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An assessment of the virtual water balance for agricultural products in EU river basins ☆

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ABSTRACT

In this paper the virtual water balance for agricultural products in river basins located in the EU28 (European Union and Croatia) is assessed. Only basins with a surface area larger than 1000 km^2 are analysed. More specifically the net virtual water import of agricultural products ($nVW_{i,\ agr}$) in these basins is assessed. The latter is defined as the difference between the water footprint of consumption ($WF_{cons,\ agr}$) and the water footprint of production ($WF_{prod,\ agr}$) for agricultural products. Overall the EU28 is a net VW importer for agricultural products, i.e. it imports more VW than it exports. However, there are large differences between different EU regions. River basins which are identified with high positive $nVW_{i,\ agr}$ values (net VW importer basins) include the densely populated and industrialised regions of western Europe like the Rhine, Elbe, Po, Seine, Scheldt or Thames basins. On the other hand high negative $nVW_{i,\ agr}$ values (net VW exporter basins) are observed for rural and sparsely populated river basins on the Iberian Peninsula (Guadiana, Ebro, Duero), in western France (Loire, Garonne) and the eastern Baltic region (Nemunas).

1. Introduction

The virtual water (VW) and water footprint (WF) concepts [2,9] have been brought into water management science in order to show the importance of consumption patterns as well as global dimensions in good water governance [16,8]. Regarding the *WF* a distinction needs to be made between the WF of production (WF_{prod}) and the WF of consumption (WF_{cons}). The WF_{prod} is the sum of

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the direct and indirect water use of domestic freshwater resources of a geographical region. The WF_{cons} is defined as the total volume of freshwater that is used to produce the goods consumed by the inhabitants of a geographical region. It is the sum of direct and indirect water use of domestic and foreign water resources through domestic consumption.

A review on the WF concept for the EU28 (the current European Union and Croatia) is given in Vanham and Bidoglio [16]. It is shown that: (1) the EU28 is a net virtual water importer; (2) 60% of the WF_{cons} is internal and 40% external to the EU28 and (3) the WF of agricultural products contributes by far the largest fraction of the total WF_{prod} (91%) and WF_{cons} (89%). Therefore substantial WF reduction potential exists in both water efficiency in agricultural production processes (WF_{prod}) and consumption behaviour adaptations of EU citizens (WF_{cons}) [15,17].

There are large spatial differences in WF_{prod} and WF_{cons} amounts throughout the EU28. As a result both net VW import and export regions exist within the EU28. Net VW import/export amounts have been quantified on the national level worldwide [11]. Integrated water resources management needs to be assessed at the river basin or catchment scale. Therefore the aim of this paper is to quantify the net VW import and export amounts for agricultural products (which account for about 90% of total WF values [16]) for the river basins of the EU28.

Up to date WF and VW analyses on the river basin level have not been the focus of much research. Some case studies include the Guadania [1] and Duero [5] river basins on the Iberian Peninsula or the Heihe [21] and Haihe [22] river basins in China. Blue monthly water scarcity based on the blue WF_{prod} for 405 global river basins was assessed by Hoekstra et al. [12].

2. Methodology

The VW balance for agricultural products is defined as [10]

$$\text{net } VW_{i,\,agr} = VW_{i,\,agr} - VW_{e,\,agr} = WF_{cons,\,agr} - WF_{prod,\,agr} \quad (1)$$

with net $VW_{i,\,agr}$ being the net VW import related to the net import of agricultural products; $VW_{i,\,agr}$ the VW import related to the import of agricultural products; $VW_{e,\,agr}$ the VW export related to the export of agricultural products; $WF_{cons,\,agr}$ the WF_{cons} related to the consumption of agricultural products and $WF_{prod,\,agr}$ the WF_{prod} related to the production of agricultural products.

In order to assess the net $VW_{i,\,agr}$ for the river basins of the EU, national values on $WF_{prod,\,agr}$ and $WF_{cons,\,agr}$ are extrapolated to livestock and population raster data and subsequently aggregated to the river basin level. All WF values are composed of a green, blue and grey component and were taken from Mekonnen and Hoekstra [14].

An overview of used data is given in Table 1. The analysis concerns average annual values for the period 1996–2005. The catchment database for continental Europe (CCM2) developed by Vogt et al. [18] (based on the digital elevation model SRTM—Shuttle Radar Topography Mission–of 90 m resolution) was used to identify the river basins (Fig. 1). Selected basins have to fulfil two conditions: (1) they are fully or partly located in the EU28 and remaining Balkan countries and (2) they have a surface area larger than 1000 km^2.

Table 1
Specification of data used in the analysis.

Data	Period	Data source
Catchment database for continental Europe (CCM2)		Vogt et al. [18]
Population, raster 1×1 km^2	2000	CIESIN [4]
WF_{prod} agricultural crops, raster $5' \times 5'$ (or $0.0833 * 0.0833^\circ$)	1996–2005	Mekonnen and Hoekstra [14]
Gridded livestock of the world (GLW), raster 1×1 km^2 (cattle, buffaloes, goats, sheep, pigs and poultry)	2000	FAO [6]
National stock data on horses, asses and mules	1996–2005	FAOSTAT [7]
National WF_{prod} data for livestock (grazing and service water)	1996–2005	Hoekstra and Mekonnen [11,14]
National WF_{cons} data for agricultural products	1996–2005	Hoekstra and Mekonnen [11,14]