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Evaluation of Water Resources through Efficiency Index and Water Productivity in EU

Marcela Taušová, Katarína Čulková *, Dušan Kudelas, Ľubomíra Gabániová, Ján Koščo and Ibrahim Mehana

Department of Earth Resources, Faculty BERG, Technical University Košice, 040 01 Kosice, Slovakia
* Correspondence: katarina.culkova@tuke.sk; Tel.: +0421-55-602-3116

Abstract: Water presents one of the earth resources as a component of environmental change, demanding the research of water use. A nusmber of authors analyzed water use from different perspectives, in different regions, not including the water efficiency index and water productivity in the whole of the EU. The presented contribution is orientated to the evaluation of water resources through the development of efficiency and productivity indexes in EU member states. The research is made by a single analysis of the index in time development, followed by countries' comparison according to the available data and software support, accessing the sustainability features in water supply that are the three-fold-goals of economic feasibility, social responsibility, and environmental integrity, linked to the purpose of the water use. The results of the contribution show the countries with a positive indexes trend, and countries with a negative indexes trend. Such results can be used for improving measurements to increase water productivity, as well as to make measurements to decrease water use.

Keywords: water use; productivity of water; environment; energy source

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1. Introduction

An awareness of the importance of changes in human behavior has grown in recent years, partly thanks to the education of an increasingly younger generation about which human activities have an impact on the climate (recycling, the use of more ecological materials, technologies of reduced consumption), and the same is gradually happening in relation to water. Multinational organizations, states, and parts of the population, are all becoming aware of the need to conserve and make more efficient use of this commodity, whose value increases with every drop wasted [1].

Despite the fact that almost two thirds of the surface of the Earth is covered by water, only 1% of it is realistically available to humanity; 0.12% is usable in industry or agriculture, but only 0.007% is drinking water [2]. Significant weather fluctuations in recent years (long droughts, torrential downpours) suggest that the problem of water availability may worsen, and significantly so [3,4]. Already, nearly 800 million people in the world lack access to safe drinking water, and in the first two months of 2022, over 120,000 people died from diseases related to poor sanitation and drinking polluted water [5]. Based on current trends, the number of water-stressed people is projected to increase to 1.8 billion by 2025, and two thirds of the population will be under water stress [6].

In response to the situation, the European Union is also committed to monitoring water efficiency in different sectors of the economy at national, regional, and local levels. This is essential to ensure the long-term sustainability of water depletion rates. The European Commission's Seventh Environmental Action Program aims to increase resource efficiency, and thus water efficiency. However, under the Water Ordinance (2000/60/EC) there is a requirement for countries to promote sustainable use, based on the long-term protection of available water resources, ensuring a balance between abstraction and groundwater exchange, with the aim of achieving a positive groundwater situation in 2025 [7]. Therefore, it is important to analyze the water status of each country and the efficiency of water use, for which several indices are used, the key ones being the water use index and the water productivity index. It is possible to observe a correlation between country development and water productivity, with developed countries having a higher water use index than developing countries, while water stress is currently increasing, especially in areas of Latin America and Africa [8–10].

These indices, especially in the context of agriculture, which uses the most water of the total volume consumed, were also addressed by Frizzone et al. [11] in a study in which they analyzed the irrigation performance around the Jaguaribe River, where they found a low performance index. Others were Koech and Langat [12], who also examined the progress of improving water use efficiency in irrigation in Australia. In his study, Rodrigues [13] also used indices to assess the economic impacts of water scarcity and water costs by evaluating the economic productivity of water.

As for water efficiency and productivity, Cheng focused on water conservation and efficiency improvements in residential buildings, which are also a significant consumer, and found that green buildings can help save up to 37.6% of water [14]. An estimation of water productivity in industry in Chile was addressed by Vásquez-Lavín, whose results could be useful in designing public policy and in realizing the implications of water-related projects [15].

The analysis of water use efficiency using the WATR index (water treatment target ratio index, formed by dividing the target water intake by the actual water intake in a region or economy) within a region in China was studied by Hu et al. [16], using the GTFWE index (green total water efficiency index, which can reflect the economic efficiency and green efficiency of water resources) by Yao [17]. Additionally, the TFWE index (total water efficiency index, defined as the ratio of optimal and actual water use) was addressed by Zheng [18]. Water use efficiency, with respect to the overall economic situation, has also been studied and assessed by other researchers such as Kaneko et al. [19], Mo et al. [20], Huang et al. [21], Velasco-Muñoz et al. [22], Wang and Zhao [23], and Li et al. [24], etc.

A proposal for new indicators that would include the consideration of water reuse, and help in identifying and providing clear distinctions between beneficial and non-beneficial water use, was made by Pereira et al. as early as 2012 [25].

In recent years, in addition to the carbon footprint, the so-called water footprint, which measures the amount of water used to produce each of the goods and services that people use, has also begun to be mentioned. Everyone should strive to reduce both of these footprints, and therefore it would be a good idea to expand people's awareness of them. Given the current state of the global climate, climate change, drinking water supplies, and the state of water reserves, it is essential to educate and raise awareness of both the carbon and water footprints and how and where to reduce them at all levels (household, schools, businesses, public administration, etc.) [26–28]. According to Owusu-Sekyere et al., (2019), there exist heterogeneous preferences for water and carbon footprint sustainability attributes, with some being environmental sustainability activists and water sustainability advocates [29]. The findings of Adetoro et al. (2020) and Adetoro et al. (2021), support the notion that water-use efficiency in sugarcane production can be improved, and water footprints reduced by implementing more efficient irrigation systems [30,31].

The ambition of this paper is to analyze the evolution of the water use index and the water productivity index in the EU, as well as at the level of individual member countries during the available years, while looking for differences between countries in order to define the key factors influencing the current situation.

2. Present State of Problem Solving

According to World Health Organization (WHO), eight million people still do not have access to clean drinking water. More than 3.5 millions of people die annually due to illness caused by the consummation of dirty and unfiltrated water. This phenomenon is directly influenced by the direct growth of the population and the stagnating level of worldwide water flows, which would present according to estimations 1.8 million people in 2025 living in areas without access to secure drinking water. Moreover, two thirds of people would live in areas where water is becoming rare natural source, due to the imbalanced use, excessive agricultural growth, and worsening climatic changes [19]. Reacting to the situation, the European Union agreed to the monitoring of effective water use in different economic sectors at the state, regional, and local level. This is necessary for providing the long-term sustainability of the measure of water use. The goal of the seventh environmental action program of the European Commission is to increase the effectiveness of source usage, and this effective water use. However, in the frame of the decree about water (2000/60/ES) [32], there is demand that countries should support sustainable use, based on the long-term protection of available water sources, providing a balance between the exhausting and the amending of underground waters, with the goal to achieve in 2025 a positive situation of underground waters [32]. Organization for food and agriculture (FAO), where countries different from the view of available drinking water [19]. The most stocks of drinking water belong to nine countries (see Table 1).

Table 1. Countries according to the drinking water stocks.

FAO Code	Country	Average Precipitation 1961–1990 (km^3/year)	Internal Resources: Surface (km^3/year)	Internal Resources: Groundwater (km^3/year)	Internal Resources: Overlap (km^3/year)	Internal Resources: Total (km^3/year)	External Resources: Natural (km^3/year)	External Resources: Actual (km^3/year)	Total Resources: Natural (km^3/year)	Total Resources: Actual (km^3/year)	IRWR/Inhab. (m^3/year)
21	Brazil	15,236	5418	1874	1874	5418	2815	2815	8233	8233	31,795
185	Russia	7855	4037	788	512	4313	195	195	4507	4507	29,642
33	Canada	5352	2840	370	360	2850	52	52	2902	2902	92,662
101	Indonesia	5147	2793	455	410	2838	0	0	2838	2838	13,381
41	China, Mainland	5995	2712	829	728	2812	17	17	2830	2830	2245
44	Colombia	2975	2112	510	510	2112	20	20	2132	2132	50,160
231	USA	5800	1862	1300	1162	2000	71	71	2071	2071	7153
170	Peru	1919	1616	303	303	1616	297	297	1913	1913	62,973
100	India	3559	1222	419	380	1261	647	636	1908	1897	1249

Source: [19,33].

It is confirmed that the first place belongs to fifth biggest country, Brazil, where there is only 8233 m^3 of drinking water. This is influenced by the Amazon River, its river basin, and the subtropical climate with sufficient rainfall. Yet one fifth of worldwide stock of drinking water can be found in Lake Baikal, spreading at the biggest Siberian town, Irkutsk, which is considered to be the oldest and deepest lake on Earth. However, in 2015 Russian scientists warned of the still worsening situation, since the level of the lake decreased to its lowest in 30 years. Presently, the lake is also threatened by the plans of investors from Mongolia that want to build two water reservoirs at the Selene River, which presents the main inflow of Baikal Lake. Experts warn that it could have a similar effect, as during the transiting of the two main inflows of Aral Lake in the 1960s, the Amu River and Syr had been transited by the Soviets to a desert, where there should have been watered fields with rice, melons, and cotton. This was the reason why Lake Aral dried almost totally during the last 40 years.

3. Materials and Methods

In the frame of monitoring effective water use in EU as a water category, two key indexes had been defined by the European Commission, published annually in Eurostat by individual member states. Mainly, it is an index of water consumption and water productivity. The ambition of the contribution is to analyze the development of the mentioned indexes in the EU, as well as at the level of individual member states, during available years, and to look for differences between countries with aim of defining key factors, and influencing the present situation.

The paper regards water legislation in the EU, provided by the Water Framework Directive (WFD). The WFD requires member states to prepare river basin management plans, including programmes of measures for each river basin district, including international river basins. In most EU member states, currently the third RBMPs are open for public consultation. To speed up the implementation of the Water Framework Directive, water concerns must be better taken into account in other EU policies and funding mechanisms (a recommendation following the Blueprint in 2012). This will help reach the Directive's objectives of good water status. The European Commission is working closely with member states and stakeholders to achieve a better integration of the Water Framework Directive with other EU policies. Operational and rural development programmes for 2014–2020 have been assessed to measure their contribution towards EU water policy. By highlighting progress so far, the resulting reports can help improve future integration:

- Evaluation of the contribution of Operational Programs to the implementation of EU water policy
- Key descriptive statistics on the consideration of water issues in the Rural Development Programs 2014–2020
- Guidance on a "Good Practice" RDP from a water perspective [31].

Data collection had been realized by the collection of previously published values of chosen indexes from portal https://ec.europa.eu/eurostat/data/database (accessed on 10 July 2022) for all available years and member states. Collected data had been registered, selected, and adjusted to the database in MS Excel according to the demands of the statistical software JMP, to which adjusted data had been transited and consequently analyzed. The created database consists of 10,004 data and every index is defined for a concrete EU member state and a concrete year.

Defining of the indexes: [34]

- Water efficiency index (WEI).
- Productivity of water.

3.1. Water Efficiency Index (WEI)

The index presents part of the evaluation table of source effectiveness. It is used for the monitoring of advances to Europe, and using waters effectively, which complete the main index in the water area. It presents the total annual taking of the water in the country as a percentage of its long-term annual average (LTAA) of available water. The total taking of the water includes water removed from any water source, permanently or temporarily. Additionally, mining and drainage waters are included, as well as rainfall takings. Only water used for the production of hydroelectric energy is excluded (used in situ) (www1.enviroportal.sk, accessed on 3 June 2022).

$$\mathrm{WEI} = \frac{\text{Total annual water taking}}{\text{LTAA}}\ [\%] \tag{1}$$

The indexes show the total water taking, presenting the pressure to the water source by identification of the country with high taking, in relation to the sources. The measure unit is in percentage.

The WEI supports the index of water use, defined as a consumption of water/source of water, expressed in percentage. In connection with EU environmental policy goals, the goal of every country is to decrease the value of the index. The EU determined the level of water stress at the index of water use at the level 20%, and at the same time determined the level of serious water stress at the index of water use is over 40%.

3.2. Water Productivity

The next index, monitoring the advance to Europe, using the waters effectively, is water productivity [35]. The index describes how much economic production is produced per m^3 of net consumed water. The calculation results from GDP, expressed in PPS units and water consumption in m^3. Eurostat uses the PPS–purchasing power standard for the calculation of water productivity to reference year 2010, to follow up trends in water productivity, with the aim to compare the countries for the same year. Since GDP measurement is in mil.EUR or mil.PPS, and water collection in mil.m^3, water productivity is the disposal in EUR per m^3 and PPS in m^3.

Racial water use increasing presents a key principle of water productivity. Effective water use (for example intelligent measurement, obligatory demands on equipment, using the water, the decree for repeated water use, decreasing of the water infrastructure fading, water saving during the watering, etc.), better demand management, better administration of public affairs, and technological innovation, etc., present examples of measurements, able to increase water productivity by the decreasing of the index input.

$$\text{Water productivity} = \frac{\text{GDP}}{\text{Total annual water taking}}\ [\text{PPS.m}^{-3}] \tag{2}$$

4. Results

The analysis of the average value of the index for all EU member states in 1990–2017 evaluates that the EU as a whole, in the frame of the summary index of surface and underground water use, achieves an index under the level of 20% (Figure 1); however, the development has an increasing trend (growth by 0.16% per year). Therefore, there is a necessity to consider effective water sources use.

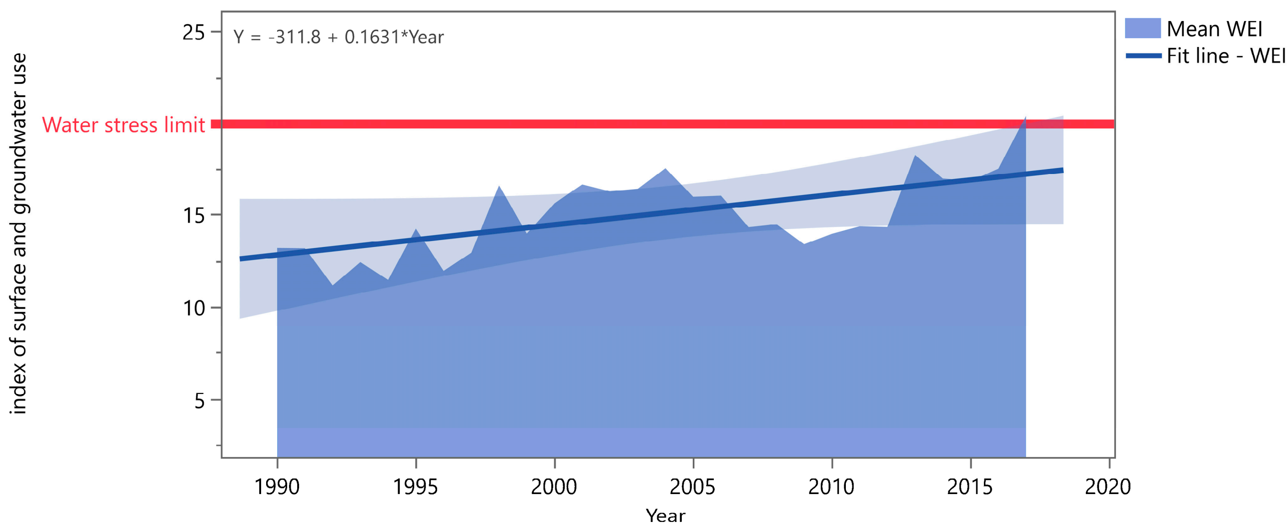
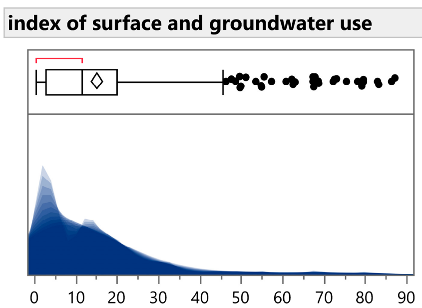


Figure 1. Index of water use (%) in 1990–2017–EU average.

The average value in 27 analyzed years was determined at the level 15.17%, using the distribution analysis, with standard deviation 16.77%. This presents a rather high decline from the average. The coefficient of variation (CV) mentions the 110.57% decline from the average (Figure 2).



Quantiles		
100.0%	maximum	87,2
99.5%		84,4315
97.5%		68,7825
90.0%		32,9
75.0%	quartile	19,925
50.0%	median	11,6
25.0%	quartile	2,9
10.0%		1,4
2.5%		0,7
0.5%		0,5635
0.0%	minimum	0,5

Summary Statistics	
Mean	15,172624
Std Dev	16,77656
Std Err Mean	0,7314928
Upper 95% Mean	16,609636
Lower 95% Mean	13,735611
N	526
CV	110,57125

Figure 2. Distribution analysis of the index results–Index of water use in 1990–2017 in EU member states.

The deviation means there is considerable annual change or it can be caused by a significant difference of the index at the level of individual states, which was consequently verified by using of ANOVA analysis through Kruskal-Wallis test. The results of the test confirmed a statistically important variance of values in EU member states. The influence of time was not confirmed (Figure 3).

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
3,7420	27	1,0000

(**a**) variability analysis according to the year

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
489,0407	28	<,0001*

(**b**) variability analysis according to the state

Figure 3. Results of Kruskal-Wallis test–variability of water use index influenced by time and the country.

By the comparing of the individual states results (Figure 4), we can state that one state, Spain, is over the level of water stress (20%) with the value of the index at the level of 28%, but the trend of development in Spain in analyzed years is positive, orientated to the decreasing of the index. Results point also to the states from the group with serious water stress (over 40%), mainly Cyprus, with an index of water use at the level of 67.4%, Malta at 51.2%, and Kosovo with a value of 86.4%. Kosovo is, at the same time, the country with the most rapid growth of the index, while from 2013 the index of water use increased from 18.4% to the present 86.4%. The other states achieved, in 2017, values under 20%, which is a positive situation.

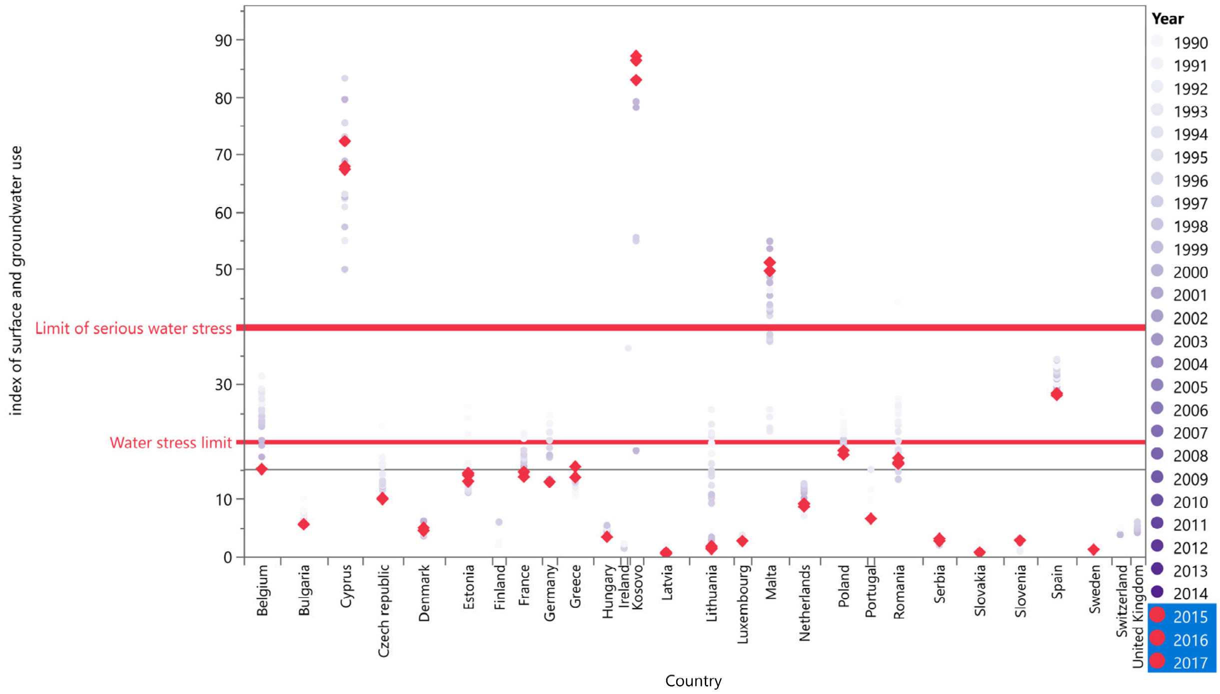
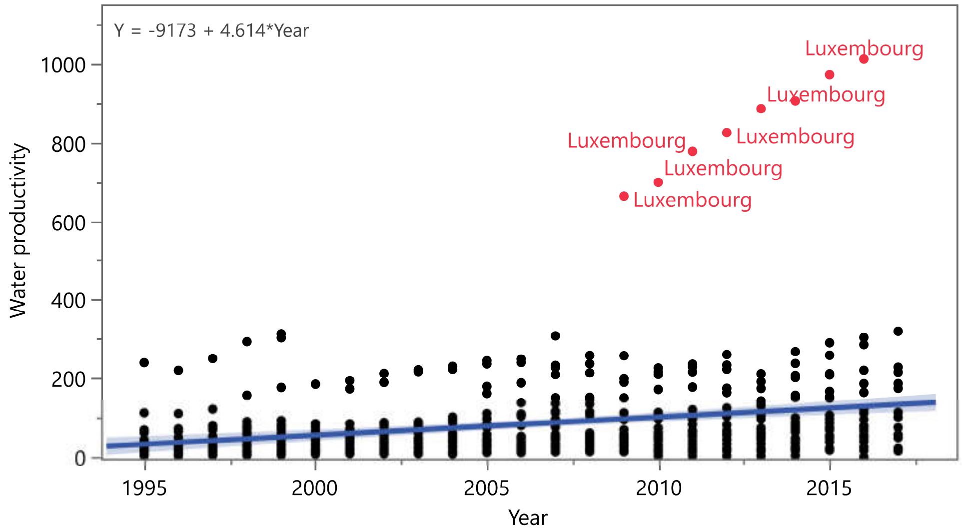


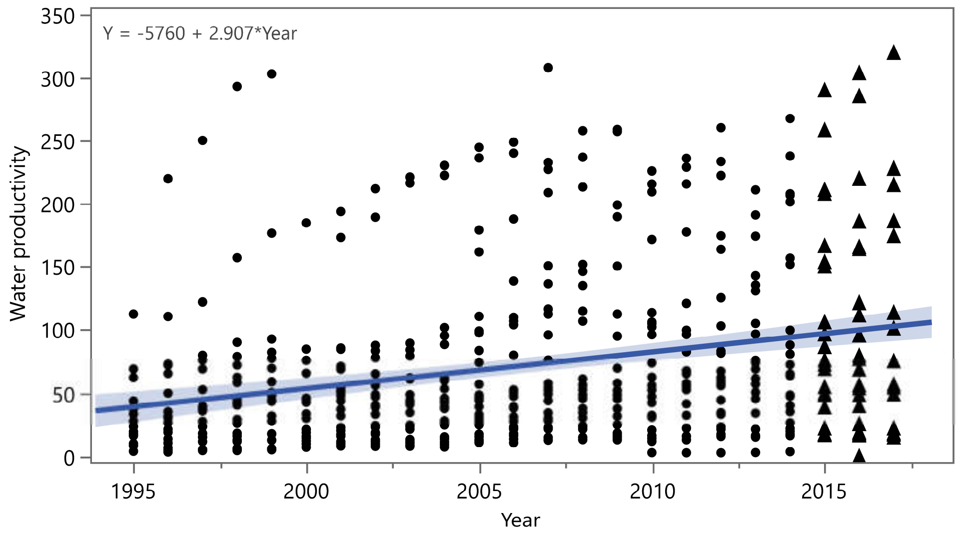
Figure 4. Comparing of EU member states–index of underground water use (%) in 1990–2017.

The next index, monitoring effective water use, presents water productivity. The goal of EU member states is to increase the value of the index, which can be achieved by the racial using of waters in all countries.

Using linear regression analysis and correlation analysis, the influence of time on the development of water productivity was investigated. A statistically significant dependence between the variables was confirmed with a correlation coefficient of 26%. The linear regression model subsequently defines the year-on-year increase in water productivity in the group of analyzed countries. Resulting from the analysis of data, published in the Eurostat database in 1994–2017, in the frame of water productivity we can state that there was registered a positive change of the index, with annual growth of the water productivity at the level 4.6%. The most significant influence on the index results is from Luxemburg, that has the highest value of the index, exceeding other analyzed states four times. Due to the objectiveness of the analysis in further analysis, Luxemburg had been excluded from the analysis and the analysis had been repeated. Additionally, in the case of repeated analysis, there was a registered index growth, in this case by 2.9% annually, which is considered as a positive situation (Figure 5).



(**a**) analysis with Luxemburg



(**b**) analysis without Luxemburg

Figure 5. Water productivity (PPS/m^3) in EU member states in 1994–2017.

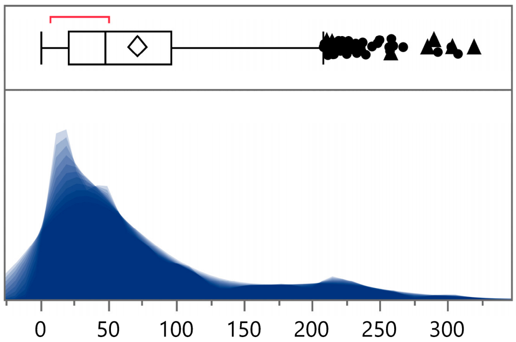
Through the Kruskal-Wallis test, the statistical important influence of the state to the index variability had been confirmed (Figure 6), which was consequently analyzed, and the countries with highest and lowest values of water use productivity had been determined. As in case of the water use index, and in case of water productivity distribution analysis defined through standard deviation (Std Dev) and the coefficient of variation (CV), the high variability of registered values with volatility was 97% of the average value (Figure 7).

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
387,4448	31	<,0001*

Figure 6. Analysis of water productivity variability according to EU member states–results of Kruskal-Wallis test.

Water productivity



Quantiles

100.0%	maximum	319,3
99.5%		305,573
97.5%		257,29
90.0%		192,62
75.0%	quartile	95,65
50.0%	median	47,9
25.0%	quartile	20,35
10.0%		11,9
2.5%		5,135
0.5%		2,8
0.0%	minimum	0

Summary Statistics

Mean	71,710751
Std Dev	69,866151
Std Err Mean	3,1466132
Upper 95% Mean	77,893208
Lower 95% Mean	65,528293
N	493
CV	97,427722

Figure 7. Distribution analysis of the index results: water productivity in 1994–2017 in EU member states with Luxemburg excluded.

An analysis of the results in the states enabled to define the states with the highest water productivity. In last years, it was registered in Luxemburg, Denmark, Malta, England, Latvia, and Slovakia, which highly over-reached average water productivity in the EU. A majority of the states observe the demanded trend of the index growth, which has a positive impact to the development of summary indexes in whole EU. However, the analysis warns of the states in which water productivity is decreasing, mainly in North Macedonia and Greece. Those are countries with very low water productivity.

The index of water productivity (Figure 8) is considerably influenced by economic structure and the rate of water economy. The lowest productivity means mainly the economic and industrial structure of the country is demanded on water use. In Europe the highest consumption of water belongs to agriculture, presented at approximately 40% of total volume of water annually. In spite of effectiveness increasing in water economy in last century, agriculture would still be the biggest consumer in the coming years, contributing to stress due to water shortage. The reason is the need to still water a larger space of agricultural soil, mainly in the countries of southern Europe. The second biggest consumer of water is energy production, the sector is responsible for approximately 28% of annual water consumption. The water is used in the sector for the cooling of electric plants, using nuclear or fossil fuel, and for production of electricity in water power plants. The mining of raw materials and production is responsible for 18%, following by consumption in households with approximately 12% of consumption. In Europe, on average 144 liters of water per person per day come to households.

However, in individual regions, there are differences from the view of sectors with highest water consumption. In southern Europe, regularly the biggest water consumer is agriculture, while in western and eastern Europe the water sources are mostly taken for cooling during energy production. In northern Europe, the biggest water consumer is the production sector. The effort of countries is presently increasing water productivity by its rational use.

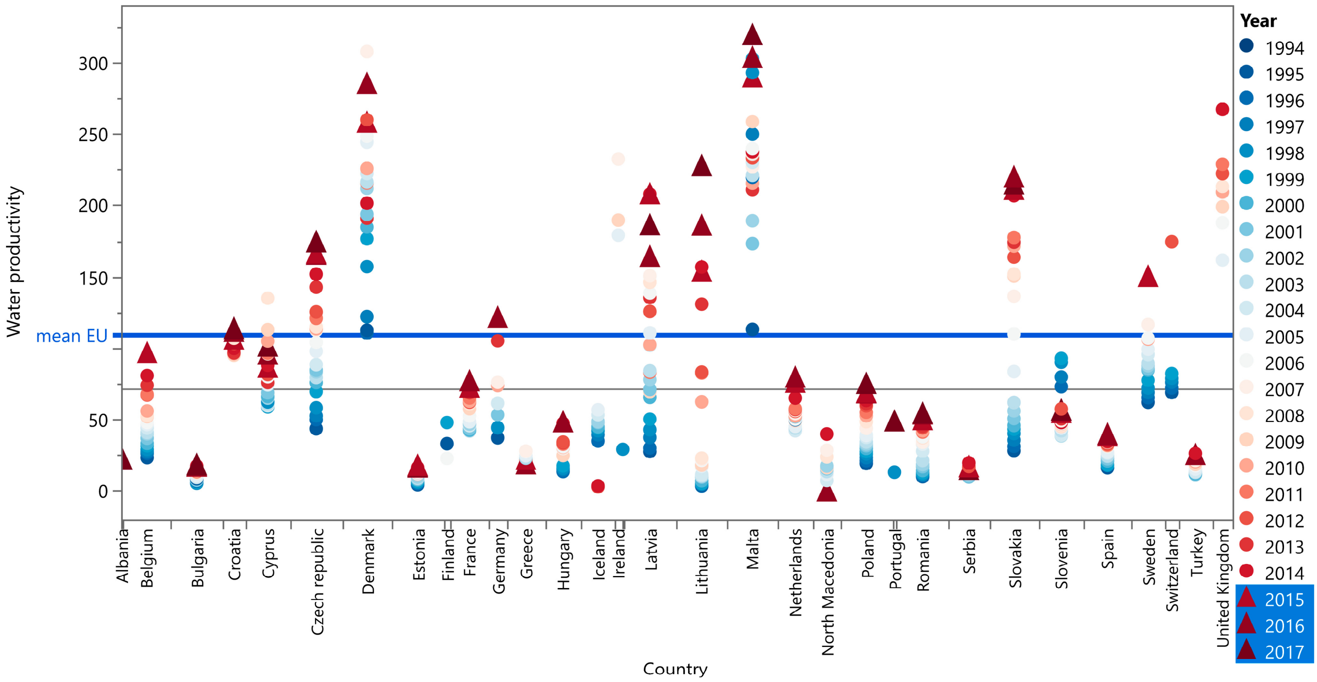


Figure 8. Analysis of variability according EU member states: water productivity (PPS/m^3).

5. Discussion

Due to the number of accepted measurements for effectiveness improving, for example, the improving of the determination of water price, or the technological improving of water equipment, there was registered in the last period a decrease of water use [36]. According to the index of water use from the agency EEA, water would be still used in sectors such as agriculture and energetics, as well as household consumption to satisfy demand, which is expected to be increased [37]. Climatic change would still burden water sources and it is expected that the number of southern regions will be threatened by increased dryness. The task is also to consider demographical trends. The number of EU inhabitants during last two decades increased by 10% and an increased trend it expected. At the same time, still more and more people are moving to the cities, which would increase the stress on water stocking in cities [38].

Several sectors, mainly massive tourism, will increase in the main holiday period the pressure to demand water. An annual stay of millions of people in various destinations in Europe is responsible for approximately 9% of total annual water consumption. The majority of this consumption is registered in accommodation and catering services [39]. Tourism will bring further increasing of water consumption, mainly in small Mediterranean islands, where there is a massive inflow of visitors.

6. Conclusions

The goal of the paper was to analyze the evolution of the water use index and the water productivity index in EU countries. According to the results, there is an obvious decrease of water use in the majority of the economic sector in Europe. Results warn also that states from the group have serious water stress. As for the water productivity, we can state there was registered a positive change of the index with annual growth. Therefore, there is a necessity to consider the task of effective water sources use. The results provide a determination of states with the highest water productivity and effective water use, which can be used for the support of EU goal achievement in the frame of institutional determinants determined on source efficiency and developing policy to decrease source efficiency gaps [40]. The results present the other area of research, orientated to the sources use, previously studied mainly in the area of waste use efficiency [41,42]. Future research can be orientated to the other source use: soil use; energetic sources use; the decreasing of carbon footprint, etc.

The total dilemma is clear. Water is necessary for everybody–people, nature, and the economy. The more we take of the water source, the higher influence to nature. Moreover, in certain regions, mainly during several months, there is simply a water shortage. It is expected that climatic change would contribute to the bigger shortage. Due to the above mentioned, we must use water effectively. By water saving we help to also save other sources, as well as protecting nature.

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