 25 – Zytomyr.

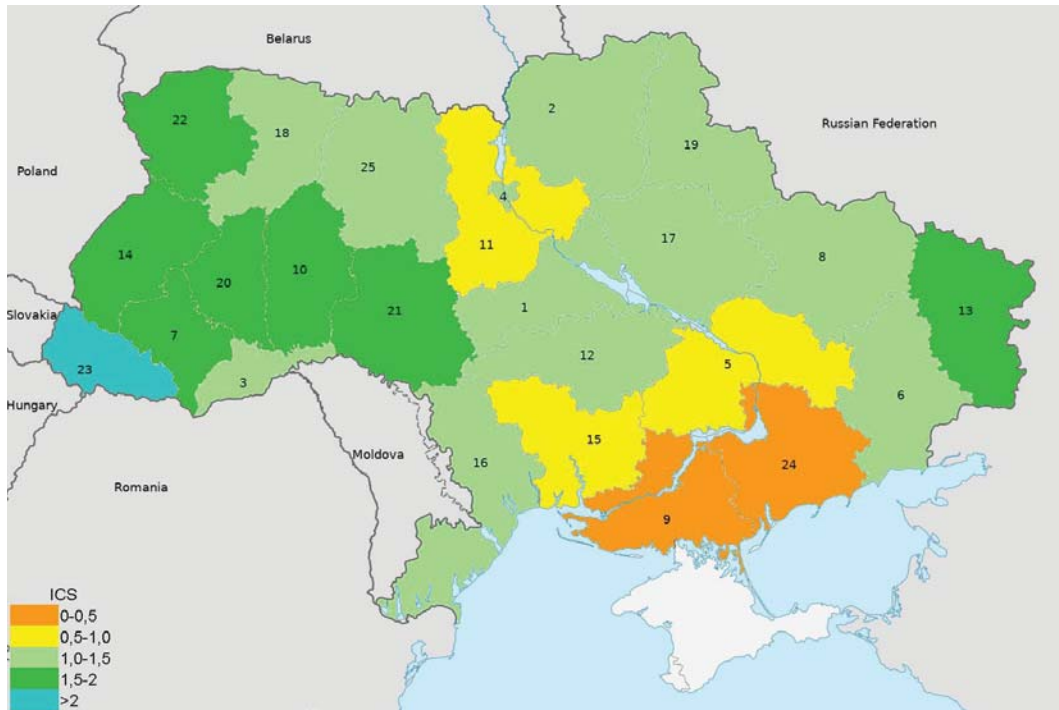
Source: processed by authors

As is shown on the map of the distribution of social coefficient (see Fig. 4), warm colors represent regions with relatively higher consumption per capita than the average of the country. The map shows that relatively higher values are in the regions along the river Dnieper. Eastwards and westwards of the river

Dnieper the values decrease. Southern regions are located in water stress climatic zone but the values of consumption per capita are much higher than the average of the country. It can be explained by the industrial and agrarian character of the water intensive economy.

On the Fig. 5 is represented the overall criterion of sustainability. It is possible to point out the five regions with lower values of the criterion: (Zaporizhia, Kherson, Mykolaiv, Dnipropetrovsk, Kiev). These regions are in need of special attention from the point of view of the overall efficiency of water usage and sustainability.

Fig. 5 – Regional distribution of integral criterion of sustainability

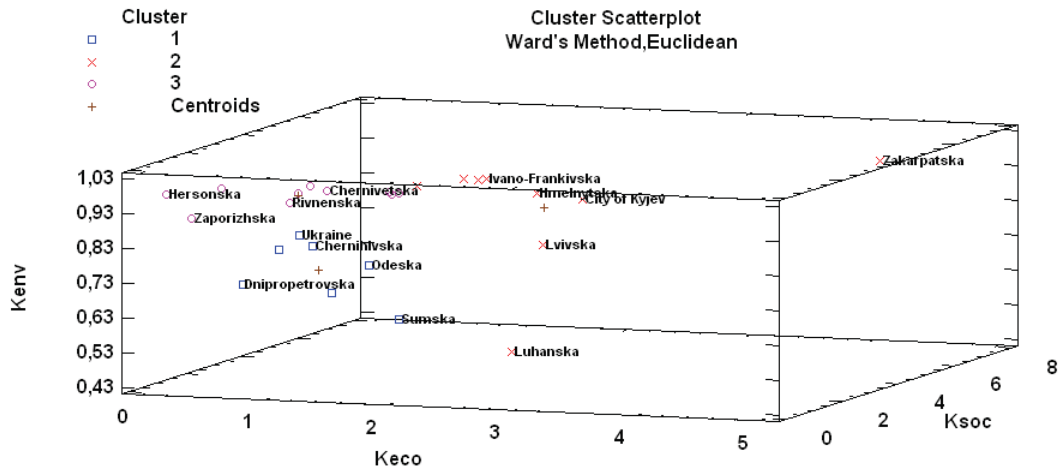


Note: 1 – Cherkasy, 2 – Chernihiv, 3 – Chernivtsi, 4 – City of Kiev, 5 – Dnipropetrovsk, 6 – Donetsk, 7 – Ivano-Frankivsk, 8 – Kharkiv, 9 – Kherson, 10 – Khmelnytskyi, 11 – Kiev, 12 – Kirovohrad, 13 – Luhansk, 14 – Lviv, 15 – Mykolaiv, 16 – Odessa, 17 – Poltava, 18 – Rivne, 19 – Sumy, 20 – Ternopil, 21 – Vinnytsa, 22 – Volyn, 23 – Zakarpattia, 24 – Zaporizhia, 25 – Zytomyr.

Source: processed by authors

The division into three main clusters allows grouping the regions by their similarity. The first cluster groups the regions that achieve low levels of pollution and their environmental footprint is low. Simultaneously this group of regions has a high variability of consumption per capita. The second cluster groups the relatively more polluting regions. This cluster is discharging absolutely the biggest amounts of untreated and insufficiently treated water. From the policy-making point of view these regions are in need of actions and projects for improvement of their filtration capacities. Prioritization should be directed from the bottom of this cluster up (Luhansk, Sumy and up).

Fig. 6 – Cluster analysis output



Source: processed by authors

The third cluster is grouping the extreme readings. Zakarpattia and Luhansk regions have the lowest values in their water consumption per capita relatively to the Ukraine average. And at the same time both regions are in the extreme positioning in pollution. Zakarpattia has one of the smallest environmental footprints and Luhansk is positioned on the other side of the distribution being relatively the most polluting, having only 43% of the discharged water normatively treated. Also, the 3D scatterplot shows that in despite its heterogeneity in terms of ecological performance the third cluster is overall a better performer in economic productivity of water usage. The interpretation of the economic productivity is from left (worse performers) to right (better performing regions). From a policy creation economic productivity of water consumption should be prioritized from left to right, and the ecological from the bottom and up. In this context the two-dimensional prioritization in policy creation in order to achieve the most effect and progress for the selected regions, should target the regions starting from the left bottom corner so it should be the first cluster of regions. The regions from the first cluster are in need not only in filtrating capacities but also in effectiveness of water usage and its economic productivity. The depth of the 3D scatter plot is in this case also helping parameter because it shows the relative consumption per capita (the lower the values of the index the higher is the relative consumption). So, in decision making regions closer to the front of the cube have bigger water consumption per capita. Regions like Dnipropetrovsk, Sumy and Luhansk are clear extreme and should be targeted in infrastructure building of filtrating stations and management of water usage in order to increase the effectiveness of water consumption.

5. Conclusion

As a heritage from the industrialization era the economy of Ukraine uses natural resources both energy and water extensively. The whole post-soviet period is characterized by diminishing volumes of water consumption because of the processes of deindustrialization and the degradation of irrigation systems

in agriculture. The geographical distribution of water resources is uneven. Environmental problems in these cases arise with special intensity. Presented methodology allows the creation of priority structure and identifies problem spots by the means of integral criterion of sustainability (ICS).

Our methodology allows studying the differences in the use of water resources in the individual regions of Ukraine, but also is applicable on other regions or countries. Internal regional discrepancies are manifested not only in the economic and social spheres but also in the environmental burden. All these factors were considered in our calculations of the ICS. Particular indices of ICS were applied to create the regional maps. Our findings show that the differences in the indexes of the use of water resources and ecological burdens are substantial; this allows the identification of extremes, respectively. The use of presented methodology could be useful for the introduction of new economic regulation tools or development of targeted project programs focusing the most stressed regions for the better and more efficient use of water resources.

We found that water consumption in absolute numbers is concentrated (up to 65%) in a relatively few industrial or agrarian regions of Ukraine (Dnipropetrovsk, Donetsk, Zaporizhia, Kiev, and City of Kiev). The main polluting regions (Dnipropetrovsk, Donetsk) where responsible for up to 65% of untreated and insufficiently treated water. The extreme values in Kherson, Zaporizhia and Kiev region, underline the regions in which the use of water resources is associated with a low regional product (up to 10 USD gross regional product from each consumed cubic meter of water). On the other side of this coefficient distribution are regions such as Zakarpattia, the city of Kiev and the Lviv region, which also represent the extreme values of above 40 USD per m³ of water consumed. The water consumption per capita was also heterogeneous. In four regions of Ukraine (Dnipropetrovsk, Zaporizhia, Kiev region, Kherson) the water usage per capita was two times higher than the Ukraine average. Kherson region has the extreme values of water usage per capita because of vast irrigation systems. This is also the reason why Kherson does not discharge vast amounts of untreated and insufficiently treated water. The results show that the ICS indicator flashes warning signs for regions like Zaporizhia, Kherson, Mykolaiv, Dnipropetrovsk, Kiev region, which performed the worst in the integral criterion of sustainability.

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