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WATER FOOTPRINT OF COTTON, WHEAT AND RICE PRODUCTION IN CENTRAL ASIA

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Summary

The hydrology of the Aral Sea Basin during the past few decades has been largely determined by the decision to develop irrigated agriculture on a large scale to produce cotton for export in the 1960s. The irrigated area has grown to 8 million hectares, using practically the entire available flow of the two main rivers, the Amu Darya and Syr Darya. Almost two decades after the disintegration of the Soviet Union, the five states of the Aral Sea Basin face the challenge of restoring a sustainable equilibrium while offering development opportunities for an increasing population. Sustainable water management is thus an imperative that will require coordinated political action of all the states involved.

The Soviet Union established its cotton-producing areas in Uzbekistan, Turkmenistan, Tajikistan, and Kyrgyzstan. Today, while cotton remains relatively important, cereal production to reduce imports has become a priority in all four nations. The cotton crop area has decreased over the past ten years, while that of winter wheat – the main grain crop – has doubled. At 39 per cent of the total (blue and green) water consumption in agriculture, wheat is the largest water-consuming crop in the five basin states, followed by cotton at 33 per cent.

The present study analyses the water footprint of Central Asian cotton (*Gossypium hirsutum* L.), wheat (*Triticum aestivum* L.) and rice (*Oryza sativa* L.) production, differentiating between the green and blue components, in order to know how the scarce water resources in the region are apparently allocated.

There are different alternatives for improving the allocation of water resources and achieving water savings in the basin. Potential options include enhancing rainwater and nutrient use efficiency, implementing state-of-the-art irrigation technology, the selection of crops and seed varieties requiring less water and optimizing cropping patterns. This report suggests that the allocation of water resources could be improved by shifting the irrigated grain production to colder, wetter regions. For instance, wheat production in Tajikistan, Turkmenistan and Uzbekistan has a water footprint in the range of 2000-4000 m^3/ton and is mainly based on irrigation water, which has a higher opportunity cost than soil moisture from rain, whereas wheat grown in northern Kazakhstan under rain-fed conditions has a water footprint of just 1400 m^3/ton. Similarly, other water-intensive, low-value crops such as rice, which requires 7000 m^3/ton in Turkmenistan, would use half that amount if grown in less arid conditions and more clayey soils in Kyrgyzstan, Tajikistan or Kazakhstan or could even be imported from outside the basin. Shifting some crops, such as grains, to rain-fed areas or areas with more rainfall could substantially reduce the volume of irrigation water consumed in the basin.

Central Asia is characterized by large regional differences in green and blue water resources availability. Virtual water trade in this region could redistribute the water resources in the region, holding considerable promise for water savings and the reallocation of water to high-value uses. Ultimately, this could help to achieve a balance between water and food for human consumption and the environmental water requirements. Experience shows that a long-term vision for water resources management is needed to guide day-to-day actions and planning. Besides, regional co-operation between the countries is essential in achieving an efficient allocation and improved water management of the shared Aral Sea Basin resources.

1. Introduction

The current water problems in the Aral Sea Basin are mainly due to the increase in irrigation to produce cotton for export in the time of the former Soviet Union. Since the 1960s, the irrigated area has grown to 8 million hectares, using practically the entire available flow of the two main rivers, the Amu Darya and Syr Darya (UNESCO, 1998). The diminishing Aral Sea is the most visible sign of the environmental disaster of the Aral Sea Basin. The area of the sea in the Amu Darya delta decreased from 400,000 ha in 1960 to 26,000 ha in 2001 (CAWATER, 2009). The lacustrine ecosystem ceased to exist, the wetlands have disappeared or are heavily damaged, with serious consequences on economic activity and health (Nandalal and Hipel, 2007). The loss of soil productivity is of immediate concern. The polluted water in the rivers and the sand storms from the contaminated soil constitute health risks, particularly as good quality drinking water is lacking in large areas of the basin (UNESCO, 1998). The five arid and semi-arid states of the Aral Sea Basin now have to rehabilitate the environment, at the same time caring for the subsistence and progress of the increasing population. Sustainable water management is thus an imperative, to be supported by coordinated political action of all the states involved.

Central Asia largely coincides with the geographical borders of the Aral Sea Basin, completely including the territories of Tajikistan, Uzbekistan, a large part of Turkmenistan, Kyrgyzstan and the south of Kazakhstan. In this region, which is arid to semi-arid (Figure 1.1.), agriculture is the main water consuming sector, responsible for about 90% of the total consumptive water use (Hoekstra and Chapagain, 2008) and around 95% of the total water withdrawals according to AQUASTAT (FAO, 2009a). Within this sector, wheat, cotton and probably alfalfa (though with limited marketability) are the largest water-consuming crops.

The present study analyses the water footprint of Central Asian production of cotton (*Gossypium hirsutum* L.), wheat (*Triticum aestivum* L.) and rice (*Oryza sativa* L.), differentiating between the green and blue water components. Such data can be instrumental in analysing how water resources could be more efficiently allocated and utilised. The present analysis focuses on the water footprint of cotton, wheat and rice in the five Central Asian countries in terms of water quantity. Even though qualitative aspects are also relevant in the region, they will not be dealt with in the present report. After a discussion of the method and data used, we first present an overview of the total water footprint in Central Asia. Second, the green and blue water footprints of cotton, wheat and rice are provided by country. It concludes that a better knowledge of the water footprint and virtual water trade in the arid and semi-arid Aral Sea Basin provides a transparent and multidisciplinary framework for informing water policy decisions.

The concept of the 'water footprint' has been proposed as an alternative indicator of water use, which looks at consumptive water use instead of water withdrawals (Hoekstra, 2003). Looking at consumptive, i.e. evaporative water use is more relevant than considering water withdrawals, because parts of the water withdrawals return to the water bodies where they were taken from, so these parts can be reused. The water footprint refers to both consumptive use of green water (rainwater) and blue water (surface and groundwater). The water footprint of a product is the volume of freshwater consumed to produce the product, measured at the place where the product

was actually produced (Hoekstra et al., 2009; Hoekstra and Chapagain, 2008). Closely linked to the concept of water footprint is the concept of virtual water trade, which represents the amount of water embedded in traded products (Allan, 1997; Hoekstra and Hung, 2005). A nation can preserve its domestic water resources by importing water-intensive products instead of producing them domestically. These domestic 'water savings' can be used to produce alternative, higher-value crops, to support environmental services, or to serve other domestic needs. At the global level, virtual water embedded in agricultural commodities can be exported from water-abundant to water-scarce regions, encouraged by the low cost and speed of food distribution. This could help to improve global water use efficiency, while at the same time ensuring food security, which is defined as the situation in which all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO, 2009a).
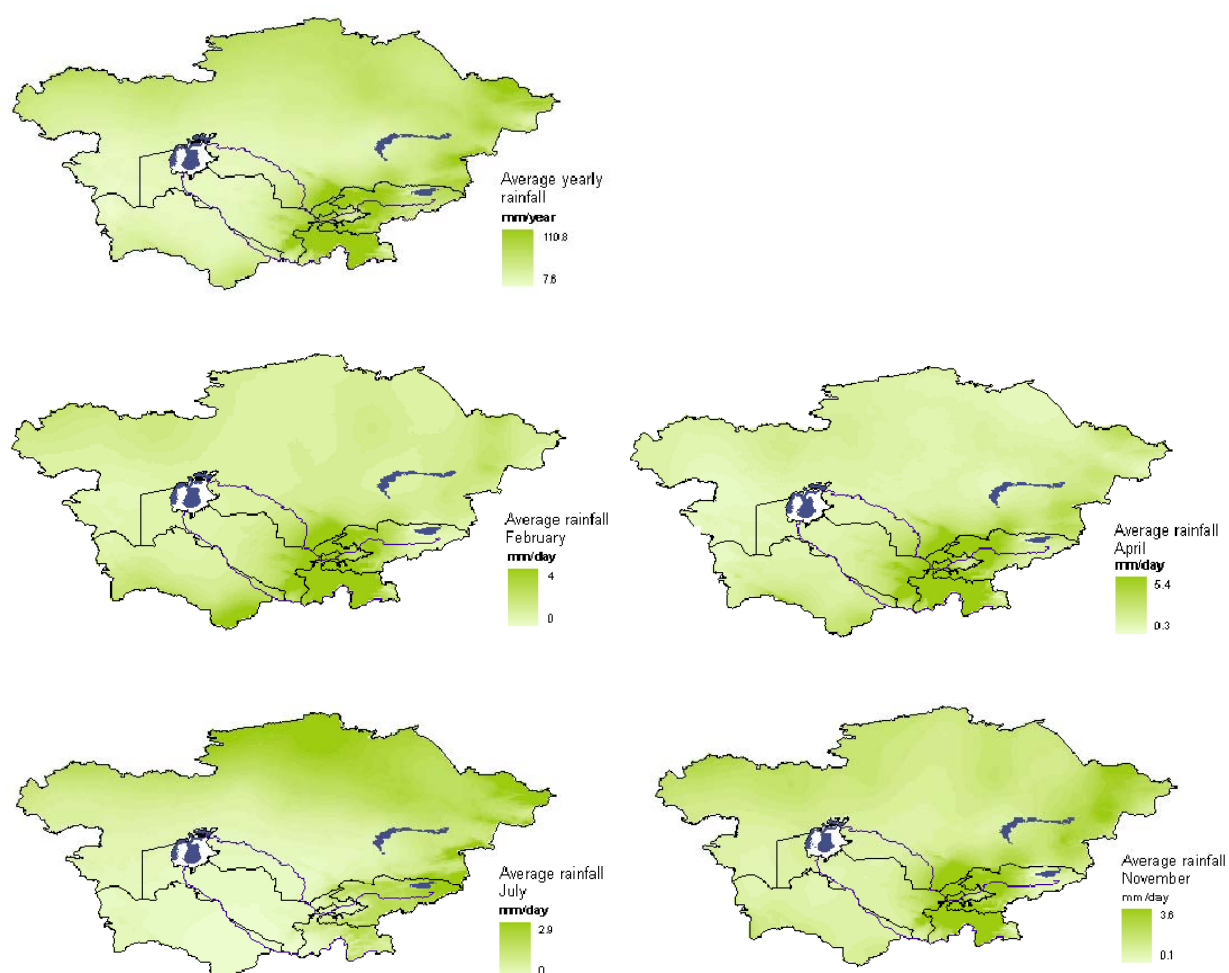

Figure 1.1. Average yearly rainfall (mm/year) and average rainfall in February, April, July and November (mm/day) in Central Asia during the period 1961-1990. Source: FAO (2009d).

Water footprint analysis makes explicit how much water is needed to produce different goods and services. In arid and semi-arid areas, knowing the water footprint of a good or service can be useful in determining how best to use the scarce water available. In this sense, it is important to establish whether the water used proceeds from rainwater stored in the soil as soil moisture and evaporated during the production process (green water) or surface water and/ or groundwater evaporated as a result of the production of the product (blue water)

(Falkenmark, 2003). Traditionally, emphasis has been given to the concept of blue water through the 'miracle' of irrigation systems. However, an increasing number of authors highlight the importance of green water (Allan, 2006; Comprehensive Assessment of Water Management in Agriculture, 2007; Falkenmark and Rockström, 2004). Virtual water and water footprint assessment could thus inform production and trade decisions, promoting the production of goods most suited to local environmental conditions and the development and adoption of water-efficient technologies. Adopting this approach however, requires a good understanding of the impacts of such policies on socio-cultural, economic and environmental conditions. Water is not the only factor involved in production and other factors, such as energy, may come to play an increasingly important role in determining water resources allocation and use.

2. Method and data

2.1 Water footprint of primary crops

The green and blue water footprints of cotton, wheat and rice production are calculated using the methodology described in Hoekstra et al. (2009). The total crop water requirement, effective rainfall and irrigation requirements per region have been estimated using the CROPWAT model (Allen et al., 1998; FAO, 2009b). The calculations have been done using climate data from the nearest and most representative meteorological stations located in the major crop-producing regions and a specific cropping pattern for each crop according to the type of climate (Monfreda et al., 2008) (Table 2.1 and Appendix I). When possible, the climate data have been taken from the CLIMWAT database (FAO, 2006a). In the case of Kazakhstan, Kyrgyzstan and Tajikistan, since data were not available in CLIMWAT, this information was obtained from the New LocClim database (FAO, 2006b).

Table 2.1. Planting and harvesting dates and yield for cotton, rice and wheat in Central Asia.

Crop	Planting date *	Harvesting date *	Yield (ton/ha) **
Cotton	1 May	11 Nov.	2.0
Rice	1 May	28 Aug.	2.5
Spring wheat ***	1 May	28 Aug.	1.0
Winter wheat ***	15 Oct.	11 June	2.2

* *Sources: Allen et al. (1998); Morgounov et al. (2007); Chapagain and Hoekstra (2004). These dates slightly vary in Turkmenistan, where cotton is planted in April, rice in March and wheat in November.*
** *Source: FAOSTAT (FAO, 2009c) period 1992-2007*
*** *Spring wheat is grown in Kazakhstan whereas winter wheat in Kyrgyzstan, Turkmenistan, Tajikistan and Uzbekistan.*

The 'green' water footprint of the crop (m^3/ton) has been estimated as the ratio of the green water use (m^3/ha) to the crop yield (ton/ha), where total green water use is obtained by summing up green water evapotranspiration over the growing period. Green water evapotranspiration is calculated based on the CROPWAT model outputs, as the minimum of effective rainfall and crop water requirement with a time step of ten days.

The 'blue' water footprint of the crop has been taken equal to the ratio of the volume of irrigation water consumed to the crop yield. In the cases of cotton and winter wheat, which are all irrigated, the irrigation water consumed is taken equal to the irrigation requirements as estimated with the CROPWAT model. In the case of rice, the irrigation water consumed is based on the CROPWAT model output and estimated as the difference between the crop water requirement and effective rainfall on a ten-day basis. When the effective rainfall is greater than the crop water requirement the irrigation requirement is equal to zero. The total evapotranspiration of irrigation water is obtained by summing up the blue water evapotranspiration over the growing period. Crop water requirements are assumed to be always fully satisfied except in the case of rain-fed spring wheat production in Kazakhstan (Morgounov et al., 2007).

Both green and blue water footprints have been estimated separately by climate station. Then, the national green and blue water footprints have been calculated as an average of the different climate stations within the crop producing regions. Data on average crop yield and production by region for the period 1992-2007 are taken from the FAOSTAT database (FAO, 2009c). Crop coefficients for the different crops are obtained from FAO (Allen et al., 1998; FAO, 2009b).

Finally, in this study we have included the concept of economic blue-water productivity (US\$/m^3) to assess the production value, expressed in market price (US\$/ton) per cubic meter of water consumed when producing the commodity (m^3/ton).

3. Water footprint in Central Asia

3.1 Total water footprint

The total water footprint of consumption in Central Asia ranges from 939 m^3/capita/year in Tajikistan to 1774 m^3/capita/year in Kazakhstan (Table 3.1). These figures are to be compared with a global average of 1240 m^3/capita/year (Hoekstra and Chapagain, 2008), which corresponds to a food supply need of 3000 kcal/person/day out of which 20% are animal products (Kuylenstierna et al., 2008).

Table 3.1. Water footprint of consumption in Central Asia during the period 1997-2001.

	Population	Water footprint of consumption		Water footprint by consumption category				
				Direct consumption of water	Consumption of agricultural goods		Consumption of industrial goods	
		Total	Per capita	Internal water footprint*	Internal water footprint*	External water footprint*	Internal water footprint*	External water footprint*
	10^6	10^9m^3/year	m^3/cap/year	m^3/cap/year	m^3/cap/year	m^3/cap/year	m^3/cap/year	m^3/cap/year
Kazakhstan	15.2	27.0	1774	39	1637	19	76	4
Kyrgyzstan	4.9	6.6	1361	63	1256	-	37	5
Tajikistan	6.2	5.8	939	69	870	-	-	-
Turkmenistan	5.2	9.1	1764	74	1619	36	23	13
Uzbekistan	24.6	24.0	979	109	771	43	47	9

Source: Hoekstra and Chapagain (2008). Note: hyphen (-) means no data available.

* The total water footprint of a country includes two components: the part of the footprint that falls inside the country (internal water footprint) and the part of the footprint that presses on other countries in the world (external water footprint). The distinction refers to the appropriation of domestic water resources versus the appropriation of foreign water resources.

Table 3.2. Water footprint of production and virtual water import in Central Asia in the period 1997-2001 (10^9 m^3/yr).

| | Water footprint related to production within Central Asia | | | | | Virtual water import | | |
| | Water footprint related to domestic water use | Agricultural water footprint | | Industrial water footprint | | For national consumption | | For re-export of imported products* |
		For national consumption	For export	For national consumption	For export	Agricultural goods	Industrial goods	
Kazakhstan	0.59	24.9	7.92	1.15	4.58	0.29	0.06	0.33
Kyrgyzstan	0.31	6.1	0.42	0.18	0.12	-	0.02	0.01
Tajikistan	0.43	5.4	1.05	-	-	-	-	-
Turkmenistan	0.38	8.4	1.07	0.12	0.05	0.18	0.07	0.05
Uzbekistan	2.68	18.9	6.24	1.15	-	1.06	0.23	0.35

Source: Hoekstra and Chapagain (2008). Note: hyphen (-) means no data available.

* Virtual-water re-export is the volume of virtual water associated with the export of goods or services to other countries or regions as a result of re-export of previously imported products.

The agricultural sector in Central Asia, considering both green and blue water consumption, represents about 90% of the total water use (Table 3.2). In this region, wheat, cotton and rice water consumption amount to about 75% of total agricultural sector water use, adding up to 39%, 33% and 3% respectively. The five Central Asian

countries are highly agrarian, with 60% of the population living in rural areas and agriculture accounting for over 45% of total number of employed people and nearly 25% of GDP on average (Lerman and Stanchin, 2006). Kazakhstan, with its strong energy sector, has a less agrarian economy than the other Central Asian countries, with agriculture accounting for only 8% of GDP (but still 33% of total employment) (ibid.). On the whole, Central Asia is a net virtual water exporting region, with Kazakhstan and Uzbekistan exporting around 30% of their total water used (Table 3.2).

Out of the total land resources of about 155 million hectares some 33 million hectares are considered suitable for irrigation, while only about 8 million hectares are irrigated (i.e. 5% of total territory of the Aral Sea Basin) (CAWATER, 2009). The non-irrigated areas (pastures, hay, meadows, long-term fallow land) occupy about 54 million hectares. This area includes some 2 million hectares of rain-fed arable land but its productivity is on average no more than one-tenth of the productivity of irrigated land. At the moment, the rain-fed land does not play any significant role in the total agricultural production in the Aral Sea Basin, with the exception of extensive (semi-nomadic) livestock husbandry (cattle and sheep) (CAWATER, 2009). Nonetheless, raising productivity of non-irrigated (rain-fed) lands is an important goal. Some crops, like wheat, which at the moment are being increasingly grown in the irrigated areas, could be moved to non-irrigated areas thus reducing substantially the volume of irrigation water withdrawn in the basin (ibid.).
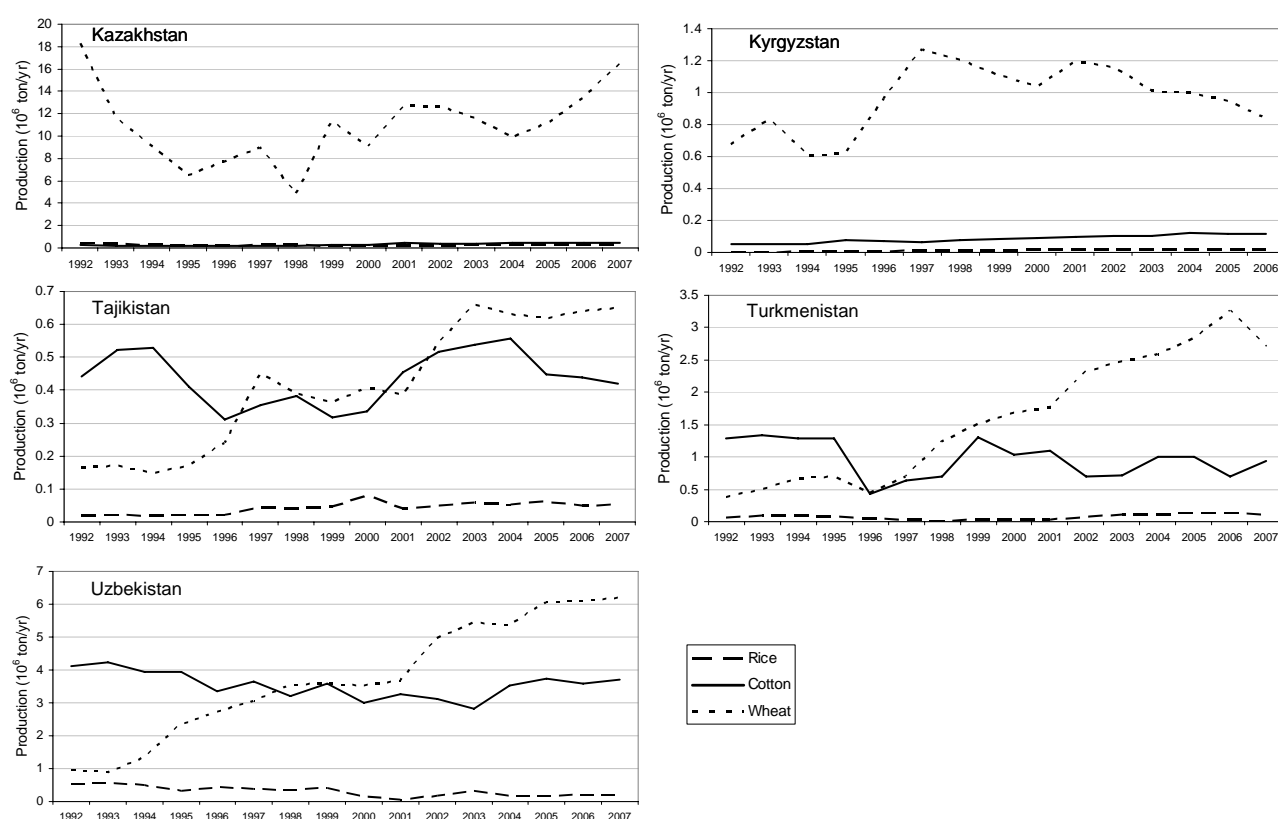

Figure 3.1. Cotton, rice and wheat production in Central Asia during the period 1992-2007 (10^6 ton/yr). Source: FAO (2009c).

Since independence, the area of irrigated land has not changed significantly in the Central Asian states. The only exception is Turkmenistan, where the area of irrigated land during 1995-1996 increased by about 400,000 hectares. Conversely, in Uzbekistan, Kyrgyzstan and particularly Tajikistan important areas have been put out of irrigation due to infrastructure decay for lack of maintenance. However, there have been big changes in crop patterns. Cotton still remains one of the most important crops, although between 1990 and 1998 its share of irrigated agriculture decreased from 45% to 25% (CAWATER, 2009). In the same period, the area under cereals (wheat, rice and others) increased from 12% to 77% (Figure 3.1). Wheat became the dominant crop in the region, which covers about 28% of the total irrigated area. Fodder crops occupied 19.6% of the total irrigated area in 1998, compared to 27.4% in 1990, which is highly undesirable from the point of view of maintaining soil fertility and crop rotation (ibid.).

3.2 Water footprint of cotton

In earlier times, Uzbekistan, Turkmenistan, Tajikistan, and Kyrgyzstan were considered the cotton zone of the Soviet Union, and cotton remains an important commodity in the region, but grain production has become increasingly important since the republics became independent in 1991 and set grain self-sufficiency as a national priority (USDA/FAS, 2002). The area sown to cotton has decreased over the past ten years, while that of wheat – the chief grain crop – has doubled (Figure 3.1). It is understood here that cash crops are any crop that is not at the basis of food for humans or livestock. In the case of Central Asia, cotton is by far the most important cash crop (Figures 3.2 and 3.3).
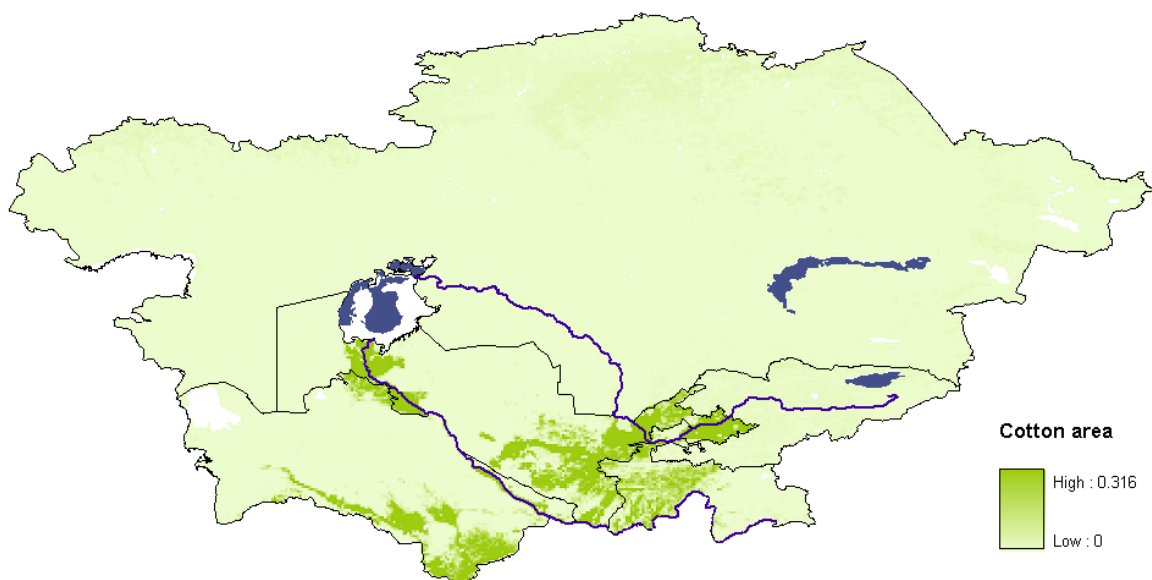

Figure 3.2. Cotton harvested area in Central Asia. Unit: proportion of grid cell area. Source: Monfreda et al. (2008).

Of the total cotton production, around 1,100,000 ton/yr is exported, representing about 16 percent of world exports (Fisher, 2005). For Turkmenistan it is estimated that cotton represents 20% of the export value of the country, the rest being essentially natural gas (UNESCO, 2000). Uzbekistan is one of the largest cotton exporters in the world (National Cotton Council of America, 2009). Every year, the country produces around 3.5 million tons of raw cotton and sells some 1 million tons of cotton fibre, generating more than US$ 1 billion – equivalent to half of the national budget revenues. The major environmental challenge of agriculture is the preservation of the environment in the long term without damaging the economy.

Cotton remains a strategically important commodity for the three largest producing countries (Uzbekistan, Turkmenistan and Tajikistan) (Fisher, 2005). The price of cotton in Central Asia was on average 841 US$/ton during the period 1997-2007. Prices of rice and wheat were 720 and 271 US$/ton respectively (FAO, 2009c). When looking at the economic blue-water productivity per crop type (Figure 3.4), we see that cotton has the highest value per water unit (with about 0.5 US$/m^3). Rice and wheat display an average productivity of less than 0.2 and 0.1 US$/m^3 respectively.
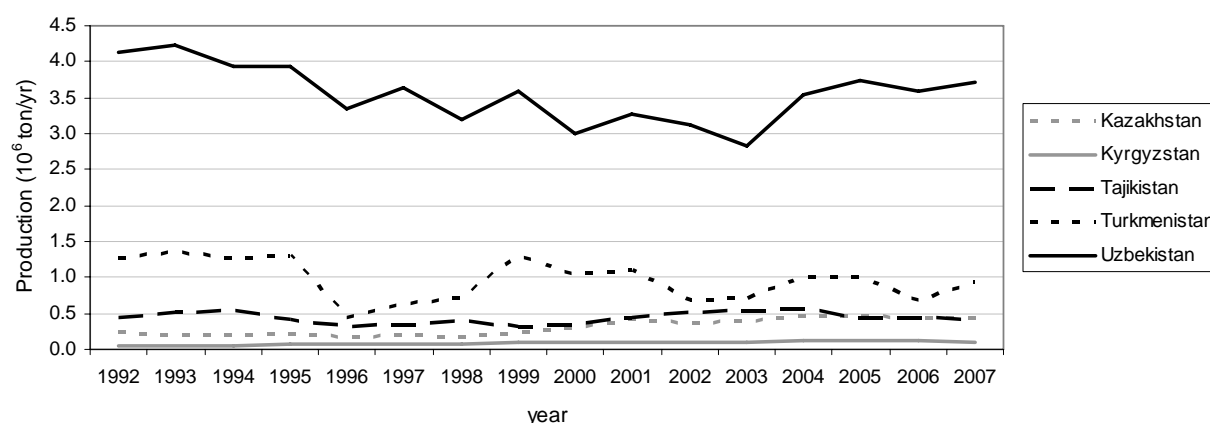

Figure 3.3. Central Asian cotton production by nation (10^6 ton/yr). Period 1992-2007. Source: FAO (2009c).

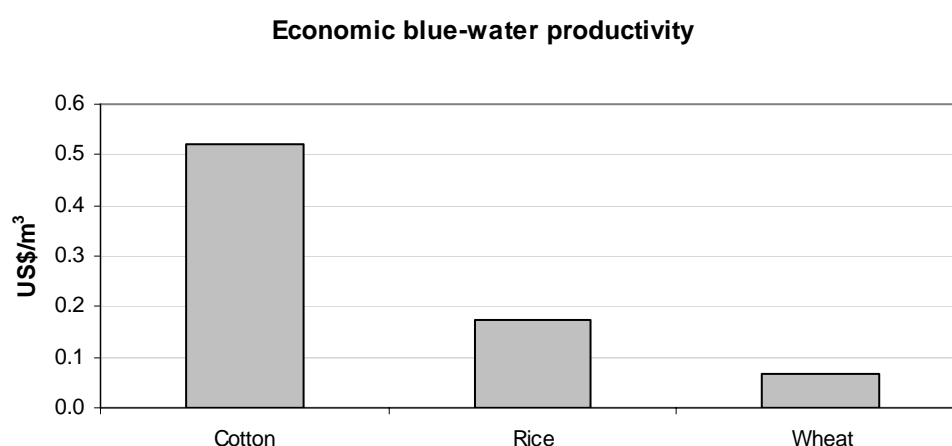**Economic blue-water productivity**

Figure 3.4. Economic blue-water productivity in Central Asia for the period 1997-2007. Source: Own elaboration based on data from FAO (2009c).

Cotton is mainly produced in the southern region of the Aral Sea Basin (Figure 3.2), using mainly blue water resources (Figure 3.5). The national average water footprint of cotton is relatively large in the southern countries. In Turkmenistan, the average blue water footprint is 6875 m^3/ton, while the green water footprint is 191 m^3/ton. The total water footprint of cotton is smaller in Kazakhstan and Kyrgyzstan, where the blue water footprint is 1461 and 2384 m^3/ton and the green water footprint 962 and 665 m^3/ton respectively (Appendix II). This smaller footprint can be explained by the lower evapotranspiration in these countries. Another reason could be the soil texture, soils in Turkmenistan are, for instance, much sandier when compared to anywhere in Kazakhstan.
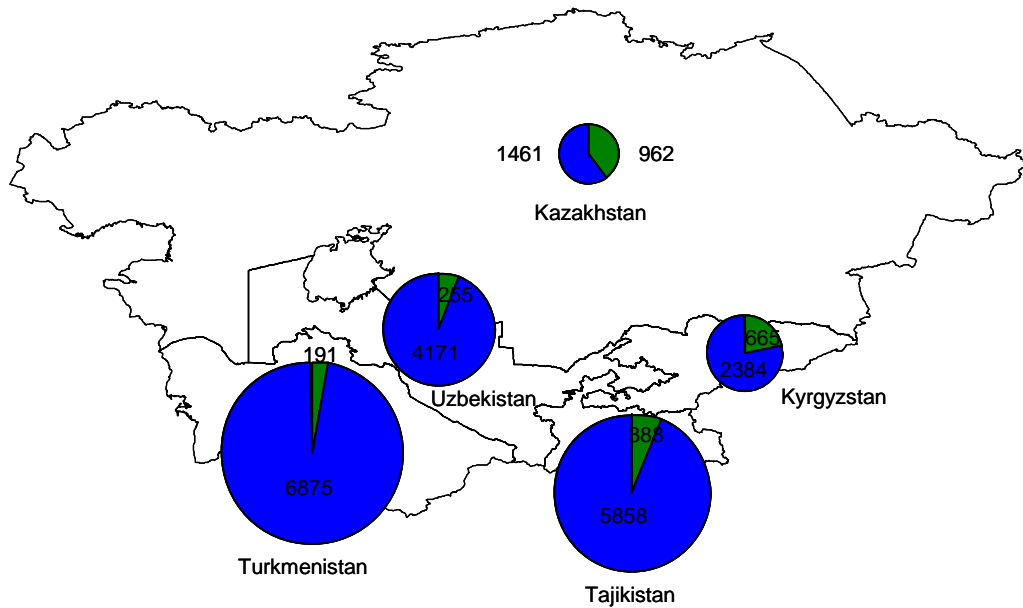

Figure 3.5. Green and blue water footprint of cotton production per unit of product, by nation. Both the size of each pie and the numbers shown in the pies reflect the water footprint per ton (m³/ton). Source: Own elaboration based on FAO data (2006a, 2006b, 2009b, 2009c).
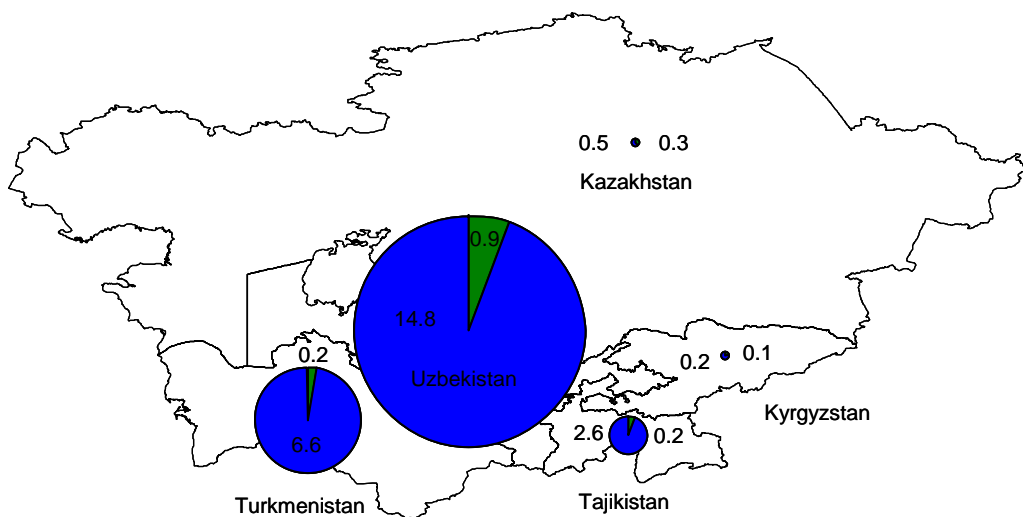

Figure 3.6. Total green and blue water footprint (10⁹ m³/year) for the Central Asian cotton production by nation. 1992-2007 year average. Source: Own elaboration based on FAO data (2006a, 2006b, 2009b, 2009c).

There are significant disparities between Central Asian countries in the efforts and priority given to improve the quality and yield of this important commodity. Nevertheless, it is possible to identify a number of issues that are common to all of the countries, which, if properly addressed, would benefit them all (Fisher, 2005). These include the improvement of existing and using alternative cotton varieties that require less water.

As shown in Figure 3.6, Uzbekistan is the main water consuming country in relation to cotton production, responsible for 60% (15.7 10^9 m³/year) of the total water consumed for cotton in the region. From the total volume of water used for cotton production in Uzbekistan, 7.9 10^9 m³/year was exported during the period 1997-2001, which is in line with what was found by Chapagain et al. (2006). This means that non-water policies, like economic and trade policy, can have major impacts on overall water use. Having clear information on the nature of water trade-offs and the different sector policies – water, agricultural, economic and trade policies – which influence them, can give policy makers a better understanding of the options available (Abdullaev et al., 2009).

3.3 Water footprint of wheat

The Central Asia region grows a total of about 15 million ha of wheat (FAO, 2009c). In northern Kazakhstan (48–55º N), spring wheat is grown on steppe lands under dry-land conditions (Morgounov et al., 2007). Throughout the southern region (36– 44º N), winter or facultative wheat is grown, primarily under irrigation (60–70%) and occupying 5–6 million ha (ibid.) (Figure 3.7). Rain-fed wheat is planted on the remaining 30–40% of the area, mostly on hillsides and in mountainous areas where irrigation is not possible (Morgounov et al., 2007).
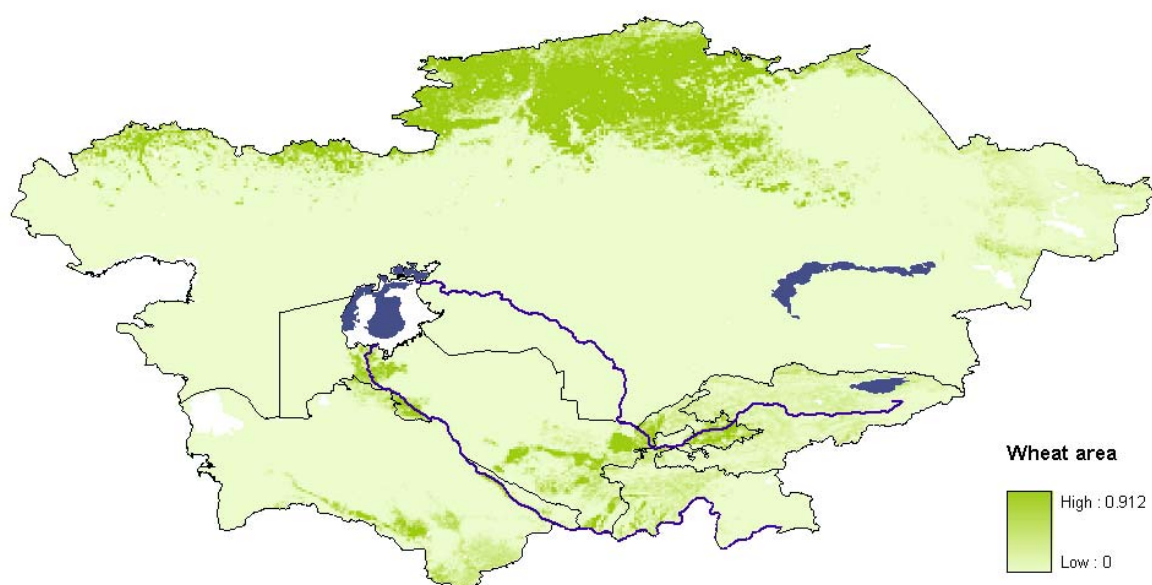

Figure 3.7. Wheat harvested area in Central Asia. Unit: proportion of grid cell area. Source: Monfreda et al. (2008).

The estimated total wheat production in Central Asia has increased significantly during the last 10 years particularly in Kazakhstan and Uzbekistan (Figure 3.8). Since 1991, wheat replaced cotton in some areas and became an important crop planted in order to increase regional food security (Morgounov et al., 2004). The modern varieties developed in the region are well adapted and combine yield potential, grain quality and disease resistance (ibid.). The average 2000-2007 wheat production for Central Asia is estimated at about 21 million ton/yr, with Kazakhstan as the main producer (57%), followed by Uzbekistan (24%), Turkmenistan (12%), Kyrgyzstan (5%) and Tajikistan (3%) (FAO, 2009c).

Regional differences in both total water consumption and the green-blue ratios are substantial (see Figures 3.9-3.10 and Appendix II). Kazakhstan is relatively efficient in the production of wheat in Central Asia; it has the lowest national average water footprint in the region and it is completely green water (i.e. 1440 m^3/ton). The Kazakh wheat is mainly cultivated in the northern part of the country under rain-fed conditions. According to the A1B climate change scenario of the IPPC (Bates et al., 2008), increases in annual precipitation exceeding 20% will occur in the northern part of Central Asia, resulting in an increase in the annual mean soil moisture content and potentially enlarging the suitability of rain-fed crop production in this area. Kyrgyzstan also has a relatively low water footprint, with a national average of 1779 m^3/ton (57% green, 43% blue). The water footprint of wheat production in Tajikistan, Turkmenistan and Uzbekistan is large, with national averages in the range of 2000-4000 m^3/ton. The blue water fraction in these countries is high as well (55-76%). Thus, it seems more efficient to produce wheat in Kazakhstan and Kyrgyzstan using less and mainly green water resources, than growing wheat in Tajikistan, Turkmenistan or Uzbekistan using their scarce blue water resources. A possibility for sustainably feeding the population of the basin would be to produce and export wheat from North Kazakhstan, the potential breadbasket of Central Asia, to the rest of the basin (UNESCO, 2000).
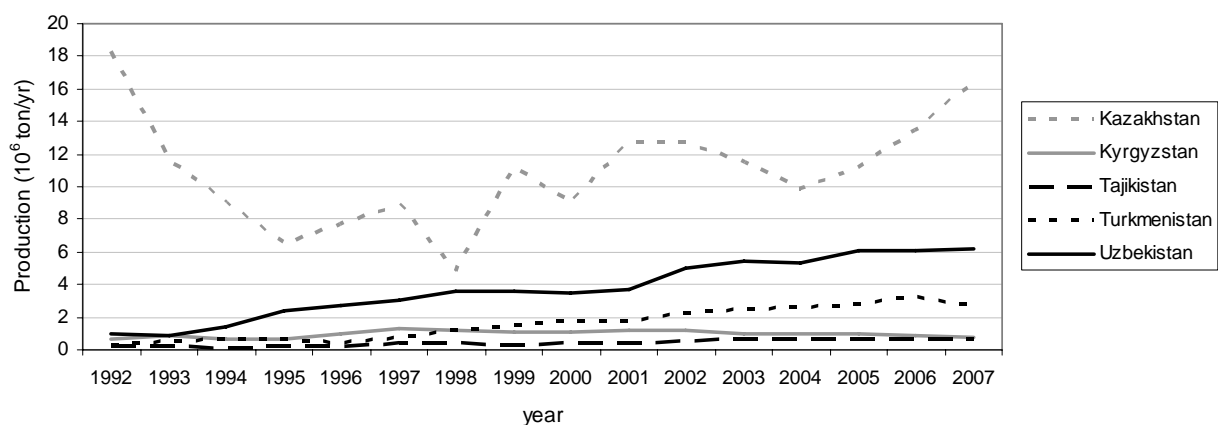

Figure 3.8. Central Asian wheat production by nation (10^6 ton/yr). Period 1992-2007. Source: FAO (2009c).
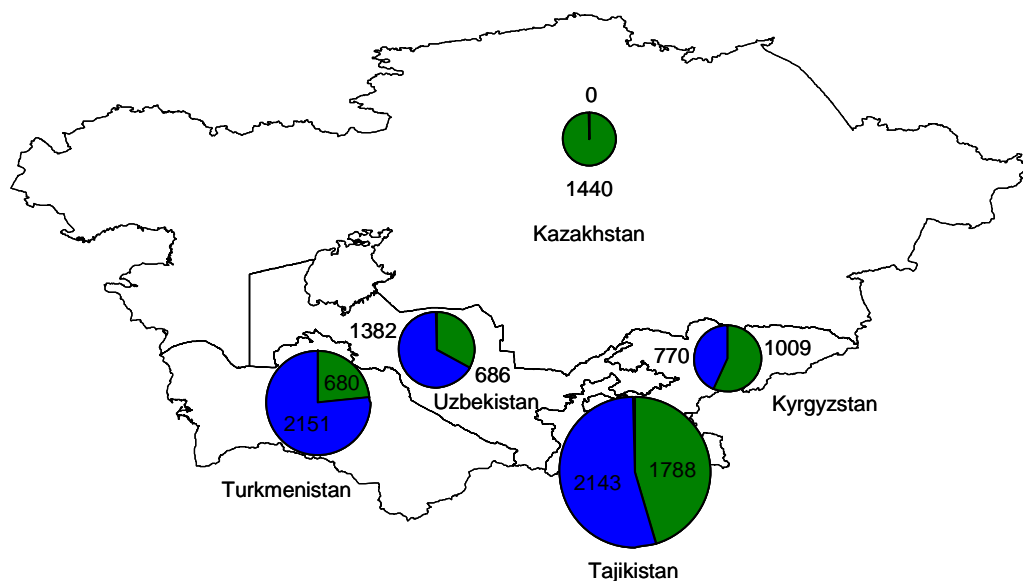
Figure 3.9. Green and blue water footprint of wheat production per unit of product, by nation: Spring wheat in Kazakhstan and winter wheat in Kyrgyzstan, Turkmenistan, Tajikistan and Uzbekistan. Both the size of each pie and the numbers shown in the pies reflect the water footprint per ton (m³/ton). Source: Own elaboration based on FAO data (2006a, 2006b, 2009b, 2009c).

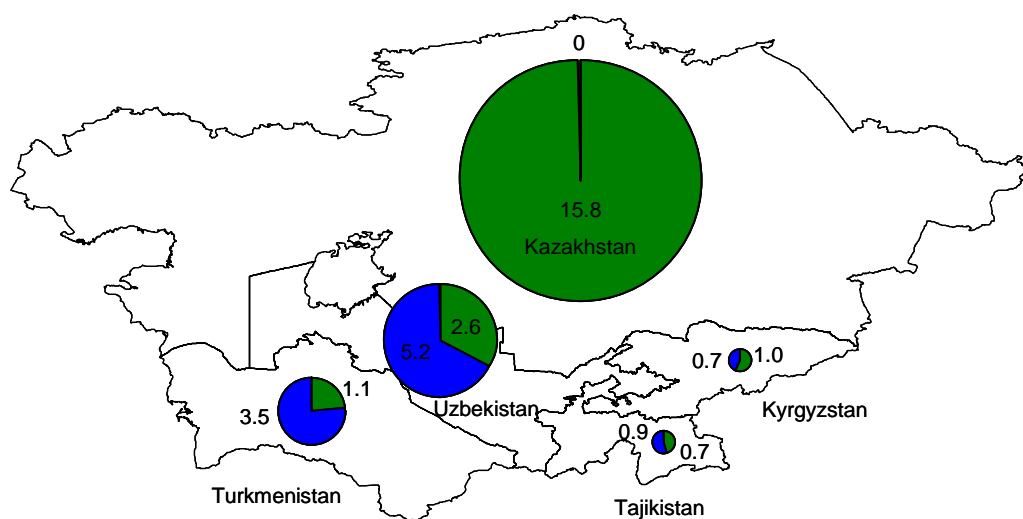*Figure 3.10. Total green and blue water footprint (10⁹ m³/year) for the Central Asian wheat production by nation: Spring wheat in Kazakhstan and winter wheat in Kyrgyzstan, Turkmenistan, Tajikistan and Uzbekistan. 1992-2007 year average. Source: Own elaboration based on FAO data (2006a, 2006b, 2009b, 2009c).*

3.4. Water footprint of rice

Rice represents 3% of the total agricultural water consumption in the region. In the last decade, rice production has mainly increased in Kazakhstan, Turkmenistan and Uzbekistan, while remaining more or less constant in Tajikistan and Kyrgyzstan (Figures 3.11-3.12).
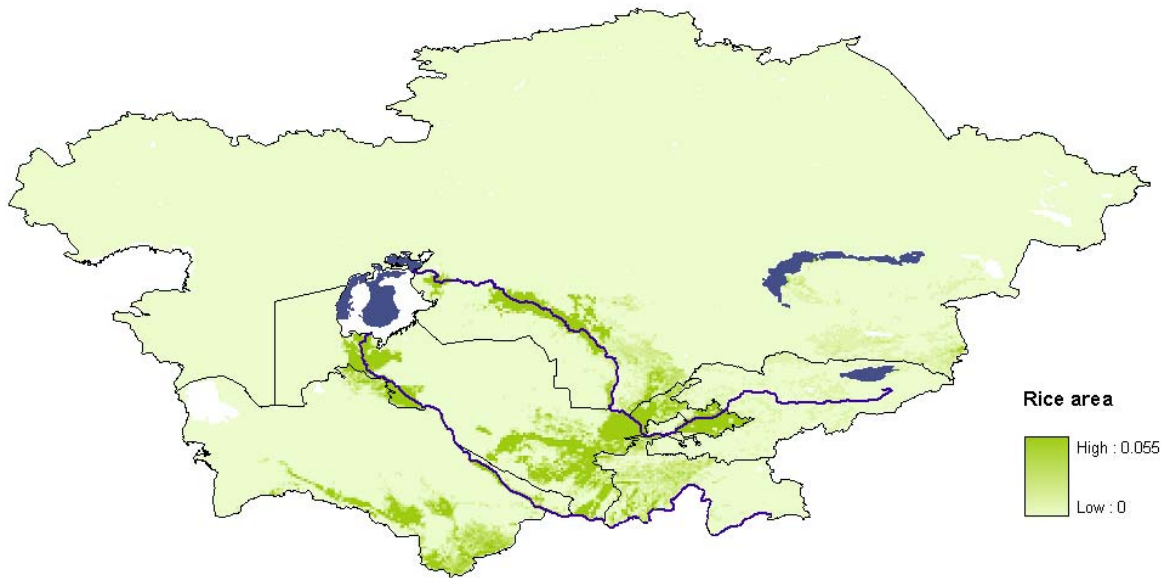

Figure 3.11. Rice harvested area in Central Asia. Unit: proportion of grid cell area. Source: Monfreda et al. (2008).
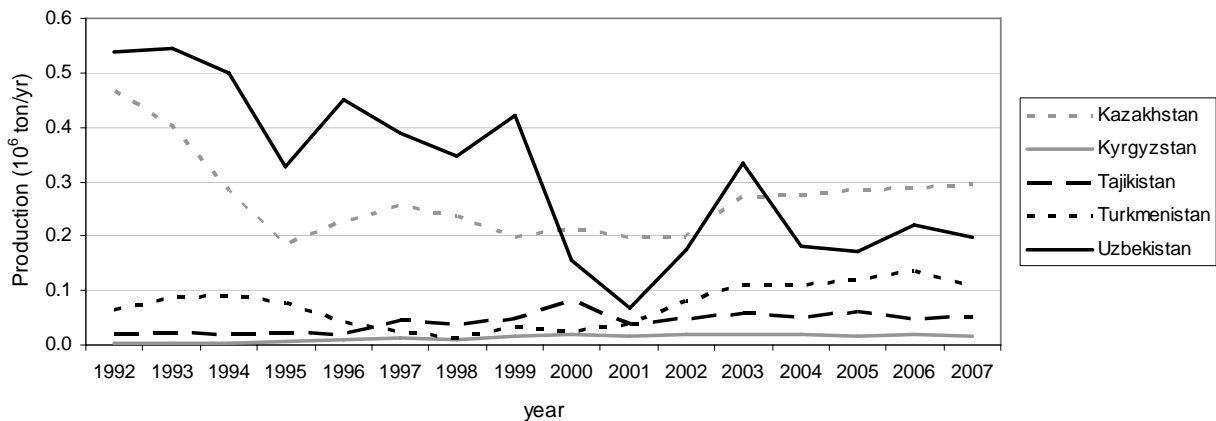

Figure 3.12 Central Asian rice production by nation (10^6 ton/yr). Period 1992-2007. Source: FAO (2009c).

Like cotton, rice is mainly produced in the southern region of the Aral Sea Basin, using primarily blue water resources (Figure 3.13). The water footprint of rice in Turkmenistan is the highest in the Central Asian region, with a total of 7014 m^3/ton (97% blue, 3% green). This is related to the fact that rice yields in the region are lowest in Turkmenistan: 1.2 ton/ha vs. 2.5-3 ton/ha in the rest of the countries (FAO, 2009c). The water footprint of rice in Uzbekistan adds up to 4240 m^3/ton of which 95% are blue. The same amount of rice would consume less water in parts of Tajikistan, Kyrgyzstan or Kazakhstan under less arid conditions and more clayey soils. The highest rice yields can be found in Kazakhstan and Tajikistan (3.1 and 2.7 ton/ha, respectively). Rice

production therefore could be allocated to the regions where it is produced more efficiently or it could even be imported from other regions outside the basin. In total, most of the water for rice production is consumed in Uzbekistan, even though the total rice production in this country is relatively similar to that in Kazakhstan (0.31 vs. 0.27 10^6 ton respectively) (Figure 3.14).
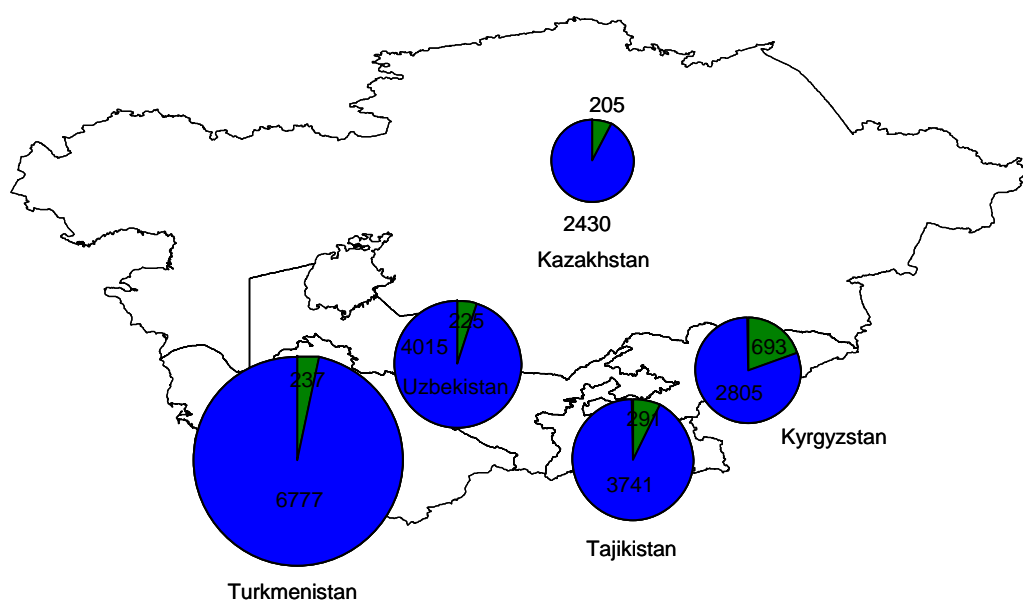
Figure 3.13. Green and blue water footprint of rice production per unit of product, by nation. Both the size of each pie and the numbers shown in the pies reflect the water footprint per ton (m³/ton). Source: Own elaboration based on FAO data (2006a, 2006b, 2009b, 2009c).
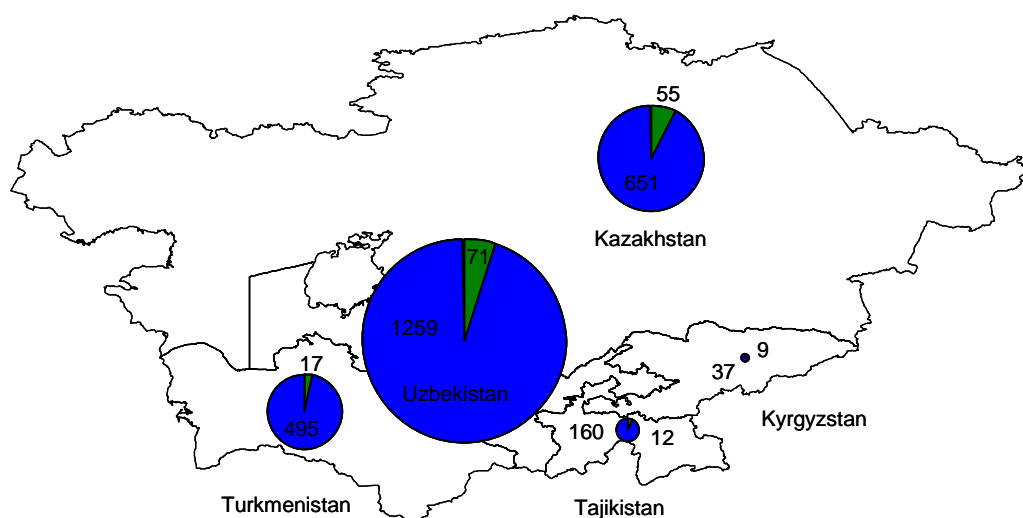
Figure 3.14. Total green and blue water footprint (10^6 m³/year) for the Central Asian rice production by nation. 1992-2007 year average. Source: Own elaboration based on FAO data (2006a, 2006b, 2009b, 2009c).

4. Conclusion

Water problems in Central Asia are mainly due to the inefficient allocation of water resources and the over-reliance on irrigation in the agricultural sector. The emphasis on intensive cotton cultivation in the Aral Sea Basin countries has played a major role in drying and polluting of the Aral Sea because of the large amounts of water and fertilizer used in cotton cultivation. Cotton mono-culture during the Soviet period exhausted the soil and led to plant diseases, which adversely affect cotton yields to this date.

Today, wheat and cotton are the most important crops in the region. Both continue to rely on irrigation using about 72% of total (blue and green) water consumption in agriculture (39 and 33 per cent, respectively). In the last decade, also irrigated rice production has increased in Kazakhstan, Turkmenistan and Uzbekistan, currently representing about 3 per cent of the total (blue and green) water consumption in agriculture. Due to the old water allocation procedures, hitherto, rice is allocated over 18,000 m^3/ha in Turkmenistan – and similar in Uzbekistan – contributing significantly to water logging. Besides, as a whole, most cotton, wheat and rice are produced in regions where their blue water footprint in terms of m^3/ton is high.

From a water resources perspective, there are different alternatives for improving the allocation of water resources and achieving water savings. The figures presented in this paper suggest that a more efficient allocation of water resources in the Central Asian region could be achieved by shifting grain production to areas with relatively high rainfall to reduce water withdrawals for irrigation. For instance, the current water consumed for growing rice in Turkmenistan is around 7000 m^3/ton mainly based on irrigation, which has a higher opportunity cost than soil moisture from rain. The water footprint of rice in Uzbekistan is also relatively large; adding up to around 4240 m^3/ton, of which 4015 m^3/ton are blue. The same amount of rice could be produced using much less water in parts of Kazakhstan (2600 m^3/ton), Kyrgyzstan (3500 m^3/ton) or Tajikistan (4000 m^3/ton) under less arid conditions and more clayey soils. Similarly, wheat production in Turkmenistan, Tajikistan and Uzbekistan has a water footprint ranging between 2000-4000 m^3/ton and uses a fairly large amount of irrigation (2150, 2140 and 1380 m^3/ton respectively). A significant amount of irrigation water could be saved if the wheat was produced for them in Kyrgyzstan or Kazakhstan, where the irrigation water used is around 770 and 0 m^3/ton respectively (and the total water footprint adds up to 1780 and 1440 m^3/ton respectively).

Kazakhstan has the potential to become the breadbasket of the region with wheat production entirely based on the soil moisture from rain and a high potential for increased rain-fed wheat production. Rainwater and nutrient use efficiency could be enhanced to improve crop productivity. This is particularly important in rain-fed systems, where it is essential to plan agriculture making the best use of the rainfall pattern. A reduction in water demand for irrigation could thus occur by importing agricultural products from more green water-abundant regions. This can save the scarce blue water resources in the arid and semi-arid areas of the basin, which can be used for higher-value uses, such as domestic purposes, industry and the environment. This could also help achieving food security since socio-economic development and protecting the water resources themselves are

important strategic factors that bring about water and food security. In order to make the final decision, however, other socio-economic and biophysical factors apart from water should also be considered.

Finally, to achieve a win-win solution to increase productivity, enhance rural employment opportunities and improve the livelihoods of the rural population while protecting the environment in the long term, a more efficient allocation and management of water resources is needed based on regional co-operation.

References

Abdullaev, I., De Fraiture, C., Giordano, M., Yakubov, M. and Rasulov, A. (2009) Agricultural water use and trade in Uzbekistan: Situation and potential impacts of market liberalization, Water Resources Development, 25(1): 47–63.

Allan, J.A. (1997) 'Virtual water': a long term solution for water short Middle Eastern economies? Water Issues Group, School of Oriental and African Studies. University of London. London.

Allan, J.A. (2006) Virtual water, Part of an invisible synergy that ameliorates water scarcity. In Water Crisis: Myth or reality? Ed. Rogers, Llamas and Martinez-Cortina. Balkema Publishers.

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. (1998) Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56. Food and Agriculture Organization. Rome.

Bates, B.C., Kundzewicz, Z.W., Wu, S. and Palutikof, J.P., Eds. (2008) Climate change and water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp. Available from: http://www.ipcc.ch/pdf/technical-papers/ccw/frontmatter.pdf [Accessed 5 March 2010]

CAWATER (2009) Land resources of the Aral Sea basin. Central Asia Regional Water Information Base (CAREWIB) Project. Swiss Agency for the Development and Cooperation, SIC ICWC, UNECE, UNEP/GRID-Arendal. Available from: http://www.cawater-info.net/aral/land_e.htm [Accessed 5 March 2010]

Chapagain, A.K. and Hoekstra, A.Y. (2004) Water footprints of nations, Value of Water Research Report Series No. 16, UNESCO-IHE, Delft, the Netherlands. Available from: www.waterfootprint.org/Reports/Report16Vol1.pdf [Accessed 5 March 2010]

Chapagain, A.K., Hoekstra, A.Y., Savenije, H.H.G. and Gautam, R. (2006) The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries. Ecological Economics 60 (1): 186-203.

Comprehensive Assessment of Water Management in Agriculture (2007) Water for food, water for life: A Comprehensive Assessment of Water Management in Agriculture. Earthscan. London.

Falkenmark, M. (2003) Freshwater as shared between society and ecosystems: from divided approaches to integrated challenges. Philosophical Transactions of the Royal Society B: Biological Sciences, 358 (1440): 2037–2049.

Falkenmark, M. and Rockström, J. (2004) Balancing water for humans and nature: The new approach in ecohydrology, Earthscan, London, UK.

FAO (2006a) CLIMWAT 2.0 database. Food and Agriculture Organization of the United Nations, Rome, Italy. Available from: http://www.fao.org/nr/water/infores_databases_climwat.html [Accessed 5 March 2010]

FAO (2006b) New LocClim 1.10 database. Food and Agriculture Organization of the United Nations, Rome, Italy. Available from: http://www.fao.org/nr/climpag/pub/en3_051002_en.asp [Accessed 5 March 2010]

FAO (2009a) AQUASTAT. Food and Agriculture Organization. Rome. Available from: http://www.fao.org/nr/water/aquastat/main/index.stm [Accessed 5 March 2010]

FAO (2009b) CROPWAT 8.0 Model. Food and Agriculture Organization. Rome. Available from: http://www.fao.org/nr/water/infores_databases_cropwat.html [Accessed 5 March 2010]

FAO (2009c) FAOSTAT Database. Food and Agriculture Organization. Rome. Available from: http://faostat.fao.org [Accessed 5 March 2010]

FAO (2009d) Global map of monthly reference evapotranspiration and precipitation – at 10 arc minutes, GeoNetwork grid database. Available from: www.fao.org/geonetwork/srv/en [Accessed 5 March 2010]

Fisher, G. (2005) New Challenges for Central Asia. Cotton Outlook Special Feature. Uzbekistan. Available from: http://www.cotlook.com/SpecialFeatures/Uzbekistan/Article_2.pdf [Accessed 5 March 2010]

Hoekstra, A.Y. (ed.) (2003) Virtual water trade: Proceedings of the International Expert Meeting on Virtual Water Trade, Delft, The Netherlands, 12–13 December 2002, Value of Water Research Report Series No.12, UNESCO-IHE, Delft, the Netherlands.

Hoekstra, A.Y. and Chapagain, A.K. (2008) Globalization of water: Sharing the planet's freshwater resources. Blackwell Publishing. Oxford, UK.

Hoekstra, A.Y. and Hung, P.Q. (2005) Globalisation of water resources: international virtual water flows in relation to crop trade, Global Environmental Change 15 (1): 45-56.

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M. and Mekonnen, M.M. (2009) Water footprint manual: State of the art 2009, Water Footprint Network, Enschede, the Netherlands. Available from: http://www.waterfootprint.org/downloads/WaterFootprintManual2009.pdf [Accessed 10 March 2010]

Kuylenstierna, J., Destouni, G. and Lundqvist, J. (2008) Feeding the future world– securing enough food for 10 billion people. In: Water for Food. The Swedish Research Council Formas. 8-21

Lerman, Z. and Stanchin, I. (2006) Agrarian reforms in Turkmenistan. In: S.C. Policy Reform and Agriculture Development in Central Asia, Babu and S. Djalalov, eds., Springer, New York, pp. 222-223.

Monfreda, C., Ramankutty, N. and Foley, J.A. (2008) Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000, Global Biogeochemical Cycles, Vol. 22, GB1022, doi:10.1029/2007GB002947.

Morgounov, A., Braun, H.J., Ketata, H., Paroda R. (2004) International Cooperation for Winter Wheat Improvement in Central Asia: Results and Perspectives. Turk J Agric For, 29: 137-142.

Morgounov, A., Gómez-Becerra, H.F., Abugalieva, A., Dzhunusova, M., Yessimbekova, M., Muminjanov, H., Zelenskiy, Y., Ozturk L. and Cakmak, I. (2007) Iron and zinc grain density in common wheat grown in Central Asia. Euphytica 155:193–203.

Nandalal, K.D.W. and Hipel, K. W. (2007) Strategic decision support for resolving conflict over water sharing among countries along the Syr Darya River in the Aral Sea Basin. Journal of Water Resources Planning and Management. 289-299.

National Cotton Council of America (2009) National Cotton Council of America. Available from: http://www.cotton.org/econ/cropinfo/cropdata/rankings.cfm [Accessed 5 March 2010]

UNESCO (1998) UNESCO's Initiative for the Aral Sea Basin. Information document. The Culture of Peace and UNESCO's Action in Member States. Tashkent, Uzbekistan. Available from: http://unesdoc.unesco.org/images/0011/001145/114523Eo.pdf [Accessed 5 March 2010]

UNESCO (2000) Water-related vision for the Aral sea basin for the year 2025. United Nations Educational, Scientific and Cultural Organization. Paris, France. Available from: http://unesdoc.unesco.org/images/0012/001262/126259mo.pdf [Accessed 5 March 2010]

USDA/FAS (2002) Central Asia wheat: 2001/02 output and 2002/03 prospects. United States Department of Agriculture, Foreign Agricultural Service. Available from:
http://www.fas.usda.gov/pecad2/highlights/2002/02/fsu_06feb02/index.htm [Accessed 5 March 2010]

Appendix I

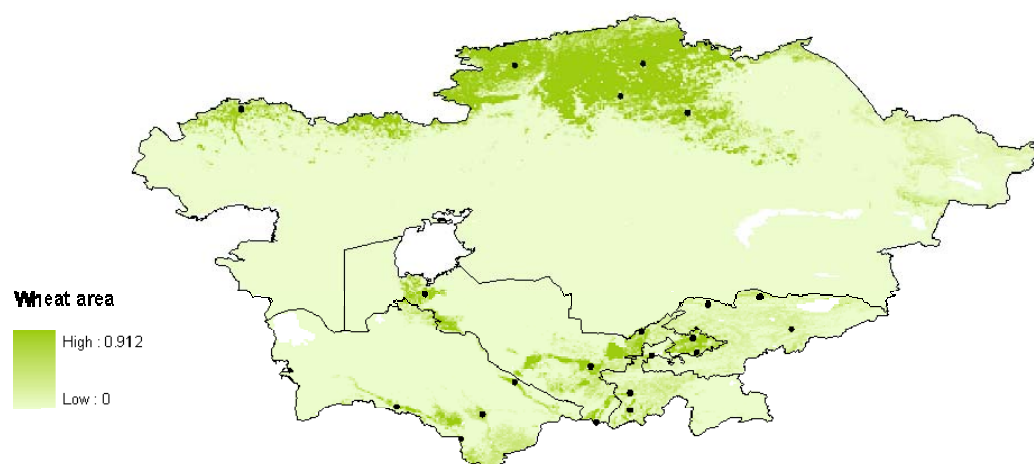Climate stations used in the cotton, rice and wheat water footprint estimations.

WHEAT AND COTTON

COUNTRY	Climate stations	Latitude $^\circ$	Longitude $^\circ$
Kazakhstan	Atbasar	51.81	68.36
	Celinograd	51.13	71.36
	Kokcetav	53.28	69.35
	Kustanaj	53.21	63.61
	Ural Sk	51.25	51.4
Kyrgyzstan	Bishkek	42.8	74.5
	Frunze	42.83	74.58
	Naryn	41.43	76
	Talas	42.51	72.25
Tajikistan	Dusanbe	38.58	68.78
	Kurgan-Tjube	37.81	68.78
	Leninabad	40.21	69.73
Turkmenistan	Ashgabad	37.96	58.33
	Bajram-Ali	37.6	62.18
	Cardzou	39.08	63.6
	Serahs	36.53	61.21
Uzbekistan	Chimbaj	42.95	59.61
	Fergana	40.36	71.75
	Namangan	40.98	71.58
	Samarkand	39.73	67
	Tashkent	41.26	69.26
	Termez	37.25	67.26

RICE

COUNTRY	Climate stations	Latitude $^\circ$	Longitude $^\circ$
Kazakhstan	Cimkent	42.3	69.6
	Kazalinsk	45.76	62.11
	Kzyl-Orda	44.76	65.53
Kyrgyzstan	Bishkek	42.8	74.5
	Frunze	42.83	74.58
	Naryn	41.43	76
	Talas	42.51	72.25
Tajikistan	Dusanbe	38.58	68.78
	Kurgan-Tjube	37.81	68.78
	Leninabad	40.21	69.73
Turkmenistan	Ashgabad	37.96	58.33
	Bajram-Ali	37.6	62.18
	Cardzou	39.08	63.6
	Serahs	36.53	61.21
Uzbekistan	Chimbaj	42.95	59.61
	Fergana	40.36	71.75
	Namangan	40.98	71.58
	Samarkand	39.73	67
	Tashkent	41.26	69.26
	Termez	37.25	67.26

Source: FAO (2006a, 2006b)
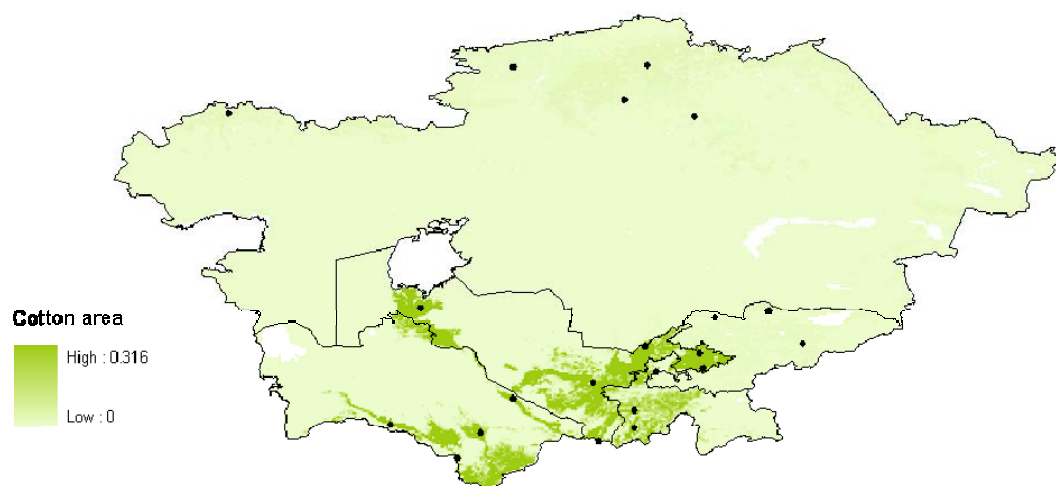
Climate stations used in the cotton water footprint estimations (dots in black) and cotton harvested area in Central Asia. Unit: proportion of grid cell area. Source of cotton area: Monfreda et al. (2008).

Climate stations used in the wheat water footprint estimations (dots in black) and wheat harvested area in Central Asia. Unit: proportion of grid cell area. Source of wheat area: Monfreda et al. (2008).
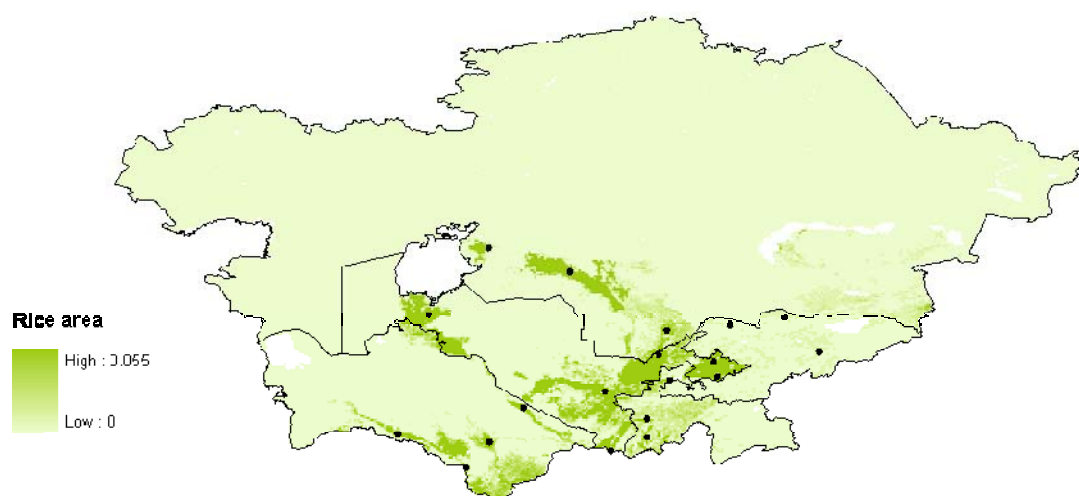

Climate stations used in the rice water footprint estimations (dots in black) and rice harvested area in Central Asia. Unit: proportion of grid cell area. Source of rice area: Monfreda et al. (2008).

Appendix II

Evapotranspiration (ET), crop water use (CWU), yield (Y), production (Prod) and water footprint (WF) for the selected crops in the five Central Asian countries.

	ET_g mm	ET_b mm	ET mm	CWU_g m³/ha	CWU_b m³/ha	CWU m³/ha	Y* ton/ha	WF_g m³/ton	WF_b m³/ton	WF m³/ton	Prod* Mton/yr	WF_g Mm³/yr	WF_b Mm³/yr	WF Mm³/yr
COTTON														
Kazakhstan	193	293	485	1925	2925	4850	2.0	962	1461	2423	0.3	297	451	749
Kyrgyzstan	166	594	760	1657	5941	7598	2.5	665	2384	3049	0.1	57	206	263
Tajikistan	64	968	1032	641	9680	10322	1.7	388	5858	6246	0.4	169	2554	2723
Turkmenistan	33	1183	1216	330	11835	12164	1.7	191	6875	7067	1.0	185	6650	6835
Uzbekistan	60	987	1047	603	9867	10470	2.4	255	4171	4426	3.6	905	14812	15717
RICE														
Kazakhstan	64	761	825	642	7608	8249	3.1	205	2430	2635	0.3	55	651	706
Kyrgyzstan	161	653	814	1613	6527	8139	2.3	693	2805	3498	0.0	9	37	46
Tajikistan	77	992	1069	772	9919	10691	2.7	291	3741	4032	0.0	12	160	172
Turkmenistan	43	1217	1260	425	12170	12595	1.8	237	6777	7014	0.1	17	495	512
Uzbekistan	59	1050	1109	589	10504	11093	2.6	225	4015	4240	0.3	71	1259	1330
SPRING WHEAT														
Kazakhstan	138	0	138	1380	0	1380	1.0	1440	0	1440	10.9	15763	0	15763
WINTER WHEAT														
Kyrgyzstan	228	174	401	2276	1736	4012	2.3	1009	770	1779	0.9	959	731	1690
Tajikistan	251	301	552	2509	3008	5517	1.4	1788	2143	3931	0.4	742	889	1631
Turkmenistan	167	529	696	1672	5287	6959	2.5	680	2151	2832	1.6	1098	3472	4571
Uzbekistan	193	390	583	1935	3897	5831	2.8	686	1382	2068	3.7	2568	5173	7741

* Source: FAO (2009c). The other columns are own estimations.

ET_g = green water evapotranspiration; ET_b = blue water evapotranspiration; ET = total evapotranspiration; CWU_g = green crop water use; CWU_b = blue crop water use; CWU = total crop water use; Y = yield; WF_g = green water footprint; WF_b = blue water footprint; WF = total water footprint; Prod = production.

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