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# Ecohydrology of the Syrdarya River under irrigation water management in the Fergana Valley

S Kenjabaev<sup>1,2\*</sup>, A Arifjanov<sup>2</sup>, H Frede<sup>3</sup> and T Apakhodjaeva<sup>2</sup>

<sup>1</sup>Scientific Information Centre of Interstate Coordination Water Commission, Tashkent, Uzbekistan

<sup>2</sup>Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, Tashkent, Uzbekistan

<sup>3</sup>Institute of Landscape Ecology and Resources Management, Justus-Liebig-University Giessen, Gießen, Germany

[kenjabaev@yahoo.com](mailto:kenjabaev@yahoo.com)

**Abstract.** Sustainable and efficient water resources management is important for the irrigation dominated agricultural system and therefore for the rural population and the environment of the arid regions. The objective of this study is to provide an overview of ecohydrology and irrigation water management in the region and to lay down some opportunities for cooperation at the transboundary level with the aim of increasing water productivity and environmental sustainability. Based on extensive literature review and analysis of secondary data from different organizations, we found that water management in the region's agriculture faces increasing challenges that are accumulated over time. It is hoped that conclusions from this study will help set the stage for productive discussions and to identify research needs in the region.

## 1. Introduction

The Fergana Valley (FV) is one of the most ancient world oases and differs by its most fertile lands. At the same time, it is a socially stressful region which is highly prone to conflicts concerning water allocation in Central Asia (CA) [1]. The high rate of population growth, the interdependence of water and energy, as well as ethnic conflicts for territory delineation [2] and limited land resources, are the main obstacles of the population's wellbeing in the region [3]. Therefore, the issues of equitable distribution of water resources among the riparian states of the FV and their mutually beneficial use are in the field of vision of the Heads of States, an integral component of regional policy, and are the object of close attention of international organizations.

No doubts, that balancing inhabitants and the ecosystem's water need is becoming a principal environmental issue, which may be linked to water governance. Countries within the Syrdarya River basin exhibit symptoms of water scarcity through increasing competition between hydropower in the upstream, and environment and agriculture demands in the downstream [4], especially when there is an increased demand for water in the agricultural sector during the vegetation period. Hence, the misbalance of water resources in the upper and lower stream of the Syrdarya is becoming not only an economic issue but also a regional political problem in Central Asia.

Considering water management issues in the FV as well as in the Syrdarya River [5–11], comprehensive study of eco-hydrology may provide a foundation for sustainable management of water



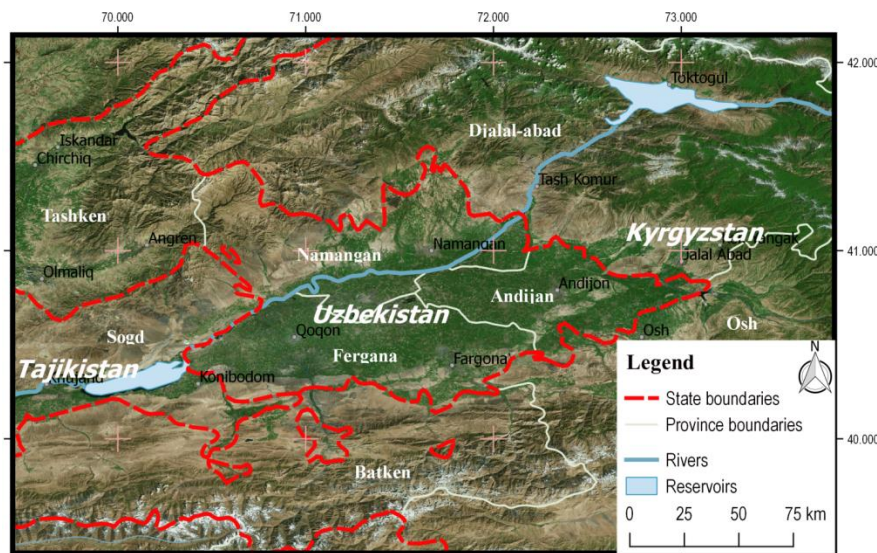
resources [12] with consideration of the effect of hydrological processes on the distribution, structure, and function of ecosystems on the water cycle [13]. With the above constraints in the background, the main objective of the research is to assess the eco-hydrological condition and irrigation water management in the FV and point out the relative importance of cooperation for sustainable management of water resources in the region.

## 2. Methods

### 2.1 Study area

The FV is one of the water-rich upstream sub-regions of the Syrdarya River basin. The length of the valley is 300 km, and a width of 170 km with floor elevation of about 450 m above the sea level (asl). According to [14], the valley has an area of 22,000 km<sup>2</sup>. It is characterized as a locked intermountain depression, embosomed in the spurs of the Ala-Tau Range in the north, the Tian Shan Mountains in the east, and the Alay Mountains in the south, with an only narrow opening to the west through which the Syrdarya River drains the valley. About 60% of the valley's territory lies in Uzbekistan (Andijan, Fergana, and Namangan provinces) which consists of a plain, central part of the valley (Fig. 1). Whereas foothills and mountain parts of the valley partially constitute three provinces of Kyrgyzstan - Djalalabad, Osh, and Batkent (15%) and one province of Tajikistan - Sogd (25%) [15].

Information and data regarding water quantity and quality of the main rivers are difficult to obtain; thus, extending the available information through the analysis of these data in temporal and special scales is very important. A dataset from the [16] was used to describe hydrology and water use by sectors in the valley. To describe the change of water chemical composition (ecology) due to irrigation water management in the FV, the database created by SANIIRI for 1960-2004 and yearbooks of UzHydromet for 2005-2010 for some selected gauging stations (GS) and three additional measurement points (A1, A2, and A3) within the valley along the Syrdarya River (Tab. 1) have been used. Open source programming software R (ver. 3.6.3) was used for analysis and graphical representation of these data [17].



**Figure 1.** The map of the Fergana valley (Source: First author's composition).

**Table 1.** Name, location and catchment area of gauging stations (GS) and sampling frequency within the Kall village (upper course) and Chinaz city (middle course) of the Syrdarya River (Source: First author's composition)

Gauging stations (GS)	Name of GS	Location of GS	Distance up to mouth (km)	Height (asl)	Catchment area (km <sup>2</sup> )	Years (number) of existing data <sup>b</sup>
GS1	Kall vill.	Uzb.	2173	378	90000	1960-1998 (8) 2001-2010 (3)
A1	coll. <sup>ξ</sup> Saryksuu	Uzb.	-	-	-	1976-1992 (11)
A2	coll. <sup>ξ</sup> SBK	Uzb.	-	-	-	1976-1992 (11)
A3	coll. <sup>ξ</sup> Sokh	Uzb.	-	-	-	1976-1992 (11)
GS2	Akdjar vill.	Taj.	2082	356	90000	1960-1973 (5); 1975-1984 (10)
GS3	Kyzil kishlak	Taj.	1941	319	136000	1960-1992 (6)
GS4	Higher Bekabad	Uzb.	1898	293	142000	1967-2010 (11)
GS5	Nadejdensky	Uzb.	1812	263	153000	1960-1961 (7) 1973-2010 (10)
GS6	Chinaz c.	Uzb.	1745	249	167000	1961-2010 (8)

<sup>ξ</sup> coll. – collector, where water quality of Syrdarya River was measured after effluent of main collectors “Saryksuu”, “Severo-Bagdatsky collector” (SBK) and “Sokh tashlama”, accordingly in downstream of 0.2 km, 5 km and 3 km within GS1 and GS3; <sup>h</sup> numbers in the bracket - an average quantity of annual data in the period.

### 3. Results and discussion

#### 3.1 Hydrology: Water resources management

The agricultural development and wellbeing of the rural population in the valley depends on water availability in transboundary small rivers (TSRs) and the flow regime of the Syrdarya River (Jaxartes in Ancient Greek or Sayhoun in Old Persian). According to [16], the natural annual runoff of the Syrdarya River averages 37.9 km<sup>3</sup> and ranges between 18.3 and 72.5 km<sup>3</sup>. Also, a number of small tributaries feed their runoff [18]. The contribution of the TSRs within the valley to the Syrdarya River equals 7.8 km<sup>3</sup> [15]. However, due to intensive irrigation, the discharge of most of them, especially from the left-bank tributaries do not reach the Syrdarya River. Moreover, the natural hydrological regime of the Syrdarya River within the valley is disturbed by ample irrigation withdrawals, water storage, and return waters into the river [19].

The change of hydrological characteristics of the rivers, availability of water resources, and its quality is associated with two main factors – anthropogenic and climate change. As an anthropogenic factor, the intensive use of water resources since the 1960s is followed by population increase, industry development, and mainly irrigation expansion. The data provided by [16] indicate the importance of water resources for agriculture which withdrawal is as much as 91% of the total water use in the valley (Tab. 2). The allocation of water resources between the sectors in the countries of CA is almost the same [20].

**Table 2.** Actual use of available water resources (%) for agricultural, municipal and industrial sectors in provinces of Fergana valley (average for 1980-2015; Source: [16])

Sectors	Provinces						
	Andijan	Fergana	Namangan	Osh	Djalalabad	Batkent <sup>ξ</sup>	Sogd
Agriculture	94.6	82.1	96.1	93.4	88.9	N/A	93.8
Municipal	4	10.8	3.1	6.3	8.1	N/A	3.5
Industrial	1.4	7.1	0.8	0.3	3	N/A	2.7

N/A - no information is available.

The climate change, apart from anthropogenic influences, is another driving force to change the natural hydrologic cycle of the river [10]. Its most hazardous and complex consequences are more frequent extreme floods and droughts [21]. The frequency of occurred drought years during 1990-2007 in the Syrdarya basin is less compared to those which occurred during 1950-1990, while high water years (prob.  $\leq 25\%$ ) and extremely high water years (prob.  $\leq 10\%$ ) were increased by 1.4 and 2 times, respectively. However, the competition for water resources in drought years creates higher water withdrawal from the main intake points. In consequence, surface runoff from fields comes to a minimum, and collector-drainage water (CDW) is used as an additional source in the place of formation. Therefore, low water years characterize less CDW effluent into the rivers. With average salinity of 1.0-2.68 g l<sup>-1</sup> [22], the CDW in the valley is used as an additional source for irrigation. CDW with salinity up to 3 g l<sup>-1</sup> has a negligible impact on nutrient and humus content of soil and cotton yield in Central Fergana. For that reason coupled with water shortage, the share of water withdrawal from CDN is an increasing twofold burden [3]

One should note that CDW in the valley is mainly formed as an inflow of groundwater into widely distributed horizontal (open and close) and vertical drainage wells (VDW) which drain deeper aquifers. In contrast, groundwater drained by horizontal drainages is formed as infiltration of surface waters (precipitation, irrigation and leaching waters, seepages from canals) and pressured underground water. An average volume of difference between underground water inflow and outflow in the territory of the valley is positive and ranges from 1500 m<sup>3</sup> ha<sup>-1</sup> in the Sogd province to 5000 m<sup>3</sup> ha<sup>-1</sup> in the Fergana province [19]. Thus, groundwater formed within the 18 aquifers of the FV [4, 23] might be a potential source for irrigation in the future which may reduce water withdrawals from the rivers.

#### ***Ecology: impact of water management to the environment***

Although FV is a relatively water-rich region comparing to the lower course regions along the Syrdarya River basin, water shortage is common in some areas because of the mismanagement of water resources in terms of excessive water use for irrigation or leaching of salts, and water allocation within the systems.

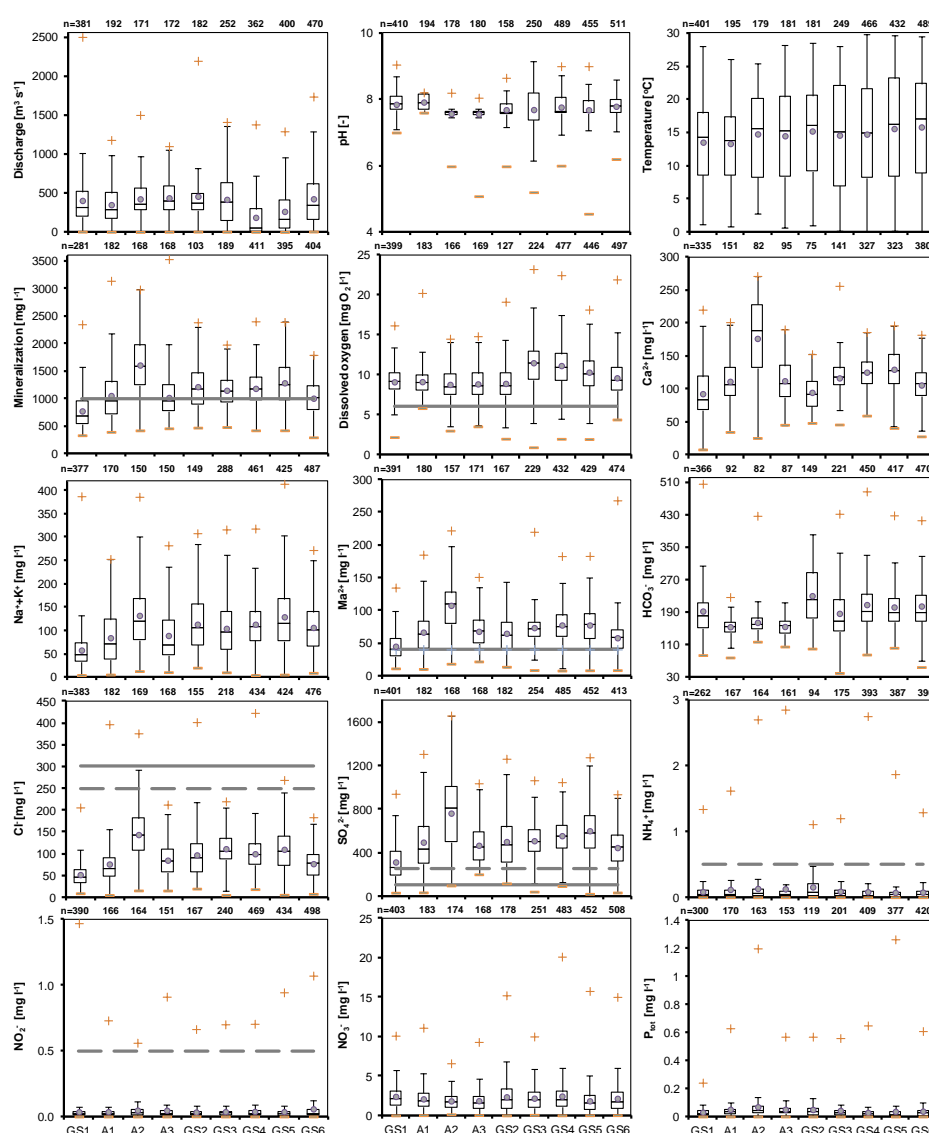
According to [24], the irrigated lands of FV located along the Syrdarya River course is suffering from substantial waterlogging as well as soil and water salinization. For instance, irrigated lands of Kyrgyzstan within the valley are characterized as good (90-96% of irrigated lands) in terms of land reclamation condition, while irrigated lands in Uzbek and Tajik parts of the valley are relatively poor owing to shallow GWL with higher mineralization and various levels of soil salinity. Hence, aging of the CDN and a decline of necessary rehabilitation and maintenance works since the breakdown of the Soviet Union [19], and the absence of an adequate drainage system [25] or a drainage system that is no longer properly functioning have created raised GWL. This in turn is causing a decrease in the productive area of irrigated lands as well as in the productivity of crops. Moreover, shallow GWL with elevated mineralization has mobilized salts, damaged buildings, and residential houses located near the CDN. As a result, the socio-economic and ecological situation in the valley is threatened [14].

Similar to Zarafshan River [26], altering the hydrological regime of the Syrdarya River, its quality is also deteriorating starting from upstream up to downstream. The water salinity was observed to rise for the last 40 years in the Syrdarya River from 300-600 mg l<sup>-1</sup> in the upper reaches to 3000 mg l<sup>-1</sup> in the lower reaches within the FV, with the prevailing salt composition of MgSO<sub>4</sub>, Ca(HCO<sub>3</sub>)<sub>2</sub>, NaCl, and CaSO<sub>4</sub>. Moreover, there is an overall increase in concentrations of some metals including sulphates and chlorides. Similar observations were done by [27] in the inner Syrdarya River basin. This impairs the water resources for drinking purposes in the middle course and sometimes spreads of diseases, such as hepatitis, typhoid, and gastrointestinal disorders causing enhanced morbidity of the local people [28-34].

Based on maximum allowable concentration (MAC) criteria, [22] have assessed the quality of water in some sections of the Syrdarya River (including right bank tributaries within FV). According to them, the quality of the Syrdarya River water within the FV (averaged 1986-1996) has fulfilled the

MAC criteria and ranged 1.7-4.4 mg l<sup>-1</sup> (total hardness), 4.5-6.0 and 0.5-1.6 mgO<sub>2</sub> l<sup>-1</sup> (COD and BOD<sub>5</sub>), 0.02-0.1, 0.002-0.013 and 0.77-1.85 mgN l<sup>-1</sup> (ammonium, nitrites and nitrates), 0.003-0.012 mg l<sup>-1</sup> (total phosphorus), 1.4-8.1, 0.6-4.5, 0-10.1 and 0.6-22.8 µg l<sup>-1</sup> (aluminum, manganese, copper and zinc).

Although analysis of available data from selected sections reveals that data was collected on a monthly basis and set of water quality parameters (including discharge) are incompletely analyzed with reduction of observations at some GSs, the given analysis in the form of box plots (Fig. 2) may be valuable to provide some information for the international scientific community about the eco-hydrologic situation along the river course. The main reason for decreasing monitoring posts and the sampling frequency is associated with the reduction of investments for these works mainly after the break-down of the Soviet Union [5, 7]. A hydro-chemical measurement after the effluent of big collectors along the river courses has not been performed since 1992.



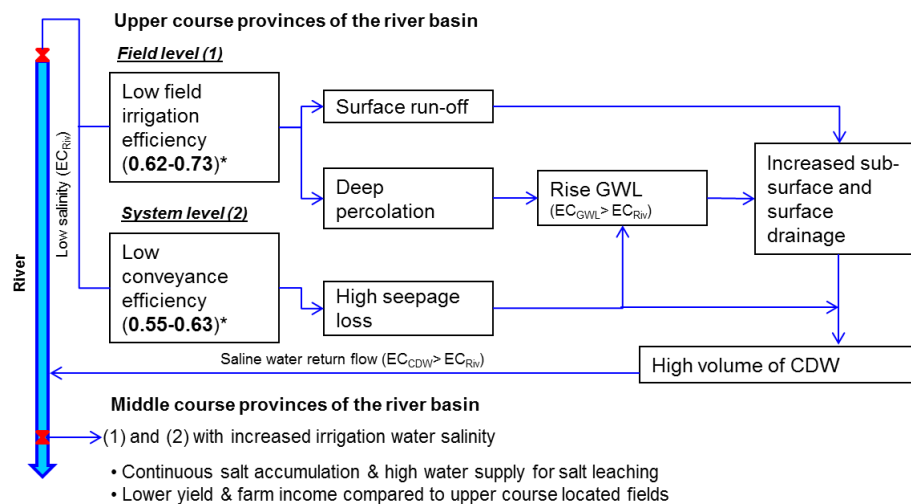
**Figure 2.** Box plots describing water quality parameters (including discharge and temperature) for the selected stations from 1960 to 2010 (Source: First author’s composition)

*Note:* *n* above the graphs - number of the samples for each station; line and dot inside the box - median and mean values; box - 25th-75th percentiles (interquartile range); whiskers - data values less than or equal 1.5 times the interquartile range; plus and minus - maximum and

minimum values; dashed and straight horizontal lines - maximum allowable concentration (MAC) for drinking purpose [35] and MAC for fishery [22, 37].

#### 4. Conclusions

Water management issues in the FV (such as low efficiency of irrigation systems, insufficient water in tail sections as a result of the non-organized distribution, unsatisfactory condition of irrigation systems and maintenance) cause formation high volume of mineralized collector-drainage water and subsequent decrease water quality of the Syrdarya River at the middle course. This challenge is schematically described in Figure 3.



**Figure 3.** Flow-chart demonstrating alteration of ecohydrology of the Syrdarya River under current water management challenges in the FV (Source: First author's composition)

The results from this study highlight certain policy measures that could improve environmental conditions, while enhancing agricultural and water management in the region. Some of the policy measures are given below:

Effective governance is needed to implement integrated water resources management (IWRM). An extensive literature review by [36] reveals that the institutional barriers which draw in the political and geographic challenges have been recognized as the main limiting factor to integrate the water-related sectors within the IWRM umbrella. These affect sustainable water management and distribution. All aspects of hydrologic integration, e.g. conjunctive use, surface- and groundwater integration, and managing water quantity and quality should be included in the IWRM framework within the river basin. It is also necessary to note, that IWRM related projects are underfunded concerning the expectations and there is a weak interconnection between the projects. IWRM is both a long-term and capital-intensive process. Governance capacity may need to be continually improved, especially in the 'closed' basins where the entire sustainable volume is nearly fully allocated, and no further allocation is possible.

Redoubled efforts at mobilizing more data, better information, and application of good scientific practices and expert knowledge that reflect better water management, economic efficiency, and environmental sustainability need to be addressed in future researches. For sustainability purposes, the financial, organizational, legal, and technical aspects of the transboundary river basin and canal management organizations need to be solved.

Improved transboundary water cooperation. Transboundary water cooperation between the riparian states has the potential to generate many significant benefits and could solve the existing problems in joint water resources management (restoration/construction of hydrological control structures, water metering and accounting, communication and networking, exchange of hydrological information,

availability and transparency of readily available information at the basin and command area, reciprocal control, border crossing, forecasting of flows, warning systems for natural hazards and disasters, etc.). Actions to mitigate water stress need to be planned in an integrated, cooperative framework to take careful consideration of all sectors in each country sharing a river basin or canal in the valley.

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