

**Spatial and Temporal Variability of Water Productivity
in the Syr Darya Basin, Central Asia**

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Abstract

Assessment of water use in irrigated agriculture through a water-productivity analysis is a widely accepted approach. However, for a long time in Central Asia water management and use were hardly assessed on economical and productivity indicators. As a result, the Aral Sea disaster took place, and water productivity in irrigated agriculture has been drastically decreasing for decades. This paper is an attempt to analyze water productivity for cotton spatially (for different levels of water use and reaches of the basin) and temporally (for the 3 years, 1999–2001) in the Syr Darya basin, one of the largest irrigation systems of Central Asia. The analysis of the information showed that water managers in years with high water availability should very much focus on improving water productivity. In years with normal and high water availability, water productivity for both cotton and rice and for collective-cooperative farms (CCFs) and private-peasant farms (PPFs) has been lower. And, therefore, the type of unit and its size have an impact on the productivity of both cotton and rice. The upper-located units have a higher mean water productivity, which can be related to much higher reuse possibility. The water productivity of cotton-growing areas of the Syr Darya basin is still lower than the average world mean. However, the cotton yields are very high. The scope for improving water productivity in the cotton-growing part of the Syr Darya basin rests mainly on the improvement of planning, delivering, distributing and accounting of water supply for irrigation.

Key words: irrigation, Syr Darya basin, water productivity

Introduction

Irrigated agriculture is the major water user in Central Asia, consuming almost 80–85% of water resources of the region. Water resources for irrigated agriculture are provided by a vast irrigation network, nested into the arable lands of the Syr Darya basin. The losses in irrigated agriculture can, on average, be accounted for, up to 50% of water withdrawals. As a negative impact of such losses and inefficient water use, the world's fourth largest lake, the Aral Sea, dried up, resulting in the loss of sustainability of the economy and ecology of the Central Asian region. At present, it is crucial that every drop of water supplied to agriculture be effectively used. In this paper, we provide values on the spatial and temporal variation of water productivity for a better understanding of how effectively water is used in irrigated agriculture. The overall expected result is to try to give an indication of

where improvements can be made in water-resources management for irrigated agriculture.

The analysis of water productivity and its improvement are becoming very critical issues, because of high population growth and overall decline in agricultural productivity. The population growth in Central Asia has been continuing even in the last 10 years (1990–2000) contributing to the socioeconomic disharmony. The population growth in the last decade was around 8 million or a growth rate of 2% (figure 1). The population growth has seriously affected the per capita water use. It dropped from 4,500 m³/per capita per year in the 1970s to 2,500 m³/per capita per year in 2002 or a 56% decrease in the last 30 years (Abdullaev et al., 2003).

Figure 1. Dynamics of population growth and per capita water use in Central Asia.

General Background

The Syr Darya basin covers an area of 444,000 km² with a population of about 18 million, with an overall population density of 19 persons per km². The Syr Darya rises in the Tien Shan mountains, running approximately 2,500 km through the upstream countries, Kyrgyzstan and Tajikistan, flowing through Uzbekistan and Kazakhstan, and finally flowing into the Aral Sea. The average temperature in the basin is 14.2 °C, with a range of -15 °C–8 °C in January and 18 °C–38 °C in July. The annual precipitation ranges from 60 mm at the Kzylorda meteorological station (tail reach) to 502 mm at the Djalalabad meteorological station (upper reach). Evaporation ranges from 1,150 mm to 1,420 mm throughout the basin.

The eastern part of the Syr Darya basin is occupied by a mountain region, which belongs to the Kyrgyz Republic (Osh and Djalalabad Provinces), from which originate the Naryn and Karadarya rivers that then form the Syr Darya. Numerous tributaries of the Syr Darya also originate from this mountain zone.

In the beginning of the 1960s, the former Soviet Union (FSU) launched efforts to increase cotton production in Central Asia. The diversion of millions of cubic meters of water to irrigate cotton fields and rice paddies through a massive infrastructural development helped increase the command area from 5 million hectares (m ha) in the 1950s to 8 m ha in the 1990s. The irrigation infrastructure of the region is described as “one of the most complicated human water development systems in the world” (Raskin et al. 1992) as human interventions have gradually modified the natural water flow and resources system. The diversions of water for agriculture from the Syr Darya are almost equal to its total annual inflow. All of the available surface water is virtually diverted to irrigation; it eliminates the scope for further expansion of command areas. The only option to guarantee food security of the region remains improved water management

Research Methods and Data Collection

The project “Adoption of Best Practices for Water Conservation in the Syr Darya and the Amu Darya River Basins of Central Asia”¹ was the second step of “Participation in Water Conservation” project, conducted in Central Asia during 1999–2000 (Horst et al. 2002). Participants of this project were 11 water management organizations (WMOs), 7 water user associations (WUAs), 18 CCFs and 25 PPFs, located in equal number in the head, middle and lower reaches, of the Syr Darya basin (figure 2).

The data collection in the “best practices” project were carried out by trained field observers for sample fields (one field observer for each pilot plot), by farm monitors for agricultural enterprises (one farm monitor for each CCF or PPF) and by district observers for water-management organizations (one district observer for each WMO).

The data collection work was farmed out to farmers, irrigation engineers and agronomists who were trained as observers. The week-long workshop and field trainings were carried out by the Scientific Information Center of Interstate Commission on Water Coordination (SIC ICWC) and the International Water Management Institute Central Asian and Caucasus office (IWMI-CAC) staff for field observers, farm monitors and district observers. To coordinate and ensure quality of data for each province one technical person was appointed as an oblast monitor. Altogether, 6 oblast monitors were hired for the project area.

The quality of the data recording was regularly checked in situ. The water measurement was performed by the use of measurement devices, which were installed in the inlet and outlet of each sample field, farm, and irrigation system/canal. The observers/monitors recorded the readings and monitored the irrigation schedule accordingly. During irrigation, the observers/monitors took hourly measurements of water depths or discharges. Records were logged into a special monitoring form developed by the SIC ICWC research team.

The monitors/observers conducted the following observations in the fields/farms/WMOs:

1. Monitoring of the crop development/yields (phenology of crops): planting dates, type of seeds, cultivations, crop-development stages, stresses in the crop development, diseases, harvesting and crop-yield determination.
2. Water accounting/balance monitoring: pre- and post-sowing irrigations, hourly inflow-outflow discharges, drainage inflow, soil moisture 3 days prior to irrigation and 3 days after irrigation and daily monitoring of groundwater level.
3. Agro-economic monitoring: crop growth and associated expenses: agricultural practices, applied with dates, amounts, expenses for such practices, water-conservation practices and expenses for application, fertilizer/pesticide/herbicide applied, dates and expenses, etc.

¹Joint project of IWMI and Scientific Information Center of Interstate Coordination Water Commission (SIC ICWC); the project is the logical continuation of the Water Saving Competition, funded the World Bank and GEF (xx Please spell out.).

4. Monitoring of salt balance: salt content of irrigation, drainage and groundwater and soil-salt content.

The following problems may have influenced the inaccuracy of collected data:

- The measurement devices were not installed accurately and readings were not correct.
- The observers were not adequately educated on the use of measurement devices and record taking.
- The incentives (salary, becoming popular, etc.) for monitoring were inadequate and observers were not maintaining the records well.

Subsequently, appropriate steps were taken to overcome the abovementioned problems.

In this paper, the water-productivity analysis was conducted with 3 years of monitoring (1999, 2000 and 2001) and for two levels of water use: CCFs and PPFs for upper, middle and tail reaches of the Syr Darya basin. Only water productivity of cotton (upper and middle reaches) and the rice crop (tail) has been analyzed.

Figure 2. Irrigated areas of the Syr Darya river.

Source: Abdullaev et al. 2003

Results and Discussions

Water-productivity analysis combines physical accounting of water with yield or economic output to give an indication of how much value is obtained from the use of water. For the project area, physical (kg/m^3) water productivity was calculated using the formula:

$$WP = \text{Output}/Q \quad (1)$$

where, WP is the water productivity (kg/m^3 or $\$/\text{m}^3$), Output is the output of irrigated agriculture, crop yields (t/ha) or its value converted into monetary units, and Q is water resources supplied or consumed, m^3 . In this paper two types of water productivity were calculated: 1) physical water productivity of total supplied irrigation water (water productivity-1 [WP1]), kg/m^3 and 2) physical productivity of evapotranspiration (water productivity-2 [WP2]), kg/m^3 .

1. Productivity of total surface water supplied to a unit (WP1): The water accounting is performed by measuring the total water inflow to the unit. It is very difficult to calculate physical productivity of irrigation water (kg/m^3) for specific crops. However, in Central Asia the share of cotton in the cropping pattern varies from 95.9% (South Kazakhstan Province) to 40.4% (Osh Province). The highest water requirement in the vegetative season (April–September) for the cotton-growing area belongs to cotton. The high share in both the cropping pattern and

the water requirement allows us to calculate physical productivity of irrigation water for cotton during the vegetative season (April–September). The physical productivity is calculated using formula (1).

2. Productivity of evapotranspiration (WP2): Biologically, crops consume water for evapotranspiration (ET), and the rest of the supplied water does not contribute to the yield formation. To assess the productivity of ET in formula (1) Q was altered to equal to ET. ET for different crops was calculated using the Alpatov method with the following formula:

$$ET = K_b * ET_{ref} \quad (2)$$

where, $ET_{ref} = 0.0018 * 0.8 * (25 + t)^2 * (100 - a)$, a=monthly average of relative air humidity (%); 0.8=coefficient of Molchanov; t=monthly average of air temperature ($^{\circ}C$). K_b =biological coefficient for different crops (Khasankhonova 1999).

Temporal and Spatial Analysis of Water Productivity in the Syr Darya Basin

Spatial Water-Productivity Analysis

The average sizes of the CCFs and PPFs are 1,558.9 and 128.2 hectares, respectively. The productivity of total surface water supplied to a unit, WP1, is the productivity of the total water supplied into the irrigation system (unit), which does not take into account the delivery losses and water supply to family plots. For this reason the water productivity of the cotton- growing area of the Syr Darya basin is underestimated. At least 25–30% of water delivered to farm gates has accounted for both losses and water supply to family plots.

The absolute highest WP1 (0.60 kg/m^3) and WP2 (0.43 kg/m^3) for the cotton-growing area have been monitored for the upper reach PPFs at 0.60 kg/m^3 . The lowest WP -1 (0.31 kg/m^3) and WP -2 (0.23 kg/m^3) have been observed for CCFs of the upper reach of the basin (table 1).

For the cotton-growing area, the water productivity of supplied water (WP1) is higher than evapotranspiration productivity (WP2). There are two reasons for this. The first is that the calculations of ET (2) are based on the calculation of the theoretical evapotranspiration. The second is that, in many “best” practices pilot projects, deficit irrigation is practiced, the cotton receiving 60-75% of the biologically required amount of water. However, cotton covers part of ET from groundwater as a result of which a higher WP1 is observed. The reason for high water productivity for PPFs can be explained by higher yields (figure 3). In the PPFs cotton yields are higher ($0.5\text{-}1.0 \text{ t/ha}$) than those of CCFs.

The upper reach of the Syr Darya basin has the highest water availability. The geology of many irrigated areas of the upper reach permits the reuse of water

released from upper located fields. As a result, if proper water accounting is conducted higher water productivity is reached. In most parts of the middle reach, especially in the plains, it is not possible to reach higher water productivity.

The average WP1 of the cotton-growing area (0.37 kg/m^3) of the Syr Darya basin, for both CCFs and PPFs, is much lower than the world average of 0.60 kg/m^3 . This indicates a great opportunity for increasing the productivity of water being supplied for irrigated agriculture. However, the average cotton yields in the Syr Darya basin, for both CCFs and PPFs are quite high (2.5–3.5 tons/ha). This indicates that it is mainly low water productivity levels that are related to inefficient high water supplies, in spite of applying “best” practices on water conservation.

The highest WP1 (0.26 kg/m^3) and WP2 (0.28 kg/m^3) for rice have been monitored for PPFs. The lowest WP1 (0.15 kg/m^3) and WP2 (0.16 kg/m^3) were also observed for PPFs. The rice growing tail has the highest water supply rates of 18,000–21,000 m^3/ha , the highest ET values of 15,000–20,000 m^3/ha , and low rice yields. ET is high because of the high groundwater tables, 0.5–0.6 meters from the soil surface in the irrigated season and 1.0–1.5 meters during winter. The role of evaporation (E) in total ET is almost 60–65%.

The highest and lowest means of water productivity are observed in PPFs and can be explained as follows: First, the agricultural operations in private farms are followed more accurately and PPFs have more incentives on the declining water supply, in order to save money spent on irrigation. Second, private farms have a limited ability to acquire good seeds and mechanisms, to plant and harvest rice in time. Last, the timely application of herbicides and pesticides is almost impossible for PPFs, because of their limited finances.

The lowest water productivities of rice in the tail area can be the result of natural conditions of the area (saline and low fertile soils).

Almost all water supplied to rice fields is spent as evapotranspiration, resulting in similar means of WP1 and WP2. However, water productivity in the rice-growing area of Central Asia (0.21 kg.m^3) is dramatically low compared to the world average of 0.7–0.8 kg/m^3 . This is because of extremely high water-supply rates, which fluctuate from 18,300 m^3/ha to 24,900 m^3/ha . The rice yields are also very low (2.2 t/ha).

There are two main indicators that determine water productivity. The first indicator is crop yields, which are determined by good agricultural operations, inputs availability, soil quality and climatic conditions. The agricultural practices of cotton in Central Asia, particularly in the Syr Darya basin have been developed through centuries and the farmers have a very good knowledge of growing cotton. The major problem is the xx nonavailability of inputs. After the collapse of the centralized planning economy, in the upper (Kyrgyzstan) and tail reach of the basin (Kazakhstan) farmers should deal with inputs by themselves. The soil quality in the upper reach of the basin is very good and there are no saline areas. In the

middle reach only 10–15 percent of the irrigated area is lightly saline. In the tail reach of the basin almost all irrigated areas are saline. The climatic conditions of the basin differ very much by reaches: in the upper reaches precipitation rates annually fluctuate between 350 and 520 mm, and in the tail, it hardly reaches 100 mm. The average cotton yields of PPFs are higher than in the CCFs in the Syr Darya basin. This is because of the financial incentives given to PPFs on receiving good yields, fewer losses of crop yields, a cheap workforce and a good knowledge of local farmers on growing cotton. In the CCFs, high losses of crop yields occur due to uncontrolled irrigation and crop diseases. For future improvement of cotton yields it may be good to finish privatization of land in all states of the Syr Darya basin. However, the average cotton yields in this basin are quite high and there is less possibility to increase crop yields at present.

In the rice-growing area, crop yields can be increased dramatically. At present, it is only 50 percent of the world average of rice yields. The introduction of new varieties of high-yielding rice types, improvement of rice-growing technology and the application of modern rice-planting and -harvesting techniques will increase rice yields almost twofold. Another alternative to rice can be growing fodder crops (alfalfa, maize) and early vegetables (melons, water melons). However, the quality of water, delivered through Syr Darya into the tail reach cannot guarantee good yields from alternative crops. In 1999–2000, in the Jana Kurgan district of the Kzylorda Province of Kazakhstan, farmers tried to plant 500 hectares of cotton instead of traditional rice. Monitoring results showed that crop yields reached hardly 1.0 t/ha.

The second indicator of water productivity is the water-supply rate. This rate for cotton for the upper reach fluctuates from 6,400 m³/ha to 8,200 m³/ha. For the middle reach it fluctuates from 6,900 m³/ha to 8,100 m³/ha. For rice, the maximum water-supply rate is 24,000 m³/ha and the minimum is 18,300 m³/ha. The higher water-supply rate in the upper reach for cotton can be due to the relatively abundant water resources. However, it is still high for the middle reach too. This is because of the state policy on cotton in Uzbekistan.² The priority given to cotton permits cotton-growing CCFs and PPFs to receive water for irrigation in quite large amounts.

Temporal Water-Productivity Analysis

The temporal analysis can help determine the water availability and climatic conditions. The highest WP1 (supplied) and WP2 (ET) for cotton was 0.60 kg/m³ observed in 2000. The lowest means of WP1 and WP2 for the cotton-growing area

² In Uzbekistan, the Ministry of Agriculture and Water Resources Management (MAWRM) signs an agreement at the beginning of the vegetative season (February) stating that farmers have to grow specific crops (mainly cotton in the vegetative season and wheat in the non-vegetative season). According to this contract, different state agencies will supply different crop inputs and the farmers should sell their crops only to the state, under fixed state prices.

observed in 2001 were 0.31 kg/m^3 and 0.23 kg/m^3 , respectively. In 2000, for both CCFs and PPFs a higher water productivity was monitored.

The highest rice WP1 and WP2 (0.26 kg/m^3 and 0.28 kg.m^3) were monitored in 2000.

The year 1999 was a normal water-availability year (average 70-80%), year 2000, a water-short year (average <70%) and year 2001, again a normal water-availability year (average >80%). In 2001, the water-supply rates were 13–15 percent higher than in 2000 and 16–17% higher than in 1999 for all types of units of cotton-growing areas.

The productivity per unit of evapotranspiration (WP2) shows the productivity of the water, which the crops used for evapotranspiration. It is very difficult to distinguish the difference between evaporation from the field and transpiration from the crops. WP2 presents the productivity of both, water evaporated from the field and transpired by the crops. In 2000, at the upper reach, the highest WP2 for was 0.43 kg/m^3 and the lowest 0.23 kg/m^3 . The big differences between WP1 and WP2 can be explained by higher ET levels. In the all cotton-growing areas, ET was much higher than the water supply. It shows that, in many parts of the Syr Darya river Basin (SRB.) deficit irrigation was practiced, which demonstrates the importance of groundwater in ET.

In 1999, the highest cotton WP1 monitored in the middle reach was 0.49 kg/m^3 , while the lowest monitored in the upper reach was 0.36 kg/m^3 . The highest for 2000 monitored in the upper reach was 0.60 kg/m^3 and the lowest, 0.36 kg/m^3 . In 2001, the highest water productivity (WP1) monitored in the middle reach was 0.50 kg/m^3 . The lowest in the upper reach was 0.31 kg/m^3 . The difference between the lowest and the highest WP1 in 1999 was 0.13 kg/m^3 . In 2000 the highest WP1 was 0.26 kg/m^3 and difference between highest and lowest WP1 was 0.19 kg/m^3 . It shows that the difference between the best and least water-productivity areas in water-short years increases dramatically by almost twofold.

The difference between WP1 and WP2 in 1999 for maximum mean was 0.26 kg/m^3 and, in 2000, WP1 and WP2 were 0.17 kg/m^3 and 0.23 kg/m^3 , respectively. These comparisons indicate that in years with less water availability the lowest difference between WP1 and WP2 can be achieved. The role of water availability in different years is very important.

In the rice-growing areas, the maximum WP1 and WP2 were observed in 2001 (0.26 kg/m^3 and 0.28 kg/m^3 , respectively) and the lowest WP1 and WP2 were observed in 1999 (0.15 kg/m^3 and 0.16 kg/m^3 , respectively). The trends of water productivity for the rice-growing area are similar to those of the cotton-growing area.

The above analysis shows that the type of unit and its size have an impact on productivity of both cotton and rice. The absolute maximum water productivity supplied (WP1) and consumed by crops (WP2) for cotton can be achieved in the

smaller production units, such as in PPFs. The upper located units have higher water productivity means, which can be related with the possibility of much higher reuse.

In the rice-growing area also, the highest water productivity has been monitored for PPFs. However, the lowest mean was also monitored for PPFs. For these reasons, it is difficult to conclude what the impacts of different types of farming units are on water productivity trends for rice-growing areas.

In the rice-growing areas, both crop yields and water management can be dramatically improved. The major reasons for the very low WP1 and WP2 are the very low rice yields and the high water-supply rates. The better agricultural practices, high-yielding varieties of rice and improved water use can help improve water productivity by almost twofold in the rice-growing areas of the Syr Darya basin.

Conclusions and Recommendations

The water productivity of cotton growing areas of the Syr Darya basin is still lower than the average world means. However, the cotton yields are very high. The scope for improving the water productivity in the cotton-growing part of the Syr Darya basin lies mainly on improving planning, delivering, distributing and accounting of water supply for irrigation.

The partial water losses during delivery and irrigation can also help improve water productivity. Also, better accounting of water can be another tool to improve water productivity.

The water managers in years of temporarily high water availability should focus much on water-productivity improvements. This is because, in normal and high water-availability years, for both cotton and rice, and for both CCFs and PPFs, the water productivity is lower.

One of the best ways of improving water productivity for cotton and rice areas is the practice of water-conservation measures. The targeting of the water-productivity improvements may result from improvements in existing agricultural and water-management practices (figure 3)

Figure 3. Best-practices strategies.

Best practices are the integration of the best water-management methods/approaches with the best agricultural practices in order to increase output per unit of water delivered/diverted to irrigated agriculture.

The water-conservation practices for different levels of water management and use will differ for targeting different parts of water-productivity functions (table 2). For water-management units, almost all attempts at water-productivity improvements are based on improving planning, distribution and supply of water. In almost 80% of cases, the farmers can improve water productivity through the application of better agricultural practices.

The approach of the “best-practices” project is to identify and select the best land/water conservation methods from the best farmers’ lands/plots, agricultural enterprises and water-management units for upscaling to the irrigated areas/systems and to the basin level.

The “best” practices are the selected methods of water conservation—at the field level, farm level and irrigation-systems level—that are adopted by the farm fields, agricultural enterprises and water-management units around the Syr Darya basin in the different geographic, soil and crop conditions (table 3).

Recommendations

The first is to speed up privatization in both the cotton- and rice-growing areas to enhance more water productivity. The PPFs have higher cotton and rice yields resulting in higher water productivity.

Second, in the cotton-growing areas, much attention on water-productivity improvements needs to be paid to improve water management through better planning and distributing and through better accounting of irrigated water.

Third, in the cotton-growing areas there is very little possibility for further increasing crop yields and water productivity. However, the application of user-driven water-conservation practices can yield some improvements in water productivity.

Fourth, in the rice-growing areas, there is a huge opportunity to increase both crop yields and water management. In average, rice yields were almost half of the world average, and the mean water productivity is almost 3 times less than average world averages. The quality of water in the tail reaches of the Syr Darya basin (rice-growing areas) can be seen as an absolute barrier for crop diversification, i.e., for shifting from rice to other high-value crops. Improvements in water management in the upper and middle reaches of the basin will lead to improvements in the quality of water delivered to the tail reaches.

Last, in years with higher water availability, more effort should be exerted to the better management of water.

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