

WATER FOOTPRINT ASSESSMENT IN NORTH-EASTERN REGION OF ROMANIA. A CASE STUDY FOR THE IASI COUNTY, ROMANIA

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Abstract. Many factors affect the water consumption pattern such as growing world population, climate changes, industrial and agricultural practices, etc. The present study provides for the first time a year-to-year analysis of water use for agricultural production, domestic water supply and industrial production from a hydrological, economical and ecological perspective in the NE region of Romania. Such an assessment can provide information to facilitate an efficient allocation of water resources to different economic and environmental demands. This assessment is also considering the general economic and social context of the Iasi county as an important area within north-eastern region of Romania. In the Iasi county, the green component takes the largest share in the total water footprint of crops because of the irrigation underdeveloped infrastructure, which makes the agricultural sector vulnerable to dry periods and floods as well. A monthly comparison between the blue water footprint and blue water availability shows that water scarcity varies greatly within the year, but also between years.

Keywords: water footprint, agriculture, water allocation, pollution, Romania.

AIMS AND BACKGROUND

Water issues influence all segments of society and all economic sectors. Population growth, rapid urbanisation and industrialisation, the expansion of agriculture and tourism, and climate change all put water under increasing stress. Given this growing pressure, it is critical that this vital resource is properly managed¹. The main user of freshwater in the world, the agricultural sector, is threatened by climate change and demands from other sectors of society – including the domestic, industrial and livestock sector, whereas increasing conflicts occur with environmental flow requirements².

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Apart from the EU Water Framework Directive requirements, development of the capacity for integrated water resources management is viewed by Romania as an important step in managing water resources more effectively³⁻⁶. Historically, Romania has experienced significant economic losses from floods, accidental spills, and droughts – costs that could be substantially reduced through improved capacity in monitoring, use of effective tools in managing water allocation and quality, and implementation of a comprehensive communication network to ensure timely response by water users and the public to forecasts and warnings⁷.

For Romania, another important issue for integrated water resources management is the efficient cooperation between stakeholders, given the possibilities and limitations of water supply⁴. In Romania, the drought of summer 2007 as well as the flooding of 2009 and 2010, have strengthened the trend toward comprehensive water resources management and increased the environmental awareness.

Scientists consider that water conflicts are mainly caused due to poor water management not just by water scarcity, and in some cases due to lack of coherent policy and institutional development. Industry and agriculture are the most important users, in terms of water consumption and wastewater discharges, at the same time producing the biggest environmental impacts^{5,6,8}.

The ‘water footprint’ concept introduced by Hoekstra⁹ and subsequently elaborated by Hoekstra and Chapagain¹⁰ provides a framework to analyse the link between human consumption, and the appropriation of the globe freshwater being a key environmental indicator¹¹. The water footprint of the people in a region is defined as the total amount of water that is used to produce the goods and services consumed by the inhabitants of the region¹².

Water footprint (WF) can provide complementary roles in the context of integrated water resources management (IWRM), because the water footprint data raises awareness among the public, government and stakeholders as to the environmental impact of societal activities¹³.

WF assessment is primarily focused on quantitative water supply issues¹⁴ and it considers where that water is used, what proportion that water use represents of the total resource in that area, and whether this proportion of water use presents risks to the environment, to communities, or to business, now or in the future.

The basic unit for river management in Romania is the river basin. The National Administration ‘Apele Romane’ through the Water Directorates manages the 11 river basins. All 11 Romanian river basins are directly or indirectly sub-basins of the Danube river as it can be seen in Fig. 1.

This study focused on the quantification of the green, blue and grey WF of 8 of the most important crops within the Iasi county, i.e. maize, wheat, sunflower, sugar-beet, potatoes, barley, vegetable and grapes. These crops represent 95% of the production quantities and 85% of the total agricultural land. The environmental flow requirement, blue water availability and water pollution level for the same

period and the economic water productivity for agriculture production within the Iasi county were also discussed.



Fig. 1. Romanian regions and study area

WF accounting at this level is convenient in providing a basis for understanding where hotspots in local watersheds can be expected and for making water allocation decisions¹⁵. The high level of spatiotemporal detail is convenient for development of site-specific strategies for WF reduction.

Through this assessment (the first realised in Romania so far), valuable information for the efficient water resources allocation are given, taking into consideration also extreme events such as droughts and flooding.

EXPERIMENTAL

Water footprint of crop production. The ‘green’, ‘blue’ and ‘grey’ WF of primary crops are calculated using the methodology described in Hoekstra and Chapagain¹⁰ and Hoekstra et al.¹¹ The total crop water requirement, effective rainfall and irrigation requirements per region have been estimated using the CROPWAT model^{16–19}. The calculation has been done using climate data for the major crop-producing regions and a specific cropping pattern for each crop according to the type of climate.

For each crop the production quantity, yield and harvested area in Iasi county are taken from the Romanian National Institute of Statistics for the Iasi county²⁰. The crop parameters have been taken from Allen et al.¹⁸, and Chapagain and Hoekstra²¹.

The climate data required as input into the CROPWAT model have been taken from the National Institute of Meteorology and Hydrology²².

Following the method as proposed by Hoekstra et al.¹¹ and applied by Siebert and Döll²³ and Mekonnen and Hoekstra²⁴, we have run 2 scenarios, one with $\alpha = 0$ (no application of irrigation, i.e. rain-fed conditions), where α is the fraction of the irrigation requirement that is actually met, and the other with $\alpha = 1$ (full irrigation). In the 2nd scenario, we have assumed that the amount of actual irrigation is sufficient to meet the irrigation requirement. The ‘green’ and ‘blue’ WF (m^3/t) are

calculated (equation (1)) by dividing the green and blue crop water use (m³/ha), respectively, by the actual crop yield (t/ha). Both the total ‘green’ and ‘blue’ WF is calculated as the weighted average under the 2 scenarios:

$$WF = \beta WF (\alpha = 1) + (1 - \beta) WF (\alpha = 0) \quad (1)$$

where β refers to the fraction of crop area that is irrigated.

The ‘grey’ component in the WF of growing a crop (WF_{grey}, m³/t) is defined as the volume of freshwater that is required to assimilate the load of pollutants based on ambient water quality standards and it have been calculated (equation (2)) following the methodology developed by Hoekstra et al.¹¹:

$$WF_{grey} = \frac{(\delta AR)/(c_{max} - c_{nat})}{Y} \text{ (m}^3\text{/t)}, \quad (2)$$

where AR is the chemical application rate per ha (kg/ha); δ – the leaching-runoff fraction (%); c_{max} – the maximum acceptable concentration of nitrogen (kg/m³); c_{nat} – the natural concentration for the pollutant considered in the receiving water body (kg/m³), and Y – the crop yield (t/ha).

Data on the application rate of nitrogen fertilisers have been obtained from the Department for Agriculture and Rural Development²⁵. The data on fertiliser use per crop are not specified for the study area, therefore it was assumed after a report from Ministry of Agriculture and Rural Development²⁶. Green, blue and grey WF has been estimated separately by crop and year for the period 2005–2008.

Environmental impact of the water footprint in the Iasi county. The total blue WF in a catchment is equal to the aggregate of all blue process WFs within the catchment. The effect of total blue WF depends on the available blue water (WA_{blue}) in the catchment (equation (3)), which is equal to the runoff from the catchment minus the so-called ‘environmental flow requirements’ (EFR) which we assumed to amount 80% of the runoff (R), following the (default) recommendation of Hoekstra et al.¹¹

$$WA_{blue} = R - EFR \quad (3)$$

The blue WF (m³/year) in a catchment needs to be compared to WA_{blue} and if WF_{blue} approaches or exceeds WA_{blue} there is a reason for concern¹¹. A blue WF in a specific catchment forms a hotspot when the environmental flow requirements in the catchment are exceeded.

Data on water withdrawal have been taken from the Siret river basin administration and the Prut river basin administration. The runoff data have been derived from Ref. 27.

Economic impact of the water footprint in the Iasi county. The land productivity (LP, €/ha) was analysed and can be calculated (equation (4)) as the production value

(market value of final output) (p_v , €/year) divided to cultivated area (A , ha/year).

$$LP[j] = \frac{p_v[j]}{A[j]}, (\text{€/ha}) \quad (4)$$

Also the economic water productivity (EWP, €/m³) was assessed (equation (5)), used exclusively to denote the amount or value of product (p_v , €/year) over the total WF of crop production.

$$EWP[j] = \frac{p_v[j]}{WF_{tot}[j]}, (\text{€/m}^3) \quad (5)$$

The value of the annual crop production is captured in the production volume multiplied with the producer price of a crop, is calculated for each year from the analysed period.

RESULTS

Water footprint of crops. The water use is already highly constrained by unbalanced conditions of demands and availability, particularly during the dry season. Thus, it can be observed that in 2007, due to the excessive drought, the yields achieved were lower compared to those in 2005, falling to about 50% for grain, about 35% for sunflower or about 67% for vegetables.

The total WF of the analysed crops as an average for the period 2005–2008 (m³/t) for the Iasi county is shown in Table 1. Per unit of product, sunflower and wheat have the largest green WF, 3183 and 3098 m³/t respectively. The highest blue WF was recorded for maize and wheat, 132 and 100 m³/t, respectively. In total terms, wheat is the largest water user in the Iasi county, resulting from the high production quantity and the high WF per kg of wheat produced.

Table 1. The average green, blue and grey virtual water content for primary crops in the Iasi county (2005–2008)

Crops	Water footprint (m ³ /t)			
	green	blue	grey	total
Wheat	3098	100	263	3461
Maize	2211	132	79	2423
Barley	1735	0	3098	4833
Potatoes	358	18	176	551
Sunflower	3183	3.5	749	3935
Sugar-beet	171	1.5	290	462
Vegetables	366	26	183	575
Vineyard	1226	7	580	1813

The variation in WF per t for the analysed crops is largely determined by the difference in crop yield, temperature and the amount of rainfall, the water availability in the soil and the amount of water needed and supplied for irrigation. Other relevant factors are the fraction of cropland that is irrigated and the fertiliser use.

In general, the influence of climate on the magnitude of the WF per t is high, a higher evapotranspiration rate leads to a higher crop water requirement and, therefore, to a higher crop water use. Thus, in the dry year (2007) crops used more water than for an average year (2005), the comparison between the blue (Fig. 2a) and green (Fig. 2b) water use by crops, the higher temperature, the higher crops green and blue water consumption.

The green component has the largest contribution to the crops WF because of the yields achieved due to undeveloped irrigation system, so most crops are thus mainly grown with rainwater. For maize and wheat, the green component contributes 91 and 90%, respectively to the total WF.

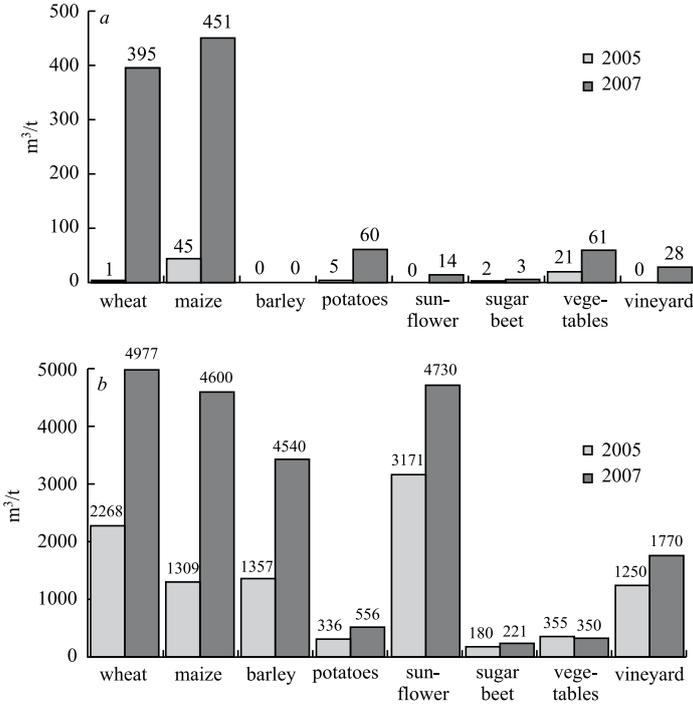


Fig. 2. Blue (a) and green (b) WF per crop for an average and a dry year

The blue component is 6% for maize, 5% for vegetables and 3% for wheat and potatoes, for the other crops, the contribution of the blue component to the WF is marginal. The blue water consumption differs by year, depending on the climate and irrigation applied to the crops.

The total volume of water used in the Iasi county as an average for the period 2005–2008, for the production of the studied crops is 1176 Mm³/year. The total blue WF is 25 Mm³/year, the total green WF is 975 Mm³/year and the total grey

WF is 175 Mm³/year. The total WF by crops differs year by year as can be seen in Fig. 3.

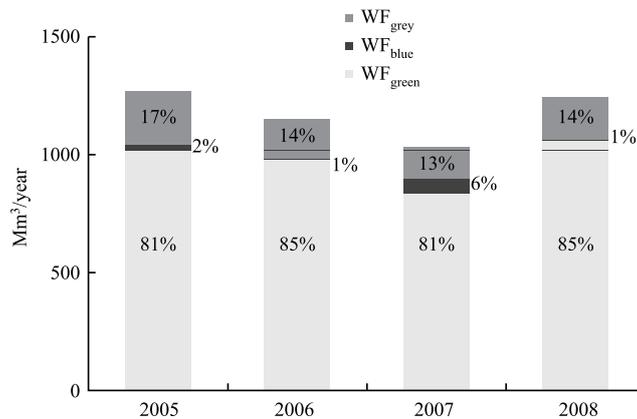


Fig. 3. Total crops water footprint in the Iasi county (2005–2008)

Comparing blue water footprint to blue water availability. The domestic water use is having an ascending trend line because of the growing number of inhabitants, the associated demands and possibly due to the losses in the network (approximately 30–40% of the water flow each day is associated with the leakages) caused by the infrastructure ageing (deteriorated pipes and joints and high-pressure fluctuations in the water distribution network). The industry water consumption decreased a lot in the recent years because many small industries failed to survive in the new market context, due to obsolete technologies and the interrelated problems in modernising the production facilities. The average blue WF in the Iasi county in the analysed period 2005–2008 was 67% for agriculture, 21% for domestic purposes and 12% for industry.

Figure 4 shows how the blue WF over the year can be compared with the blue water availability (WA_{blue}), environmental flow requirement (EFR) and the total renewable water resources (TRWR) within the Iasi county. Environmental flow requirement is not passing the limit during the year, but blue WF exceeds in 2007 the blue water availability due to excessive drought.

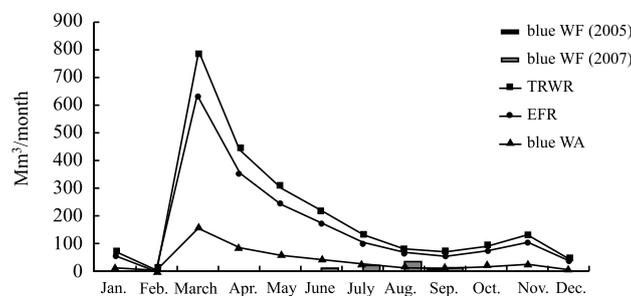


Fig. 4. Blue WF over the years compared to total renewable water resources, blue water availability and EFR

The blue WF (in 2005 and 2007), calculated monthly (Fig. 5a), has a big impact on blue water availability if is listed monthly and the problem was noticed in the dry year (2007) from July until September, when the temperature was relatively high and the precipitation was very low. If blue WF is compared to blue water availability by year (Fig. 5b), it can be seen that it does not go beyond the limit. Due to this fact, the comparison between the blue WF and blue water availability, done monthly gives a more accurate picture of the temporal variation of water scarcity than the annual analysis.

Blue water scarcity can lead to water supply collapses, crop failure in irrigated fields as happened in 2007, can increase the infrastructure costs, to make more water accessible for economic use and also can lead to higher levels of water pollution, because there is less water to dilute contaminants.

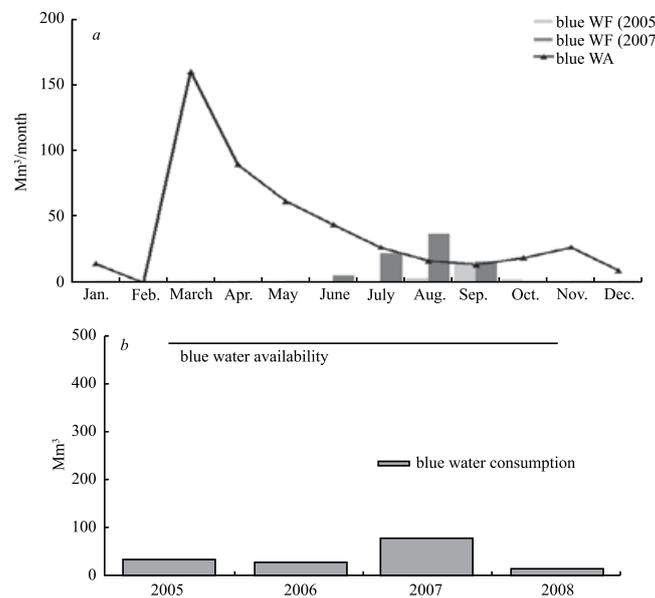


Fig. 5. Blue WF (a dry and average year) compared to blue water availability done on a monthly basis (a) and the annual blue WF compared to blue water availability in the Iasi county (b)

Economic water productivity. Regarding the economic water productivity (€/m³) there are certain marked differences among crops and among years. Our results suggest that the agricultural WF is relatively dependent on water scarcity. Therefore, in order to have a comprehensive understanding of the WF concept, it is essential to consider the real opportunity cost of water resources.

Concerning the land economic productivity per crop in rain fed and irrigated conditions, vegetables have the highest revenues per ha (4000–6000 €/ha), followed by potatoes (about 900–3000 €/ha), vineyard (900–2000 €/ha) and sugar-beet (400–900 €/ha). Finally grain cereals and industrial crops have productivities of less than 600 €/ha.

Both economic water productivity and consumptive water use are highly variable among crops. As expected, the crops with lower WF and higher economic value, such as vegetables, potatoes, grapes and sugar-beet, present the highest economic water productivity. On the opposite side, cereals such as wheat and maize present the lowest economic water productivity. The total production value (2005–2008) is 142 million €/year, the lowest production value was in 2007 of 83.8 million €/year, because of the excessive drought the yields achieved were much lower compared to those in 2008 when was recorded the highest production value of 210.1 million €/year. The water scarcity situation in 2007 severely complicates both the local food production and other kinds of economic development in the Iasi county.

Agricultural performance has been fairly weak. This lack of competitiveness is illustrated by low yield levels, low growth, and a worsening agro-food trade balances, as agriculture and the food industry can not keep up with increases in food demand driven by rapid overall economic growth, in the face of foreign competitiveness, particularly the EU competition.

CONCLUSIONS

Water footprint can provide complementary data to support integrated water resources management (IWRM), because the water footprint data raises awareness among the general public, government and stakeholders considering the environmental impact of societal activities. The WF concept is not the only tool used when management decisions are made, but it provides an opportunity to make a significant contribution as it integrates factors for each of the sectors within the sustainability framework. Using the concept at the local scale provides a useful tool for use in regional land and water use planning.

Considering the period 2005–2008, the blue WF in agriculture oscillated between 3.3 and 66 Mm³/year (the highest value was recorded in the driest year, 2007) and the green WF between 838 Mm³/year in 2007, to 1066 Mm³/year in 2008. The total WF of agriculture fluctuates between 1035 Mm³/year in 2007 to 1270 Mm³/year in 2005, whereas average crop water use amounts to 1176 Mm³/year. The blue water use by crops (m³/t) increases in dryer years (2007) and decreases in average or humid years (2005 or 2008), this might be explained by a lower rainfall level, a higher crop evapotranspiration and a higher irrigation application rate.

The *green* water component has the largest contribution to the WF of crops in the Iasi county, but also depends on the climate and the yield achieved. In a dry year (2007), blue water contributes 7% to the total WF of growing crops, in an average hydrological year (2005) 2% and in a humid year 0.5%. The grey component contributes 17% to the total WF in 2005 and 13% in 2007, with nitrogen application rates of 75.6 and 60.2 kg N/ha, respectively.

There is a variety of options that could be taken to reduce the WF of crops. The green WF can be reduced by increasing yield through improved agricultural practice. Careful timing of water application, water saving irrigation techniques and optimising storage reservoirs to decrease evaporation losses, can reduce the blue WF. The implementation of land management strategies such as adopting soil, nutrient, manure and crop protection plans will reduce diffuse pollution and hence the grey WF.

One of the limitations found during this research refers to the lack of quantification data about how much water used for crops irrigation supplied from surface, groundwater or from the county distribution system, also at the basin level there is no information available regarding water exchanges between different water users and the costs involved.

The concept of WF is useful in illustrating the true influence of economic activity on water. With greater awareness should come measures to improve water productivity ('output per drop') in water-stressed environments and to reduce the polluting side effects of the production. In addition, the agriculture efficiency in the Iasi county depends on the climate because the irrigation infrastructure has been eroded both at national and local level, while the irrigated area has decreased by more than half. Many farmers could raise water productivity by adopting proven agronomic and water management practices because raising land productivity generally leads to increases in water productivity or by changing from low- to high-value crops, as well as stimulating the crops that are convenient and adapted to the local climate to decrease the irrigation demand.

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