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SEPTEMBER 2014

THE WATER FOOTPRINT IN MOROCCO

THE ADDED VALUE OF WATER FOOTPRINT ASSESSMENT FOR NATIONAL WATER POLICY

VALUE OF WATER

RESEARCH REPORT SERIES NO. 67

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Units

1 $Mm^3 = 1\times10^6\ m^3$ = million m^3
1 $Gm^3 = 1\times10^9\ m^3$ = billion m^3

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Summary

Morocco is a semi-arid country in the Mediterranean facing water scarcity and deteriorating water quality. Its limited water resources constrain the activities in different sectors of the economy. The national water strategy includes options to reduce water demand and increase supply, but does not consider possibilities to save water through international virtual water trade or to increase water use efficiency through changing the allocation of water to different crops (the main water consumers).

The objective of this study is to assess the added value of understanding the water footprint (WF) of the economy and international virtual water trade in formulating national water policy in Morocco. The question is whether a thorough Water Footprint Assessment (WFA) can provide new insights and response options that are currently not considered in the country's national water strategy and river basin plans. The study includes analysis of the WF of activities in Morocco (on river basin level and monthly scale), the virtual water trade balance of the country and the WF in the context of water availability and waste assimilation capacity. Based on this, response options are formulated to reduce the WF within Morocco, alleviate water scarcity and allocate water resources more efficiently. Results and conclusions from the WFA are compared with the scope of analysis of and action plans included in Morocco's national water strategy and river basin plans in order to evaluate the added value of WFA relative to these existing plans.

Main results of the WFA are:

- The total WF within Morocco in the period 1996-2005 was 38.8 billion m³/yr (77% green, 18% blue, 5% grey). The largest contribution comes from crop production, mainly wheat and barley, followed by olives and maize. Evaporation from storage reservoirs accounts for the second largest form of blue water consumption nationally, after irrigated crop production. The largest WFs are found in the Oum Er Rbia and Sebou basins, the main agricultural areas. The green WF is largest in the rainy period December-May, whereas the blue WF is largest in the period April-September, when irrigation demands increase.
- In the period 1996-2005, Morocco's water resources have mainly been used to produce relatively low-value water-intensive (in US$/m³) crops such as cereals, olives and almonds. These crops also took the largest share in the country's harvested area, although they had the lowest value per hectare cultivated (in US$/ha). More economic return per drop and per hectare of land cultivated was generated by production of grapes, sugar beets, citrus fruits (oranges, mandarins etc.) and tomatoes.
- Morocco was a net virtual water importer in the period 1996-2005. Virtual water import was 12.6 billion m³/yr, with an average cost of 0.98 US$/m³, and virtual water export was 4.3 billion m³/yr, with an average earning of 1.66 US$/m³. Only 31% of the virtual water export originated from Moroccan water resources (the remainder was re-export). Virtual water import and export were related to trade in crop products for respectively 95% and 91%. By importing products instead of producing them domestically, Morocco saved 27.8 billion m³/yr (75% green, 21% blue and 4% grey) of domestic water, equivalent to 72% of the WF within Morocco.

- Blue water scarcity on a monthly scale is severe in all river basins. Seasonal shortages result in a large alteration of natural runoff. Also groundwater scarcity and pollution are significant in most basins, especially in the basins of Bouregreg, Oum Er Rbia and Tensift. In order to move towards sustainable use of Morocco's blue water resources, discussing and agreeing on blue WF caps, per river basin, per month, and for surface and groundwater separately, would be useful.
- Potential green plus blue water savings by partial relocation of crop production across basins are in the order of 1.9 and 1.2 billion m³ per year when all main crops or only annual crops are relocated, respectively. Lowering the WFs of the main crops in each river basin down to benchmarks (which are defined as the lowest water consumption of a crop in a comparable basin) can lead to green plus blue water savings of 2.8 billion m³/yr. When the water productivities of the twelve main water-consuming crops were to be improved by 10% throughout Morocco, it could potentially save 2.5 billion m³/yr of water (green plus blue).
- Morocco obtained fairly large water savings by food (virtual water) imports in the period 1996-2005 (27.8 billion m³/yr, see above). Increasing food imports to relieve pressure on domestic water resources increases food dependency and has negative effects on the domestic agricultural sector, which plays a critical role in the economic and social stability of Morocco.
- About 4% of the water used in the Moroccan agricultural and industrial sectors is used for making export products (period 1996-2005). The remainder is applied for producing products that are consumed by the Moroccan population. However, most of the virtual water export from Moroccan resources relates to the export of products with a relatively low economic value per m³ water exported (in US$/m³).

Several insights and response options emerged from the WFA, which are currently not considered in the national water strategy of Morocco and the country's river basin plans. They include:

(i) New insights in the water balance of Morocco and the country's main river basins:
  - The evaporative losses from storage reservoirs account for a significant part of the blue WF within Morocco. This sheds fresh light on the national water strategy that proposes to build another 60 large and 1000 small dams by 2030.
  - Blue water scarcity on a monthly scale is severe and hidden by annual analysis of demand versus supply, which is the common scale of analysis in Morocco's river basin plans.

(ii) New insights in how economically efficient water and land resources are used:
  - Analysis of the economic value of crop products per unit of water and land used in the period 1996-2005 shows that agricultural policy may be better brought in line with water policy by reconsidering which crops to grow.
  - It is shown that export was not optimal from a water-economics point of view, which raises the question whether the foreign income generated by export covers the direct and indirect costs of mobilization and (over)exploitation of Morocco's water resources. This might not be the case considering the costs of construction and maintenance of the large dams and intra- and inter-basin water transfers in the country and the costs associated with the negative externalities of water (over)consumption, such as the salt-intrusion in Morocco's coastal aquifers.

(iii) New response options to reduce the WF of crop production:

- Analysis of the WF of the main crops in Morocco and its variation across the river basins offers new ways of looking at reducing water consumption in the agricultural sector. The estimated potential water savings by partial relocation of crops to basins where they consume less water and by reducing WFs of crops down to benchmark levels are significant compared to demand reducing and supply increasing measures considered in the national water strategy of Morocco.

Given these new insights and response options, it is concluded that analysing the WF of activities and international virtual water flows has an added value for formulating national water policy. WFA forces to look at end-users and -purposes of freshwater, which is key in determining efficient and equitable water allocation within the boundaries of what is environmentally sustainable, both on the river basin and national level. This is especially relevant for water-scarce countries such as Morocco. Furthermore, considering the green and grey components of a WF provides new perspectives on blue water scarcity, because pressure on blue water resources might be reduced by more efficient use of green water and by less pollution.

1. Introduction

Morocco is a semi-arid country in the Mediterranean that faces both water scarcity and deteriorating water quality. The country's limited water resources constrain the activities in different sectors of the economy. Agriculture is the largest water consumer and withdrawals for irrigation peak in the dry period of the year, which contributes to low surface runoff and desiccation of streams. Currently, 130 reservoirs are in operation to deal with the mismatch in time of water demand and natural water supply and to serve for hydroelectric generation and flood control (Ministry EMWE, 2011). Groundwater resources also play an important role in the socio-economic development of the country, in particular by ensuring the water supply for rural communities (Ministry EMWE, 2012a). However, most aquifers are being overexploited and many suffer from worsening water quality by intrusion of salt water, caused by the overexploitation, and nitrates and pesticides that leach from croplands, caused by excessive use of fertilizers. Surface water downstream of some urban centres is also polluted, due to untreated wastewater discharges.

In 1995, the Moroccan Water Law (no. 10-95) came into force and introduced decentralized integrated water management and rationalisation of water use, including the polluter-pays and user-pays principles. It also prescribes the development of national and river basin master plans (Official State Gazette, 1995). Although not formally established, these plans should be elaborated in accordance with the national water strategy (S. Laraichi, personal communication, May 24, 2013). To cope with water scarcity and pollution, the national water strategy includes action plans to reduce demand, increase supply and preserve and protect water resources (Ministry EMWE, 2011). It also proposes legal and institutional reforms for proper implementation and enforcement of these actions. Demand management focuses on improving the efficiency of irrigation and urban supply networks and valorisation of water to rationalise its use. Plans to increase supply include the construction of more dams and a large North-South inter-basin water transfer, protection of existing hydraulic infrastructure, desalinization of seawater and reuse of treated wastewater.

Although the national water strategy considers options to reduce water demand in addition to options to increase supply, it does not analyse potential water saving through international virtual water trade or through changing the allocation of water to different crops (the main water consumers). Analysis of the water footprint (WF) of activities in Morocco and the virtual water trade balance of the country therefore might reveal new insights to alleviate water scarcity.

The concept of WF introduced by Hoekstra (2003) and subsequently elaborated by Hoekstra and Chapagain (2008) and Hoekstra *et al*. (2011a) is an indicator of freshwater use that looks not only at direct water use of a consumer or producer, but also at the indirect water use. As such, it provides a link between human consumption (final products) and the appropriation of freshwater systems. The WF of a product is the volume of freshwater used to produce the product, measured over its full supply chain (Hoekstra *et al*., 2011a). The total freshwater volume consumed or polluted within the territory of a nation as a result of activities within the different sectors of the economy is called the WF of national production. Trade in products with a water footprint at the place of their production is said to cause virtual water flows or trade.

The WF is specified spatially and temporarily: it shows not only the volume of water consumed or polluted, but also where and when. Three different components of a WF are distinguished: green, blue and grey. The green WF is the volume of rainwater evaporated or incorporated into a product. The blue WF refers to the volume of surface or groundwater evaporated, incorporated into a product or returned to another catchment or the sea. The blue WF thus differs from the traditional measure of gross water abstraction, as it refers to net water abstraction, i.e. gross abstraction minus the volume of water that is returned to where it was abstracted. The grey WF relates to pollution and is defined as the volume of freshwater required to assimilate the load of pollutants given natural background concentrations and existing ambient water quality standards (Hoekstra *et al*., 2011a).

Mekonnen and Hoekstra (2011) quantified and mapped the WFs of nations (incl. Morocco) from a production and consumption perspective and estimated international virtual water flows and national and global water savings as a result of international trade. They state that understanding the WF of a nation is highly relevant for developing well-informed national policy. On the regional level, Aldaya *et al*. (2010b) conclude that WF analyses can provide a transparent framework to identify measures to increase water use and allocation efficiency at the catchment level. In a case study for an agricultural region in Spain, they found that significant changes in water demand can occur not only by changing the amount of irrigated area but also by modifying the cropping patterns. By expressing the economic value of farm output per unit of water consumed, they showed that Spain uses its scarce water resources mainly to produce low-value water-intensive crops. According to Aldaya *et al*. (2010a), understanding WFs and virtual water trade in arid and semiarid countries broadens the understanding of water and food security. Chahed *et al*. (2011) argue that an integrated analysis of all water resources at the national scale, including the green water used in rain-fed agriculture and the water resources virtually embedded in traded foodstuffs, is essential in facing the great challenges of food security in arid countries.

The objective of this study is to assess the added value of understanding the WF of the economy and international virtual water trade in formulating national water policy in Morocco. The question is whether a thorough Water Footprint Assessment (WFA) can provide new insights and response options that are currently not considered in the country's national water strategy and river basin plans. The study includes analysis of the WF of activities in Morocco, the country's virtual water imports and exports, and the WF in the context of water availability and waste assimilation capacity. Based on this, response options are formulated to reduce the WF within Morocco, alleviate water scarcity and allocate water resources more efficiently. Results and conclusions from the WFA are compared with the scope of analysis of and action plans included in Morocco's national water strategy and river basin plans in order to evaluate the added value of WFA relative to these existing plans. Specifically, the WFA in this study aims to:

1. Analyse the green, blue and grey WF of the different sectors of Morocco's economy at river basin level on a monthly scale. The study is largely based on data from Mekonnen and Hoekstra (2011), who estimated the WF of nations (incl. Morocco) over the period 1996-2005 related to: crop production, grazing, industrial production, domestic water supply and animal water supply. Their estimates are supplemented with first-time estimates of the evaporation from the Moroccan irrigation supply network and storage reservoirs.

2. Place the blue WF within Morocco in the context of natural runoff and groundwater availability and compare the nitrogen-related grey WF on groundwater with the waste assimilation capacity of the groundwater system. The monthly blue WF is compared with monthly natural runoff, since water scarcity usually manifests itself on a monthly scale (Hoekstra *et al*., 2012).
3. Assess the water consumption (in m^3/ton), economic water productivity (in US$/$m^3$) and economic land productivity (in US$/ha) of the main crops in Morocco and the variation of these parameters across river basins within the country.
4. Analyse Morocco's gross virtual water imports and exports related to international trade in commodities and the water savings associated with this trade, based on estimates by Mekonnen and Hoekstra (2011). It includes analysis of which part of its resources Morocco uses for producing export products and the economic value of imports and exports per unit of water imported and exported, respectively.
5. Discuss the WF of consumption by the Moroccan population as estimated by Mekonnen and Hoekstra (2011).
6. Formulate response options to reduce the WF within Morocco and allocate water resources more efficiently, including:
   - Reducing the WF of crop production by partial relocation of crop production across river basins (which is possible due to spatial differences in crop water use) or by improving water productivities (through improvement with a certain percentage or through improvements towards certain benchmarks).
   - Setting maximum sustainable WFs (WF caps) per river basin.
   - Resource allocation to different crops (based on economic water and land productivities).
   - Smart virtual water import and export.

The WF of Morocco has not been assessed previously on the river basin level on a monthly scale. In addition, the study is innovative by including in a national WFA specific estimates of the evaporative losses from the irrigation supply network and from storage reservoirs. Furthermore, this is the first national WFA that includes quantitative estimates of the potential water savings by (a) relocation of crop production to regions with lower water consumption per ton of crop; and (b) lowering WFs of crops down to benchmarks (which are defined as the lowest water consumption of a crop achieved in a basin with comparable reference evapotranspiration).

The applied methodology and data are described in Chapter 2. Chapter 3 includes analysis of the WF of activities within Morocco, the virtual water trade balance of the country and the WF in the context of water availability and waste assimilation capacity. Based on this, response options are formulated in Chapter 4. The added value of WFA for national water policy is discussed in Chapter 5. Chapter 6 discusses uncertainties and limitations and Chapter 7 presents the final conclusions.

2. Method and data

The applied methods, assumptions and data for the estimates and analyses in this study are described in this chapter. The study follows the terminology and methodology of *The Water Footprint Assessment Manual* (Hoekstra *et al*., 2011a), which contains the Global Standard for Water Footprint Assessment developed by the Water Footprint Network.

2.1. Scope and study area

The water footprint (WF) of Morocco's production is estimated at river basin level on a monthly scale for the activities included in Table 1. Due to data limitations, the grey WF is analysed on an annual scale and the WFs of grazing and animal water supply are analysed at national and annual level. The study considers the average climate, and production and trade conditions over the period 1996-2005.

The watershed delineation is determined from a digital elevation model with a spatial resolution of 30 arc seconds obtained from NIMA (2013), after which catchments and sub-catchments are merged to equal the action zones of Morocco's river basin agencies (Figure 1). Unless stated otherwise, when we speak in this report about catchments, watersheds or river basins, this division is meant. The basin of Sud Atlas corresponds with more than one river basin agency action zone, namely the ones of (Souss-Massa-)Draa and Guir-Ziz-Rhéris-Maîder. The southern basins of Sakia El Hamra and Oued Eddahab are excluded from the analysis, because water-consuming activities in these river basins are very limited compared to the northern river basins of Morocco. Moreover, the runoff in the basins of Sakia El Hamra and Oued Eddahab is practically negligible (Shahin, 2007).

Table 1. Water footprint estimates included in this study.

Water footprint of	Components	Period	Source
Crop production	Green, blue, grey	1996-2005	Mekonnen and Hoekstra (2010b)
Grazing	Green	1996-2005	Mekonnen and Hoekstra (2011)
Animal water supply	Blue	1996-2005	Mekonnen and Hoekstra (2011)
Industrial production	Blue, grey	1996-2005	Mekonnen and Hoekstra (2011)
Domestic water supply	Blue, grey	1996-2005	Mekonnen and Hoekstra (2011)
Storage reservoirs	Blue	-	Own elaboration
Irrigation water supply network	Blue	1996-2005	Own elaboration

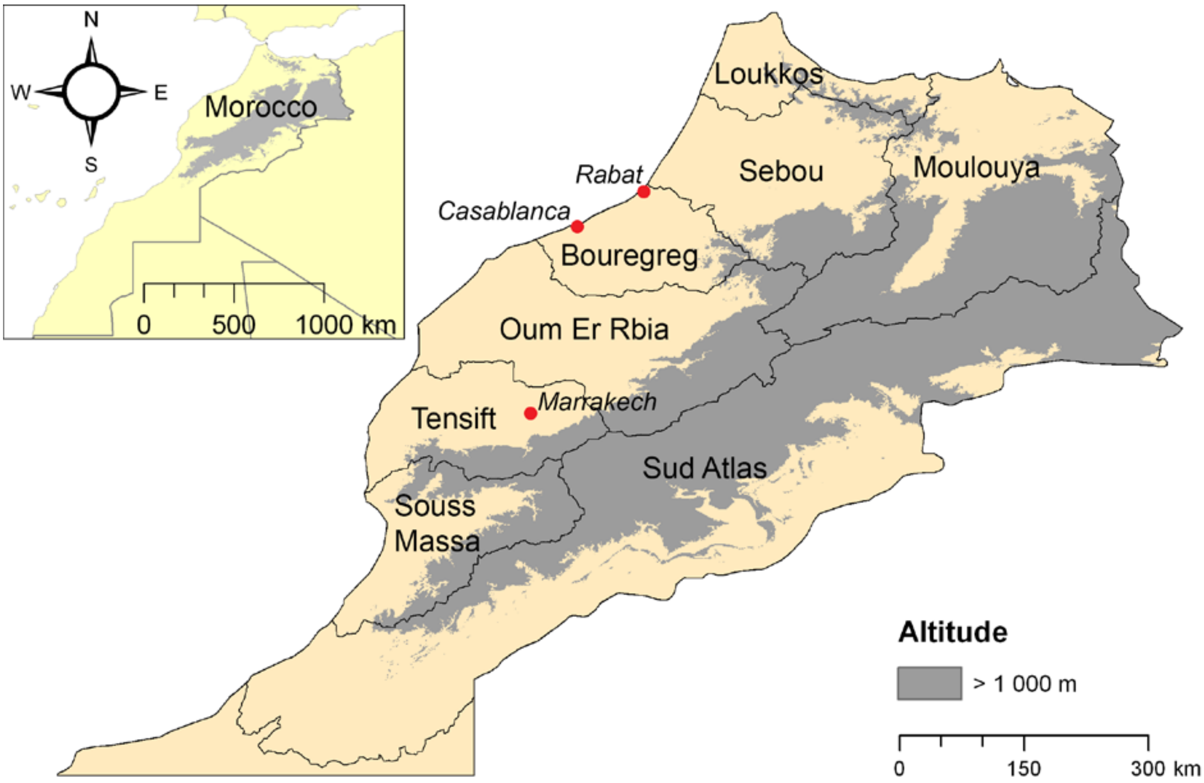

Figure 1. Study area with river basin delineation.

2.2. Water footprint of agriculture, industry and households

The WFs of agriculture, industry and households are obtained from Mekonnen and Hoekstra (2010b, 2011), who estimated these parameters globally at a 5 by 5 arc minute spatial resolution (~10 by 10 kilometres in Morocco). They used a grid-based dynamic water balance model which computes a daily soil water balance and calculates crop water requirements, actual crop water use (both green and blue) and actual yields under non-optimal crop growth conditions. 'Non-optimal conditions' means that actual crop evapotranspiration is lower when the actual available soil moisture in the root zone is below its maximum. Estimates of the grey WF of crops by Mekonnen and Hoekstra (2010b) relate to nitrogen use only. They assume that crops receive the same amount of nitrogen fertilizer per hectare throughout the country and that 10% of the applied fertilizers leach to surface or groundwater. The application rates in Morocco used by Mekonnen and Hoekstra (2010b) vary from crop to crop: 5.0 kg/ha for olives; 13.5 kg/ha for wheat; 58.6 kg/ha for oranges; and 102.3 kg/ha for sugar beets. In their grey WF calculation, a maximum acceptable concentration of 10 mg/l nitrate-nitrogen (NO_3-N) is used, which corresponds to 44 mg/l of nitrate (NO_3) (Self and Waskom, 2013), and natural nitrogen concentrations are assumed to be zero.

The WF of grazing is calculated by Mekonnen and Hoekstra (2010c) at national level based on livestock feed consumption. Chapagain and Hoekstra (2003) estimated the water consumption for drinking and servicing of livestock over the lifetime of animals (i.e. the WF of animal water supply). Both these WFs are excluded from the monthly analysis at river basin level, because they are not available at this resolution level.

The blue WF estimates by Mekonnen and Hoekstra (2011) of industrial production and domestic water supply are based on water abstraction data from the AQUASTAT database of the Food and Agriculture Organization of the Unites Nations. For industries it is assumed that 5% is actual consumption and that the remainder is return flow. For households a consumptive portion of 10% is assumed. The part of the return flow that is disposed into the environment without prior treatment is taken as a measure of the grey WF, thus conservatively assuming a dilution factor of 1. For rural areas zero treatment is assumed. The WF of industrial production and domestic water supply are both mapped with a global population density map. The annual blue WF estimates for industries and households by Mekonnen and Hoekstra (2011) are distributed throughout the year according to the monthly distribution of public water supply obtained from Ministry EMWE (2013a). These distributions are available for the basins Loukkos, Sebou, Bouregreg and Oum Er Rbia. For the other basins an average of these distributions is taken.

The following raster data (at 5x5 arc minute resolution) are obtained from Mekonnen and Hoekstra (2010a, 2011):

- Harvested area per crop (in ha/yr)
- Crop yield (in ton/ha)
- Production per crop (in ton/yr)
- The green and blue WF of crops (in m^3/month) and the grey WF of crops (in m^3/yr)
- The blue and grey WF of industrial production (in m^3/yr)
- The blue and grey WF of domestic water supply (in m^3/yr)

All data are averages over the period 1996-2005. The raster data are aggregated per river basin according to the delineation shown in Figure 1. Reported WF estimates in this study slightly differ (in the order of 1%) from the reported values by Mekonnen and Hoekstra (2010b; 2011), due to different methods applied in retrieving the data from the database.

2.3. Water footprint of storage reservoirs

The monthly WF of storage reservoirs per catchment, i.e. evaporation from reservoirs (in m^3/month), is calculated as the surface area of storage reservoirs (in m^2) times the open water evaporation (in m/month). Data per reservoir on long-term monthly average open water evaporation (1939-2011) and surface area at different reservoir levels for the basins Loukkos, Sebou, Bouregreg and Oum Er Rbia are obtained from Ministry EMWE (2013c). The surface areas of reservoirs at upper storage level in the other basins are derived from AQUASTAT's geo-referenced database of African dams (FAO, 2013b), which includes 105 dams in Morocco. Reservoir area is reported in 1,000 square metres, but comparison with data from the Ministry EMWE (2013c), shows the correct unit is more likely to be hectares (10,000 square metres) and is therefore treated as such in this study. For the basins for which no reservoir specific evaporation data are available, monthly average daily Penman-Monteith potential evaporation is obtained from a model simulation with the global hydrological model PCR-GLOBWB carried out by Sperna Weiland *et al*. (2010). These values are derived at points corresponding with the locations of reservoirs in these catchments (more than one location/reservoir for large catchments). At these locations, the Penman-Monteith potential evaporation equals the evaporation from open water. Simulation was carried out for the period 1961-1990 with a time step of one day. Appendix IV contains a comparison of open water evaporation estimates per river basin (in mm/yr) according to the different data sources used.

Although for the basins of Loukkos, Sebou, Bouregreg and Oum Er Rbia reservoir areas are known at different water levels, for reasons of consistency, the surface area of reservoirs at upper storage level is taken as a starting point for all basins. Since storage levels vary throughout the year (and over the years), and reservoir areas accordingly, assuming upper storage levels would give an overestimation of the evaporation from reservoirs. Therefore, but due to lack of data on monthly storage levels and associated reservoir areas, for all months a fraction of the evaporation at upper storage level (43%) is taken as estimate of the WF of storage reservoirs. This fraction represents the average reservoir area as fraction of its area at upper storage level, calculated as the average over the reservoirs in the basins of Loukkos, Sebou, Bouregreg and Oum Er Rbia for which data on surface area at different reservoir levels are available from Ministry EMWE (2013c).

2.4. Water footprint of irrigation supply network

The WF of the irrigation supply network refers to the evaporative loss in the network and is estimated based on a factor K, which is defined as the ratio of the blue WF of the irrigation supply network to the blue surface WF of crop production at field level (i.e. crop evapotranspiration of irrigation water stemming from surface water). K is calculated as (see Appendix I for the derivation of the formula and a clarifying figure):

$$K = \left[\frac{1}{e_a \times e_c} - \frac{1}{e_a} \right] \times f_E$$

in which e_a represents the field application efficiency, e_c the irrigation canal efficiency and f_E the fraction of losses in the irrigation canal network through evaporation (as opposed to percolation), assumed at 50%. The efficiencies e_a and e_c are estimated based on data from ABH Sebou (2011) and FAO (2013a) (Table 2).

Table 2. Field and conveyance efficiencies in Morocco's irrigation supply network.

	Type of irrigation				Weighted efficiency*
	Surface	Sprinkler	Localized	Spate	
Field application efficiency	70%	85%	90%	70%	73%
Conveyance efficiency	80%	90%	90%	100%	82%
Scheme irrigation efficiency	56%	77%	81%	70%	60%
% in total area equipped for irrigation	81%	10%	7%	2%	

* Weighted average of the irrigation efficiencies according to the area equipped with a specific irrigation type in the total area equipped for irrigation in Morocco. Since the efficiencies used are targets to be achieved with the national irrigation water saving programme, the estimate can be regarded as conservative for the current situation. Sources: irrigation efficiencies from ABH Sebou (2011); area equipped for irrigation from FAO (2013a).

The resultant K for Morocco's irrigated agriculture as a whole is 15%, i.e. the evaporative loss from the irrigation water supply network represents a volume equal to 15% of the blue surface WF of crop production at field level on average. Figure 2 shows how the irrigation water conveyance network looks like in the Tadla region in the Oum Er Rbia basin. The blue WF of crop production at field level is taken from Mekonnen and Hoekstra (2010b) and the part related to surface water is estimated based on the fraction of irrigation water withdrawn from surface water (as opposed to groundwater) per river basin based on data from the associated river basin plans (Appendix II).

Figure 2. Primary (A) and secondary (B) irrigation channels in the Oum Er Rbia basin on the plains of Tadla.

2.5. Economic water and land productivity

The WF of crops per unit of production (in m³/ton) is calculated by dividing the annual WF per hectare (in m³/ha) by the annual yield (in ton/ha), using data from Mekonnen and Hoekstra (2011). Economic water productivity, the economic value of farm output per unit of water consumed (in US$/m³), is calculated as the average producer price for the period 1996-2005 (in US$/ton) obtained from FAO (2013d) divided by the green plus blue WF (in m³/ton). Similarly, economic land productivity, the economic value of farm output per hectare of harvested land (in US$/ha), is calculated as the producer price multiplied by crop yield (in ton/ha). Producer prices reported by FAO (2013d) are the prices received by farmers for primary crops as collected at the farm gate or first point of sale. Since no producer price for dates is available for Morocco, an average producer price for dates is taken based on data for Algeria (1,02 US$/ton) and Tunisia (1,01 US$/ton).

2.6. Virtual water flows and associated economic value

Green, blue and grey virtual water flows related to Morocco's import and export of agricultural and industrial commodities for the period 1996-2005 are obtained from Mekonnen and Hoekstra (2011), who estimated these flows at a global scale based on trade matrices and WFs of traded products at the locations of origin. The total virtual water export partially originates from domestic resources and partially from foreign resources (re-export). The virtual water export that originates from domestic resources is estimated based on the relative share of the virtual water import to the total water budget:

$$V_{e,dom.res.} = \frac{WF_{national}}{V_i + WF_{national}} \times V_e$$

in which $WF_{national}$ is the WF within the nation, V_i the virtual water import and V_e the virtual water export. The equation is applied separately for agricultural and industrial products. Within the first category the formula is applied separately for the main export commodities and further per crop category.

The average earning per unit of water exported (in US$/m³) is calculated by dividing the value of export (in US$/yr) by the virtual water export (in m³/yr). Similarly, the cost per unit of virtual water import is calculated by dividing the import value (in US$/yr) by the virtual water import (in m³/yr). Both are calculated separately for crop, animal and industrial products and for specific crop products associated with large virtual water trade volumes. The average economic values of imports and exports for the period 1996-2005 are derived from the SITA database from the International Trade Centre (ITC, 2007), which covers trade data from 230 reporting countries disaggregated by product and partner countries and has also been used by Mekonnen and Hoekstra (2011) to estimate the international virtual water flows.

2.7. Water footprint in the context of water availability and waste assimilation capacity

To assess the environmental sustainability of the WF within Morocco, the monthly blue WF (the sum of the net abstractions from surface- and groundwater) in each river basin is compared to the monthly natural runoff (surface water plus groundwater) in the basin. In addition, in order to specifically evaluate the sustainability of groundwater consumption, the annual ground-WF (the net abstraction from groundwater) is compared to the annual groundwater availability. Furthermore, the nitrogen-related grey WF (the water needed to assimilate the nitrogen fertilizers that reach groundwater due to leaching) is compared with the waste assimilation capacity of aquifers.

The ground-WF is calculated from the total blue WF of crop production, industrial production and domestic water supply based on the fraction withdrawn from groundwater per river basin as provided by the river basin plans (Appendix II). It is assumed that the return flows from the groundwater abstracted for the industrial and domestic sectors return to the surface water system, not to the groundwater. Thus, while the return flows from these sectors are not considered as consumptive water use (blue WF) from an overall water resources point of view, they can be regarded as consumptive use from the groundwater system perspective. Therefore, for the evaluation of the sustainability of groundwater consumption, the ground-WF of the industrial and domestic sectors is taken equal to groundwater withdrawals for these sectors.

Monthly historical runoff series (1939-2011) (later referred to as ‘series’) for the basins of Oum Er Rbia, Bouregreg, Sebou and Loukkos are obtained from Ministry EMWE (2013b). The series represent actual inflow per sub-catchment as received from the river basin agencies. Only small-scale withdrawals upstream of these points are subtracted from natural inflow. Large-scale withdrawals for irrigation are not subtracted from the inflow figures, since these are withdrawn from the reservoirs at the downstream end of the sub-catchments.

Natural runoff is therefore considered equal to the actual inflow series, which are also taken as estimate of surface water availability in the river basin plans. Generally, environmental flow requirements are not considered in Morocco's river basin plans and local studies on the minimum flows Moroccan rivers require to sustain aquatic and riparian ecosystems, and the livelihoods that depend on them, are lacking. Therefore environmental flow requirements are not subtracted from natural runoff in this study either. Monthly natural runoff for the four river basins is calculated by summation of the monthly inflows of the sub-catchments. Subsequently, a long-term average of these monthly inflows is taken for the period 1980-2011. In Morocco, a significant decrease in water availability is observed since the eighties. However, the chosen period is considered to represent the current climate and as an appropriate context for the WF estimates over the period 1996-2005.

The long-term average annual runoff in the basins of Bouregreg, Oum Er Rbia and Sebou, derived from the monthly historical runoff series, does not differ significantly from the figures mentioned in the corresponding river basin plans (ABH Bouregreg et de la Chaouia, 2012; ABH Oum Er Rbia, 2011; ABH Sebou, 2011). For the Loukkos basin, however, there is a large discrepancy. ABH Loukkos (2011) estimates the average annual runoff at 3,600 Mm^3/yr for the period 1945-2010, while the series used in this study give an average annual runoff of 2,113 Mm^3/yr for the same period. The series used exclude some small Mediterranean basins in the east of the action zone of the river basin agency of Loukkos, but their runoff is relatively small (<230 Mm^3/yr) according to ABH Loukkos (2011). The reason of the discrepancy remains unclear. Therefore the blue water resources in the Loukkos basin might be underestimated. The historical runoff series for the basin of Oum Er Rbia excludes the runoff in the Atlantic coast basins south of the watershed from the Oum Er Rbia river, but within the action zone of the river basin agency of Oum Er Rbia, the unit of analysis in this study. In the river basin plan of this agency, the water availability in these coastal basins is estimated to be 40 Mm^3/yr (ABH Oum Er Rbia, 2011). This volume is added to the long-term average runoff in the Oum Er Rbia basin and distributed over the months according to the variation of the originally obtained series. Although the long-term average annual runoff for the basins of Sebou and Bouregreg from the series used in this study does not significantly differ from the figures mentioned in the corresponding river basin plans, their natural runoff might be slightly underestimated. The series for Sebou exclude a part of the coastal area (also excluded in surface water availability assessment in the river basin plan of Sebou (ABH Sebou, 2011)) and the plains of Berrechid and Chaouia south of Casablanca in the Bouregreg basin are excluded in the series for Bouregreg. Net precipitation in these areas is thus not accounted for.

Monthly historical runoff series are not available for the river basins of Moulouya, Souss Massa, Sud Atlas and Tensift. Alternatively, annual natural runoff in the basins is obtained from the corresponding river basin plans (ABH Moulouya, 2011; ABH Souss Massa Draa, n.d.a; ABH Souss Massa Draa, n.d.b; ABH Tensift, 2011; Direction de la Region Hydraulique du Guir Rheris Ziz, 2012) and subsequently distributed over the months according to different sources:

- For Moulouya, annual natural runoff relates to the period 1981-2003 and is distributed according to mean monthly precipitation over the period 1971-2005 obtained from Tekken and Kropp (2012).

- For Sud Atlas, annual natural runoff is calculated as the sum of the annual natural runoff in the basins of Draa, Guir-Ziz-Rhéris-Maîder and the North-Eastern region Zousfana and relates to different periods, but all within the time span of 1970-2010. Distribution over the months is according to mean monthly precipitation over the period 1973/75-1994 in the basins of Ziz-Rhéris obtained from Riad (2003).
- For Tensift, annual natural runoff relates to the period 1980-2010 and is distributed according to the average monthly natural discharge of the river Tensift and its tributaries within the period 1970-2006 obtained from JICA, MATEE and ABHT (2007).
- For Souss Massa, annual natural runoff relates to the period 1971-2007 and is distributed according to the same temporal variation as for the Tensift basin, due to lack of data. The basin of Tensift is considered most comparable with the basin of Souss Massa, since both are located in the Middle/South of Morocco and their streams spring from the High (and Anti) Atlas and discharge into the Atlantic Ocean.

Groundwater availability is defined by Hoekstra *et al*. (2011a) as the rate of groundwater recharge minus the fraction of natural groundwater outflow required to sustain environmental flow requirements in the river. As discussed previously, environmental flow requirements are not considered in this study. In this study, groundwater availability is assessed on river basin scale and defined as the recharge by infiltration of rainwater and from rivers, minus the direct evaporation from aquifers. Underground connections between aquifers are not included to avoid double counting. In most of the river basin plans the mentioned fluxes are given per aquifer and groundwater availability is calculated as defined. For the basins of Draa, Guir-Ziz-Rhéris-Maîder (both part of Sud Atlas basin in this study) and Souss Massa these fluxes are not available. Instead, for the basin of Souss Massa, data on aquifer recharge by infiltration of rainwater and streams are obtained from Laouina (2001). For the Sud Atlas basin, groundwater availability is taken as the sum of available groundwater in the basins Draa and Guir-Ziz-Rhéris-Maîder and the North-Eastern region Zousfana. For the latter region, above mentioned fluxes are available and groundwater availability is calculated according to the above definition. The terms used to indicate the groundwater resources in the river basin plans of Draa and Guir-Ziz-Rhéris-Maîder are taken as estimate of the groundwater availability in these basins. However, different terms are used and no clear definition is given. The river basin plan of Draa speaks of exploitable resources (ABH Souss Massa Draa, n.d.a), whereas the plan for the rivers Guir-Ziz-Rhéris-Maîder speaks of renewable resources (Direction de la Region Hydraulique du Guir Rheris Ziz, 2012). The latter probably comes close to the definition of groundwater availability in this study. The exploitable resources can be smaller than the natural water availability due to political, social, economic or environmental constraints (FAO, 2003). Some aquifers cross the border between action zones of river basin agencies and are included in both river basin plans. These are the aquifers of Bahira and Haouz underneath the Tensift and Oum Er Rbia basins and the aquifer of Chaouia côtière underneath the Bouregreg and Oum Er Rbia basins (Appendix III). Table 3 shows how the groundwater availability in these aquifers is accounted to the river basin action zones. The estimate of the groundwater availability for these aquifers is based on data in the river basin plan of the agency that contains the major part of the aquifer.

Table 3. Aquifers underlying different river basin agency action zones.

Name of aquifer crossing hydrological border (double-counted in river basin plans)	Major part of aquifer in basin of	Minor part of aquifer in basin of
Chaouia côtière	Bouregreg (~90%)	Oum Er Rbia (~10%)
Bahira	Tensift (~75%)	Oum Er Rbia (~25%)
Haouz	Tensift (~80%)	Oum Er Rbia (~20%)

Percentages are estimated based on map in Appendix III.

Blue water scarcity is defined per catchment as the ratio of the blue WF to the blue water availability (Hoekstra *et al*., 2011a). In this study, blue water scarcity for the water system as a whole is calculated per river basin per month as the ratio of the monthly blue WF to the monthly natural runoff. The blue water scarcity for the groundwater system in particular is calculated per river basin on an annual basis as the ratio of the annual ground-WF to the annual groundwater availability. Blue water scarcity manifests itself on a monthly scale, but varying groundwater stocks throughout the year do not have to be problematic as long as annual withdrawals remain far below annual recharge. Following Hoekstra *et al*. (2012), blue water scarcity values have been classified into four levels of water scarcity. The classification in this study corresponds with their classification, with the note that the current study does not account for environmental flow requirements in the definition of blue water availability, since they are generally not considered in Morocco's river basin plans and local studies on environmental flow requirements are lacking. This is compensated for by using stricter threshold values for the different scarcity levels, so that the resultant scheme is equivalent to that of Hoekstra *et al*. (2012):

- low blue water scarcity (<0.20): the blue WF is lower than 20% of natural runoff; river runoff is unmodified or slightly modified.
- moderate blue water scarcity (0.20-0.30): the blue WF is between 20 and 30% of natural runoff; runoff is moderately modified.
- significant blue water scarcity (0.30-0.40): the blue WF is between 30 and 40% of natural runoff; runoff is significantly modified.
- severe water scarcity (>0.40): the monthly blue WF exceeds 40% of natural runoff, so runoff is seriously modified.

The water pollution level is defined as the total grey WF in a catchment divided by the waste assimilation capacity, whereby actual runoff is taken as a measure of the latter (Hoekstra *et al*., 2011a). The water pollution level thus shows the fraction of actual runoff that is required to dilute pollutants in order to meet ambient water quality standards. A water pollution level beyond 1 means that ambient water quality standards are violated. The nitrate-related grey WF of crop production as computed in this study is assumed to mostly contribute to groundwater pollution (because of the leaching of fertilizers) and is therefore compared with the waste assimilation capacity of groundwater. As a measure of the latter, we use the actual groundwater availability, calculated as (natural) groundwater availability minus the ground-WF.

2.8. Partial relocation of crop production and benchmarking water productivities

The potential water savings by changing the pattern of crop production across river basins (which is possible due to spatial differences in crop water use) are quantified by means of an optimization model. The total green plus blue WF of twelve main crops in the country (in Mm^3/yr) is minimized by changing the spatial pattern of production (in ton/yr) over the river basins under constraints for production demand (in ton/yr) and land availability (in ha/yr). The analysed crops are five annual crops (barley, maize, sugar beets, tomatoes and wheat) and seven perennial crops (almonds, dates, grapes, olives, oranges, sugar cane, mandarins). Results are compared with a base case, which corresponds with the average green plus blue WF of the analysed crops over the period 1996-2005. Land availability is restricted per river basin and taken equal to the average harvested area in the period 1996-2005 obtained from Mekonnen and Hoekstra (2010b). The input data and base case are recorded in Appendix VIII. Two cases are distinguished: 1) all twelve crops mentioned above can be relocated; 2) only the five annual crops can be relocated. For both cases, the restriction is imposed that the total national production per crop (in ton/yr) should be equal to (or greater than) the total national production of the crop in the base case, which is defined as the average production in the period 1996-2005 obtained from Mekonnen and Hoekstra (2010b).

Additionally, an assessment is made of the potential water savings by reducing the WFs of the twelve main crops down to certain benchmark levels. For each basin and crop a benchmark is set in the form of the lowest water consumption (green plus blue) of that crop which is achieved in a comparable river basin in Morocco. In this case, basins are considered comparable when the reference evapotranspiration (ET_0 in mm/yr) is in the same order of magnitude (Table 4). Reference evapotranspiration expresses the evaporating power of the atmosphere and does not consider crop characteristics and soil factors (Hoekstra *et* al., 2011a). Differences in soil and development conditions are thus not accounted for.

Table 4. Comparison of river basins based on reference evapotranspiration (ET_0). Period 1961-1990.

No.	River basin	ET_0 (mm/yr)	Considered comparable with river basin no.
1	Sud Atlas	1,652	-
2	Souss Massa	1,450	3
3	Moulouya	1,409	2
4	Tensift	1,389	5
5	Oum Er Rbia	1,387	4
6	Sebou	1,266	7,8
7	Bouregreg	1,239	6,8
8	Loukkos	1,212	6,7

Source: ET_0 from FAO (2013e).

2.9. Evaluating the added value of Water Footprint Assessment for national water policy in Morocco

In order to assess whether WFA provides new insights and response options in addition to the existing water management plans in Morocco, the results and conclusions from the WFA are compared with the scope of analysis of and action plans included in Morocco's national water strategy (Ministry EMWE, 2011) and river basin plans (ABH Bouregreg et de la Chaouia, 2012; ABH Loukkos, 2011; ABH Moulouya, 2011; ABH Oum Er Rbia, 2011; ABH Sebou, 2011; ABH Souss Massa Draa, n.d.a; ABH Souss Massa Draa, n.d.b; ABH Tensift, 2011; Direction de la Region Hydraulique du Guir Rheris Ziz, 2012). A summary of the action plans in the national water strategy is provided in Appendix IX. The action plans in the river basin plans conform to the national water strategy.

3. Water Footprint Assessment for Morocco

3.1. Water footprint of national production

The total WF within Morocco in the period 1996-2005 was 38.8 Gm³/yr (Table 5). Crop production is the largest contributor to this total, accounting for 78% of all green water consumed, 83% of all blue water consumed (evaporative losses in the irrigation water supply network included) and 66% of the total volume of polluted water. Evaporative losses from storage reservoirs are estimated at 884 Mm³/yr, which is 13% of the total blue WF within Morocco. For most reservoirs, these losses are ultimately linked to irrigated agriculture and in some cases potable water supply.

Table 5. Water footprint of Morocco's production (in Mm³/yr). Period: 1996-2005.

Water footprint of	Period	Green	Blue	Grey	Total	% of total
Crop production [a)]	1996-2005	23,245	5,097	1,378	29,719	77%
Grazing [a)]	1996-2005	6,663	-	-	6,663	17%
Animal water supply [a)]	1996-2005	-	151	-	151	0%
Industrial production [a)]	1996-2005	-	18	69	88	0%
Domestic water supply [b)]	1996-2005	-	125	640	765	2%
Storage reservoirs [b)]	-	-	884	-	884	2%
Irrigation water supply network [b)]	1996-2005	-	549	-	549	1%
Total water footprint	1996-2005	29,908	6,824	2,087	38,819	100%
% of total		77%	18%	5%	100%	

Sources: [a)] Mekonnen and Hoekstra (2011); [b)] Own elaboration.

The green, blue and grey WF per river basin and the variation in the green and blue WF throughout the year are shown in Figures 3 and 4, respectively. These figures exclude the WF of grazing and animal water supply, since these values are only available as annual national aggregates. For more spatial detail, see Appendix V, where the green, blue, grey and total WF of production are shown on a 5 by 5 arc minute grid scale.

The largest WFs (green, blue and grey) are found in the basins of Oum Er Rbia and Sebou, the basins containing the main agricultural areas of Morocco. Together, these two basins account for 63% of the total WF of national production. In general, the green WF is largest in the rainy period December-May, while the blue WF is largest in the period April-September when irrigation demands increase.

In the basins of Bouregreg and Loukkos, evaporation from storage reservoirs accounts for 45% and 55% of the total blue WF, respectively (Table 6). Irrigated agriculture is the largest blue water consumer in the other basins, but evaporation from storage reservoirs is also significant in these basins. Main irrigated crops in the Oum Er Rbia basin are maize, wheat, olives and sugar beets, which together account for 60% of the total irrigation water consumed in the period 1996-2005. In the basin of Sebou, 56% of the blue WF of crop production relates to the irrigation of wheat, olives, sugar beets, sugar cane and sunflower seed.

Inter-basin water transfers from the Oum Er Rbia basin to the basins of Bouregreg (91 Mm³/yr) and Tensift (212 Mm³/yr) add up to a volume of 302 Mm³/yr (ABH Oum Er Rbia, 2011). Since this volume of water is transferred out of the Oum Er Rbia basin, it is a blue WF within this basin, although not included in the presented WF figures. The transferred volume compares to 12% of the total blue WF of activities within the Oum Er Rbia basin (2,478 Mm³/yr).

Table 6. Blue water footprint within each river basin per purpose (in Mm³/yr). Period: 1996-2005.

River basin	Industrial production [a]	Domestic water supply [a]	Irrigation supply network [b]	Storage reservoirs [b]	Crop production [a]	Total	% of total
Bouregreg	4	25	2	113	105	249	4%
Loukkos	2	12	17	253	174	458	7%
Moulouya	2	12	40	42	334	430	6%
Oum Er Rbia	3	21	244	182	2,027	2,478	37%
Sebou	4	25	182	196	1,612	2,020	30%
Souss Massa	1	9	12	41	217	280	4%
Sud Atlas	1	9	17	52	194	273	4%
Tensift	2	11	36	5	433	486	7%
Total	18	125	549	884	5,097	6,673	100%
% of total	0.3%	1.9%	8.2%	13.3%	76.4%	100%	

Sources: [a] Mekonnen and Hoekstra (2011); [b] Own elaboration.

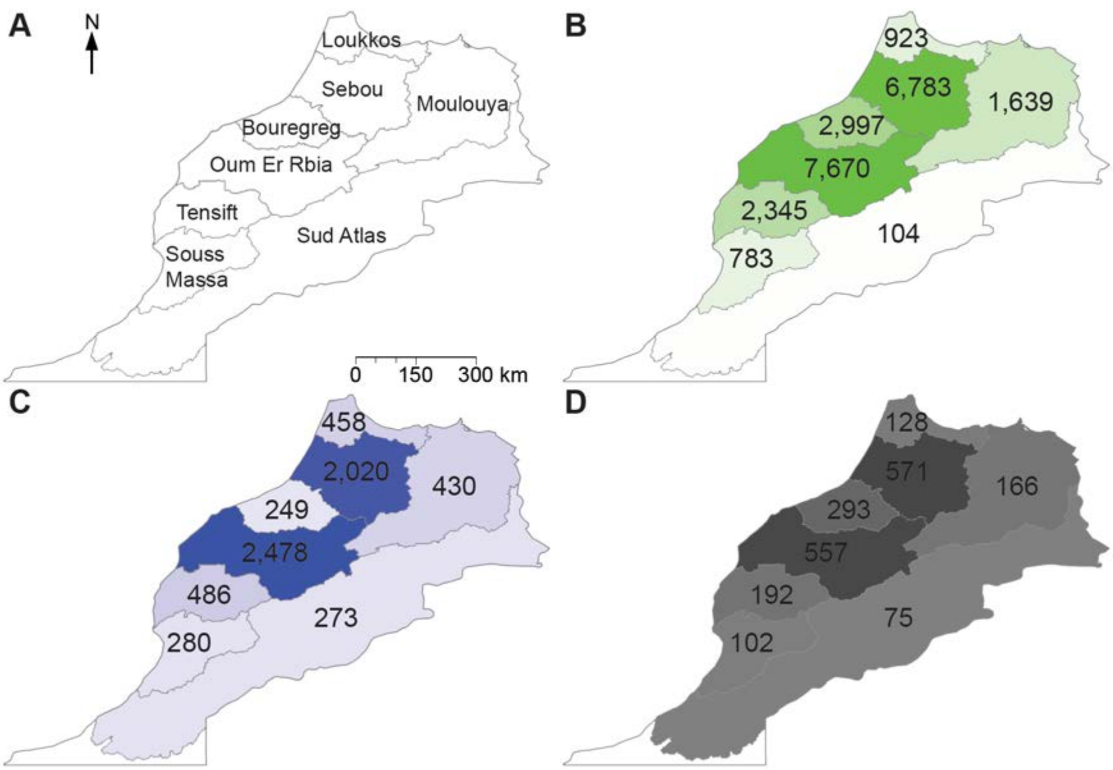

Figure 3. Morocco's river basins (A) and the green (B), blue (C) and grey (D) water footprint per river basin (in Mm³/yr). Period: 1996-2005.

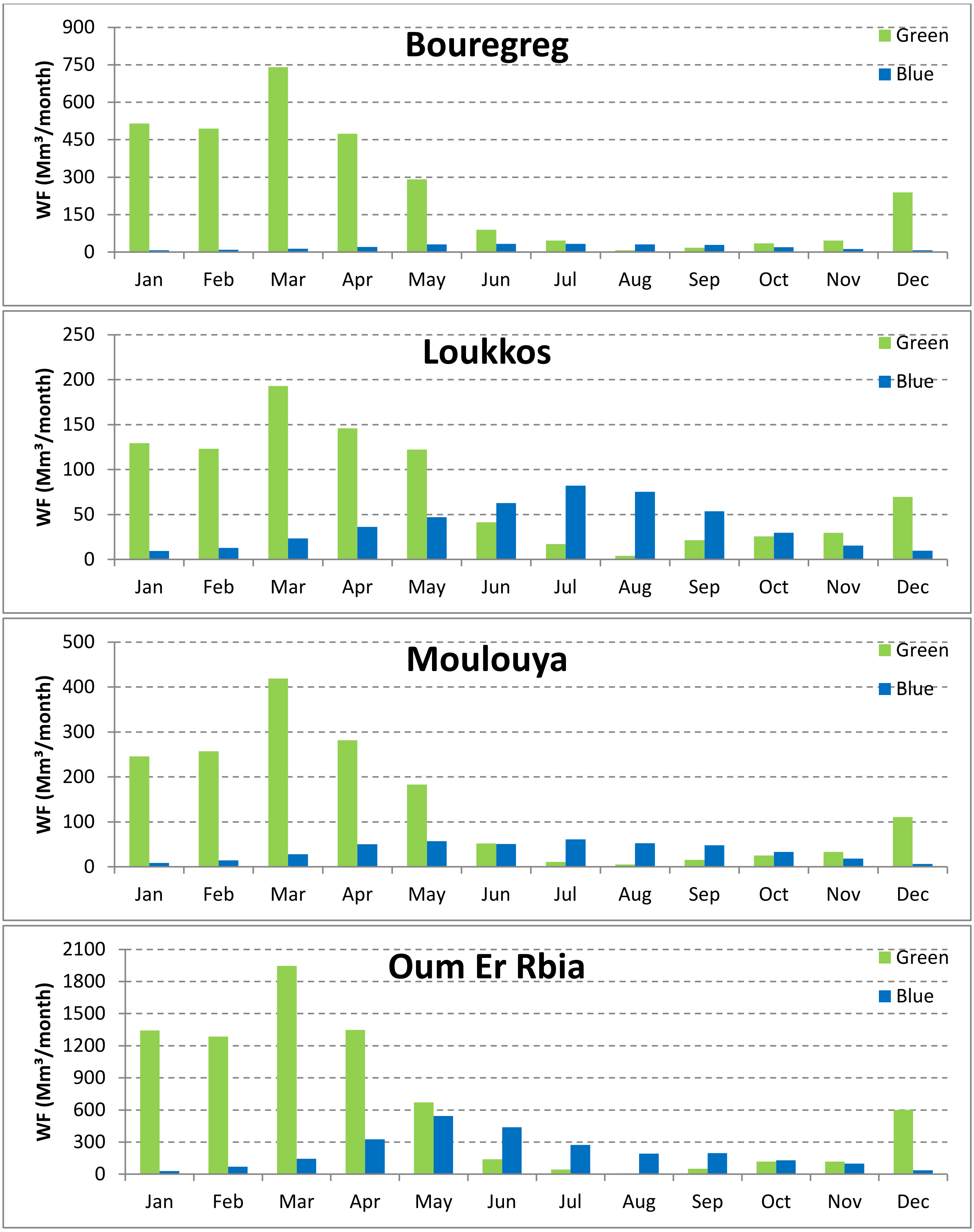

Figure 4. Monthly distribution of the green and blue water footprint per river basin (in Mm³/month).
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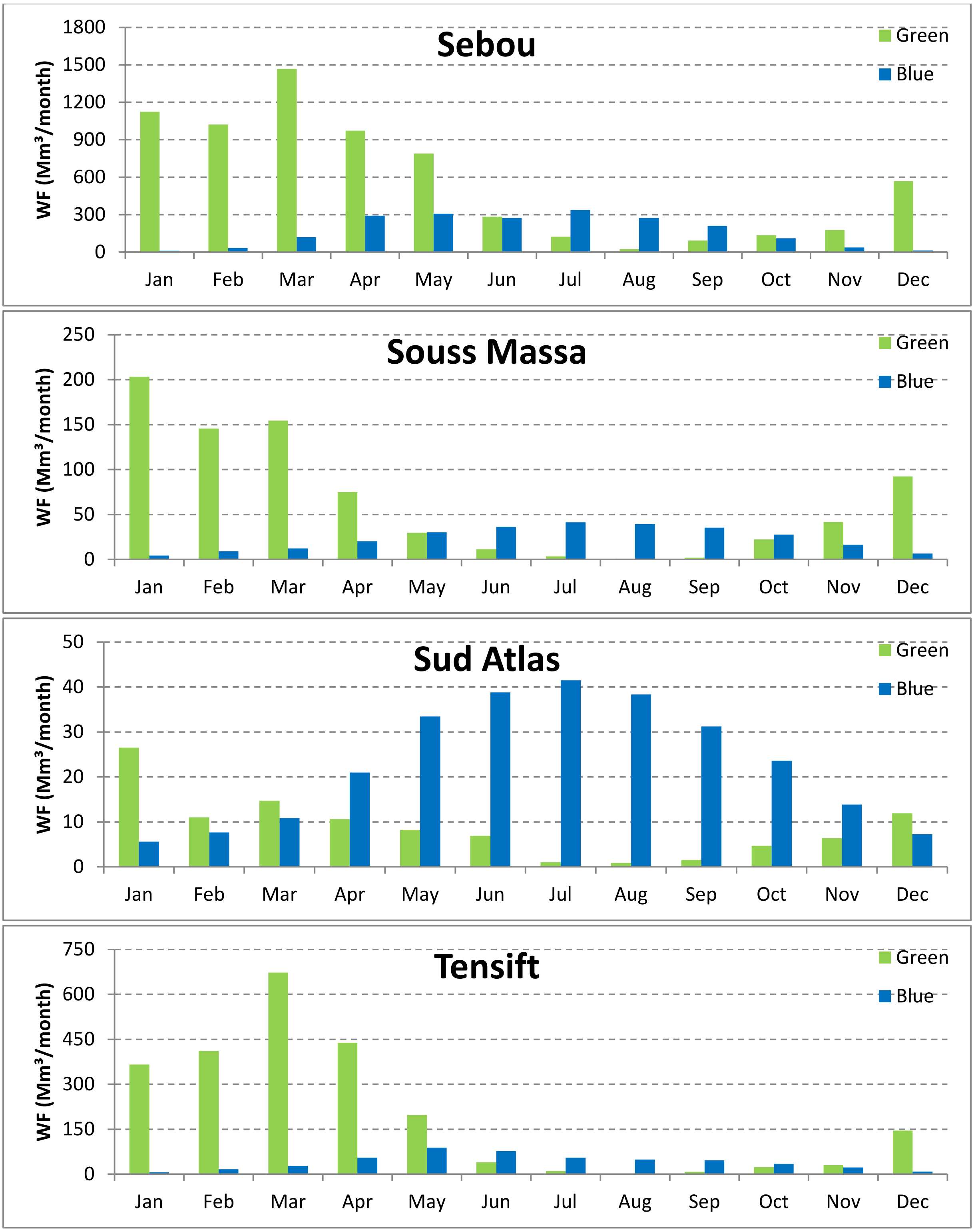

Figure 4 (continued). Monthly distribution of the green and blue water footprint per river basin (in Mm³/month).

3.2. Water footprint of main crops

The WF of crop production in the period 1996-2005 was 29,719 Mm^3/yr, of which 95% was consumed by crops (green and blue WF) and 5% was needed to assimilate the nitrogen fertilizers that reach the water systems due to leaching or runoff (grey WF). The WF per ton of production and its variation over the river basins is analysed for the top-ten of water consuming crops in the period 1996-2005 and for three additional crops / crop categories that play an important role in the Moroccan agricultural sector: sugar cane, tomatoes and the category of tangerines, mandarins, clementines and satsumas. The category of tangerines etc. and tomatoes are principal export products and sugar cane production forms a significant, well-organised sector (Ministry of Agriculture and Fisheries of Morocco, 2010).

In the period 1996-2005, most green water was consumed by the production of wheat, barley and olives (Figure 5). The largest blue WFs relate to the production of wheat, olives and maize. For wheat, the number-one blue water consuming crop, the blue WF is largest in the period March-May and peaks in April.

The country-average green plus blue WF of crops per ton produced is shown in Figure 6. Almonds, dates and maize consume most water per ton of production, followed by olives, barley and wheat. Blue water consumption is largest for dates, maize, olives, almonds and grapes. It should be noted that barley and fodder crops are completely rain-fed throughout the study area. Sugar beets are only grown in the basins of Oum Er Rbia, Bouregreg, Moulouya, Sebou and Loukkos. Sugar cane is only grown in the basins of Bouregreg, Moulouya, Sebou and Loukkos.

Due to differences in climatic conditions, water consumption of crops (in m^3/ton) varies significantly across river basins (Figures 7-8). In general, water consumption of crops is above country-average in the basins of Oum Er Rbia and Tensift and below country-average in the northern basins of Bouregreg, Sebou, Loukkos and Moulouya. In the basins of Sud Atlas and Souss Massa the picture is diverse. Barley, dates, fodder crops, maize and wheat consume significantly less water in the Sud Atlas basin compared to the average (up to 64% less for wheat), while the other crops consume more than average water in this basin. In the Souss Massa basin these crops (except for maize) also consume less water than average, while the other crops consume above average water. For all analysed crops, the blue/green water use ratio is above country-average in the Sud Atlas basin, even up to seven times more for the production of wheat. In other words, crops in the Sud Atlas basin receive relatively much irrigation water. Appendix VI includes data per river basin on the WF of crops in Mm^3/yr and m^3/ton.

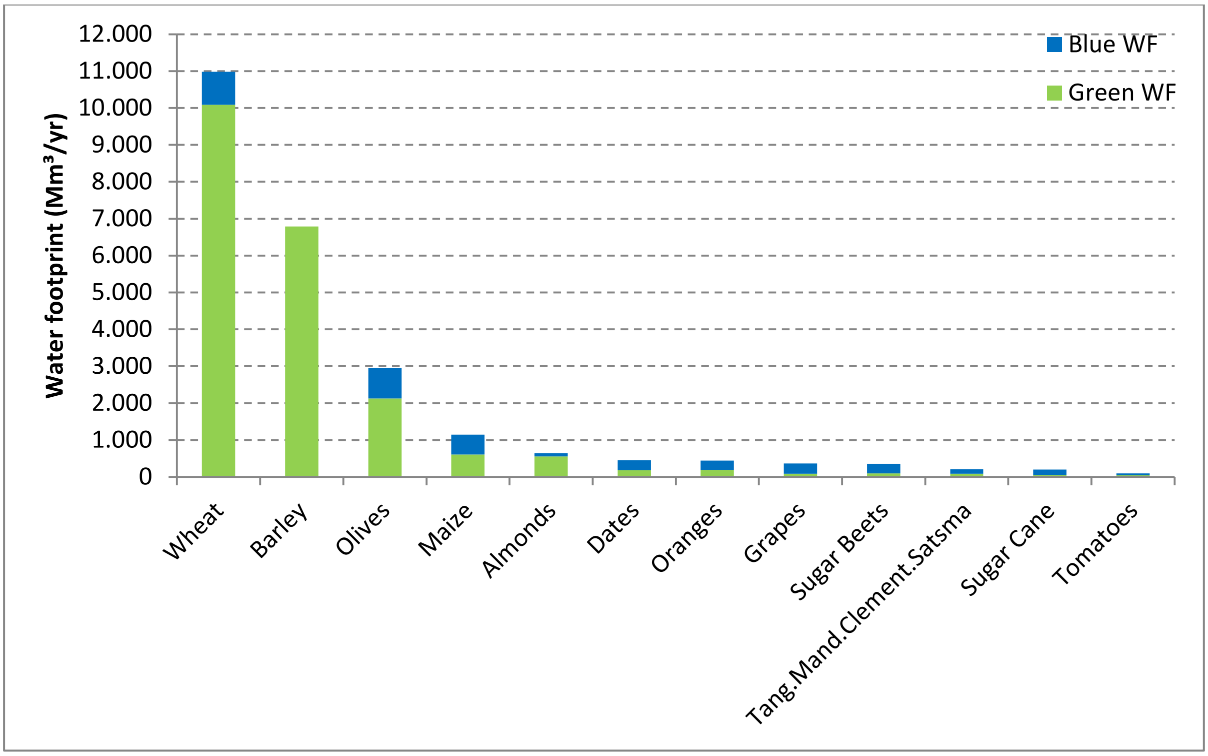

Figure 5. The water footprint of main crops in Morocco (in Mm³/yr). Period: 1996-2005. Data source: Mekonnen and Hoekstra (2010b).

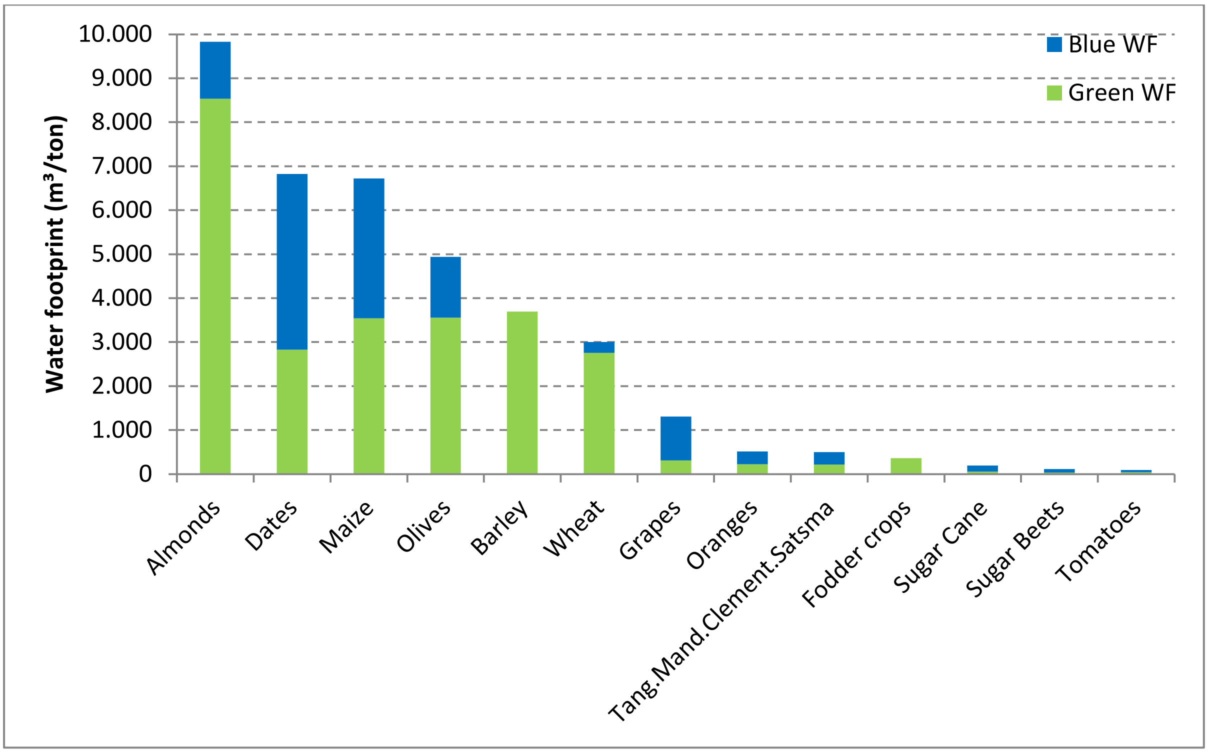

Figure 6. Country-average water consumption of main crops (in m³/ton). Period: 1996-2005. Data source: Mekonnen and Hoekstra (2010b).

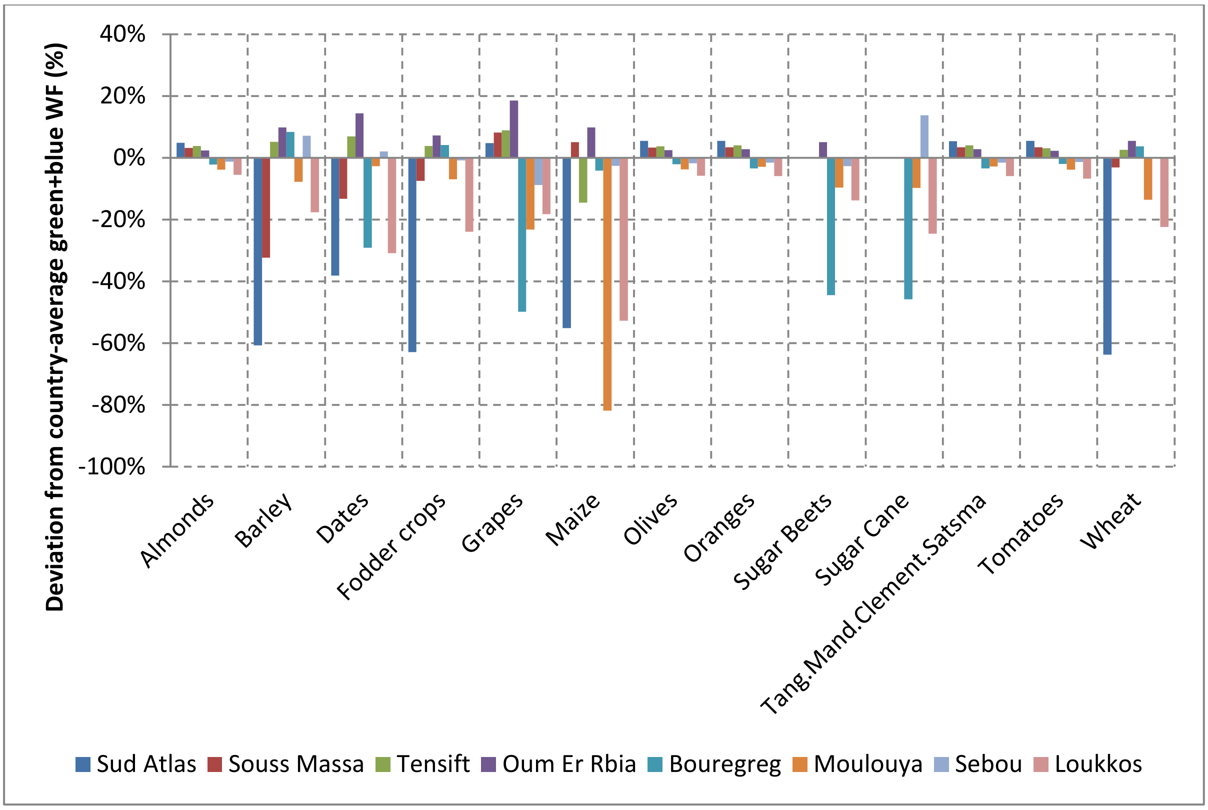

Figure 7. Variation in green plus blue water footprint (in m³/ton) across river basins. Period: 1996-2005.

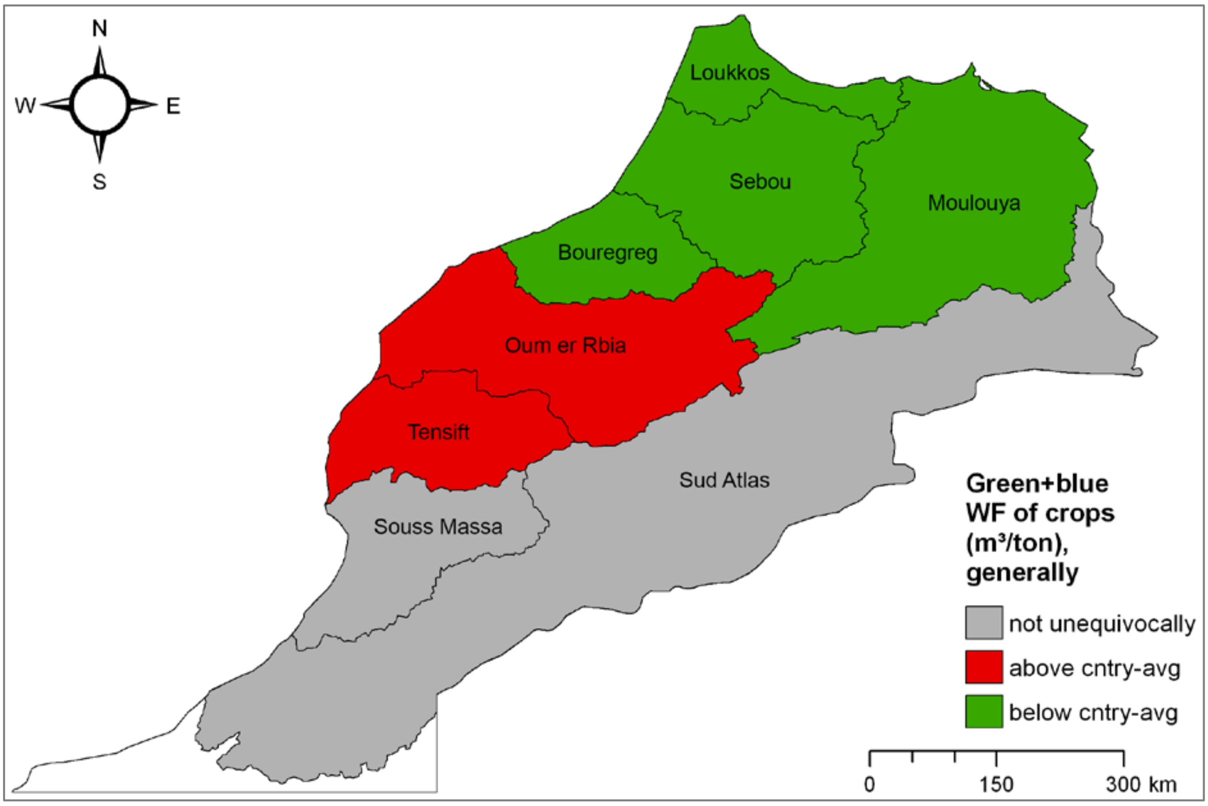

Figure 8. Green plus blue water footprint of main crops (in m³/ton) compared to the country-average.

3.3. Economic water and land productivity of main crops

Here, the value of the main crops analysed in the previous section is assessed per unit of water used for their production (economic water productivity – EWP) and per hectare of land harvested (economic land productivity – ELP). Fodder crops are excluded in this analysis, because no data are available on their producer price.

The five crops that consumed most green plus blue water in the period 1996-2005 are the crops with the lowest EWP, ranging from 0.08 US$/m³ for wheat to 0.02 US$/m³ for almonds (Figure 9). Grapes, sugar beets and citrus fruits (oranges and mandarins etc.) have higher economic value per drop, ranging from 0.26 US$/m³ for grapes to 0.54 US$/m³ for mandarins and others. Tomatoes consumed least water among the analysed crops, while they had the highest EWP (1.82 US$/m³). Production of tomatoes thus yielded 22 times more value per drop than production of wheat in the same period.

ELP is lowest for the five crops that take up the largest share in the harvested area in the period 1996-2005, ranging from 375 US$/ha for olives to 112 US$/ha for almonds (Figure 10). Sugar crops, dates, grapes and citrus fruits had higher ELP, but the highest value per hectare cultivated was obtained by production of tomatoes, namely 8,291 US$/ha, which is equivalent to 26 times the ELP of wheat in the same period. Moroccan tomatoes are largely grown in greenhouses (mainly in the Souss Massa basin) where yields are generally higher than when produced on open fields.

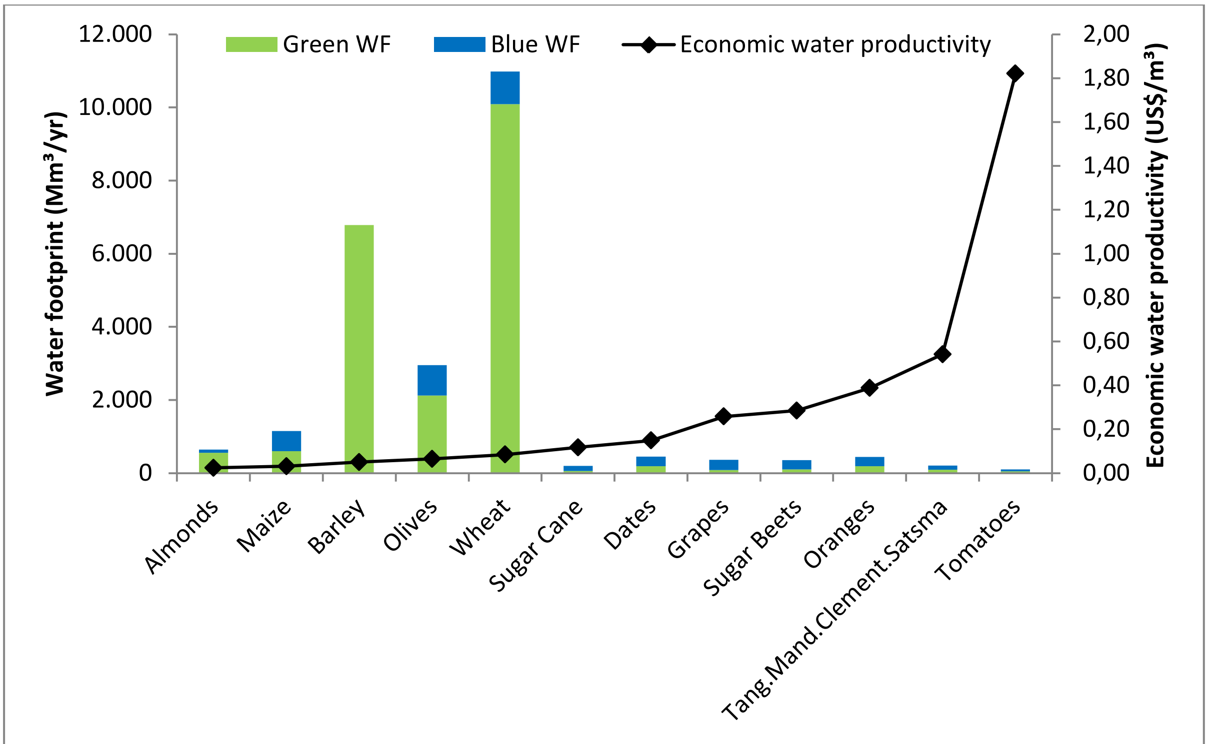

Figure 9. Economic water productivity (in US$/m³) and green and blue water footprint (in Mm³/yr) of main crops in Morocco. Period: 1996-2005. Sources: water footprint from Mekonnen and Hoekstra (2010b); producer prices from FAO (2013d).

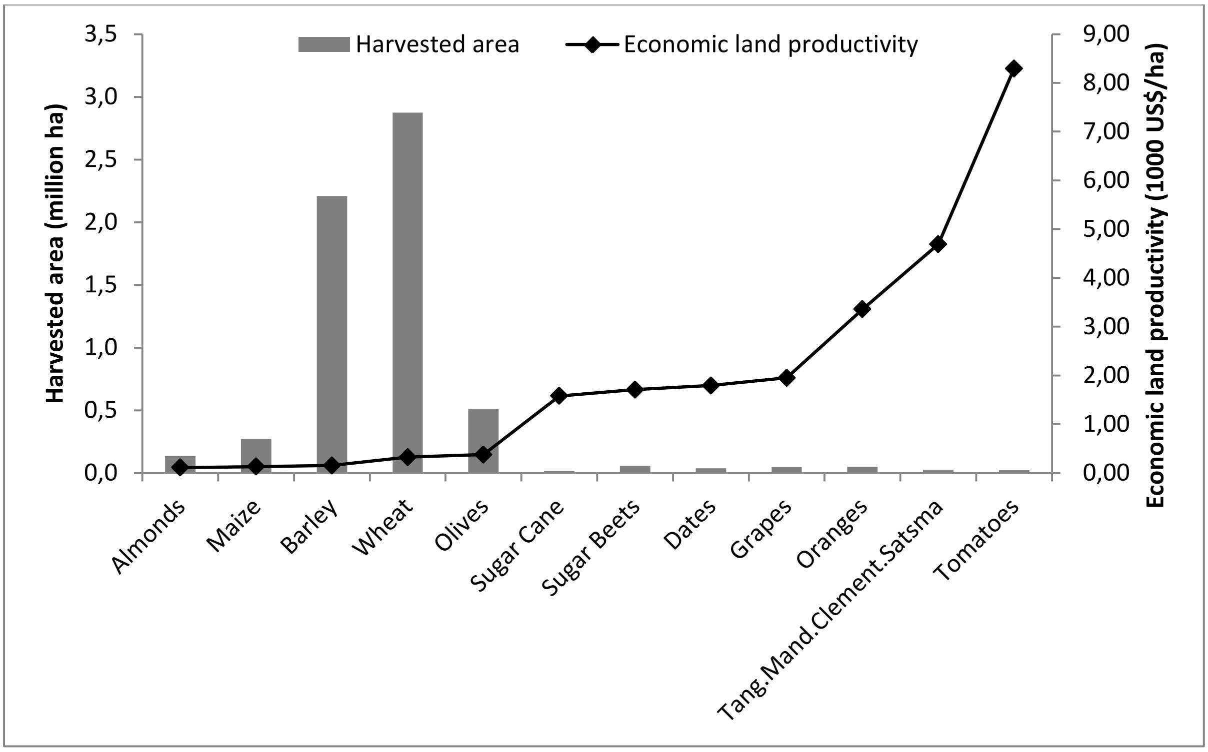

Figure 10. Economic land productivity (in US$/ha) and harvested area (in ha/yr) of main crops in Morocco. Period: 1996-2005.Sources: harvested area and yield from Mekonnen and Hoekstra (2010b); producer prices from FAO (2013d).

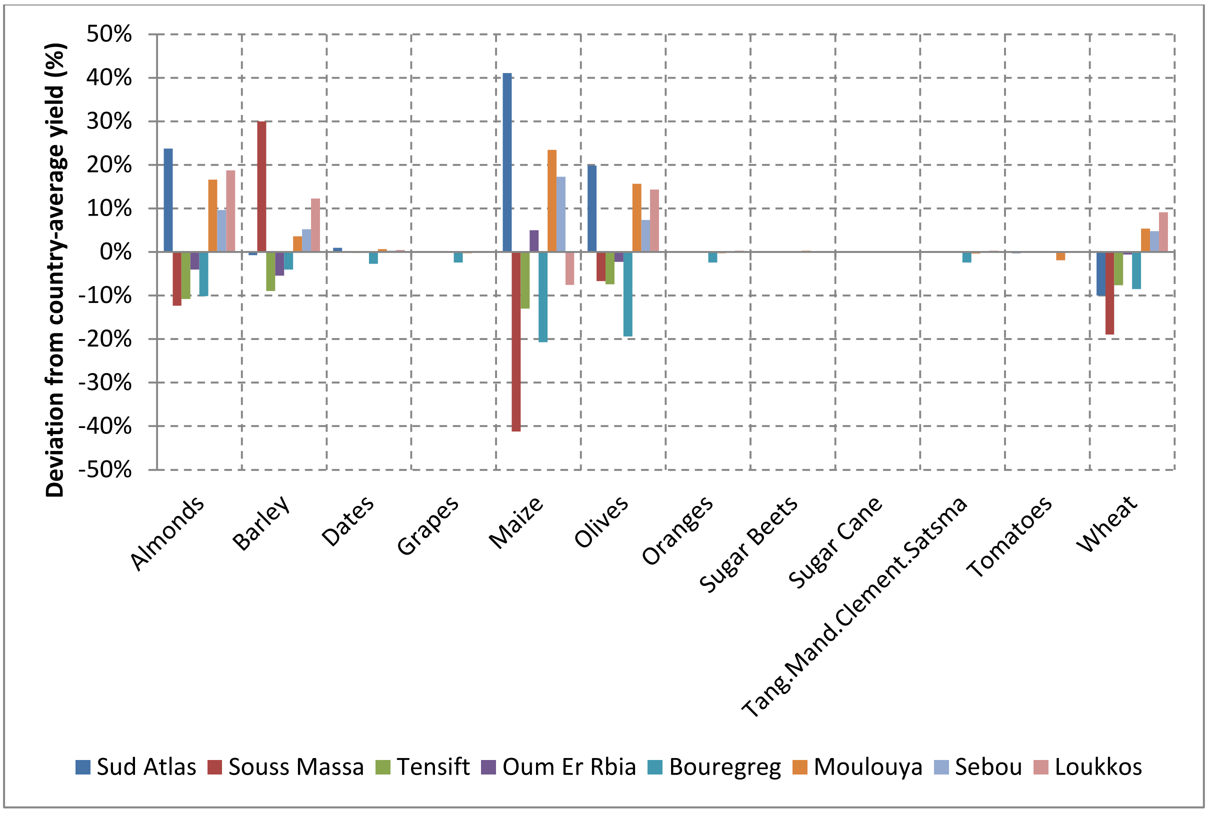

Figure 11. Variation in crop yield across river basins. Period: 1996-2005.

EWP of crops varies across the basins according to their water consumption (m³/ton) as discussed in section 3.2, being large in basins where water consumption is small and vice versa. ELP of crops varies across the basins analogue to differences in yield. Significant differences in crop yields across the basins are observed for almonds, barley, maize, olives and wheat (Figure 11). In general, yields (and thus ELPs) of these crops are above country average in the basins of Moulouya, Sebou and Loukkos and below country-average in the southern basins. However, this general picture is not unequivocally, in particular for the basins Sud Atlas and Souss Massa.

3.4. Virtual water trade balance and national water saving through trade

Morocco's virtual water trade balance over the period 1996-2005 is shown in Figure 12. Virtual water import exceeds export, which makes Morocco a net virtual water importer. About 31% of the virtual water export originates from Moroccan water resources; the remainder is related to re-export of imported virtual water.

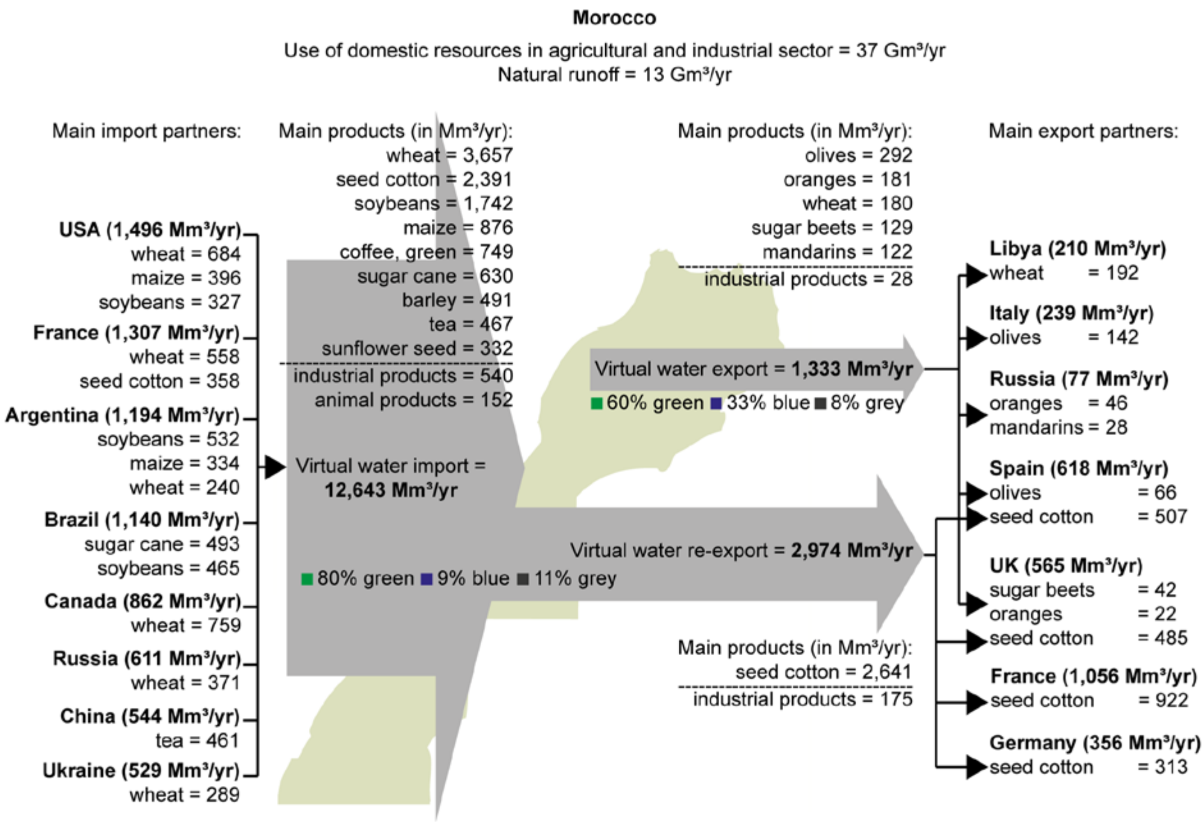

Figure 12. Morocco's virtual water trade balance related to trade in agricultural and industrial commodities. Period: 1996-2005. Data source: Mekonnen and Hoekstra (2011).

3.4.1. Morocco's virtual water import

Gross virtual water import over the period 1996-2005 was 12,643 Mm³/yr (80% green, 9% blue, 11% grey) (Table 7). Import of crop products contributes 95% to this total, while imports of animal and industrial products contribute 1% and 4%, respectively. The main countries from which Morocco imports virtual water are shown in Table 8. Imports from these countries together account for 61% of the total virtual water imported.

The total economic value of the imports in the period 1996-2005 was 12.4 billion US$/yr. Import of industrial products accounted for 83%, import of crop products for 16% and import of animal products for 1%. The average cost of imported commodities per unit of virtual water imported was 0.98 US$/m³.

The total economic value of crop products imported by Morocco was 1,975 million US$/yr. About 34% of the total cost of imported crop products is related to import of seed cotton products and 23% is related to the import of wheat products. Costs of seed cotton products imported are for 99.9% related to fabrics and textiles. The average cost of imported crop products per unit of virtual water imported was 0.17 US$/m³.

Import of crop products had the largest contribution to the total virtual water import. Imported crops associated with large virtual water import are shown in Table 9. Import of wheat products (mainly from Canada, US, France, Russian Federation, Ukraine and Argentina), seed cotton products (mainly from France, India, Spain, UK) and soybean products (mainly from Argentina, Brazil and the USA) together account for 65% of the total virtual water import related to crop products.

Table 7. Virtual water import and import expenditure. Period: 1996-2005.

	Related to crop products	Related to animal products	Related to industrial products	Total
Green (Mm³/yr)	9,964	119	-	10,083
Blue (Mm³/yr)	1,100	24	42	1,166
Grey (Mm³/yr)	888	9	498	1,394
Total (Mm³/yr)	11,951	152	540	12,643
Economic value of imports (million US$/yr)	1,975	125	10,329	12,429
Value per m³ imported (US$/m³)	0.17	0.82	19.14	0.98

Sources: virtual water imports from Mekonnen and Hoekstra (2011); economic value of imports from ITC (2007).

Table 8. Virtual water import from main trade partners (in Mm³/yr). Period: 1996-2005.

Country	Crop products	Animal products	Industrial products	Total	% of total
United States of America	1,481	1.7	13.4	1,496	12%
France	1,201	38.8	67.0	1,307	10%
Argentina	1,192	1.9	0.2	1,194	9%
Brazil	1,136	0.5	3.0	1,140	9%
Canada	858	2.1	2.0	862	7%
Russian Federation	486	0.3	124.7	611	5%
China	508	0.6	35.4	544	4%
Ukraine	497	0.6	31.2	529	4%
World total	11,951	152	540	12,643	100%

Source: Mekonnen and Hoekstra (2011).

Table 9. Crops associated with large virtual water import. Period: 1996-2005.

Products	Virtual water import related to crop products					Economic value (million US$/yr)	Value per m³ imported (US$/m³)
	Green (Mm³/yr)	Blue (Mm³/yr)	Grey (Mm³/yr)	Total (Mm³/yr)	% of total		
Wheat	3,279	69	309	3,657	31%	463	0.13
Seed cotton	1,500	722	168	2,391	20%	673	0.28
Soybeans	1,631	88	23	1,742	15%	218	0.13
Maize	708	39	129	876	7%	132	0.15
Coffee, Green	741	0	8	749	6%	36	0.05
Sugar cane	545	42	43	630	5%	141	0.22
Barley	422	8	61	491	4%	64	0.13
Tea	374	32	61	467	4%	69	0.15
Sunflower Seed	304	7	21	332	3%	36	0.11
Other	462	91	64	617	5%	144	0.23
Total	9,964	1,100	888	11,951	100%	1,975	0.17

Sources: virtual water imports from Mekonnen and Hoekstra (2011); economic value of imports from ITC (2007).

3.4.2. Morocco's virtual water export

Gross virtual water export over the period 1996-2005 was 4,307 Mm³/yr (36% green, 57% blue, 6% grey) (Table 10). Export of crop products contributed 91% to the total and exports of animal and industrial products 5% each. The total economic value of exports in the period 1996-2005 was 7.1 billion US$/yr. Export of industrial products accounted for 51%, export of crop products for 48% and export of animal products for 1%. The average earning of exported commodities per unit of virtual water exported was 1.66 US$/m³. The economic value of crop products exported by Morocco was 3.4 billion US$/yr. About 75% of the total earning of exported crop products is related to export of seed cotton products (almost completely in the form of fabrics and textiles). The average value of exported crops per unit of virtual water exported was 0.87 US$/m³. Exports of tomatoes, mandarins and seed cotton products returned an above average value per m³ exported. For tomatoes this was even 8 times the average for crop products.

Table 10. Virtual water export and export earnings. Period: 1996-2005.

	Related to crop products	Related to animal products	Related to industrial products	Total
Green (Mm³/yr)	1,399	171	-	1,570
Blue (Mm³/yr)	2,429	21	17	2,467
Grey (Mm³/yr)	78	5	186	270
Total (Mm³/yr)	3,906	197	203	4,307
Economic value of exports (million US$/yr)	3,418	47	3,674	7,138
Value per m³ exported (US$/m³)	0.87	0.24	18.07	1.66

Sources: virtual water exports from Mekonnen and Hoekstra (2011); economic value of exports from ITC (2007).

The countries shown in Table 11 together receive 81% of Morocco's total virtual water export. Table 12 shows the crop products associated with large virtual water export. Export of seed cotton products (mainly to France, Spain, UK and Germany) accounts for 68% of the total virtual water export related to crop products.

Table 11. Virtual water export to main trade partners (in Mm³/yr). Period: 1996-2005.

Country	Crop products	Animal products	Industrial products	Total	% of total
France	1,056	2.2	61.8	1,120	26%
Spain	618	7.6	26.4	651	15%
United Kingdom	565	0.0	17.3	582	14%
Germany	356	0.1	12.0	368	9%
Italy	239	8.8	9.9	258	6%
Libyan Arab Jamahiriya	210	25.8	1.5	237	6%
United States of America	144	0.0	9.6	153	4%
Belgium	127	0.1	7.3	134	3%
World total	3,906	197	203	4,307	100%

Source: Mekonnen and Hoekstra (2011).

Table 12. Crops associated with large virtual water export. Period: 1996-2005.

Products	Virtual water export related to crop products					Economic value (million US$/yr)	Value per m³ exported (US$/m³)
	Green (Mm³/yr)	Blue (Mm³/yr)	Grey (Mm³/yr)	Total (Mm³/yr)	% of total		
Seed cotton	652	1,992	0	2,645	68%	2,559	0.97
Olives	214	83	3	299	8%	31	0.10
Wheat	211	19	8	238	6%	4	0.02
Oranges	73	97	11	181	5%	152	0.84
Sugar beets	31	79	19	129	3%	5	0.04
Tang., mand. etc.	49	65	8	122	3%	168	1.37
Maize	12	11	1	12	1%	0	0.02
Tomatoes	10	11	3	10	1%	169	7.13
Other	147	71	26	244	6%	330	1.35
Total	1,399	2,429	78	3,906	100%	3,418	0.87

Sources: virtual water exports from Mekonnen and Hoekstra (2011); economic value of exports from ITC (2007).

Part of the total virtual water export is from Moroccan water resources, another part is re-exported from foreign resources (Table 13). The total volume of Moroccan water virtually exported out of the country is estimated at 1,333 Mm³/yr, which means that about 4% of the water used in the Moroccan agricultural and industrial sectors is used for making export products. The remainder is used to produce products that are consumed by the inhabitants of Morocco. Virtual export of blue water from Moroccan resources was 435 Mm³/yr, which is equivalent to 3.4% of Morocco's long-term average natural runoff (section 3.6). Specific crop products associated with large virtual water export from Moroccan origin are olives, oranges, wheat, sugar beets and mandarins. Only export of the latter returned a value larger than the average for crop products.

Table 13. Virtual water export from Morocco (in Mm³/yr). Period: 1996-2005.

Products		Export from Moroccan resources				Total re-export from foreign resources	Total
		Green	Blue	Grey	Total		
Agricultural products	Seed cotton	1	3	0	4	2,641	2,645
	Olives	209	81	2	292	7	299
	Wheat	160	14	6	180	58	238
	Oranges	73	97	11	181	0	181
	Sugar beets	31	79	19	129	0	129
	Tang.mand.clement.satsma	49	65	8	122	0	122
	Maize	7	6	0	14	10	24
	Tomatoes	10	11	3	24	0	24
	Perennials (excl. olives)	29	15	5	49	12	61
	Annuals (excl. tomatoes)	28	15	7	51	6	57
	Citrus fruits (excl. oranges and tang. mand. etc.)	1	1	0	2	0	3
	Pulses	22	2	6	31	3	34
	Other	177	41	8	226	61	287
	Total agricultural products	796	432	76	1,305	2,799	4,103
Industrial products		-	2	26	28	175	203
Total		796	435	102	1,333	2,974	4,307

Source: total virtual water export from Mekonnen and Hoekstra (2011).

3.4.3. Morocco's water savings related to trade

The national water saving of Morocco related to international trade is the volume of water that is saved by importing products instead of producing them domestically. In total, Morocco saved 27.8 Gm³/yr (75% green, 21% blue and 4% grey) by trade in agricultural and industrial products in the period 1996-2005 (Table 14). The total water saving is 72% of the WF within Morocco. The blue water saving is even 87% of the blue WF within Morocco. The majority of the green (99%), blue (100%) and grey (91%) water savings is related to trade in crop products. Wheat import from France resulted in a water saving for Morocco of 3.77 Gm³/yr (Mekonnen and Hoekstra, 2010a).

Table 14. National water saving of Morocco related to international trade (in Mm³/yr). Period: 1996-2005.

	Green	Blue	Grey	Total
Related to trade in crop products	20,542	5,920	971	27,434
Related to trade in animal products	256	15	5	277
Related to trade in industrial products	-	8	90	98
Total	20,798	5,944	1,066	27,808

Source: Mekonnen and Hoekstra (2011).

3.5. Water footprint of consumption and external water dependency

The WF of Moroccan consumption was 50.0 Gm³/yr (81% green, 12% blue, 6% grey) in the period 1996-2005, corresponding to 1725 m³/yr per capita (Mekonnen and Hoekstra, 2011). Only 1.5% of this WF is at home (16% blue, 84% grey). The remainder refers to indirect water use of the consumer: 97.5% of the WF of the Moroccan consumer relates to consumed agricultural products and 1% to industrial products. Consumption of cereals and animal products contribute 40% and 36%, respectively (Figure 13). The large consumption of cereals is the reason that they have the largest contribution in Moroccan crop production and are principal import products. Cereals are the main water consuming crops in Morocco and account for the largest virtual water import flows. The consumption of meat and dairy products contributes to the WF of Moroccan through the WF of animal water supply, but mainly through the WF related to the production of the feed that animals consume during their lifetime. Within Morocco, a vast amount of green water consumption is associated with the production of fodder crops and the pastures for livestock grazing (see sections 3.1-3.2).

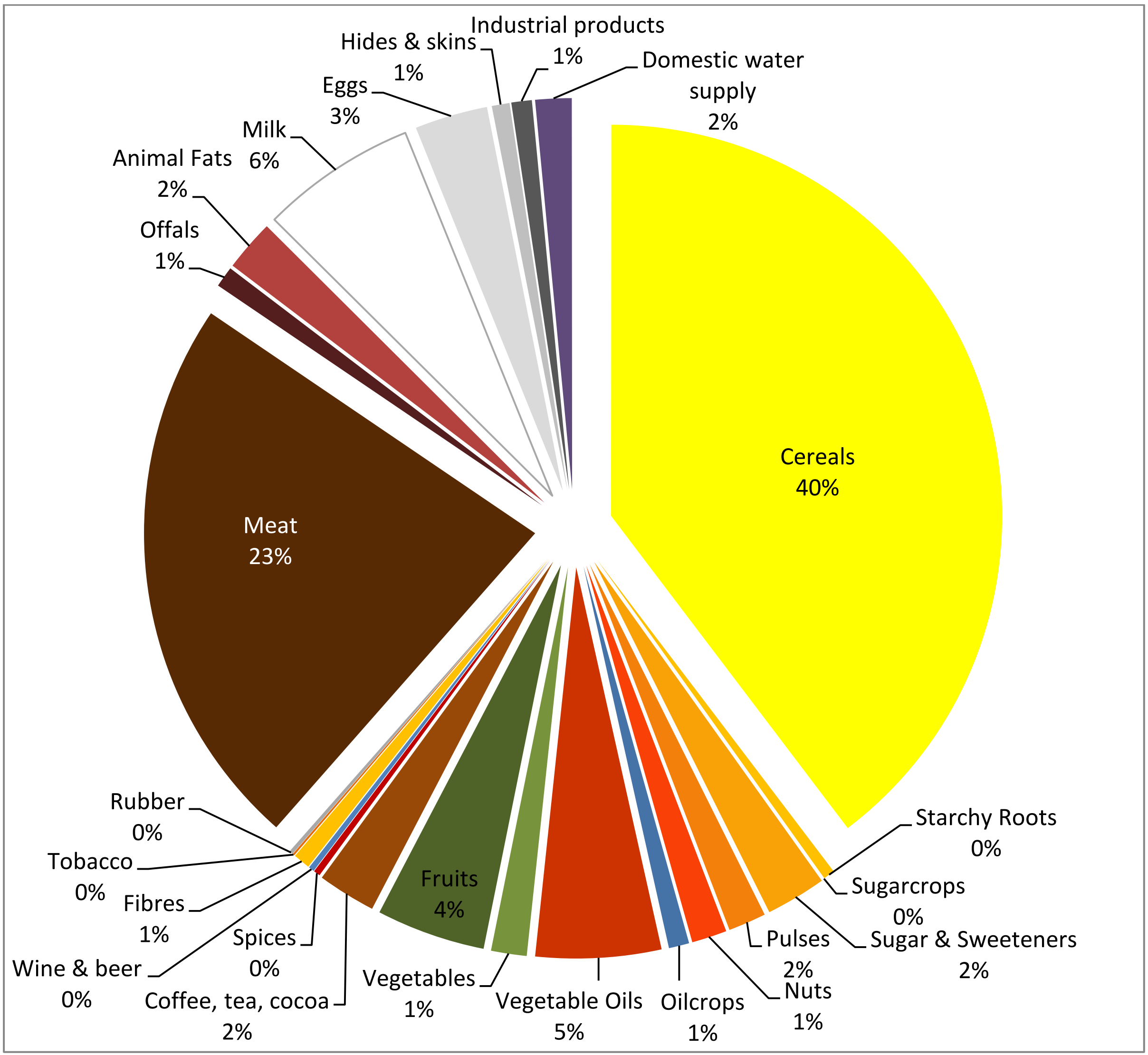

Figure 13. Composition of the water footprint of the average consumer in Morocco. Period: 1996-2005. Data source: Mekonnen and Hoekstra (2011).

Twenty-nine per cent of the WF of Moroccan consumption lies outside Moroccan territory. This external component is 14.6 Gm^3/yr (84% green, 7% blue and 8% grey). The internal component is 35.4 Gm^3/yr (80% green, 14% blue and 6% grey). The largest part of the external WF of Moroccan consumption lies in the United States, France, Argentina, Brazil, Canada, the Russian Federation, China and the Ukraine (see section 3.4.1). Morocco thus depends on the water resources in these countries.

3.6. Blue water footprint of production in the context of water availability

The annual rainfall volume in Morocco is estimated at about 150 billion m^3 (Ait Kadi, 2002; EMWIS, 2012; FAO, 2013c; Riad, 2003). The rainfall pattern has high inter- and intra-annual variability and is also heterogeneous in space (INECO, 2009; Hachimi, 2009). Average annual rainfall is over 1000 mm in the northern mountainous areas and less than 300 mm in nearly 85% of the country, namely in the basins Moulouya, Tensift, Souss-Massa, areas south of the Atlas mountains and the Saharan zone (Ministry EMWE, 2012b). Morocco's water resources are completely produced internally and no outflow is submitted to treaties (FAO, 2013c). Surface runoff is controlled by large reservoirs to cope with its large intra- and inter-annual variability. Currently, 130 reservoirs are in operation with a total water supply capacity of 17.5 billion m^3 per year (Ministry EMWE, 2011). Morocco's annual groundwater resources are estimated at about 4 billion m^3 and are spread over 96 aquifers of which 75 are surficial and 21 are deep aquifers (Ministry EMWE, 2011). So, about 21 billion m^3 per year is exploitable given storage sites (17 Gm^3/yr) and groundwater development (4 Gm^3/yr). However, long-term average natural (undepleted) runoff over the past approximately 30 years is lower, namely 13 billion m^3 per year. The inter-basin water transfers from Oum Er Rbia (302 Mm^3/yr) to the basins of Bouregreg (91 Mm^3/yr) and Tensift (212 Mm^3/yr) can be seen as additional water availability in the receiving basins and reduced availability in Oum Er Rbia, because the transfers are not included in the total blue WF presented here.

Blue water scarcity manifests itself on a monthly scale as shown in Figure 14, where the total blue WF is placed in the context of long-term average monthly natural runoff per river basin. As shown in Table 15, in each basin, except the basin of Sud Atlas, the monthly average water scarcity indicates severe water scarcity. The table also shows that when water scarcity is calculated on annual basis (annual blue WF divided by annual blue water availability), the outcomes mask the severe water scarcity that happens in all basins during a large part of the year. In all basins, the total blue WF exceeds natural runoff during a significant period of the year. In the months June, July and August severe water scarcity occurs in all river basins. Crops with a large blue WF in July are: sugar beets and dates in the basins of Oum Er Rbia and Sebou; sunflowers in the Sebou basin; maize in the Oum Er Rbia basin; and grapes in the basins of Sud Atlas, Souss Massa and Oum Er Rbia. Demand for potable water peaks in the period of June to August due to tourism. Evaporation from storage reservoirs is large in these months due to the strong evaporative power of the atmosphere. Annual runoff in the Oum Er Rbia basin is almost completely consumed (inter-basin water transfers not yet considered), which raises the question whether it is wise to export water out of this basin to the basins of Bouregreg and Tensift.

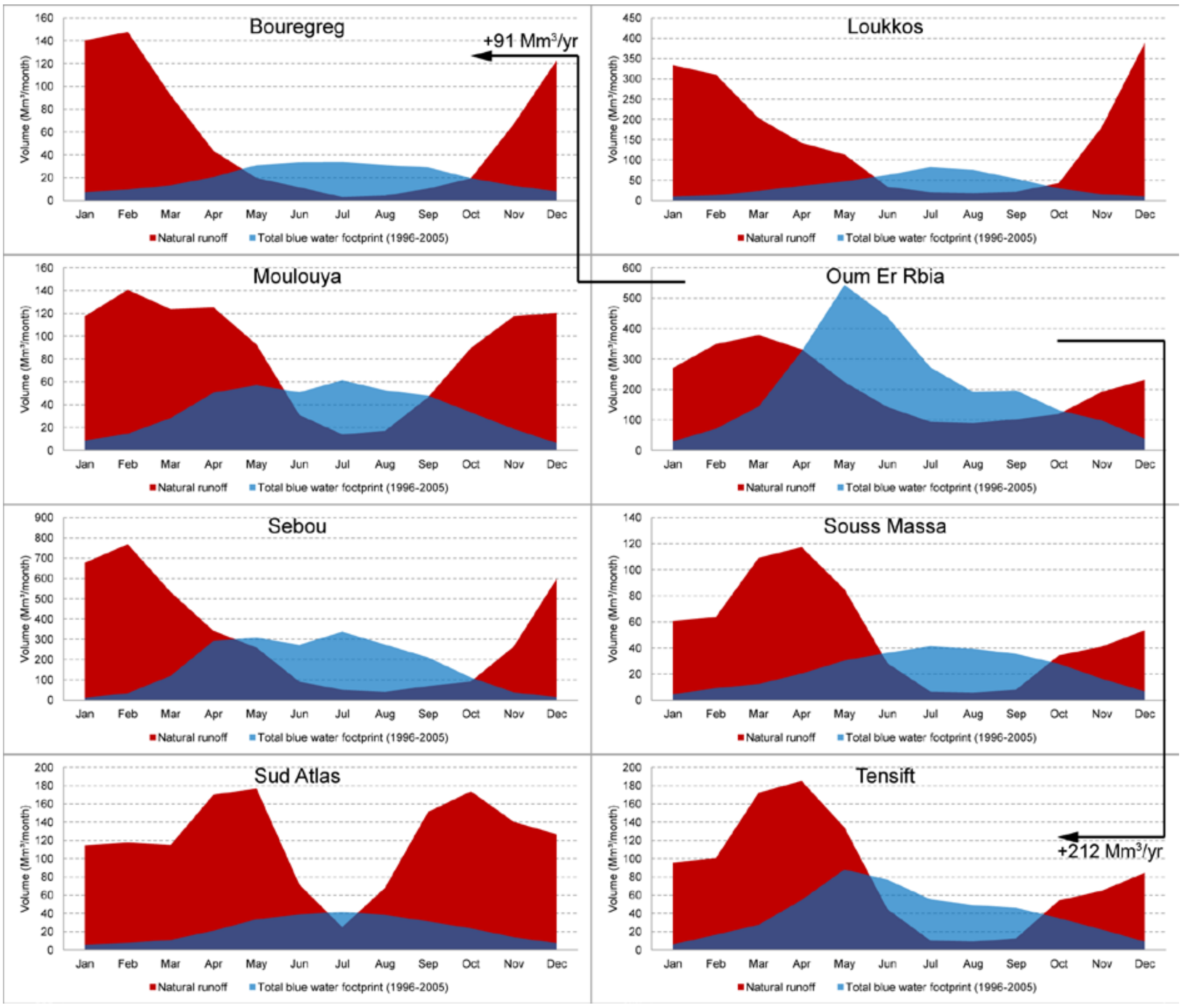

Figure 14. Total blue water footprint versus natural runoff per river basin and inter-basin water transfers (indicated by arrows). Natural runoff is estimated as the inflow of reservoirs (see section 2.7), which is considered undepleted runoff, since large-scale blue water withdrawals come from the reservoirs. The estimates can be considered conservative, because net precipitation in areas downstream of reservoirs is not included. Note that the natural runoff estimates here are significantly lower than the national renewable water resources as reported by FAO (2013c), which can partly be explained by the previous statement.

Table 15. Blue water scarcity per river basin.

River basin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg. monthly scarcity	Annual scarcity
Bouregreg	0.05	0.06	0.14	0.47	1.57	2.89	11.3	7.30	2.78	1.01	0.19	0.06	2.32	0.37
Loukkos	0.03	0.04	0.12	0.25	0.42	1.85	4.04	4.11	2.49	0.69	0.08	0.02	1.18	0.25
Moulouya	0.07	0.10	0.23	0.40	0.62	1.65	4.41	3.09	1.03	0.37	0.16	0.05	1.02	0.41
Oum Er Rbia	0.11	0.20	0.38	0.98	2.42	3.08	2.91	2.14	1.93	1.10	0.51	0.16	1.33	0.98
Sebou	0.02	0.04	0.22	0.86	1.19	3.01	6.66	6.72	3.05	1.21	0.14	0.02	1.93	0.53
Souss Massa	0.07	0.14	0.11	0.17	0.36	1.28	6.35	6.82	4.45	0.81	0.40	0.12	1.76	0.46
Sud Atlas	0.05	0.07	0.09	0.12	0.19	0.54	1.67	0.56	0.21	0.14	0.10	0.06	0.32	0.19
Tensift	0.06	0.16	0.16	0.29	0.66	1.72	5.39	5.40	3.66	0.64	0.34	0.11	1.55	0.50
Total	0.05	0.09	0.22	0.56	1.03	2.23	4.15	2.98	1.55	0.66	0.22	0.06	1.15	0.52

Blue water scarcity is defined as the ratio of the total blue water footprint in a catchment over the natural runoff in that catchment. Colour marking according to scarcity classification in section 2.7: low=green, moderate=yellow, significant=orange, severe=red.

The natural flow regime is a primary determinant of the structure and function of aquatic and riparian ecosystems for streams and rivers (Poff *et al*., 2010). Part of the natural runoff, with its temporal variation, needs to be maintained for the environment. Generally, environmental flow requirements are not considered in Morocco's river basin plans, nor are the effects of heavily modified natural flows. However, the Moulouya basin was subject to a project for the integration of aquatic biodiversity considerations in the planning of water management (IUCN, 2010). In the Moulouya basin, the water level is low in summer, which makes it difficult to maintain aquatic biodiversity (IUCN, 2010). Irregular release of water from dams also has negative impacts on the aquatic fauna and flora in the basin. IUCN (2010) warns for the desiccation of streams in the basin, which is partly caused by the natural cycle of drought, but aggravated by human abstractions. Minoia (2012) states ecosystem values were not considered in the construction of dams in the Sebou basin. Drainage of the wetlands has caused a loss of important habitats, which led to an impoverishment of biodiversity and ecosystem functions in the basin (Minoia, 2012). Although some wetlands are recognised as biological reserves, they are still threatened by decreasing inflows (Minoia, 2012). The effects of heavily modified river flows and stream desiccation on aquatic and riparian ecosystems, and the livelihoods that depend on these systems, require attention and local case studies should be carried out to map these effects.

3.6.1. Blue groundwater footprint in the context of groundwater availability

The ground-WF in the context of groundwater availability per river basin is presented in Figure 15 and Table 16. The total ground-WF in Morocco constitutes about half of the country's groundwater availability. Groundwater stress is severe in all river basins, except for the basins of Loukkos and Sud Atlas. In the Bouregreg basin, the annual ground-WF exceeds annual groundwater availability. As confirmed in the 2012 river basin plan for this basin (ABH Bouregreg et de la Chaouia, 2012), most of the aquifers in this basin are indeed overexploited, especially the main aquifers of Berrechid and Chaouia côtière. For the other basins, the assessment of inflow-outflow balances per aquifer (incl. withdrawals) in the corresponding river basin plans shows a different picture than obtained here, generally more severe. In Loukkos, these balances are al negative or around zero, although ABH Loukkos (2011) states there are no signs of overexploitation yet. Also in the basins of Oum Er Rbia, Sebou, Moulouya and Tensift most of the aquifers suffer from abstractions that exceed natural inflows, particularly the aquifers of Bahira and Haouz (ABH Moulouya, 2011; ABH Oum Er Rbia, 2011; ABH Sebou, 2011; ABH Tensift, 2011). The groundwater reserves in the Souss Massa basin are also seriously deteriorated (EMWIS, 2012). The picture shown here may be milder than what emerges from the river basin plans, because the ground-WF estimates relate to the period 1996-2005, while most balances in the river basin plans include more recent withdrawals, which are likely to be larger. Moreover, the unit of analysis in this study (river basin agency action zone) is larger than the unit used in the river basin plans (individual aquifers), whereby in this study overexploitation of one aquifer might be masked by lower exploitation of another.

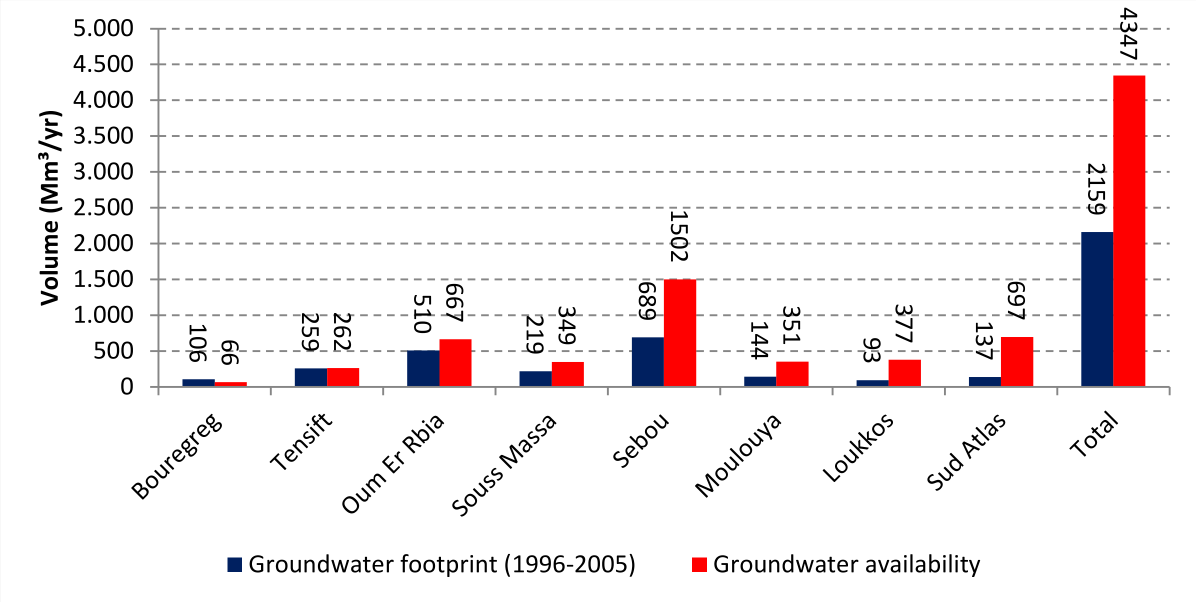

Figure 15.Groundwater footprint versus groundwater availability per river basin (in Mm³/yr). Basins are sorted from the left to the right from highest to lowest scarcity.

Table 16. Blue water scarcity related to groundwater.

River basin	Groundwater footprint (1996-2005) (Mm³/yr)	Groundwater availability (Mm³/yr)	Blue water scarcity (-)	Level of water scarcity
Bouregreg	106	66	1.60	Severe
Tensift	259	262	0.99	Severe
Oum Er Rbia	510	667	0.77	Severe
Souss Massa	219	349	0.63	Severe
Sebou	689	1,502	0.46	Severe
Moulouya	144	351	0.41	Severe
Loukkos	93	377	0.25	Moderate
Sud Atlas	137	697	0.20	Moderate
Total	2,159	4,347		

Basins are sorted top-down from highest to lowest scarcity.

3.7. Grey water footprint of crop production in the context of available waste assimilation capacity

The grey WF of crop production as reported in this study refers to the water needed to assimilate the nitrogen fertilizers that reach the water systems due to leaching or runoff, given an ambient (i.e. environmental) water quality standard of 10 mg/l of nitrate-nitrogen (NO_3-N). Leaching of nitrogen fertilizers to groundwater is assumed to dominate runoff to surface water, so that the grey WF mostly refers to the groundwater system. The available waste assimilation capacity is therefore assumed to equal the actual groundwater availability (natural groundwater availability as shown in Table 16 minus ground-WF). Figure 16 compares the grey WF of crop production to the actual groundwater availability per river basin. Table 17 shows the water pollution level per river basin.

The ground-WF exceeds groundwater availability in the Bouregreg basin, so there is no waste assimilation capacity left, which results in an infinite water pollution level. In the basins of Tensift and Oum Er Rbia waste assimilation capacity is also exceeded, even by 43 times the natural groundwater availability in the Tensift basin. Nitrate pollution of groundwater in these basins is indeed severe according to the river basin plans of these basins. The aquifers in the basin of Bouregreg are located in areas with intensive agriculture and suffer from diffuse nitrate pollution by the irrational use of nitrogen fertilizers, being worst in the aquifers of Chaouia côtière and Témara (ABH Bouregreg et de la Chaouia, 2007). Groundwater quality degradation by nitrates in the basin of Tensift is largest in the aquifers of Bahira and Essaouira (ABH Tensift, 2011). ABH Oum Er Rbia (2009) states that levels of nitrates exceed the maximum permissible limit in drinking water (50 mg/l), especially in the aquifers of Tadla, Bahira, Sahel-Doukkala and Turonian Tadla. The most contaminated areas are usually located at the base of the irrigated perimeters of Tadla and are the result of the intensive use of chemical fertilizers (ABH Oum Er Rbia, 2009). In the Sahel-Doukkala aquifer (near the Atlantic coast in the Oum Er Rbia river basin agency action zone) nitrate levels up to 100 mg/l were measured in 2004, caused by excessive use of chemical fertilizers, but also by the infiltration of untreated domestic wastewater from the various cities in the basin (ABH Oum Er Rbia, 2009). Also in the basins in which waste assimilation capacity is not yet fully consumed according to this study, nitrate pollution is locally severe according to the river basin plans. Part of the aquifers in the basins of Moulouya and Loukkos suffer from significant nitrate pollution (ABH Loukkos, 2011; ABH Moulouya, 2011). In the Sebou basin, 34% of the groundwater quality measuring stations indicates a very bad quality, again mainly due to nitrate pollution as a cause of heavy agricultural activity in the basin (ABH Sebou, 2011). Water pollution according to the river basin plans can be worse than the calculated water pollution levels in Table 17 suggest, because the water quality measurements recorded in these plans are partly more recent than the period considered in this study and they are measured at specific points, whereas this study estimates the average presence of nitrates in the groundwater.

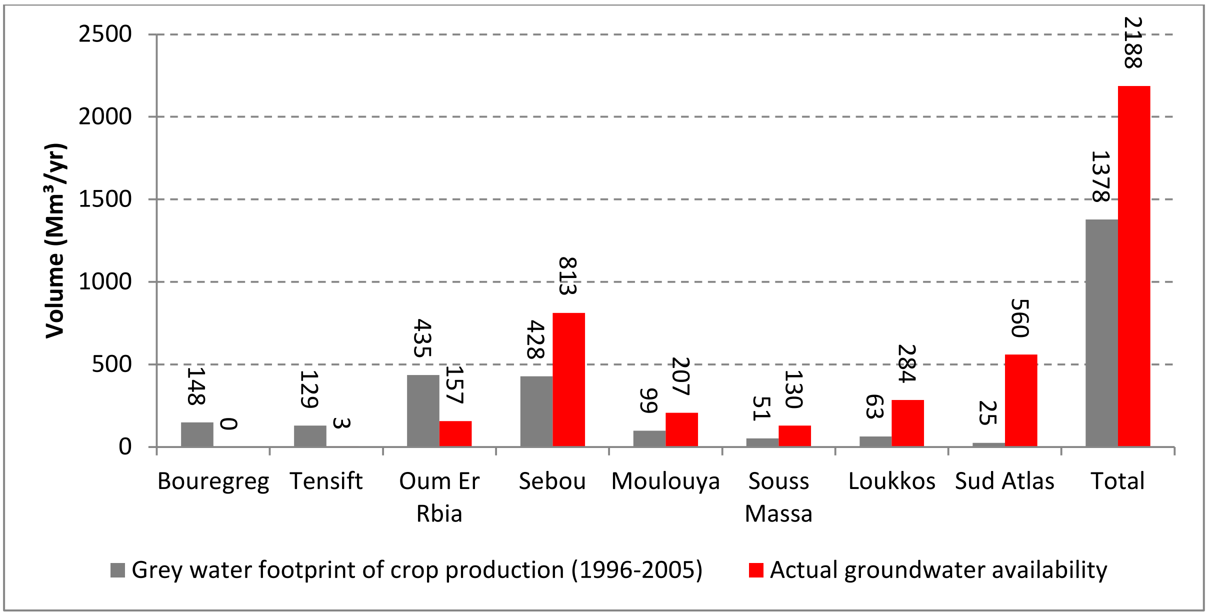

Figure 16. Grey water footprint of crop production versus actual groundwater availability (in Mm³/yr). Basins are sorted from the left to the right from highest to lowest water pollution level.

Table 17. Water pollution level related to nitrogen in groundwater.

River basin	Grey water footprint of crop production (1996-2005) (Mm^3/yr)	Actual groundwater availability (waste assimilation capacity) (Mm^3/yr)	Water pollution level (-)	Waste assimilation capacity exceeded?
Bouregreg	148	0	∞	Yes
Tensift	129	3	43.2	Yes
Oum Er Rbia	435	157	2.78	Yes
Sebou	428	813	0.53	No
Moulouya	99	207	0.48	No
Souss Massa	51	130	0.39	No
Loukkos	63	284	0.22	No
Sud Atlas	25	560	0.04	No
Total	1,378	2,188	0.63	No

Basins are sorted top-down from highest to lowest water pollution level. Source: Grey water footprint of crop production from Mekonnen and Hoekstra (2010b).

4. Response options

This chapter examines possible response options to alleviate water scarcity in Morocco. Firstly, options to reduce the WF of crop production (the largest contributor to the WF within Morocco) are considered and associated water savings are quantified (section 4.1). Secondly, the idea of establishing WF caps per river basin to limit increasing WFs in the already water-scarce basins of Morocco is discussed (section 4.2). Next, the possibility of allocating land and water resources to different crops is discussed, in order to see whether one can make more economically efficient use of these resources (section 4.3). Lastly, a discourse is provided about water scarcity and allocation in Morocco in relation to the country's virtual water trade balance (section 4.4).

4.1. Reducing the water footprint of crop production

As shown in section 3.1, crop production contributes most to the WF of national production. For the twelve crops that together constituted 87% of the total water consumption of crops in the period 1996-2005 (24.6 Gm^3/yr), the potential water savings are estimated by looking at three types of strategies: partial relocation of production across river basins (which is possible due to spatial differences in crop water use) (section 4.1.1), an overall improvement of water productivities (section 4.1.2) and benchmarking water productivity (section 4.1.3). The analysed crops are: almonds, barley, dates, grapes, maize, olives, oranges, sugar beets, sugar cane, mandarins etc., tomatoes and wheat.

4.1.1. Partial relocation of crop production across basins

Water consumption per ton of crop production varies across the different river basins of Morocco as shown in section 3.2. These regional differences in crop water use provide an opportunity for reduction of the WF of crop production by changing the spatial pattern of crop production within the country. Potential water savings by a partial relocation of crops are assessed for two different cases: harvested land of all twelve crops considered is interchangeable and restricted per river basin (case A); only annual crops (barley, maize, sugar beets, tomatoes and wheat) can be relocated, perennials cannot (case B). Summarised results are presented in Tables 18-20. A full overview of the input data, base case and results for the two alternative cases A and B is provided in Appendix VIII.

Potential water savings (green plus blue) are in the order of 1.9 and 1.2 Gm^3 per year in case A and B, respectively. Blue water savings are 1.3 Gm^3/yr in case A and 0.7 Gm^3/yr in case B. These are significant savings when put in the context of the actions plans in Morocco's national water strategy to mobilize 1.7 Gm^3/yr by 2030 through the construction of 60 large and 1000 small local dams and the North-South inter-basin water transfer of 0.8 Gm^3/yr.

Largest potential water savings can be obtained by partial relocation of the production of maize and wheat, particularly by moving maize production from the Oum Er Rbia basin to the Moulouya basin and wheat production from the Bouregreg basin to the basin of Sebou. Relocation of crop production in case A results in decreased WFs (green plus blue) in all basins, except for the basin of Bouregreg where the WF increases. In case B, the WFs in the basins of Bouregreg, Sebou and Loukkos increase, particularly due to increased wheat production in these basins, while the WFs in the other basins decrease. Precipitation in the basins of Sebou and Loukkos is generally larger than in other parts of Morocco (Ministry EMWE, 2011).

Though the total blue WF in Morocco decreases in both cases, it increases in some basins. The blue WF in the Bouregreg basin increases in both cases, even with almost one billion m^3 per year in case A. In case B, the blue WF also increases in the basin of Moulouya and slightly in the Sud Atlas basin. An increased blue WF in the Bouregreg basin is of serious concern. Although this basin is among the least water stressed on an annual scale, it is the most water stressed basin on a monthly scale, especially in July and August, and the annual ground-WF in the basin exceeds annual groundwater availability. River runoff in the Moulouya basin is also seriously depleted at the moment.

It should be noted that this optimization only looked at potential water savings on an annual scale. When considering relocation of crop production it is necessary to assess how the green and blue WFs of crops manifest themselves on a monthly scale. Since most crops consume more water during a specific time of the year (varying from crop to crop), an annual optimization of crop production allocation might well aggravate monthly water scarcity in some river basins. This is particularly relevant for blue water consumption, but it also important to assess whether green water resources (rain) are sufficient.

Table 18. Water savings by partial relocation of crop production per crop.

		Case A		Case B	
	Base case green plus blue water footprint (Mm^3/yr)	Saving (green+blue) (Mm^3/yr)	Relative saving (%)	Saving (green+blue) (Mm^3/yr)	Relative saving (%)
Almonds	641	14	2%	0	0%
Barley	6,787	-116	-2%	-202	-3%
Dates	449	131	29%	0	0%
Grapes	367	183	50%	0	0%
Maize	1,148	939	82%	939	82%
Olives	2,951	58	2%	0	0%
Oranges	440	15	3%	0	0%
Sugar beets	353	157	44%	157	44%
Sugar cane	200	91	46%	0	0%
Tang.mand.	209	7	3%	0	0%
Tomatoes	99	2	2%	2	2%
Wheat	10,981	413	4%	278	3%
Total	24,625	1,896	8%	1,174	5%

Table 19.Water savings by partial relocation of crop production per river basin.

		Case A		Case B	
	Base case green plus blue water footprint (Mm³/yr)	Saving (green+blue) (Mm³/yr)	Relative saving (%)	Saving (green+blue) (Mm³/yr)	Relative saving (%)
Sud Atlas	306	189	62%	12	4%
Souss Massa	903	175	19%	14	2%
Tensift	2,525	388	15%	124	5%
Oum Er Rbia	8,498	1,229	14%	821	10%
Bouregreg	2,813	-994	-35%	-95	-3%
Moulouya	1,737	605	35%	412	24%
Sebou	6,905	154	2%	-95	-1%
Loukkos	939	151	16%	-19	-2%
Total	24,625	1,896	8%	1,174	5%

Table 20. Blue water savings by partial relocation of crop production per river basin.

	Case A		Case B	
	in Mm³/yr	% of natural runoff	in Mm³/yr	% of natural runoff
Sud Atlas	144	10%	-1	0%
Souss Massa	157	26%	5	1%
Tensift	323	33%	115	12%
Oum Er Rbia	1,161	46%	769	30%
Bouregreg	-982	-144%	-175	-26%
Moulouya	85	8%	-58	-6%
Sebou	283	7%	38	1%
Loukkos	104	6%	4	0%
Total	1,276	10%	697	5%

4.1.2. Overall improvement of water productivities of crops

The WF of Moroccan crop production could be reduced by improving water productivities of crops (i.e. reducing WFs of crops). Currently, 80% of Morocco’s usable agricultural surface is occupied by traditional agriculture and only 20% is used for agriculture with modern technology (ADA, 2013). Therefore, water productivities of crops can probably easily be improved by 10 or 20 per cent by using more efficient techniques to reduce water use and/or improve yields. Room for improvement is also illustrated by comparison of the yields and WFs of the main water consuming crops in Morocco with these variables in other North African countries. For instance, average maize yields in the period 1996-2005 were 4 and 12 times higher in Algeria and Egypt than in Morocco, respectively (Table 21).

If a 10 or 20 per cent improvement in water productivity would be achieved for the twelve crops analysed, it would lead to the water savings recorded in Table 22. Obviously, largest potential water savings can be obtained by improving the water productivities of the main-water consuming crops (especially wheat and barley) in the main production areas. When the water productivities for the twelve crops are improved by 10% in all basins, the total green plus blue water saving is estimated at 2.5 Gm³/yr of which 0.37 Gm³/yr is blue water. Logically, water savings are double if productivities where to be improved by 20%.

Table 21.Comparison of yields and green plus blue water footprints for the four main water-consuming crops in Morocco with other North African countries. Period 1996-2005.

Crop	Country	Yield (ton/ha)	Times yield in Morocco	Green plus blue WF (m³/ton)	Times green plus blue WF in Morocco
Wheat	Morocco	1.27	1.0	10,981	1.0
	Algeria	1.15	0.9	3,355	0.3
	Egypt	6.23	4.9	1,118	0.1
	Tunisia	1.56	1.2	2,447	0.2
Barley	Morocco	0.83	1.0	6,787	1.0
	Algeria	1.13	1.4	2,859	0.4
	Egypt	2.58	3.1	2,314	0.3
	Tunisia	0.91	1.1	3,636	0.5
Olives	Morocco	1.17	1.0	2,951	1.0
	Algeria	1.41	1.2	4,279	1.4
	Egypt	6.78	5.8	1,922	0.7
	Tunisia	0.53	0.5	9,115	3.1
Maize	Morocco	0.63	1.0	1,148	1.0
	Algeria	2.69	4.3	964	0.8
	Egypt	7.51	12.0	1,219	1.1
	Tunisia	-	-	0	0.0

Source: data for Morocco from Mekonnen and Hoekstra (2010b); for other countries, yield data from FAO (2013d), water footprint data from Mekonnen and Hoekstra (2010b).

Table 22. Water savings by improving water productivities of main crops per river basin.

	Water productivity improved with 10%			Water productivity improved with 20%		
	Saving (green+blue) (Mm³/yr)	Saving (blue) (Mm³/yr)	Saving (blue) (% of natural runoff)	Saving (green+blue) (Mm³/yr)	Saving (blue) (Mm³/yr)	Saving (blue) (% of natural runoff)
Sud Atlas	31	19	1%	61	39	3%
Souss Massa	90	16	3%	181	31	5%
Tensift	252	32	3%	505	65	7%
Oum Er Rbia	850	151	6%	1,700	302	12%
Bouregreg	281	10	1%	563	19	3%
Moulouya	174	23	2%	347	46	4%
Sebou	690	108	3%	1,381	216	6%
Loukkos	94	12	1%	188	25	1%
Total	2,462	371	3%	4,925	743	6%

4.1.3. Reducing water footprints of crops to benchmark levels

According to Hoekstra (2013), based on the variability of WFs found across regions and among farms within regions, for all crops, certain benchmarks can be established that can act as a reference or target for all farmers that have WFs above the benchmark. Benchmarks can be defined as a certain WF that is achieved by the best 10 or 20 per cent of the producers or alternatively, as the WF associated with the 'best-available technology'.

Since water consumption of crops (in m^3/ton) varies across the different river basins of Morocco (as shown in section 3.2), it is worthwhile to develop reasonable benchmarks for the WF of crops within Morocco. Here, potential water savings are estimated when for each basin and crop WFs are lowered down to benchmarks. For each basin, benchmarks are set as the lowest water consumption of a specific crop that is achieved in a river basin in Morocco with comparable reference evapotranspiration (see Table 4, section 2.8). The green plus blue WF benchmarks are recorded in Table 23. The water savings when in each basin the WFs of the main crops are lowered down to these benchmarks are presented in Table 24.

The total green plus blue water saving is 2.8 Gm^3/yr, a reduction of 11%. Fifty-two per cent of this saving is related to improved water productivities in the Sebou basin alone. Largest potential water savings are associated with the benchmarking of the water productivities of cereals, especially wheat. Blue water savings are estimated at 0.42 Gm^3/yr and are largest in the basins of Sebou and Oum Er Rbia.

Table 23. Green plus blue water footprint benchmarks (in m^3/ton).

	Loukkos	Boure-greg	Sebou	Oum Er Rbia	Tensift	Moulou-ya	Souss Massa	Sud Atlas
Almonds	**9,295**	9,295	9,295	**10,061**	10,061	**9,450**	9,450	10,309
Barley	**3,043**	3,043	3,043	3,882	**3,882**	2,498	**2,498**	1,451
Dates	**4,716**	4,716	4,716	7,295	**7,295**	5,917	**5,917**	4,222
Grapes	655	**655**	655	1,420	**1,420**	**1,002**	1,002	1,366
Maize	**3,178**	3,178	3,178	5,746	**5,746**	**1,219**	1,219	3,015
Olives	**4,651**	4,651	4,651	**5,063**	5,063	**4,756**	4,756	5,209
Oranges	**487**	487	487	**532**	532	**502**	502	545
Sugar beets	65	**65**	65	**124**	-	**106**	-	-
Sugar cane	105	**105**	105	-	-	**175**	-	-
Tang.Mand.	**471**	471	471	**515**	515	**486**	486	528
Tomatoes	**89**	89	89	**97**	97	**92**	92	100
Wheat	**2,329**	2,329	2,329	3,079	**3,079**	**2,595**	2,595	1,088
ET_0 (mm/yr)	1,212	1,239	1,266	1,387	1,389	1,409	1,450	1,652

Column separators indicate which basins are considered comparable based on reference evapotranspiration (ET_0), see also section 2.8. For each crop, the water footprint in the basin that sets the benchmark for comparable basins is printed **bold**. Source: ET_0 from FAO (2013e).

Table 24. Potential water savings by reducing the WFs of main crops to benchmark levels (in Mm³/yr).

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Moulou-ya	Sebou	Louk-kos	Total
Almonds	0	2	1	0	3	0	8	0	14
Barley	0	0	0	100	158	222	238	0	717
Dates	0	0	0	10	0	4	48	0	63
Grapes	0	20	0	5	0	0	18	4	48
Maize	0	13	0	175	32	0	33	0	254
Olives	0	9	4	0	10	0	35	0	59
Oranges	0	1	1	0	1	0	6	0	9
Sugar beets	0	0	0	0	0	0	70	4	73
Sugar cane	0	0	0	0	0	0	79	10	89
Tang.mand.	0	1	0	0	0	0	3	0	4
Tomatoes	0	0	0	0	1	0	1	0	3
Wheat	0	14	0	102	417	0	904	0	1,436
Total (gn+bl)	0	60	6	392	623	226	1,444	18	2,768
Total (blue)*	0	23	2	113	11	2	258	12	422
Total (blue) (% of natural runoff)	0%	4%	0%	4%	2%	0%	7%	1%	3%

*Assuming that the green/blue water ratio remains the same for all basins and crops.

4.1.4. Overview of potential water savings in crop production

Table 25 summarizes the estimated potential water savings by partial relocation of crop production, improving water productivity of crops by a certain percentage and reducing WFs down to certain benchmark levels. All these strategies are aimed at more efficient use of water resources. The estimated savings are all under the assumption that the total production of crops does not increase. In order to actually obtain the water savings presented here, and for them to lead to environmental gains, it would be necessary to constrain the continuing growth of total water demand following increases in production (see section 4.2).

Table 25.Potential water savings in crop production.

	Partial relocation of crop production		Overall improved water productivity		Reducing WFs to bench-mark levels
	All analysed crops*	Only annual crops**	By 10%	By 20%	
Absolute saving (green+blue) (Mm³/yr)	1,896	1,174	2,462	4,925	2,768
Relative saving (green+blue) (%)	8%	5%	10%	20%	11%
Absolute saving (blue) (Mm³/yr)	1,276	697	371	743	422
% of total natural runoff in Morocco	10%	5%	3%	6%	3%

* Analysed crops are: almonds, barley, dates, grapes, maize, olives, oranges, sugar beets, sugar cane, mandarins etc., tomatoes and wheat.

** Annual crops are: barley, maize, sugar beets, tomatoes and wheat.

4.2. Water footprint caps per river basin

In all studied river basins natural runoff is seriously modified during a significant period of the year. In order to move towards sustainable use of blue water in these basins, discussing and agreeing on a blue WF cap would be useful. A 'WF cap' is to be understood as a maximum WF not to be exceeded (Hoekstra, 2013). Such a cap is needed in addition to WF reducing measures as discussed in section 4.1, because these measures might not be achieved as quickly as needed and, in case of increased water productivity of crops, it is likely that farmers will increase their production volume once they require less water per unit of production (Hoekstra, 2013).

Ideally, a blue WF cap is set for each river basin in Morocco (and sub-basins) and for each month of the year. The urge for a cap on the blue WF seems large for all Moroccan river basins given the high water scarcity levels (section 3.6). Caps should also be defined for dry, humid and wet years separately. The danger of defining a cap for an average year is that it becomes an impossible target in drier years (Hoekstra, 2013). Therefore the level of the cap should be considered carefully on a regular basis, also taking into account climate change. In defining the maximum sustainable level of blue water consumption, it should be taken into account that part of the natural runoff needs to be reserved to maintain minimally required flows in the river (Poff et al., 2010). Local case studies are necessary to determine these environmental flow requirements for each of the Moroccan rivers and the effects of violating them. Moreover, the maximum sustainable level of blue water consumption would need to be defined for surface and groundwater bodies separately. Based on observations for the Murray-Darling basin in Australia, Hoekstra (2013) points out that if the cap is only set for one of them, it may lead to an accelerated exploitation of the other. The current national water strategy of Morocco's Ministerial Department of Water already proposes to limit the pumping from overexploited aquifers by revision of the pricing system, reduction of allowed withdrawal thresholds, cancelling subsidies that provide incentive for overexploitation and designating areas of prohibited or restricted pumping (Ministry EMWE, 2011). These plans are also adopted in the river basin plans.

Setting a cap is a political matter and the level of the cap will depend on negotiations and trading off different interests (Hoekstra, 2013). Morocco's High Council for Water and Climate seems an appropriate forum for discussing and agreeing on the proposed caps. All national actors concerned by water issues have a seat in the Council, where they debate on the national policy and main policy directions in water resource management (INECO, 2009). One of the Council's tasks is to elaborate and formulate an opinion on the allocation of water among the various user sectors and the diverse regions of the country or of a single basin (Official State Gazette, 1995). Since overexploitation of Morocco's water resources is severe at this moment, it is more realistic to agree on blue WF caps that gradually move in time from the current blue WFs in the basins to levels that can be regarded as sustainable (Hoekstra, 2013), at which natural surface runoff is less modified and groundwater levels are maintained on the long-term.

The Moroccan government will need to put regulations in place to ensure that the actual total blue WF in each river basin remains below the cap. Reinforcement of the control and sanction system for overexploitation, particularly by reinforcing the water police and encouraging satellite monitoring and aerial surveillance, is part of the national water strategy (Ministry EMWE, 2011). In order to adequately control whether the actual total blue WF in each river basin remains below the cap, the WF of activities in the basin would need to be estimated on a regular basis. A close cooperation between the river basins agencies and the regional offices for agricultural development (Office Régional de Mise en Valeur Agricole – ORMVA) would be suitable for this task. The ORMVA of the irrigated perimeter of Tadla in the Oum Er Rbia basin already estimates daily reference evapotranspiration in their region and determines the water allocation to the farmers based on calculations of crop water requirements.

It would be wise to cap the grey WF as well. In section 3.7 is shown that nitrate pollution by excessive use of fertilizers is large in most river basins and exceeds waste assimilation capacity of groundwater in the basins of Bouregreg, Tensift and Oum Er Rbia. In Morocco, ambient water quality standards for nitrates (and other chemicals) in surface and groundwater bodies already exist (ABH Oum Er Rbia, 2009). These would have to be translated to critical loads and regulations should be put in place to make sure these are not exceeded. When critical loads are reached, the grey WF equals the waste assimilation capacity (total runoff in case of the water system as a whole, or groundwater runoff in case of aquifers). Currently, there are plans to reduce pollution by agriculture. The river basin agency of Oum Er Rbia, for example, has a quite elaborate (and funded) plan to gain knowledge about the behaviour of agricultural pollutants in Moroccan and local conditions (e.g. soil type) and how they contaminate the water, develop best practices in fertilizer use and conduct demonstration projects and campaigns to raise awareness among farmers and policy makers to extend the best practices (ABH Oum Er Rbia, 2011). In addition to these plans, a cap on the grey WF of agriculture should be agreed upon to make sure pollution does not exceed the waste assimilation capacity of the rivers and aquifers. This is necessary, because best practices in fertilizer use can lead to increased yields, which might give incentive for extension of the area on which fertilizers are applied, possibly leading to an increase in the total load of pollutants that reaches water bodies.

4.3. Resource allocation to different crops

Next to looking at the improvement of physical water productivities (i.e. more crop per drop; see section 4.1), it is useful to consider the potential to improve economic water productivity (i.e. more value per drop) (Hoekstra, 2013). Similarly, one can argue to consider economic land productivity (Chouchane *et al*., 2013). In Appendix VII we therefore show the estimated economic water and land productivity per crop and per basin.

In the period 1996-2005, Morocco's water resources have been mainly used to produce relatively low-value water-intensive (in US$/m^3) crops such as cereals, olives and almonds. These crops also took the largest share in the country's harvested area, although they had the lowest value per hectare of cultivated land (in US$/ha). Higher economic returns per drop of water and per hectare of land cultivated are generated by production of grapes, sugar beets, citrus fruits (oranges, mandarins, etc.) and tomatoes.

A different allocation of water and land resources to crops that yield more value per drop and per hectare of land cultivated could be desirable. It would be worthwhile to consider a different mix of crops to grow, which uses land and water resources more efficiently from a purely economic point of view, for example by producing more citrus fruits and tomatoes instead of cereals, olives and almonds. From a water resources point of view, it is wise to base such choices also on the timing of crop water requirements. For example, wheat (with low economic water productivity) has no blue WF in the severely water scarce month of July, whereas citrus fruits (with high economic water productivity) have a large blue WF in this month.

The Green Morocco Plan to strengthen the position and increase the importance of Moroccan agriculture includes plans to transform current production systems, essentially dominated by cereal production, into high value-added crops, such as olives (77%), almonds (9%) and figs (ADA, 2013). Looking at the value of these crops per unit of water and cultivated land (see section 3.3), producing olives and almonds instead of cereals does not seem to be a step towards more economically efficient use of water and land.

Greenhouse cultivation of tomatoes (and other crops) should be encouraged, particularly in combination with rainwater harvesting. Yields in greenhouses are generally higher than on open fields and greenhouse cultivation allows for off-season cultivation. From a water resources perspective, it would be useful to optimize the latter in such a way that the moments when crops need water better coincide with rainfall and natural runoff, thereby improving use of rainwater and modifying the natural flow regime less severe than currently. Of course, the choice for the cultivation season is also influenced by other production factors (light and temperature) and, for export products, trade barriers during certain periods of the year.

Wheat, barley, sugar beets and sugar cane are currently subsidized per unit of production and subsidies exist for seed handling and storage units for cereals and sugar beets (Ministry of Agriculture and Fisheries of Morocco, 2011). Acquisition of olive plants and date palms is also subsidized as well as the creation of new citrus fruit plantations (per hectare) (Ministry of Agriculture and Fisheries of Morocco, 2011). The current subsidy system therefore still provides incentives for the production of relatively low-value water-intensive (in US$/m^3) cereals and olives.

The Green Morocco Plan is built on the principle of aggregation, which is a form of organization based on bringing together agriculturists for the implementation of agricultural investment projects (ADA, 2013). However, subsidies for these aggregation projects regarding cereals and olives production are higher for projects concerning irrigated production than the same projects regarding rain-fed production. For example, aggregation projects regarding rain-fed production of olives around a complex for trituration and bottling are subsidized for 450 Moroccan Dirham/ha, while the same projects regarding irrigated production of olives are subsidized for 1,100 Moroccan Dirham /ha (Ministry of Agriculture and Fisheries of Morocco, 2011). Of course, aggregation projects in irrigated agriculture can lead to more efficient use of irrigation water thanks to modern technology brought by the aggregator. Nevertheless, this difference in subsidy may provide an incentive for aggregators to invest in and develop irrigated production instead of rain-fed production. Given the high pressure on Moroccan blue water resources, wise use of rainwater should be encouraged. Increasing green water productivities in Morocco’s rain-fed areas reduces the need for irrigated production in water-scarce basins, and thus helps to reduce the blue WF (Hoekstra, 2013). This is relevant for modern agriculture in favourable rain-fed lands, but also for traditional agriculture located in non-irrigated, unfavourable and mountainous areas or oases, which remains strongly dependent on rainfall (ADA, 2013). The Green Morocco Plan also proposes the experimental use of semi-desert zones to increase the usable agricultural surface area (ADA, 2013), which will inevitably increase pressure on blue water resources, because crop growing in the semi-desert is likely to fully rely on irrigation water.

It should be noted that the choice of which crops to produce (i.e. the cropping pattern) is closely linked to the demand for crops (national and global) and significant changes in the amount of crops produced are likely to influence the prices and thus economic water and land productivities. Moreover, the cropping pattern is part of the national strategy regarding food security. Although the cropping pattern in the large irrigated perimeters of Morocco is officially liberalized (Ait Kadi, 2002), the previously discussed subsidies influence the farmers' choices on what to plant.

4.4. Wise virtual water trade

In this section, Morocco's trade pattern – with its associated virtual water import and use of domestic water resources for producing export products – is discussed from a water resources point of view. An important note is that water cannot be used as the only indicator for judging the rationality of trade patterns, because international trade in agricultural commodities depends on a great variety of factors, including for instance the availability and cost of land, labour, capital, technology and other endowments, available infrastructure and costs of engaging in trade, national food policies, taxes and subsidies, trade policies and international trade agreements (Hoekstra and Chapagain, 2008; Kumar and Singh, 2005). However, given the fact that trade patterns and policies are generally discussed without taking water into account at all, it is useful to add this specific perspective to the usual discourse on trade (Hoekstra et al., 2011b).

4.4.1. Virtual water import

Morocco already achieved fairly large water savings by virtual water import in the period 1996-2005 (see section 3.4.3). This is a result of Morocco's agricultural strategy which has shifted from the food self-sufficiency objective to the food security objective, meaning that domestic food needs are met through strategic levels of national agricultural production and the gap is covered by relying on the international market (Ait Kadi, 2002). Further externalizing the Moroccan WF through virtual water import could relieve pressure on Moroccan water resources. There are, however, a number of drawbacks of virtual water import that need to be considered (Hoekstra, 2013). First, Morocco should be able to generate sufficient foreign exchange to afford import of water-intensive agricultural commodities. Second, food self-sufficiency might be reduced even further when food imports increase. Moroccan agriculture is directly responsible for the food security of 30 million consumers (ADA, 2013). Third, import of agricultural commodities affects the Moroccan agricultural sector: it reduces employment in this sector and results in economic decline and worsening of land management in rural areas. Agriculture currently accounts for 15% of GDP and employs 41% of the labour force (World Bank, 2012), the latter even being 80% in rural areas (Ministry of Agriculture and Fisheries of Morocco, 2010).

Fourth, since 80% of the 14 million rural inhabitants depend on revenues from the agricultural sector (ADA, 2013), promoting food imports might threaten the livelihoods of those people and reduce access to food for the poor. Lastly, virtual water imports may reduce pressure on Moroccan water resources, but it may create extra pressure in the countries where the imports come from. Increasing food (virtual water) imports to relieve pressure on Moroccan water resources will thus increase food dependency and have negative effects on the domestic agricultural sector, which plays a critical role in the economic and social stability of Morocco. Decisions regarding import of water-intensive commodities should carefully take into account these drawbacks. Moreover, increasing food imports seems to conflict with the aim of the Green Morocco Plan to strengthen the Moroccan agricultural sector and make it a lever for social and economic development.

The question remains whether the virtual water import in the period 1996-2005 was efficient from a water-economics point of view. In the period 1996-2005, the average cost of imports was 0.98 US/m³ (equivalent to 1.02 m³ of virtual water per US$ spent) and 0.17 US$/m³ for crop products (equivalent to 5.88 m³ of virtual water per US$ spent). The average value of export products in the same period was 1.66 US$/m³ (equivalent to 0.60 m³ of virtual water per US$ earned) and 0.87 US$/m³ for crop products (equivalent to 1.15 m³ of virtual water per US$ earned). It can be said that the imported products required relatively a lot of water per unit of money spent, while the exported products produced required relatively little water per unit of money earned.

Since the largest part of imports comes from the United States, France, Argentina, Brazil, Canada, the Russian Federation, China and the Ukraine, Morocco depends on these countries. This constitutes a risk given the chance that food supplies from these countries could cease for whatever reason.

4.4.2. Virtual water export

About 4% of the water used in the Moroccan agricultural and industrial sector is used for making export products. The remainder of the water is applied for producing products that are consumed by the Moroccan population. As pointed out by Hoekstra and Chapagain (2007), it seems appropriate, from a water point of view, that most of the scarcely available water in Morocco is being used for the production of commodities that are consumed domestically and not for export.

From an economic point of view, the question is whether the exported commodities yield a relatively high income of foreign currency per unit of water used. As shown in section 3.4.2, most of the virtual water export from Moroccan resources relates to the export of products with a relatively low economic value per m³ water exported, such as wheat (0.02 US$/m³), sugar beets (0.04 US$/m³) and olives (0.10 US$/m³). Oranges give substantially higher economic value (0.84 US$/m³), but still little given the severe water scarcity in Morocco. Of the main export crop products analysed in this study only mandarins (1.37 US$/m³) and tomatoes (7.13 US$/m³) yielded a value larger than the average for crop products. These figures imply that it might be wise to use Morocco’s scarce water resources to produce mandarins and tomatoes for export instead of low-value water-intensive crops. However, it should be noted that demand for specific crop products on the world market is limited and large-scale changes in the production for export are likely to have their effect on food prices (thus affecting the economic value per m^3 of water exported).

Part of the Green Morocco plan is to increase the export earnings by 5.5 fold in the upcoming 10 to 15 years in the sectors where Morocco is competitive: citrus fruits, olives, fruits and vegetables (ADA, 2013). The current system of state subsidies supports this by subsidizing the export of citrus fruits and tomatoes per ton exported (Ministry of Agriculture and Fisheries of Morocco, 2011). Export of olive oil and strawberries are subsidized similarly. Looking at its export value per unit of water consumed, olive production for export does not seem to be the most beneficial purpose to allocate water to.

It remains unanswered whether the foreign currency earned by export products covers the costs of the water consumption in Morocco for making these products. This might not be the case considering the costs of the construction and maintenance of the large dams and intra- and inter-basin water transfers in the country. Moreover, costs are even higher if one takes into account the costs associated with the negative externalities of water (over)consumption, such as the salt-intrusion in Morocco's coastal aquifers. An in-depth review of the export policy from a water resources point of view is therefore recommended.

5. Added value of Water Footprint Assessment for national water policy

Several insights and response options emerged from the Water Footprint Assessment (WFA) that are currently not considered in the national water strategy of Morocco and the country's river basin plans. They include:

(i) New insights in the water balance of Morocco and the country's main river basins:
- The evaporative losses from storage reservoirs account for a significant part of the blue WF within Morocco. This sheds fresh light on the national water strategy that proposes to build another 60 large and 1000 small dams by 2030.
- Blue water scarcity on a monthly scale is severe and hidden by annual analysis of demand versus supply, which is the common scale of analysis in Morocco's river basin plans.

(ii) New insights in how economically efficient water and land resources are used:
- Analysis of the economic value of crop products per unit of water and land used in the period 1996-2005 indicate that agricultural policy may be better brought in line with water policy by reconsidering which crops to grow.
- It is shown that the export policy in this period was not optimal from a water-economics point of view, which raises the question whether the foreign income generated by export covers the direct and indirect costs of mobilization and (over)exploitation of Morocco's water resources. This might not be the case considering the costs of the construction and maintenance of the large dams and intra- and inter-basin water transfers in the country and the costs associated with the negative externalities of water (over)consumption, such as the salt-intrusion in Morocco's coastal aquifers.

(iii) New response options to reduce the WF of crop production:
- Analysis of the WF of the main crops in Morocco and its variation across the river basins offers new ways of looking at reducing water consumption in the agricultural sector. The estimated potential water savings by partial relocation of crops to basins where they consume less water and by reducing WFs of crops down to benchmark levels are significant compared to demand reducing and supply increasing measures considered in the national water strategy of Morocco.

Given these new insights and response options, it is concluded that understanding the WF of activities in Morocco and the country's virtual water trade has an added value for formulating national water policy. The assessment provides a comprehensive water balance and allows critical analysis of the water allocation to different purposes. The analysis offers a basis for comparing the water consumption of activities and crops across different regions, which exposes new views on how and where to reduce WFs. In addition, the analysis of economic water productivities forms a basis for considering if available water resources are used economically efficient and if the production value per unit of water outweighs the (in)direct costs of water (over)exploitation. Furthermore, while water resources studies usually focus on blue water scarcity, the study of green and grey WFs proves to be a useful broadening of the scope of analysis, because more efficient use of green water and a reduction of the grey WF will contribute to the reduction of the pressure on blue water resources.

6. Discussion

The water footprint (WF) in Morocco is mostly green (77%). This underlines the importance of green water resources, also (or especially) in semi-arid countries with a high dependency on blue water, and is in line with other studies showing the dominance of the green over the blue water flow in Africa (and most of the world) (Rockström *et al*., 2009; Schuol *et al*., 2008). The relevance of the green WF should not be underestimated. Although rain is free and evaporation happens anyway, green water that is used for one purpose cannot be used for another purpose (Hoekstra, 2013).

Storage reservoir evaporation accounts for a significant share (13%) in the blue WF in Morocco. The need for seasonal storage of water is evident given the large mismatch in time of natural runoff and water demand (see Figure 14). However, the large evaporation from reservoirs shows that these should be seen as water consumers, besides their role in water supply. This WF can ultimately be linked to the end-purpose of the reservoir, which for most cases in Morocco is primarily serving irrigated agriculture. Therefore, to reduce the need for seasonal storage and hence the WF of storage reservoirs, it would be worthwhile to take the timing of crop water demands with respect to natural water availability into account in deciding which crops or crop varieties to grow. Furthermore, local alternatives to the large surface water reservoirs are groundwater dams, which enhance underground water storage in alluvial aquifers and thereby loose less water by evaporation (Al-Taiee, 2012).

Our analysis shows that from a strictly water-economics point of view it would be worthwhile to reconsider which crops to grow in Morocco (due to the low value in US$/m³ and US$/ha for some crops compared to others). In practice, the choice of which crops to produce is part of the national strategy regarding food security and closely linked to the demand for crops (national and global). Nevertheless, we consider it useful and important to analyse economic water and land productivities (as done in this study) in addition to these considerations. Especially for water-short countries as Morocco it is relevant to evaluate the economic efficiency of water allocation. This also relates to the question whether the foreign income generated by export products, which have a footprint on national resources, outweighs the direct and indirect costs associated with the resource use.

6.1. Uncertainties and limitations

The WF estimates presented in this study include uncertainties that reflect the uncertainties in input data and assumptions used and the limitations of the study. Estimates from this study of the total WF of irrigation (i.e. the blue WF of crop production plus the WF of the irrigation supply network, but excluding the WF of storage reservoirs) are compared with the volume of water supplied to farmers for irrigation in the current situation (2010, for most basins) as recorded in the river basin plans (Figure 17). They correlate quite well, but the number of data points is limited. The WF of irrigation is consistently lower than the water supply to irrigation. The precise reason for this cannot be pointed out, since the blue WF of crop production is largely influenced by the input data used and assumptions made by Mekonnen and Hoekstra (2010b), but their blue WF estimates can easily contain an uncertainty of ±20% (Hoff *et al*., 2010; Mekonnen and Hoekstra, 2010a,b). However, it is to be expected that the WF of irrigation is lower for three reasons: 1) the basin data are more recent and irrigation demands have increased in the past decade; 2) the WF of the irrigation supply network is a conservative estimate, because it is based on targeted field and conveyance efficiencies to be achieved with the national irrigation water saving programme (see section 2.4); 3) the water that is lost in the irrigation water supply network by percolation and the excess water applied to the crop field that percolates are not included in the WF estimates, since they are not evaporative losses (see section 2.4). On the contrary, the estimates of the blue WF of crop production are based on the assumption that actual irrigation is sufficient to meet the irrigation demand, though this is not always the case in Morocco due to limited water availability.

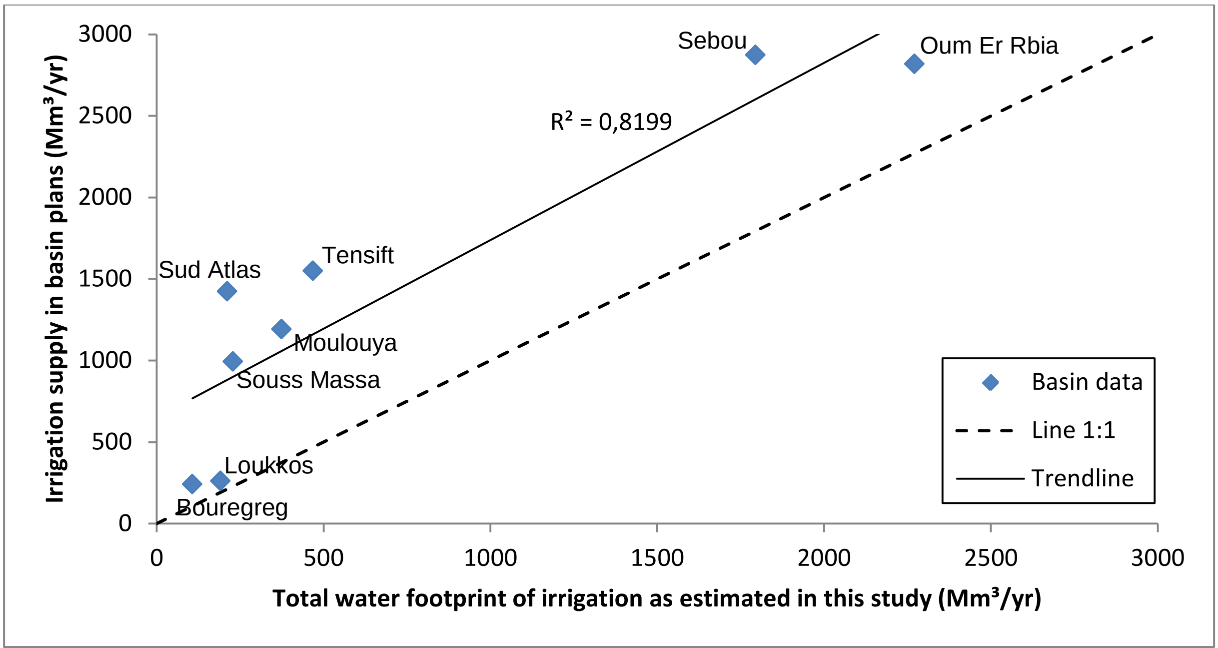

Figure 17. Comparison of the water footprint (WF) of irrigation as estimated in this study (i.e. blue WF of crop production plus WF of irrigation supply network) with the volumes of water supplied to farmers for irrigation as recorded in the river basin plans.

The WFs of industrial production and domestic water supply are sensitive to the consumptive fractions assumed. The WFs of storage reservoirs in the basins for which no reservoir-specific data are available contain uncertainty due to the input data used (especially regarding the surface area of reservoirs), but this is hard to quantify. Note that the estimated WFs of storage reservoirs in these basins are relatively small compared to the estimates for the basins for which reservoir-specific data are available.

The WF estimates in this study can be improved by using local data, especially by calculating the WF of crops at field level with data (e.g. from the regional offices for agricultural development) on which crops are grown when and where, evapotranspiration and fertilizer use. Moreover, the WF estimates here are averages over the period 1996-2005. For further research it is recommended to estimate the WF of activities and specific crops taking into account inter-annual variability (e.g. estimates for dry years, average years and humid years) and using more recent data and future projections. The current and future WFs are probably larger due to growth of the Moroccan population and growing water needs as projected in the river basin plans. Combined with the effects of climate change this will also increase water scarcity.

Although figures on water availability are obtained from the river basin plans or the Ministry of Energy, Mining, Water and Environment (EMWE), the way they are precisely estimated is often unclear and so is the uncertainty in them. River basin plans are developed by consultants in commission of the river basin agencies. The Water Law prescribes that these plans should include, among others, an assessment of the quantitative evolution of the hydrological resources in the basin (Official State Gazette, 1995). However, methods and definitions to do so are not formally established.

In general, the river basin plans indicate larger pressure on groundwater resources than suggested in this study. This might be caused by the fact that the river basin plans include more recent withdrawals and because the unit of analysis in this study (river basin agency action zone) is larger than the unit used in the river basin plans (individual aquifers), whereby in this study overexploitation of one aquifer might be masked by low exploitation of another. Also local pollution according to the river basin plans is sometimes worse than the water pollution level estimated here. This could be explained by the fact that the water quality measurements recorded in the basin plans are partly more recent and are measured at specific points, whereas this study considered average concentration levels of nitrates in the groundwater.

Given the uncertainties and limitations of the study, the presented WF estimates and water scarcity values should be interpreted with care. Nevertheless, the order of magnitude of the estimates in this study gives a good indication to which activities and crops Morocco’s water resources are allocated, in which months and basins the WFs are relatively large or small and where and when this leads to highest water scarcity.

The economic water and land productivities of crops (EWP and ELP) are, apart from the WFs and yields, dependent on the producer prices. Variations in these prices largely influence the EWP and ELP of crops. The results presented in this study show that Moroccan water and land could have been used economically more efficient in the period 1996-2005. Future decisions on what crops to grow in order to make more economically efficient use of water and land resources should be based on an elaborate analysis of current (and future) WFs and prices. Decisions that influence international crop trade should include considerations of the earnings per m^3 of water exported (and costs per m^3 water imported).

Uncertainties in the estimated potential water savings by partial relocation of crop production are closely linked to the uncertainties in the estimates of the WFs of crop production. Details on the areas of land allocated to specific crops and the associated production and WFs should be interpreted carefully. However, the order of magnitude of the estimated savings gives a rough indication of the potential of this measure. When considering relocation of crop production it is necessary to assess how the green and especially blue WFs of crops manifest themselves on a monthly scale. This study looked at annual water savings, but the associated relocation of crops might well aggravate monthly water scarcity in some river basins. Furthermore, the feasibility and desirability of relocation of crop production are of course largely determined by social and economic factors that should be taken into account as well. Besides, one should keep in mind that the estimated water savings by relocating crop production depend on the spatial differences in water productivities found; the same water savings may be obtained by increasing water productivities in the places where they are currently low.

7. Conclusions

Main results of the Water Footprint Assessment are:

- The total water footprint (WF) of Moroccan production in the period 1996-2005 was 38.8 Gm^3/yr (77% green, 18% blue, 5% grey). Crop production is the largest contributor to this WF, mainly related to the production of wheat and barley, followed by olives and maize. Evaporation from storage reservoirs accounts for the second largest form of blue water consumption nationally, after irrigated crop production. Largest WFs are found in the basins Oum Er Rbia and Sebou, the main agricultural areas. The green WF is largest in the rainy period December-May, whereas the blue WF is largest in the period April-September when irrigation demands increase.
- In the period 1996-2005, Morocco's water resources have been mainly used to produce relatively low-value water-intensive (in US$/$m^3$) crops such as cereals, olives and almonds. These crops also took the largest share in the country's harvested area in the same period, although they had the lowest value per hectare cultivated (in US$/ha). More economic return per drop and per hectare of land cultivated was generated by production of grapes, sugar beets, citrus fruits (oranges and mandarins etc.) and tomatoes.
- Morocco was a net virtual water importer in the period 1996-2005. Virtual water import was 12.6 Gm^3/yr with an average cost of 0.98 US$/$m^3$ and virtual water export was 4.3 Gm^3/yr with an average earning of 1.66 US$/$m^3$. Only 31% of the virtual water export originated from Moroccan water resources (remainder was re-export). Virtual water import and export were for 95% and 91% related to trade in crop products, respectively. By import of products instead of producing them domestically, Morocco saved 27.8 Gm^3/yr (75% green, 21% blue and 4% grey) of domestic water, equivalent to 72% of the WF within Morocco.
- Blue water scarcity on a monthly scale is severe in all river basins. Seasonal shortages result in high alteration of natural runoff. Also groundwater scarcity and pollution are significant in most basins, especially in the basins of Bouregreg, Oum Er Rbia and Tensift. In order to move towards sustainable use of Morocco's blue water resources, discussing and agreeing on blue WF caps, per river basin, per month and for surface and groundwater separately, would be useful.
- Potential green plus blue water savings by partial relocation of crop production across basins are in the order of 1.9 and 1.2 billion m^3 per year when all main crops or only annual crops are relocated, respectively. Lowering the WFs of the main crops in each river basin down to benchmarks (which are defined as the lowest water consumption of a crop in a comparable basin) can lead to estimated green plus blue water savings of 2,768 Mm^3/yr. When the water productivities of the twelve main water-consuming crops were to be improved by 10% throughout Morocco, it could potentially save 2,462 Mm^3/yr of water (green plus blue).
- Morocco obtained fairly large savings by food (virtual water) imports in the period 1996-2005 (27.8 Gm^3/yr, see above). Increasing food imports to relieve pressure on domestic water resources increases food dependency and has negative effects on the domestic agricultural sector, which plays a critical role in the economic and social stability of Morocco.
- About 4% of the water used in the Moroccan agricultural and industrial sector is used for making export products (in the period 1996-2005). The remainder is applied for producing products that are consumed by

the Moroccan population. However, most of the virtual water export from Moroccan resources relates to the export of products with a relatively low economic value per m^3 water exported (in US$/$m^3$).

On the basis of these new insights and response options it is concluded that Water Footprint Assessment has an added value for national water policy in Morocco. Water Footprint Assessment forces to look at end-users and -purposes of freshwater, which is key in determining efficient and equitable water allocation within the boundaries of what is environmentally sustainable, both on the river basin and on the national level. This is especially relevant for water-scarce countries such as Morocco. Furthermore, considering the green and grey components of a WF provides new perspectives on blue water scarcity, because pressure on blue water resources might be reduced by more efficient use of green water and by less pollution.

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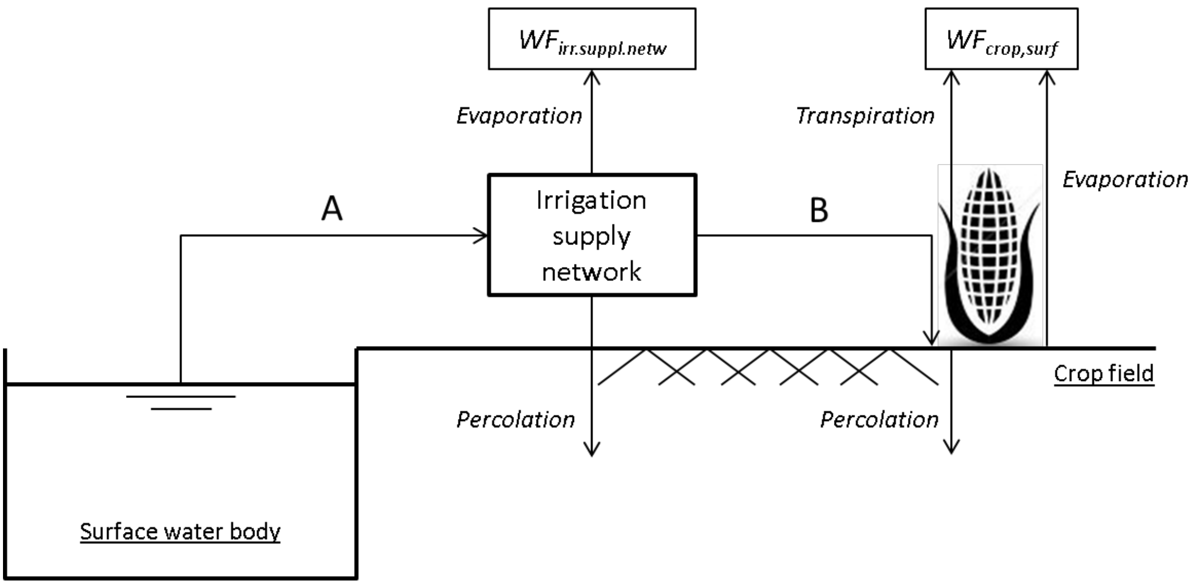
Appendix I: Derivation of K-factor in water footprint of irrigation supply network

Definitions

A	= volume withdrawn for irrigation from surface water body
B	= volume of water applied to the crop field
e_a	= field application efficiency
e_c	= conveyance efficiency
f_E	= fraction of losses in network that evaporates (remainder percolates)
K	= fraction of surface water footprint of crop production at field level that is lost by evaporation from the irrigation supply network
$WF_{crop,surf}$	= surface water footprint of crop production at field level (i.e. the part of the irrigation water that originates from surface water and is lost at the crop field through evapotranspiration)
$WF_{irr.sppl.netw}$	= water footprint of irrigation supply network (i.e. evaporative losses from network)



Derivation

$$e_a = \frac{WF_{crop,surf}}{B} \rightarrow B = \frac{WF_{crop,surf}}{e_a}$$

$$e_c = \frac{B}{A} \rightarrow A = \frac{B}{e_c} = \frac{WF_{crop,surf}}{e_a \times e_c}$$

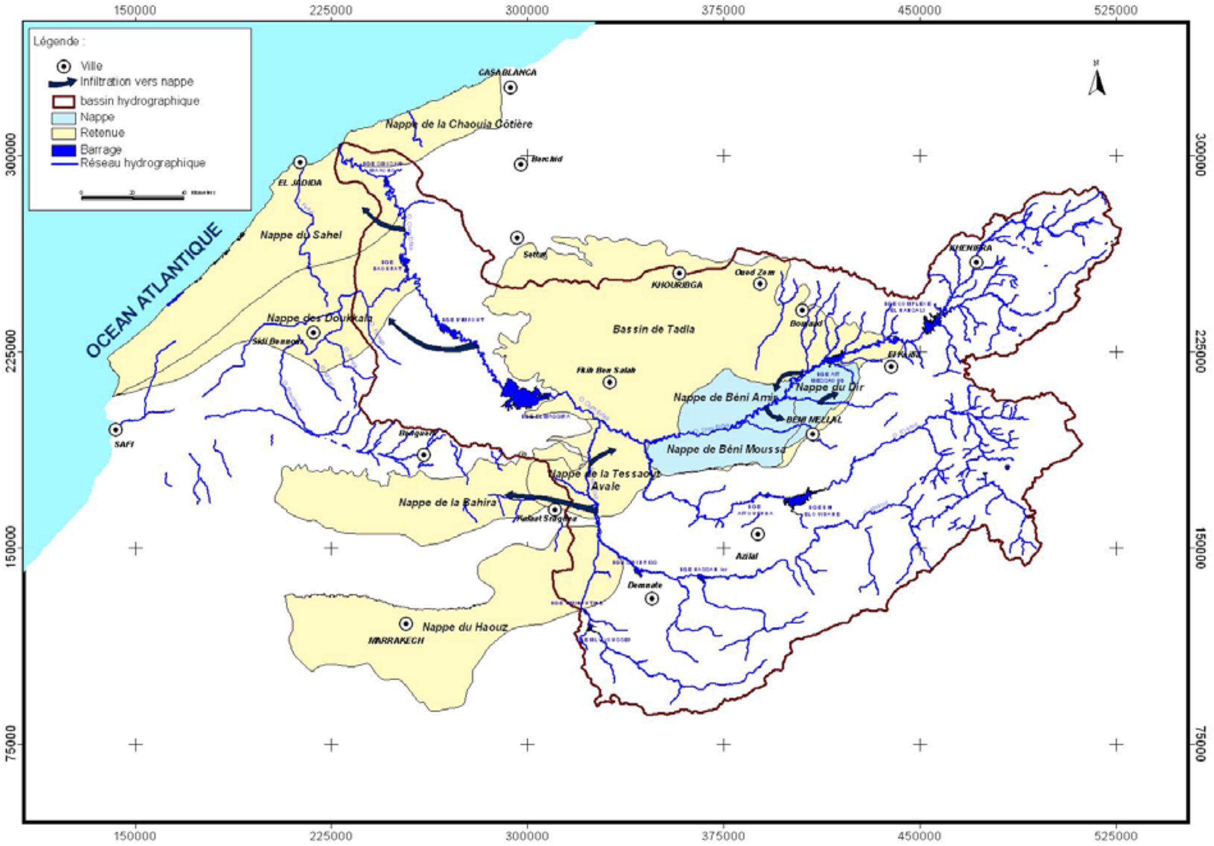
$$WF_{irr.sppl.netw} = K \times WF_{crop,surf} \qquad \text{with} \qquad K = \left[\frac{1}{e_a \times e_c} - \frac{1}{e_a}\right]$$

Appendix II: Fraction of total blue water supply withdrawn from groundwater per river basin

River basin	Best estimate fraction withdrawn from groundwater for domestic and industrial purposes (%)	Description	Data from year	Source
Boure-greg	4	% of groundwater abstractions in the water abstracted for the production of potable water.	2006	ABH Bouregreg et de la Chaouia (2009)
Loukkos	22	% of groundwater abstractions for drinking and industrial water in the total demand for drinking and industrial water.	2010	ABH Loukkos (2011)
Moulouya	50	% of groundwater abstractions for drinking and industrial water in the total of abstractions for drinking water (also for livestock) and industrial water.	2010	ABH Moulouya (2011)
Oum Er Rbia	38	% of groundwater abstractions for drinking and industrial water in the total of abstractions for drinking and industrial water.	2011	ABH Oum Er Rbia (2011)
Sebou	88	% of groundwater abstractions for drinking water in the total demand for drinking water.	2010	ABH Sebou (2011)
Souss Massa	71	% of groundwater abstractions for drinking water, water for tourism and industrial water in the total of abstractions for drinking water, water for tourism and industrial water.	2010	ABH Souss Massa Draa (n.d.b)
Sud Atlas	47	% of abstractions from groundwater in the total of abstractions for drinking, industrial and irrigation water for agriculture. Based on data for Guir-Ziz Rheris only (assumed to be representative for whole Sud Atlas).	2010	Direction de la Region Hydraulique du Guir Rheris Ziz (2012)
Tensift	45	% of abstractions from groundwater in the total of abstractions for drinking, industrial and irrigation water for agriculture and for golf spaces and parks.	2010	ABH Tensift (2011)

River basin	Best estimate fraction abstracted from groundwater for irrigation (%)	Description	Data from year	Source
Boure-greg	88	% of groundwater abstractions for irrigation in total of abstractions for irrigation.	2006	ABH Bouregreg et de la Chaouia (2008)
Loukkos	34	% of groundwater abstractions for irrigation in total of abstractions for irrigation.	2010	ABH Loukkos (2011)
Moulouya	21	% of groundwater abstractions for irrigation in total of abstractions for irrigation.	2010	ABH Moulouya (2011)
Oum Er Rbia	20	% of groundwater abstractions for irrigation in total of abstractions for irrigation.	2011	ABH Oum Er Rbia (2011)
Sebou	25	% of groundwater abstractions for irrigation in total of abstractions for irrigation.	2010	ABH Sebou (2011)
Souss Massa	63	% of groundwater abstractions for irrigation in total of abstractions for irrigation.	probably 2010	ABH Souss Massa Draa (n.d.b)
Sud Atlas	43	% of groundwater abstractions for irrigation in total of abstractions for irrigation. Based on data for Guir-Ziz Rheris only (assumed to be representative for whole Sud Atlas).	2010	Direction de la Region Hydraulique du Guir Rheris Ziz (2012)
Tensift	45	% of abstractions from groundwater in the total of abstractions for drinking, industrial and irrigation water for agriculture and for golf spaces and parks.	2010	ABH Tensift (2011)

Appendix III: Map of aquifers (partially) in action zone ABH Oum Er Rbia



Source: ABH Oum Er Rbia (2011).

Appendix IV: Open water evaporation from different sources

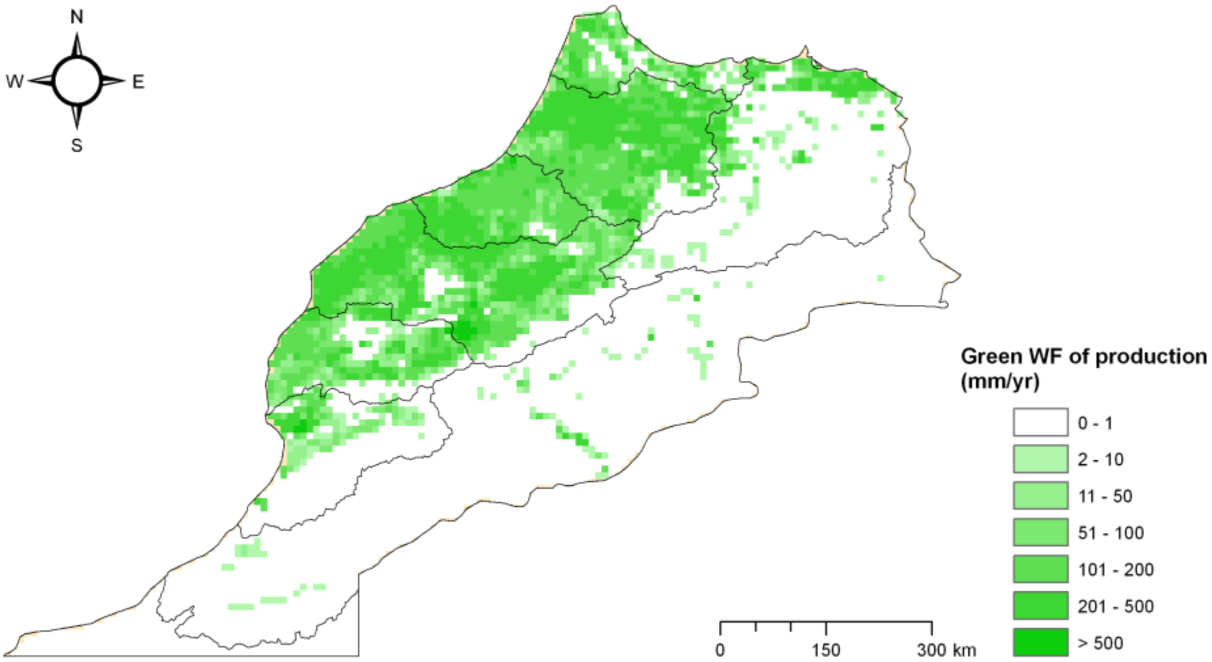
The table below shows how the best estimates of open water evaporation in the river basins compare with each other and with reference evapotranspiration by FAO (2013e). The first main column relates to the estimates used in this study, namely reservoir specific data from the Ministry EMWE (2013c) for four basins and estimates from the global hydrological model PCR-GLOBWB for the other basins (Sperna Weiland *et al.*, 2010). The second column shows the variation in estimates across the basins according to PCRGLOB-WB estimates only. For comparison, the third column shows variation in reference evapotranspiration across the basins.

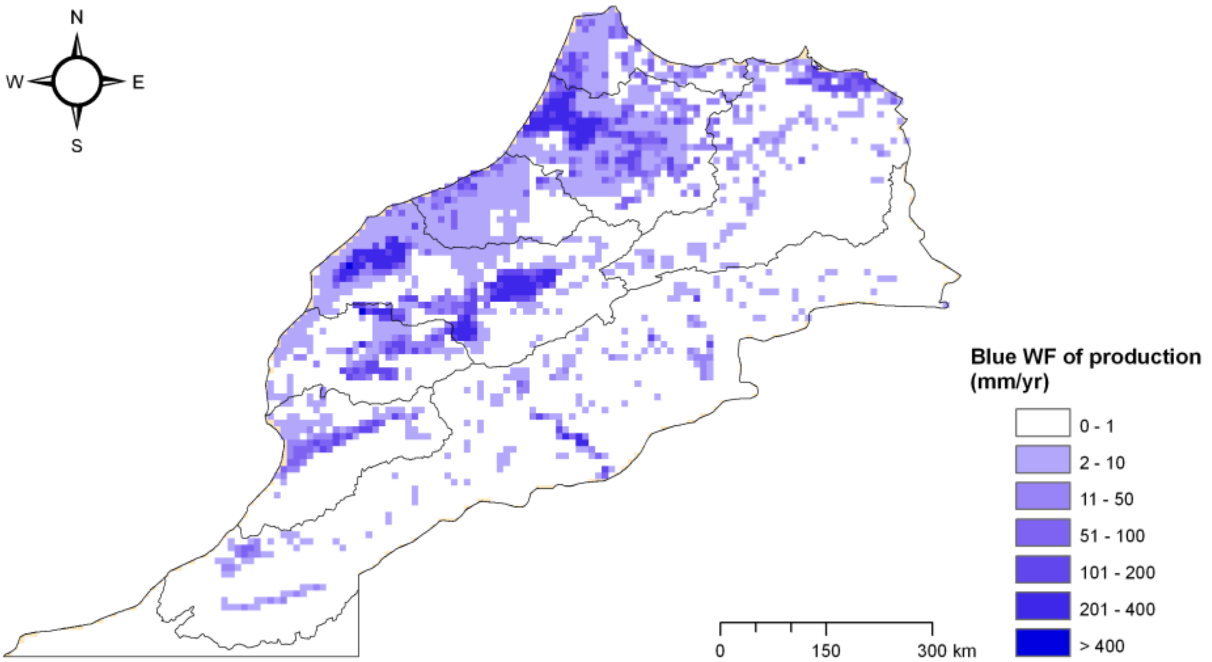
Ministry EMWE (1939-2011) (*) & PCRGLOB-WB (1961-1990)			PCRGLOB-WB (1961-1990)			Reference evapotranspiration (1961-1990)		
Rank	Basin	E_O (mm/ yr)	Rank	Basin	E_O (mm/ yr)	Rank	Basin	ET_0 (mm/ yr)
1	Souss Massa	2,193	1	Souss Massa	2,193	1	Sud Atlas	1,652
2	Oum Er Rbia*	1,956	2	Tensift	1,850	2	Souss Massa	1,450
3	Tensift	1,850	3	Sud Atlas	1,702	3	Moulouya	1,409
4	Sud Atlas	1,702	4	Oum Er Rbia	1,597	4	Tensift	1,389
5	Bouregreg*	1,529	5	Bouregreg	1,326	5	Oum Er Rbia	1,387
6	Loukkos*	1,472	6	Sebou	1,257	6	Sebou	1,266
7	Sebou*	1,390	7	Moulouya	1,228	7	Bouregreg	1,239
8	Moulouya	1,228	8	Loukkos	1,159	8	Loukkos	1,212

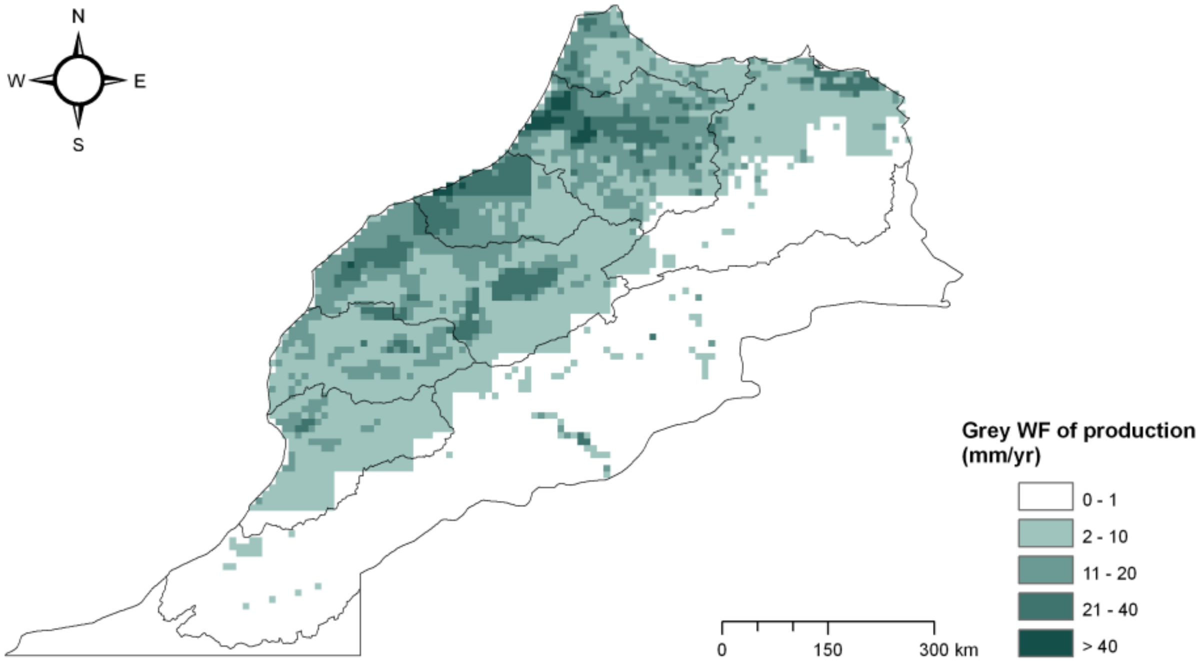
Sources: open water evaporation for basins with (*) from Ministry EMWE (2013c); open water evaporation from PCRGLOB-WB simulation from Sperna Weiland et al. (2010); reference evapotranspiration from FAO (2013e).

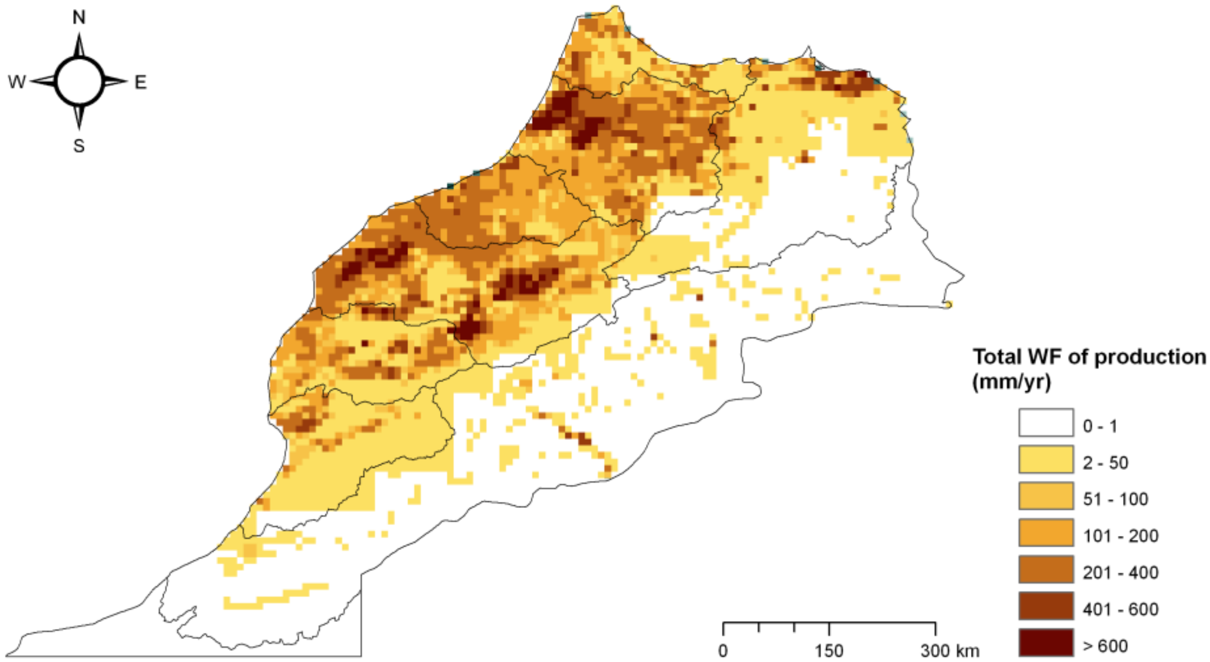
Appendix V: Water footprint of production (1996-2005) at 5x5 arc minute resolution

Data include the water footprints of crop production, industrial production and domestic water supply only, since other estimates are not available on grid scale. Data per grid cell are calculated as the water footprint within a grid cell (in m³/yr) divided by the area. Source: Mekonnen and Hoekstra (2011).






N
W
E
S
Grey WF of production
(mm/yr)
0 - 1
2 - 10
11 - 20
21 - 40
> 40
0
150
300 km


N
W
E
S
Total WF of production
(mm/yr)
0 - 1
2 - 50
51 - 100
101 - 200
201 - 400
401 - 600
> 600
0
150
300 km

Appendix VI: Water footprint of main crops per river basin (1996-2005)

River basin	FAO crop code	Crop	Water footprint per ton of crop (m^3/ton)				Total water footprint (Mm^3/yr)			
			Green	Blue	Grey	Total	Green	Blue	Grey	Total
Bouregreg	221	Almonds	9,311	308	1,118	10,737	84	3	10	97
	44	Barley	4,003	0	146	4,148	659	-	24	683
	577	Dates	2,839	1,999	342	5,181	10	7	1	18
	900a	Fodder crops	377	0	20	397	57	-	3	60
	560	Grapes	201	454	101	756	1	2	1	4
	56	Maize	5,139	1,308	305	6,752	50	13	3	66
	260	Olives	4,354	482	52	4,888	245	27	3	275
	490	Oranges	212	287	35	534	10	14	2	26
	157	Sugar beets	19	47	20	85	0	0	0	0
	156	Sugar cane	26	79	15	120	2	6	1	9
	495	Tang.mand.etc.	205	278	34	517	5	7	1	12
	388	Tomatoes	42	51	12	106	7	8	2	17
	15	Wheat	3,097	18	116	3,231	1,644	10	62	1,715
Loukkos	221	Almonds	8,236	1,059	843	10,138	34	4	3	42
	44	Barley	3,043	0	125	3,168	172	-	7	179
	577	Dates	2,477	2,239	331	5,047	12	11	2	24
	900a	Fodder crops	275	0	14	290	20	-	1	21
	560	Grapes	432	635	101	1,169	5	7	1	12
	56	Maize	3,040	138	262	3,440	1	0	0	1
	260	Olives	3,633	1,018	37	4,688	142	40	1	183
	490	Oranges	264	222	35	522	16	13	2	31
	157	Sugar beets	34	67	20	121	4	7	2	13
	156	Sugar cane	47	99	15	161	11	23	3	37
	495	Tang.mand.etc.	256	215	34	505	8	6	1	15
	388	Tomatoes	49	39	12	101	3	2	1	6
	15	Wheat	2,270	59	97	2,426	410	11	18	438
Moulouya	221	Almonds	7,554	1,897	856	10,306	30	8	3	41
	44	Barley	3,405	0	135	3,539	832	-	33	865
	577	Dates	2,800	3,840	331	6,971	17	23	2	41
	900a	Fodder crops	337	0	18	355	19	-	1	20
	560	Grapes	322	680	100	1,102	13	27	4	44
	56	Maize	955	264	196	1,415	1	0	0	1
	260	Olives	3,186	1,571	37	4,793	144	71	2	217
	490	Oranges	227	275	35	537	18	21	3	42
	157	Sugar beets	32	75	20	126	4	10	3	16

River basin	FAO crop code	Crop	Water footprint per ton of crop (m³/ton)				Total water footprint (Mm³/yr)			
			Green	Blue	Grey	Total	Green	Blue	Grey	Total
Moulouya	156	Sugar cane	43	132	15	189	2	5	1	7
	495	Tang.mand.etc.	220	267	34	520	8	10	1	20
	388	Tomatoes	44	47	12	104	3	3	1	6
	15	Wheat	2,312	283	100	2,695	435	53	19	507
Oum Er Rbia	221	Almonds	8,585	1,476	1,041	11,102	167	29	20	216
	44	Barley	4,054	0	148	4,201	2,356	-	86	2,442
	577	Dates	2,917	4,891	333	8,142	55	93	6	155
	900a	Fodder crops	388	0	21	409	108	-	6	114
	560	Grapes	418	1,129	101	1,648	17	45	4	66
	56	Maize	3,486	3,901	230	7,617	372	417	25	814
	260	Olives	3,511	1,552	43	5,106	643	284	8	936
	490	Oranges	208	324	35	567	48	75	8	131
	157	Sugar beets	33	91	20	144	44	122	27	193
	156	Sugar cane	-	-	-	-	-	-	-	-
	495	Tang.mand.etc.	201	313	34	548	23	35	4	62
	388	Tomatoes	44	54	12	110	14	17	4	36
	15	Wheat	2,826	342	107	3,275	3,247	393	123	3,763
Sebou	221	Almonds	8,575	1,137	919	10,631	162	22	17	201
	44	Barley	3,955	0	133	4,088	1,032	-	35	1,066
	577	Dates	3,236	3,725	332	7,293	69	80	7	156
	900a	Fodder crops	359	0	16	376	111	-	5	116
	560	Grapes	439	750	101	1,290	15	25	3	44
	56	Maize	3,221	3,328	206	6,755	32	33	2	67
	260	Olives	3,688	1,166	40	4,894	640	202	7	849
	490	Oranges	248	261	35	544	72	76	10	159
	157	Sugar beets	33	82	20	134	46	116	28	191
	156	Sugar cane	59	162	15	235	40	111	10	161
	495	Tang.mand.etc.	240	253	34	526	34	36	5	75
	388	Tomatoes	47	47	12	106	13	13	3	30
	15	Wheat	2,730	271	101	3,103	3,670	364	136	4,170
Souss Massa	221	Almonds	7,956	2,185	1,136	11,277	20	6	3	29
	44	Barley	2,498	0	108	2,606	475	-	20	495
	577	Dates	1,700	4,216	333	6,250	5	13	1	19
	900a	Fodder crops	335	0	24	360	12	-	1	13
	560	Grapes	279	1,133	101	1,513	14	56	5	75
	56	Maize	6,732	332	411	7,475	15	1	1	17
	260	Olives	2,967	2,135	45	5,148	80	58	1	139
	490	Oranges	162	373	35	570	6	14	1	21

River basin	FAO crop code	Crop	Water footprint per ton of crop (m³/ton)				Total water footprint (Mm³/yr)			
			Green	Blue	Grey	Total	Green	Blue	Grey	Total
Souss Massa	157	Sugar beets	-	-	-	-	-	-	-	-
	156	Sugar cane	-	-	-	-	-	-	-	-
	495	Tang.mand.etc.	157	361	34	551	3	7	1	10
	388	Tomatoes	37	61	12	111	2	3	1	5
	15	Wheat	2,883	25	131	3,039	126	1	6	133
Sud Atlas	221	Almonds	4,946	5,364	814	11,124	3	3	0	7
	44	Barley	1,451	0	141	1,592	36	-	4	40
	577	Dates	922	3,300	329	4,551	1	5	1	7
	900a	Fodder crops	134	0	24	159	1	-	0	1
	560	Grapes	227	1,140	102	1,468	21	105	9	135
	56	Maize	662	2,353	171	3,187	5	19	1	26
	260	Olives	2,061	3,148	35	5,245	22	34	0	57
	490	Oranges	151	394	35	580	3	8	1	11
	157	Sugar beets	-	-	-	-	-	-	-	-
	156	Sugar cane	-	-	-	-	-	-	-	-
	495	Tang.mand.etc.	146	382	34	561	1	4	0	5
	388	Tomatoes	31	69	12	113	0	1	0	1
	15	Wheat	634	454	118	1,206	19	14	4	37
Tensift	221	Almonds	8,536	1,674	1,120	11,330	56	11	7	74
	44	Barley	3,882	0	154	4,036	1,225	-	48	1,274
	577	Dates	2,527	4,768	333	7,628	17	32	2	51
	900a	Fodder crops	376	0	24	399	34	-	2	36
	560	Grapes	327	1,093	101	1,522	4	12	1	17
	56	Maize	3,896	1,849	278	6,024	128	61	9	197
	260	Olives	3,354	1,768	46	5,167	208	110	3	321
	490	Oranges	188	350	35	573	16	30	3	48
	157	Sugar beets	-	-	-	-	-	-	-	-
	156	Sugar cane	-	-	-	-	-	-	-	-
	495	Tang.mand.etc.	182	339	34	554	8	14	1	23
	388	Tomatoes	41	57	12	111	5	7	1	13
	15	Wheat	2,826	254	115	3,194	536	48	22	606

Source: Mekonnen and Hoekstra (2010b).

Appendix VII: Economic water and land productivity of crops per river basin

River basin	FAO crop code	Crop	Green plus blue water footprint (m³/ton)	Yield (ton/ha)	Average annual producer price (US$/ton)	Economic water productivity (US$/m³)	Economic land productivity (US$/ha)
Bouregreg	221	Almonds	9,618	0.43	233	0.02	100
	44	Barley	4,003	0.80	184	0.05	147
	577	Dates	4,839	1.72	1,014	0.21	1,744
	900a	Fodder crops	377	-	-	-	-
	560	Grapes	655	5.65	337	0.51	1,904
	56	Maize	6,447	0.50	209	0.03	104
	260	Olives	4,835	0.94	321	0.07	302
	490	Oranges	499	16.35	201	0.40	3,279
	157	Sugar beets	65	50.99	33	0.51	1,706
	156	Sugar cane	105	69.87	23	0.22	1,582
	495	Tang.mand.etc.	483	16.90	271	0.56	4,582
	388	Tomatoes	93	47.85	173	1.86	8,300
	15	Wheat	3,115	1.16	254	0.08	296
Loukkos	221	Almonds	9,295	0.57	233	0.03	132
	44	Barley	3,043	0.93	184	0.06	172
	577	Dates	4,716	1.78	1,014	0.22	1,802
	900a	Fodder crops	275	-	-	-	-
	560	Grapes	1,067	5.81	337	0.32	1,956
	56	Maize	3,178	0.58	209	0.07	121
	260	Olives	4,651	1.33	321	0.07	429
	490	Oranges	487	16.80	201	0.41	3,368
	157	Sugar beets	101	51.01	33	0.33	1,706
	156	Sugar cane	146	69.84	23	0.16	1,581
	495	Tang.mand.etc.	471	17.36	271	0.58	4,707
	388	Tomatoes	89	47.87	173	1.95	8,304
	15	Wheat	2,329	1.39	254	0.11	353
Moulouya	221	Almonds	9,450	0.56	233	0.02	130
	44	Barley	3,405	0.86	184	0.05	159
	577	Dates	6,640	1.78	1,014	0.15	1,805
	900a	Fodder crops	337	-	-	-	-
	560	Grapes	1,002	5.78	337	0.34	1,945
	56	Maize	1,219	0.77	209	0.17	161
	260	Olives	4,756	1.35	321	0.07	433
	490	Oranges	502	16.71	201	0.40	3,350
	157	Sugar beets	106	51.14	33	0.31	1,711

River basin	FAO crop code	Crop	Green plus blue water footprint (m³/ton)	Yield (ton/ha)	Average annual producer price (US$/ton)	Economic water productivity (US$/m³)	Economic land productivity (US$/ha)
Moulouya	156	Sugar cane	175	69.91	23	0.13	1,583
	495	Tang.mand.etc.	486	17.26	271	0.56	4,678
	388	Tomatoes	92	46.90	173	1.89	8,134
	15	Wheat	2,595	1.34	254	0.10	341
Oum Er Rbia	221	Almonds	10,061	0.46	233	0.02	107
	44	Barley	4,054	0.79	184	0.05	145
	577	Dates	7,808	1.77	1,014	0.13	1,791
	900a	Fodder crops	388	-	-	-	-
	560	Grapes	1,547	5.81	337	0.22	1,955
	56	Maize	7,387	0.66	209	0.03	137
	260	Olives	5,063	1.14	321	0.06	366
	490	Oranges	532	16.79	201	0.38	3,367
	157	Sugar beets	124	51.05	33	0.27	1,708
	156	Sugar cane	-	-	23	-	-
	495	Tang.mand.etc.	515	17.36	271	0.53	4,705
	388	Tomatoes	97	47.85	173	1.78	8,300
	15	Wheat	3,168	1.26	254	0.08	321
Sebou	221	Almonds	9,712	0.52	233	0.02	122
	44	Barley	3,955	0.88	184	0.05	161
	577	Dates	6,961	1.77	1,014	0.15	1,799
	900a	Fodder crops	359	-	-	-	-
	560	Grapes	1,189	5.80	337	0.28	1,954
	56	Maize	6,549	0.73	209	0.03	153
	260	Olives	4,854	1.25	321	0.07	403
	490	Oranges	509	16.78	201	0.39	3,364
	157	Sugar beets	114	50.96	33	0.29	1,705
	156	Sugar cane	220	69.82	23	0.10	1,581
	495	Tang.mand.etc.	492	17.34	271	0.55	4,702
	388	Tomatoes	94	47.87	173	1.85	8,304
	15	Wheat	3,001	1.33	254	0.08	339
Souss Massa	221	Almonds	10,141	0.42	233	0.02	98
	44	Barley	2,498	1.08	184	0.07	199
	577	Dates	5,917	1.77	1,014	0.17	1,793
	900a	Fodder crops	335	-	-	-	-
	560	Grapes	1,412	5.81	337	0.24	1,955
	56	Maize	7,063	0.37	209	0.03	77
	260	Olives	5,102	1.09	321	0.06	350
	490	Oranges	535	16.78	201	0.37	3,365

River basin	FAO crop code	Crop	Green plus blue water footprint (m^3/ton)	Yield (ton/ha)	Average annual producer price (US$/ton)	Economic water productivity (US$/$m^3$)	Economic land productivity (US$/ha)
Souss Massa	157	Sugar beets	-	-	33	-	-
	156	Sugar cane	-	-	23	-	-
	495	Tang.mand.etc.	517	17.34	271	0.52	4,702
	388	Tomatoes	99	47.82	173	1.76	8,295
	15	Wheat	2,908	1.03	254	0.09	262
Sud Atlas	221	Almonds	10,309	0.59	233	0.02	138
	44	Barley	1,451	0.83	184	0.13	152
	577	Dates	4,222	1.79	1,014	0.24	1,811
	900a	Fodder crops	134	-	-	-	-
	560	Grapes	1,366	5.79	337	0.25	1,950
	56	Maize	3,015	0.88	209	0.07	184
	260	Olives	5,209	1.40	321	0.06	449
	490	Oranges	545	16.78	201	0.37	3,364
	157	Sugar beets	-	-	33	-	-
	156	Sugar cane	-	-	23	-	-
	495	Tang.mand.etc.	528	17.34	271	0.51	4,701
	388	Tomatoes	100	47.65	173	1.73	8,265
	15	Wheat	1,088	1.15	254	0.23	291
Tensift	221	Almonds	10,210	0.43	233	0.02	99
	44	Barley	3,882	0.76	184	0.05	139
	577	Dates	7,295	1.76	1,014	0.14	1,789
	900a	Fodder crops	376	-	-	-	-
	560	Grapes	1,420	5.80	337	0.24	1,954
	56	Maize	5,746	0.54	209	0.04	114
	260	Olives	5,122	1.08	321	0.06	347
	490	Oranges	538	16.78	201	0.37	3,366
	157	Sugar beets	-	-	33	-	-
	156	Sugar cane	-	-	23	-	-
	495	Tang.mand.etc.	521	17.35	271	0.52	4,704
	388	Tomatoes	98	47.84	173	1.77	8,299
	15	Wheat	3,079	1.17	254	0.08	299

Sources: water footprint and yield from Mekonnen and Hoekstra (2010b); producer prices from FAO (2013d).

Appendix VIII: Input and output data regarding the crop relocation assessment

Period of data: 1996-2005.

Input data

Harvested area (1000 ha/yr)

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Mou-louya	Sebou	Louk-kos	Total
Almonds	1.0	6.1	15.3	42.3	21.1	7.1	36.1	7.3	136.3
Barley	30.2	175.5	416.5	738.1	206.1	283.4	297.8	60.4	2207.9
Dates	0.9	1.8	3.8	10.8	2.0	3.3	12.1	2.6	37.2
Grapes	15.9	8.5	1.9	6.9	0.9	6.8	5.8	1.8	48.6
Maize	9.4	6.2	60.2	162.7	19.8	0.8	13.4	0.5	273.0
Olives	7.7	24.8	57.6	160.8	59.7	33.6	138.5	29.3	512.0
Oranges	1.1	2.2	5.0	13.7	3.0	4.7	17.4	3.6	50.7
Sugar beets	-	-	-	26.3	0.1	2.6	27.9	2.0	58.9
Sugar cane	-	-	-	-	1.0	0.6	9.8	3.3	14.8
Tang.mand.	0.5	1.1	2.4	6.5	1.4	2.2	8.3	1.7	24.1
Tomatoes	0.2	0.9	2.4	6.8	3.3	1.2	5.8	1.1	21.7
Wheat	26.8	42.3	161.4	908.9	456.2	140.5	1008.5	130.0	2874.5
Total	93.7	269.4	726.4	2083.8	774.6	486.8	1581.4	243.6	6259.8

Source: Mekonnen and Hoekstra (2010b).

Yield (ton/ha)

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Mou-louya	Sebou	Louk-kos	Ave-rage
Almonds	0.59	0.42	0.43	0.46	0.43	0.56	0.52	0.57	0.48
Barley	0.83	1.08	0.76	0.79	0.80	0.86	0.88	0.93	0.83
Dates	1.79	1.77	1.76	1.77	1.72	1.78	1.77	1.78	1.77
Grapes	5.79	5.81	5.80	5.81	5.65	5.78	5.80	5.81	5.79
Maize	0.88	0.37	0.54	0.66	0.50	0.77	0.73	0.58	0.63
Olives	1.40	1.09	1.08	1.14	0.94	1.35	1.25	1.33	1.17
Oranges	16.78	16.78	16.78	16.79	16.35	16.71	16.78	16.80	16.75
Sugar beets	-	-	-	51.05	50.99	51.14	50.96	51.01	51.01
Sugar cane	-	-	-	-	69.87	69.91	69.82	69.84	69.83
Tang.mand.	17.34	17.34	17.35	17.36	16.90	17.26	17.34	17.36	17.31
Tomatoes	47.65	47.82	47.84	47.85	47.85	46.90	47.87	47.87	47.80
Wheat	1.15	1.03	1.17	1.26	1.16	1.34	1.33	1.39	1.27

Source: Mekonnen and Hoekstra (2010b).

Water footprint, green plus blue (m³/ton)

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Mou-louya	Sebou	Louk-kos	Ave-rage
Almonds	10,309	10,141	10,210	10,061	9,618	9,450	9,712	9,295	9,833
Barley	1,451	2,498	3,882	4,054	4,003	3,405	3,955	3,043	3,692
Dates	4,222	5,917	7,295	7,808	4,839	6,640	6,961	4,716	6,824
Grapes	1,366	1,412	1,420	1,547	655	1,002	1,189	1,067	1,305
Maize	3,015	7,063	5,746	7,387	6,447	1,219	6,549	3,178	6,724
Olives	5,209	5,102	5,122	5,063	4,835	4,756	4,854	4,651	4,941
Oranges	545	535	538	532	499	502	509	487	517
Sugar beets	-	-	-	124	65	106	114	101	118
Sugar cane	-	-	-	-	105	175	220	146	193
Tang.mand.	528	517	521	515	483	486	492	471	501
Tomatoes	100	99	98	97	93	92	94	89	95
Wheat	1,088	2,908	3,079	3,168	3,115	2,595	3,001	2,329	3,003

Source: Mekonnen and Hoekstra (2010b).

Fraction of blue water footprint in total green plus blue water footprint (-)

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Mou-louya	Sebou	Louk-kos	Ave-rage
Almonds	0.52	0.22	0.16	0.15	0.03	0.20	0.12	0.11	0.13
Barley	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dates	0.78	0.71	0.65	0.63	0.41	0.58	0.54	0.47	0.59
Grapes	0.83	0.80	0.77	0.73	0.69	0.68	0.63	0.60	0.76
Maize	0.78	0.05	0.32	0.53	0.20	0.22	0.51	0.04	0.47
Olives	0.60	0.42	0.35	0.31	0.10	0.33	0.24	0.22	0.28
Oranges	0.72	0.70	0.65	0.61	0.57	0.55	0.51	0.46	0.57
Sugar beets	-	-	-	0.73	0.71	0.70	0.72	0.66	0.72
Sugar cane	-	-	-	-	0.75	0.75	0.73	0.68	0.73
Tang.mand.	0.72	0.70	0.65	0.61	0.57	0.55	0.51	0.46	0.57
Tomatoes	0.69	0.62	0.58	0.55	0.55	0.52	0.51	0.44	0.54
Wheat	0.42	0.01	0.08	0.11	0.01	0.11	0.09	0.03	0.08

Source: Mekonnen and Hoekstra (2010b).

Base case

Base case production (1000 ton/yr)

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Mou-louya	Sebou	Louk-kos	Total
Almonds	0.6	2.6	6.5	19.4	9.1	4.0	18.9	4.1	65.2
Barley	24.9	189.9	315.6	581.3	164.6	244.5	260.8	56.4	1,838.1
Dates	1.6	3.1	6.7	19.0	3.4	5.9	21.5	4.7	65.9
Grapes	92.3	49.3	11.0	39.9	5.3	39.5	33.7	10.6	281.6
Maize	8.2	2.3	32.8	106.8	9.8	0.6	9.9	0.3	170.7
Olives	10.8	27.0	62.1	183.3	56.2	45.3	173.5	39.0	597.2
Oranges	19.1	37.5	84.4	230.8	48.7	77.9	291.8	59.9	850.0
Sugar beets	-	-	-	1,344.2	5.8	130.4	1,420.1	104.3	3,004.8
Sugar cane	-	-	-	-	73.1	38.9	687.3	232.9	1,032.2
Tang.mand.	9.4	18.4	41.4	113.3	23.9	38.1	143.2	29.4	417.1
Tomatoes	8.2	45.0	114.3	325.5	157.2	56.7	277.7	54.6	1,039.2
Wheat	30.7	43.6	189.6	1,149.1	530.9	188.3	1,344.1	180.4	3,656.7
Total	205.8	418.6	864.5	4,112.6	1,088.0	870.1	4,682.6	776.6	13,019

Source: Mekonnen and Hoekstra (2010b).

Base case water footprint, green plus blue (Mm^3/yr)

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Mou-louya	Sebou	Louk-kos	Total
Almonds	6	26	66	195	87	37	184	38	641
Barley	36	475	1,225	2,356	659	832	1,032	172	6,787
Dates	7	18	49	148	17	39	149	22	449
Grapes	126	70	16	62	3	40	40	11	367
Maize	25	16	188	789	63	1	65	1	1,148
Olives	56	138	318	928	272	216	842	181	2,951
Oranges	10	20	45	123	24	39	149	29	440
Sugar beets	0	0	0	166	0	14	162	11	353
Sugar cane	0	0	0	0	8	7	151	34	200
Tang.mand.	5	10	22	58	12	19	71	14	209
Tomatoes	1	4	11	32	15	5	26	5	99
Wheat	33	127	584	3,640	1,654	489	4,034	420	10,981
Total	306	903	2,525	8,498	2,813	1,737	6,905	939	24,625

Source: Mekonnen and Hoekstra (2010b).

Optimization results – Case A

Allocated production (1000 ton/yr)

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Mou-louya	Sebou	Louk-kos	Total
Almonds	0	0	0	0	65	0	0	0	65
Barley	0	292	551	996	0	0	0	0	1,838
Dates	0	0	0	0	66	0	0	0	66
Grapes	0	0	0	0	282	0	0	0	282
Maize	0	0	0	0	0	171	0	0	171
Olives	0	0	0	0	341	0	256	0	597
Oranges	0	0	0	0	850	0	0	0	850
Sugar beets	0	0	0	0	3,005	0	0	0	3,005
Sugar cane	0	0	0	0	1,032	0	0	0	1,032
Tang.mand.	0	0	0	0	417	0	0	0	417
Tomatoes	0	0	0	0	1,039	0	0	0	1,039
Wheat	107	0	0	1,020	0	356	1,835	338	3,657
Total	107	292	551	2,016	7,097	527	2,091	338	13,019

Allocated land (1000 ha/yr)

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Mou-louya	Sebou	Louk-kos	Total
Almonds	0	0	0	0	152	0	0	0	152
Barley	0	269	726	1,265	0	0	0	0	2,261
Dates	0	0	0	0	38	0	0	0	38
Grapes	0	0	0	0	50	0	0	0	50
Maize	0	0	0	0	0	221	0	0	221
Olives	0	0	0	0	363	0	204	0	567
Oranges	0	0	0	0	52	0	0	0	52
Sugar beets	0	0	0	0	59	0	0	0	59
Sugar cane	0	0	0	0	15	0	0	0	15
Tang.mand.	0	0	0	0	25	0	0	0	25
Tomatoes	0	0	0	0	22	0	0	0	22
Wheat	94	0	0	807	0	266	1,377	244	2,787
Total	94	269	726	2,071	775	487	1,581	244	,6247
Harvested area – allocated land	0	0	0	12	0	0	0	0	0

Water footprint, green plus blue (Mm³/yr)

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Mou-louya	Sebou	Louk-kos	Total
Almonds	0	0	0	0	627	0	0	0	627
Barley	0	728	2,137	4,037	0	0	0	0	6,903
Dates	0	0	0	0	319	0	0	0	319
Grapes	0	0	0	0	184	0	0	0	184
Maize	0	0	0	0	0	208	0	0	208
Olives	0	0	0	0	1,650	0	1,243	0	2,892
Oranges	0	0	0	0	425	0	0	0	425
Sugar beets	0	0	0	0	196	0	0	0	196
Sugar cane	0	0	0	0	108	0	0	0	108
Tang.mand.	0	0	0	0	202	0	0	0	202
Tomatoes	0	0	0	0	97	0	0	0	97
Wheat	117	0	0	3,231	0	924	5,508	788	10,568
Total	117	728	2,137	7,268	3,808	1,132	6,751	788	22,729

Optimization results – Case B

Allocated production (1000 ton/yr)

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Mou-louya	Sebou	Louk-kos	Total
Almonds	1	3	7	19	9	4	19	4	65
Barley	0	243	485	1,109	0	0	0	0	1,838
Dates	2	3	7	19	3	6	21	5	66
Grapes	92	49	11	40	5	40	34	11	282
Maize	0	0	0	0	0	171	0	0	171
Olives	11	27	62	183	56	45	174	39	597
Oranges	19	37	84	231	49	78	292	60	850
Sugar beets	0	0	0	0	3,005	0	0	0	3,005
Sugar cane	0	0	0	0	73	39	687	233	1,032
Tang.mand.	9	18	41	113	24	38	143	29	417
Tomatoes	0	0	0	0	1,039	0	0	0	1,039
Wheat	76	0	0	526	704	278	1,804	269	3,657
Total	210	381	698	2,241	4,968	698	3174	650	13,019

Allocated land (1000 ha/yr)

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Mou-louya	Sebou	Louk-kos	Total
Almonds	1	6	15	42	21	7	36	7	136
Barley*	0	225	641	1,409	0	0	0	0	2,274
Dates	1	2	4	11	2	3	12	3	37
Grapes	16	8	2	7	1	7	6	2	49
Maize*	0	0	0	0	0	221	0	0	221
Olives	8	25	58	161	60	34	139	29	512
Oranges	1	2	5	14	3	5	17	4	51
Sugar beets*	0	0	0	0	59	0	0	0	59
Sugar cane	0	0	0	0	1	1	10	3	15
Tang.mand.	1	1	2	7	1	2	8	2	24
Tomatoes*	0	0	0	0	22	0	0	0	22
Wheat*	66	0	0	416	605	207	1,353	194	2,842
Total	94	269	726	2,065	775	487	1,581	244	6,241
Annuals*	66	225	641	1,824	685	428	1,353	194	5,418
Perennials	27	44	86	241	89	58	228	50	824
Harvested area (annuals) – allocated land (annuals)	0	0	0	18	0	0	0	0	0

Water footprint, green plus blue (Mm³/yr)

	Sud Atlas	Souss Massa	Tensift	Oum Er Rbia	Boure-greg	Mou-louya	Sebou	Louk-kos	Total
Almonds	6	26	66	195	87	37	184	38	641
Barley	0	608	1,884	4,496	0	0	0	0	6,989
Dates	7	18	49	148	17	39	149	22	449
Grapes	126	70	16	62	3	40	40	11	367
Maize	0	0	0	0	0	208	0	0	208
Olives	56	138	318	928	272	216	842	181	2,951
Oranges	10	20	45	123	24	39	149	29	440
Sugar beets	0	0	0	0	196	0	0	0	196
Sugar cane	0	0	0	0	8	7	151	34	200
Tang.mand.	5	10	22	58	12	19	71	14	209
Tomatoes	0	0	0	0	97	0	0	0	97
Wheat	83	0	0	1,666	2,192	721	5,414	627	10,703
Total	294	890	2,400	7,676	2,908	1,325	7,000	958	23,451

Appendix IX: Summary of national water strategy of Morocco

This appendix contains an English summary of the action plans in the national water strategy of Morocco, originally in French (Ministry EMWE, 2011).

The national water strategy is based on three levers, namely:

1. Much more ambitious goals to meet water needs in a sustainable way, but also durable protection against the effects of global warming.
2. Radical change in behaviour (use and management of water) through coordinated demand and resource management on:
    - Securing measures for the protection and replenishment of groundwater reserves and lakes.
    - Rationalisation of water demand.
    - Generalization of wastewater treatment and reuse.
    - A diverse portfolio of innovative solutions for mobilization of water, combining all relevant local solutions with better interconnection of regions.
    - Pro-active protection measures (of the environment and the fight against flooding).
3. Real long-term water management:
    - National visibility on long-term water needs and availability, regularly updated and improved.
    - Political commitment and effort from all stakeholders, supported by a regulatory framework and adapted governance.
    - More ambitious public and private funding.

The main action plans of the national water strategy are grouped along 6 axes:

1. <u>Demand management and valorisation of water</u>

    In the agricultural sector potential (irrigation) water savings are estimated at about 2.5 Gm³/yr by:
    - Conversion to drip irrigation: potential of 2 Gm³/yr with a conversion rate of 44,000 ha/yr.
    - Improved efficiency of irrigation supply networks: potential of about 400 Mm³/yr.
    - Adoption of a water-pricing system based on volumes.
    - Awareness raising and supervision of farmers for water saving techniques.

    These efforts will be particularly significant in the four major agricultural areas of Morocco: Sebou, Oum Er Rbia, Tensift and Souss-Massa.

    In the sectors of public water supply, industry and tourism potential water savings are estimated at about 120 Mm³/yr by:
    - Improving the efficiency of supply networks: national average of 80%.
    - Standardization and encouragement of the use of appropriate technologies for water savings: pipes, sanitary equipment, etc.

- Revision of the tariff system: pricing that gives incentive for more efficient use of water and better cost recovery.
- Improving the efficiency of water use in industry and tourism sector and encourage the reuse of water.
- Taking into account best practices in water-saving in construction standards.

2. <u>Supply management and development</u>

   Continuation of large-scale mobilization of water by:

   - Realisation of another 60 large dams by 2030: aimed capacity of 7 Gm³ in total, mobilizing an additional amount of 1.7 Gm³/yr.
   - North-South water transfer from basins Loukkos and Sebou to Bouregreg, Oum Er Rbia and Tensift: 1st phase, 400 Mm³/yr from Sebou; 2nd phase, 400 Mm³/yr from Loukkos. The inter-basin connection allows flexible allocation management to cope with sudden changes in inflow of the basins.

   Small-scale mobilization of new water resources is also planned, namely:

   - Continuation of the program of small and medium dams: realisation of 1000 small dams by 2030. These dams play an important role in local development of irrigation, livestock watering and protection against flooding.
   - Realise pilot projects on rainwater harvesting/capturing: a pilot in a basin before potential implementation on a large-scale (as done in India and Australia).

   Plans for unconventional mobilization of water resources are:

   - Desalinisation of seawater and demineralization of brackish water: objective is to realize a potential production of potable water of 400 Mm³/yr. On medium term it is expected to realize facilities in Agadir and Laayoune. On long-term also in Tiznit- Sidi Ifni, Chtouka, Essaouira, Safi, El Jadida, Casablanca, Al Hoceima and Saidia.
   - Reuse of treated wastewater: 300 Mm³/yr of treated wastewater for reuse in irrigation of golf courses, parks and crops in some cases, as well as for artificial recharge of groundwater.

   Other supply-related plans are:

   - Strengthening the maintenance of existing water infrastructure and interconnection systems. This allows for the diversification of supply sources and therefore more secure and substantial gains in efficiency and synergy.
   - In rural areas, widespread access to potable water will be pursued through the upgrading of existing public systems to secure their operation and realization of individual systems for isolated and dispersed population.

3. <u>Preservation and protection of water resources, the natural environment and sensitive areas</u>

   The strategy proposes the following for the protection and restoration of groundwater systems:

- Limitation of pumping from aquifers (revision of the pricing system, downward revision of allowed withdrawal thresholds for overexploited aquifers, cancel subsidies that provide incentive for overexploitation, areas of prohibited or restricted pumping, efficient techniques, establishment of a drilling permit).
- Reinforcement of the control and sanction system for overexploitation, particularly by reinforcing the water police and encouraging satellite monitoring and aerial surveillance.
- Reinforcement of the responsibility of the river basin agencies in management of aquifers and generalisation of aquifer contracts:
    - Systematic use of alternative, conventional and unconventional, water resources to relieve pressure on groundwater resources.
    - Programs of artificial groundwater recharge: storage of 180 Mm^3/yr.
    - Reinjection of treated wastewater to coastal aquifers used for irrigation (100 Mm^3 by 2030).
    - Substitution of groundwater by surface water as a source for water withdrawal by ONEP (drinking water service) (90 Mm^3 by 2030).

The strategy aims to prevent pollution and fight against it by:

- Acceleration of the implementation of the national program of sanitation and wastewater treatment: target access level to sanitation of 90% by 2030.
- Establishment of a national program for rural sanitation: target access level to sanitation of 90% by 2030.
- Development of a national program of prevention and fight against industrial pollution.
- Establishment of a national management plan for domestic and similar waste.

Protection of fragile wetlands, natural lakes, oases and the coast by:

- Protection of watersheds upstream of dams against erosion.
- A protection program for springs.
- A protection program for wetlands and natural lakes.
- Preservation of oases and the fight against desertification.
- Protection of the coast.
- Limitation and control of pumping from aquifers that directly affect natural lakes.
- Improving the supply to lakes by diversion of rivers and development of thresholds and small dams upstream.

4. <u>Reduction of vulnerability to natural hazards related to water and climate change adaptation</u>

Improving the protection of people and property against flooding by:

- Completion of the measures included in the national plan for protection against inundations: target of 20 protected sites per year.
- Incorporation of the inundation risk in spatial, urban and watershed planning.
- Improving knowledge in the fields of weather forecasting and urban hydrology.

- Development of flood warning systems and emergency plans.
- Development of financial mechanisms (insurance and natural disaster funds).

Drought management plans at the river basin level, which aim for:

- Characterization of drought: identification and proposal of monitoring indicators.
- Implementation of structural measures: diversification of water supply sources.
- Elaboration of emergency plans.
- Development of financial mechanisms such as insurance and natural disasters funds.

5. <u>Further regulatory and institutional reforms</u>

Proposed further regulatory and institutional reforms, supplementing the advances made after the establishment of the Water Law 10-95 in 1995, are:

- Completion of the legal framework necessary for the implementation of all provisions of Law 10-95, related to:
    - Prevention of and fight against flooding.
    - Declaration of the state of water scarcity and management during periods of drought.
    - Implementation of the principle “the polluter pays”.
- Review of the Water Law and its implementation regulations to incorporate the domains it does not cover, namely:
    - Wastewater discharges in sea.
    - Desalination of sea water.
    - Water conservation.

6. <u>Modernisation of information systems and capacity building</u>

To support the implementation of the national water strategy, parallel development of human and material resources in the water sector by the administration should aim at:

- Modernisation of the administration and the development of information systems, particularly the implementation of a water information system for professionals and the public.
- Modernisation of the network of measures.
- Reinforcement of research and development.
- Capacity building.

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