EVALUATION OF THE REGIONAL WATER USAGE IN HUNGARY WITH WATER ALLOWANCE COEFFICIENT (WAC)

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Abstract. We created a Water Allowance Coefficient based on Water Footprint calculations. The Water Allowance Coefficient quantifies the value of water resource availability potential, as impacted by market price. The method was applied to regional Hungarian data. Water Footprint is the absolute value of man's freshwater-usage and evaluates freshwater use throughout the entire product path. In addition, it also shows the parties responsible for undue water usage and water pollution. It consists of three main parts: green, blue, and grey water footprints, which division was taken into consideration during the specification of the Water Allowance Coefficient. The value of the Water Allowance Coefficient was derived through differentiation of water type and, in our case, also by region. By correcting these data with market prices, we calculated the adjusted values of the Water Allowance Coefficient on both regional and national levels. As the most prominent result, we approximated the value of freshwater on tillable agricultural lands to be 1,185 EUR/ha. Nearly half of this value is associated with rainwater, nearly a third is that of atmospheric and ground and about one fifth is that of water required to dilute contaminated water. Our results offer an entirely new basis for the optimization of water management.

Keywords: *water footprint, agricultural water values, natural resources, water allowance coefficient, water evaluation*

Abbreviations:

AWV – Adjusted Water Value
CSO – Central Statistical Office of Hungary
FAO – Food and Agricultural Organization
IWMI – International Water Management Institute
WAC – Water Footprint based Water Allowance Coefficient
WF – Water Footprint

Introduction

Water is distributed throughout Hungary, but its temporal and spatial distribution experience significant variations in both quantity and quality. Water, as a natural resource, plays a role in the sustenance of life; it is also a natural creation used by all of humanity and by society to satisfy its material needs (Rees, 1985). Water is renewable, in other words, a circulating natural resource. This means that in spite of its usage, it can be regenerated in a timeframe that is usable to humans (Savenije, 2002). However, this renewable resource can also be exhausted, if the rate of usage or pollution exceeds that of renewal or purification (Binswanger, 2001). In a system approach, according to Tyteca (2001), the economy can be pictured as inlaid between social and environmental systems, such that these systems are related to each other. Water appears in all three of these system components, and the water circulation in the ecological system is an irreplaceable medium and a living space, both on micro and macro levels.

Review of literature

Man established its societies and developed its culture and economy on the shores of the word's main rivers (Fogarassy, 2014). This economy is based on water usage, since basically all economic sectors use water, both directly and indirectly (Savenije et al., 2014). Decision makers include different driving forces in their strategic planning as well as in water resource management, which can define our competitiveness. These driving forces are generally exemplified as demographic, technological, economic, social, environmental, and institutional, or can even be changing aspects of international processes. These factors can be external, on which we cannot exercise influence, internal, which include the present situation and traditions, or a mix of these types (Rushforth et al., 2013). Water supplies are defined by area and influenced by extreme weather increasingly due to climate change, while needs are basically driven by anthropogenic in nature and are exemplified by agricultural and irrigation habits, urbanization and the spread of megacities, and the changing economy and culture of the middle class. The conflicts that arise from anthropogenic water demand can be reduced or increased by the virtual trade of water, which in turn can lead to the unified regulation factors used in product pricing (Fogarassy et al., 2014a).

For example, according to the IWMI report (Molden, 2007), insufficient water related investments that are required to provide a water supply that matches water demand or human inefficiency can cause economic water deficits. In this case, water deficit depends mostly on how various institutions work and how they favour some and ignore the voices of others, e.g. most notably those of women. One driver of economic water deficit is development of inappropriately sized infrastructure, which may then negatively impact people performing irrigation, or even their access to drinking water. And even if the infrastructure is present, the water supply capacity to meet needs of individuals or industry may be unbalanced (Schyns – Hoekstra, 2014). An economic approach to water management is being increasingly applied. Externalities of water usage are significant in the consumption habits of households, industrial water withdrawal, agricultural irrigation, and livestock production, and also influential for water treatment. In areas where the cost/benefit ratio of water exploitation and usage are marginal on one side of a political border compared to that across the political boundary, sensitive diplomatic cooperation and market relations that foster transnational economic and social processes may come into play and even be critical (Boulay et al., 2013). However, this could also be true for relations between areas or sectors within national borders. For example the taxation and regulation system as well as market incentives in agricultural irrigation have a huge impact on water consumption and contamination. Cross-border relations cannot be ignored, regardless of whether they are horizontal or vertical. This means that optimization and efficiency improvements in water management can also have inherent additional benefits, for example in reducing energy consumption (Pfister et al., 2009; Hertwich – Peters, 2009), cutting back on carbon dioxide emissions through the distribution of so-called low-carbon mechanisms, or promoting adaption to climate change.

It is necessary to indicate not only economic profitability, but also ecological and social benefits related to water. Optimizing water management and water usage for multiple goals is necessary at all times, and where centralised methods for optimization are inefficient, we propose using a demand-driven water resource management, which can also be applied by the market to influence it (Fang et al., 2014). Obviously, economic values and prices affect availability and usage.

Materials and Methods

The water footprint, devised by the Dutch professor Hoekstra and associates, is a prominent tool used to evaluate freshwater exploitation by man. It is composed of three parts. The blue water footprint refers to the usage of above and below ground fresh water. The green water footprint refers to the quantity of rainwater that was used, or green water, which is critical for plant production (Mekonnen – Hoekstra, 2011). The grey water footprint is a measure of freshwater contamination and can be characterized by the quantity of freshwater required to dilute or process water pollutants sufficiently to meet local water quality requirements (Hoekstra – Mekonnen, 2012). In essence, the Water Footprint is equivalent to human freshwater usage. The method is a multi-sector, multi-dimensional estimation of water usage. It illustrates the water required to process a given product or service on its entire product path (Hoekstra, 2010). It is a static estimation which includes the water usage and pollution along each and every step of the production chain. With this method, we can define the water demand associated with each link of the product chain, with which the level of their responsibility in water usage also becomes apparent. The complex Water Footprint calculation, expanded by the fresh water expropriation evaluation method, was the main basis of the research methodology (Hoekstra et al., 2011). All of the calculations are based on the total Water Footprints of production and manufacturing processes, which are then complemented by the respective water demands of production processes' various steps (Wichelns – Raina, 2013). The Water Footprint provides a wide overview of human water related economic activity, thus new, original relations were seen, which, if spread domestically, can also contribute to making fair and reasonable decisions that adapt to changing needs. The method can be applied flexibly to domestic conditions and distinguishes three different types of water (green, blue, and grey). If a more in-depth breakdown of green, blue, and grey components is needed, they can be subdivided into additional categories, five for the green water, and as many as there are different pollutant types for grey water. Data required for this method is usually available from general statistics (the Hungarian Central Statistical Office [CSO], FAO, FertiStat, Eurostat, etc.), and, if necessary, are included in the calculation as estimated or default values (Fogarassy et al., 2014b). Information and currently available results about water footprints can be viewed on the water footprint's website: www.waterfootprint.org. By further advancing this method, we defined the water allowance coefficient and its adjusted values. Using cluster analysis, we arranged the results into groups. For this, we used Ward's hierarchical merging method. Where it was necessary, we homogenized data using standardization. We analysed the results of the cluster method using the aggregation table and illustrated it with a vertical icicle plot and dendrogram. Our statements were based on centroids and variances. By using the cluster analysis, we highlighted the applicability of data and methods needed for working out macro-economic frameworks and strategies related to water and water management, optimized for given areas.

Results

To reach our results, we first assumed that the link between water and human activities is economic. Monetizing water as a natural resource could raise numerous theoretical questions. During our research, we considered solely economic aspects and not moral, ethical or philosophical ones. As part of a research project at Szent István University, Hungary (Fogarassy – Neubauer, 2014), the monetary evaluation of water as an agricultural natural resource was conducted by domestic calculations related to water price. This value is linked to the regional average irrigation rate per hectare, which is finally corrected by the Water Allowance Coefficient (WAC) (explained in the next section). The WAC is based on the Water Footprint (WF) of domestic wheat production, since the WF accounts for water availability for both direct and indirect use, and it can also address the absolute amount of our freshwater needs.

Water Allowance Coefficient (WAC)

The Water Allowance Coefficient (WAC) was defined by further developing the Water Footprint assessment system; it is interpreted as the potential availability of fresh water. Its base in Hungary is derived from estimations of Neubauer (2014) on the Water Footprint of Hungarian wheat production. During the Water Footprint assessment, in general that the lower the Water Footprint value, the more efficient is the water resource usage of the produced product. Therefore, Water Footprint decreases in certain regions exhibit favourable values compared to the national value, while other regions show unfavourable differences. Based on these, a Water Allowance Coefficient (WAC) was defined, along the lines of existing regional wheat Water Footprint calculations. The WAC is given in Equation 1.

$$\mathrm{WAC_i} = 100/\mathrm{WF}_{wheat,i}\ \% \qquad \text{(Eq.1)}$$

where:

WAC_i = wheat Water Footprint-based Water Allowance Coefficient in region *i*.

$\mathrm{WF}_{wheat,i}$ = Difference between the national average and the Water Footprint of wheat production in region *i*, %.

The value of the WAC is between zero and one ($0 < \mathrm{WAC}_i < 1$) if the Water Footprint of wheat produced in the region is higher, meaning it is unfavourable compared to the national value ($\mathrm{WF}_{wheat,i} > \mathrm{WF}_{wheat,\ national}$). If the regional wheat Water Footprint is lower, then it is more favourable than the national value ($\mathrm{WF}_{wheat,i} < \mathrm{WF}_{wheat,\ national}$) and the WAC is greater than one ($\mathrm{WAC}_i > 1$). The lower the WAC, i.e. the closer it is to zero, the more unfavourable is use of available water resources in the region for wheat production. In other words, higher WAC values increase the monetary value of available water in the region (*Table 1.*).

Table 1. *Water Footprint changes of the wheat based Water Allowance Coefficient (WAC) by type and region, Hungary = 1.*

Regions	**Water Footprint change based on Water Allowance Coefficient (WAC)**			
	WAC*green*	WAC*blue*	WAC*grey*	WAC*total*
	100 WF*green*%	**100 WF*blue*%**	**100 WF*grey*%**	**100 WF*total*%**
Southern Great Plain	1.01	0.76	0.99	0.91
Northern Great Plain	0.88	0.94	0.86	0.89
Southern Transdanubia	1.04	1.23	1.23	**1.14**
Western Transdanubia	1.12	1.39	1.11	**1.19**
Central Transdanubia	1.12	0.96	1.04	**1.05**
Northern Hungary	1.03	1.45	0.93	**1.11**
Central Hungary	0.76	0.81	0.81	0.79
Hungary average	**1.00**	**1.00**	**1.00**	**1.00**

Source: Fogarassy et al., 2014b

Adjusted Water Value

According to the CSO (2013a) database, the average consumer price of water was 1.067 EUR/m^3 in the year 2012. Understanding the retrospective data show increasing values annually, the price of water per m^3 is calculated in our research on the basis of the identified fixed price, without any average calculations. The following *Table 2* is developed by supplementing CSO (2013b) data with the average consumer price, which is actually a technical auxiliary table for calculating water values according to Equation 2.

$$\bar{X}_{p,irr,i} = \bar{X}_{irr,i} \cdot \bar{X}_{p,cons} \qquad \text{(Eq.2)}$$

where:

$\bar{X}_{p,irr,i}$ = Average price of irrigation water in region *i* on a hectare (EUR/ha).
$\bar{X}_{irr,i}$ = Average volume of irrigation in region *i* (m^3/ha).
$\bar{X}_{p,cons}$ = Average consumer price of water (EUR/m^3).

The factors that modify agricultural production value are derived by assigning these data to the WAC of the region in the form of a correction co-factor. The value of the Hungarian average per hectare is almost 1,177 EUR, which can change according to WAC changes and types by region.

Based on the course of agricultural usage of water resources, the regional values corrected by WAC and complemented by green, blue, and grey coefficient values, the values of *Table 3* are derived as seen below, by linking the results of the WAC (*Table 1*) and its Adjusted Water Value (*Equation 2* and *Table 2*).

Table 2.*Average volume of consumed irrigation water by regions (m3/ha) (2004–2012) complemented by the average consumer price of water use (EUR/ha)*

Regions	**Average irrigation (m^3/ha) (2004–2012)**	**Average price (EUR/ha)**
	$\bar{X}irr$	$\bar{X}p,irr$
Central Hungary	1,213	1,295
Central Transdanubia	687	733
Western Transdanubia	805	859
Southern Transdanubia	623	665
Northern Hungary	741	791
Northern Great Plain	1,195	1,276
Southern Great Plain	1,133	1,210
Hungary average	**1,099**	**976**

Note: Average water fee price ($\bar{X}_{p,con}$) is determined at the price 1.067 EUR/m^3.
Source: own calculations on the basis of CSO (Pfister et al., 2009) data.

Table 3. *Average volume of consumed irrigation water by region (m3/ha) (2004–2012) complemented by the average consumer price of water use (EUR/ha)*

Regions	**Adjusted values of WAC (EUR/ha) (AWV)**			
	AWV*green*	**AWV*blue***	**AWV*grey***	**AWV*total***
Central Hungary	984.60	1,049.37	1,049.37	**1,027.78**
Central Transdanubia	821.16	703.85	762.50	**762.50**
Western Transdanubia	962.14	1,194.09	953.55	**1,036.59**
Southern Transdanubia	691.81	814.97	818.20	**774.99**
Northern Hungary	814.80	1,147.06	753.70	**905.18**
Northern Great Plain	1,122.73	1,199.28	1,097.21	**1,139.74**
Southern Great Plain	1,222.09	919.59	1,197.89	**1,113.19**

Note: AWVgreen, AWVblue, AWVgrey, AWVtotal: green, blue, grey, and total water value according to Adjusted Water Values of Water Allowance Coefficient values. The gained results may show little distortion due to rounding errors.
Source: own calculation

Changes in the data of *Table 3* are different from the changes of basic regional Water Footprint values. Favourable and critical regions differ from the results of fundamental calculations. Its reasons are the values, and their different regional weightings, inserted into the Water Footprint values and AWV of WACs, just like the differences of volume of average irrigation per hectare.

Further values related to AWV types became apparent on the basis of the above Table, which values were determined with the use of average consumer prices per hectare. From these, it became apparent that the value of rainwater is the lowest in the Southern Transdanubia region and the highest in the Southern Great Plain region. It also turned out that the value of irrigation water measured on the basis of the average consumer price, compared to the other regions and their values, is very favourable in the Central Transdanubia region at 703.85 EUR/ha. The next favourable value of this type is about 111 EUR/ha higher, and the most expensive AWV of irrigation water is in the Western Transdanubia and Northern Great Plain regions (1,194 EUR/ha and 1,199 EUR/ha, respectively). It is also apparent from the Table that the value of water needed to dilute polluted water, which is actually an indirect water need, is the lowest in Northern Hungary, and the highest in the Southern Great Plain. These are the highlighted values in *Table 3*. The equation for regional level calculations based on the Water Footprint is as follows (Equation 3):

$$\mathrm{AWV}_i = (100/\mathrm{WF}_{wheat,i}\ \%) \cdot (\bar{X}_{irr,i} \cdot \bar{X}_{p,cons}) \qquad \text{(Eq.3)}$$

where:

AWV_i = Adjusted Water Value of Water Allowance Coefficient in region i (EUR/ha).

$\mathrm{WF}_{wheat,i}$ = Changes of Water Footprint of wheat production in region i, %.

$\bar{X}_{irr,i}$ = Average volume of irrigation at region i (m^3/ha).

$\bar{X}_{p,cons}$ = Average price of consumer water fee (EUR/m^3).

Because of the applied methodology, the sum of regional values is not equivalent to the total national value. Thus, the Hungarian water value is as follows (*Table 4*).

Table 4. *Calculation and types of Water Footprint-based value of water used for agricultural production, Hungary*

Type of Water Footprint (WF)	**Water Footprint values** (m^3/t)	**Changes of Water Footprint values (%)** *(WFtotal=100%)*	**Water Allowance Coefficient (WAC)** *based on changes of WF (100/WF%)*	**Value of water used for agricultural production** *on a hectare, based on average price of water consumption (EUR/ha)*
WF*green*	593	47	0.47	**AWV***green* = 551.35
WF*blue*	407	32	0.32	**AWV***blue* = 375.39
WF*grey*	268	21	0.21	**AWV***grey* = 246.34
WF*total*	**1,268**	**100**	**1**	**AWV*total* = 1,173.08**

Source: own calculation, based on Fogarassy-Neubauer (2014).

The per hectare value of water used in agriculture in Hungary, including its green, blue, and grey components, is determined by calculations using the data in *Table 4.* As a national average, we can see that rainwater has the highest value, 551.35 EUR on a tillable hectare. This is almost half of the total AWV. This is followed by irrigation water, which is almost one third of the total value. The smallest part is the value of water need to dilute polluted water with 21%. According to CSO (2013c) data, the tillable territory of Hungary is *5,338,000* hectares. Completing the national, aggregated AWV with this, the following estimation can be made (Equation 4 and *Table 5*):

$$AWV_{agg} = AWV \cdot T_{agr} \tag{Eq.4}$$

where:

AWV_{agg} = Aggregated adjusted value of WAC in Hungary (EUR).
AWV = Adjusted value of WAC in Hungary (EUR/ha).
T_{agr} = Volume of agricultural territory (ha).

Table 5. *Aggregate value of water used for agricultural production, based on the average price of water consumption, Hungary*

Type of Adjusted Water Value and WAC based on changes of Water Footprint (WF) *(100 / WF %)*	**Value of water used for agricultural production** *on a hectare, based on average price of water consumption (EUR/ha) (AWV)*	**Aggregated adjusted value of Water Allowance Coefficient on Hungary** *(in EUR) (AWVagg).*
AWV*green* (0.47)	551.35	2,943,106,300
AWV*blue* (0.32)	375.39	2,003,831,820
AWV*grey* (0.21)	246.34	1,314,962,920
AWV*total* (1)	**1,173.08**	**6,261,901,040**

Source: own calculation

From the results of *Table 5*, we can see the corrected total water values in Hungary based on agricultural water use. The Water Footprint calculations are based on the Adjusted Values of the Water Allowance Coefficient. According to these, the value of rain water (green water) is close to 2,943,106,300 EUR. The value of irrigation water (blue water) is more than 2,003,831,820 EUR, and the volume of water needed to dilute (grey water) is over 1,314,962,920 EUR. According to this estimation, the national aggregate water value is more than 6,261,901,040 EUR.

Discussion

During the cluster analysis of the wheat Water Footprint (WF_{wheat}), Water Allowance Coefficient (WAC) and Adjusted Water Value of Water Allowance Coefficient (AWV), we put the usual first step (i.e. the exclusion of extreme values) aside, since the observation unit was the total statistic population. We used *Ward's method* in all cases. We only took the variables from the merging process into account.

Cluster analysis of regions by types of wheat Water Footprint

Using calculations with the WF_{wheat} data of the seven regions, we derived either two or three clusters. We chose the three cluster solution, as homogenous groups were created around the variables in this case. According to the results, regions in the first cluster have average, the ones in the second have low, and those in the third have high Water Footprints (*Figure 1.*).

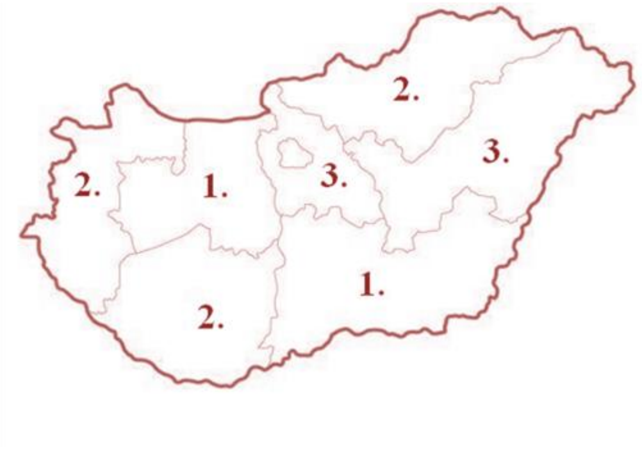

Figure 1. *Clusters of Hungarian regions by Water Footprint types of wheat Cluster 1 – Irrigation water intensive regions,Cluster 2 – Low water intensive regions, Cluster 3 – Water intensive regions, Source: self-made, 2015*

Cluster analysis of regions by Water Allowance Coefficient types

In this case, we also derived either two or three clusters. In this case, we chose the two cluster solution because of its homogeneity. According to the results, regions in the first cluster have low, and those in the second have high Water Allowance Coefficients (*Figure 2*).

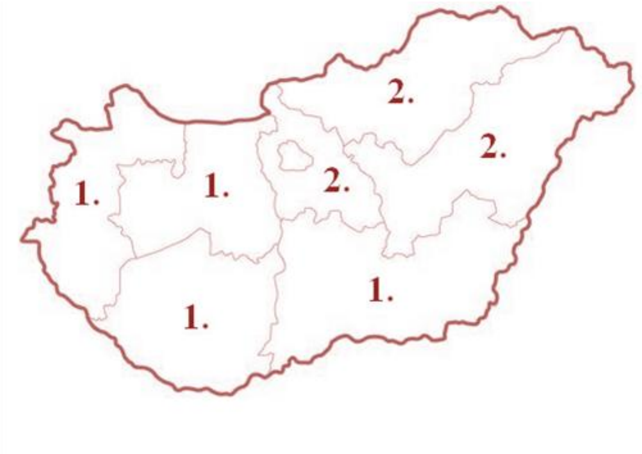

Figure 2. *Clusters of Hungarian regions by Water Allowance Coefficient types, Cluster 1 – Regions reducing water value, Cluster 2 – Regions increasing water value, Source: self-made, 2015*

Cluster analysis of regions by Adjusted Water Value types

In this case, we also derived either two or three clusters. Because it is not recommended to treat a single region as a separate cluster, we chose the two cluster solution. According to the results, regions in the first cluster have low, and ones in the second have high Adjusted Water Values (*Figure 3*).

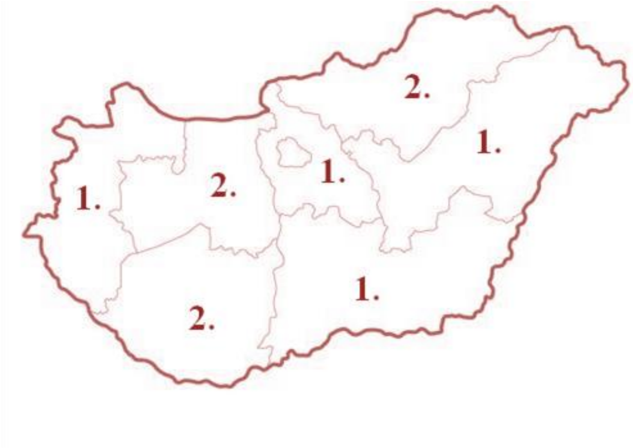

Figure 3.*lusters of Hungarian regions by Adjusted Water Value types, Cluster 1 – Regions with higher water value, Cluster 2 – Regions with lower water value, Source: self-made, 2015*

Aggregated cluster analysis of regions value types

In the course of this cluster analysis, our first step was to perform standardization. Based on the resulting values, it can be stated that either two, three, or four clusters were distinguished. We chose the two cluster solution in this case, as well. In the case of the first cluster, all values of the variables are close to average with the exception of the low Green Water Footprint value, while Water Allowance Coefficient type values are changeable in the second cluster and the Adjusted Blue Water Value is low. This therefore means that the amount of rainwater consumed during the production of wheat, in addition to the mean of all other variables, is lower than the average in case of first cluster regions. In the second cluster, the variability of the Water Allowance Coefficient and the low monetary value of irrigation water are typical besides the mean values of the other variables (*Figure 4*).

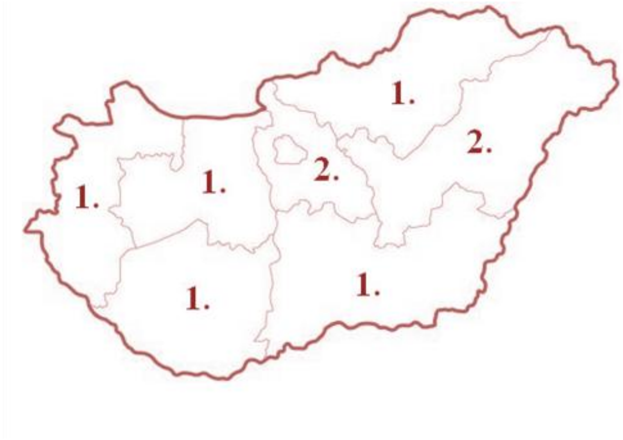

Figure 4. *Clusters of regions of Hungary by aggregated value, Cluster 1 – Average regions with low Green Water Footprint, Cluster 2 – Regions with low irrigation water value and variable WAC, Source: self-made, 2015*

Updating the already available national water footprint calculations was a given opportunity, and it also offers further options for comparison. Their results also allow us to get closer to yet again further advanced assumptions on optimizing national water usage. The water footprint allows us to define a greater number of advanced methods. In order for these to be based correctly, we have to contribute to a clear definition of the water footprint method, all the while increasing the number of national water footprint research projects. We believe that the method concerning the water allowance coefficient (WAC) requires more critical appraise so that it can define an indicator as precisely as possible. If it has flaws, they must be corrected. For example, some of the elements of the water allowance coefficient, with its adjusted values (AWV), offer a chance for reporting to decision makers about the value of the water resource's agricultural usage. However, basing a quota trade on this estimation is a decision which should not be treated lightly. It offers extra information not only about the region overall, but also about the divided green, blue, and grey water footprints of the water allowance coefficient's adjusted values (AWV), including their reasons and the level and way of relations to other variables, such as economic indicators, population density, time factors, demographic data, and costs of materials. We also think that the additional analyses of the water allowance coefficient's adjusted values (WAC) require the inclusion of other related factors, such as population density, income, investments, or some time factor. In addition, the use of the water allowance coefficient (WAC) simultaneously with other natural resource evaluation methods allows it to become useful as a correction factor for evaluating soil, for example.

Conclusion

When we performed the regional cluster analysis, it became obvious that it is necessary to conduct further analyses on either the district or micro-region level, maybe even beyond national borders, mainly due to the low amount of analysis elements. However, this requires the unified water footprint calculations as well as the database. Additionally, we must also see that the characteristics of water as a natural resource aren't related to administrative borders; therefore, when they are used or their usage is evaluated, we have to include this fact as a factor which modifies results. The further analysis of clusters, adjusted with other variables outside of the cluster arrangement methods and with soundness analyses, can also shed light on other, nationally unique connections. We think that the different segmentations with the water footprint can simplify the defining of frameworks related to water usage optimization and their implementation to regional characteristics, and, if we harmonize calculations, are acceptable even across borders.

The water footprint results we arrived at showed regions from the perspective of water demand and also opened up the path to further domestic research and analyses in the field of changing water usage habits. We defined a regional water value estimation system using water footprint estimations, including their pros and cons, which system also received a new function when corrected with market price, and was therefore capable of showing a momentary state of the monetary value of water usage, which resulted in its involvement in estimating the true value of water.

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