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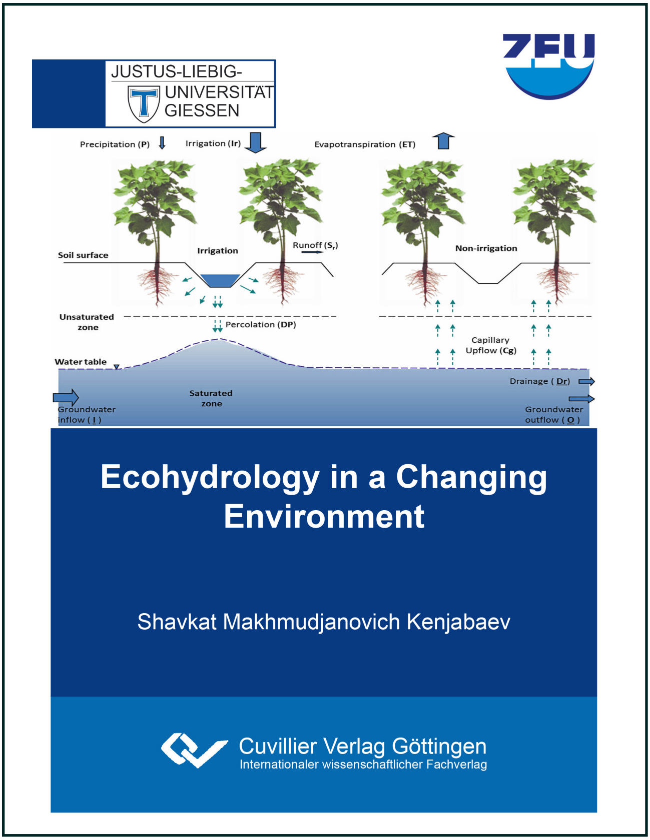

Ecohydrology in a Changing Environment

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1 INTRODUCTION

1.1 Background and problem statement

The complex of ecological problems in Central Asia, especially in Uzbekistan, is linked to rapid on-going demographic and economic processes. However, geographical location has its own peculiarity. Aridity of the climate in Uzbekistan makes water resources as main limiting factor for sustainable economic development (Chub et al., 1998; RECCA, 2011). Annual precipitation, ranging from 80-200 mm in plain to 300-400 mm in foothills and 600-800 mm in mountain rangelands (Chub, 2007), is considerably lower than the evaporation demand of atmosphere (FAO IPTRID et al., 2004). Thus, agriculture, accounting about 90% withdrawal of total available water resources in Uzbekistan, is impossible without irrigation (Qadir et al., 2009). Moreover, agricultural production is highly vulnerable to climate change (Lioubimtseva & Henebry, 2009). High fluctuation of precipitation and temperature increase may influence land use in irrigated lands, create difficulties in water management at regional and local scales, and increase competition of scarce water resources among water users in various sectors.

Population growth is another factor that impacts the natural resource use. Population density in Uzbekistan increased from 35.6 people per km^2 in 1980 to 65.0 people per km^2 in 2011 (ADB, 2012). Consequently, the demand for food increased and led to the expansion of irrigated lands and, thereby, potential for the degradation of surface and groundwater quality by agricultural activities has increased. The expansion of the irrigated lands has resulted in increasing water withdrawal from two main rivers (Amudarya and Syrdarya) and induced the problems of land degradation, contamination of water resources and environmental disaster of the Aral Sea disaster. In their natural state, many of these lands are poorly drained. Therefore, intensive development of irrigated lands in the 2nd half of XX century increased irrigated lands with artificially drained area on about 2.9 million ha in Uzbekistan (Dukhovny et al., 2007). No doubts that development of collector-drainage network (CDN) has positively impacted on irrigated lands preventing salt accumulation in soils and creating a favorable soil aeration condition, thus, prolonging the suitability of land for crop production in a long-term perspective. However, coupling with the development of irrigation and drainage systems the steady rise of the return water was observed. This increase was caused by low irrigation and drainage efficiencies on the one hand and misuse (over irrigation) of water resources on the other hand. At the same time, the collector-drainage infrastructure in the region is designed in such a way (naturally and artificially) to discharge most of its effluent into the rivers (FAO IPTRID et al., 2004). Thus, gradual increase of water mineralization in the Syrdarya and Amudarya Rivers was observed in space and time resolution since 1950-1960 and 1970, respectively (FAO IPTRID et al., 2004). As a result, environmental and epidemiological fragility as well as hygienic and sanitary conditions are emerging as a major problem (Statistical Bulletin, 2006), especially in lower course provinces of Uzbekistan.

At present, most of the lands suitable for irrigated agriculture are developed in Uzbekistan. Nowadays, about 9.6% out of total area (447,700 km^2) is used for irrigated agriculture (Goscomzemgeodezcadastr, 2009; Chub, 2007). Agriculture, contributing about 30% to the annual GDP in Uzbekistan's economy (World Bank, 2013), is meantime a major source of employment and income for the rural population. Agricultural sector is characterized by a production system with main crop rotation of cotton cultivated as cash crops for export, and winter wheat as well as other crops for the maintenance of national food security. In recent years, the share of cotton and wheat cultivated area was almost equaled in Uzbekistan (Abdullaev et al., 2009a). However, change of cropping pattern, especially increased wheat cultivation has impacted crop rotation, crop water requirement and irrigation water management. Abdullaev et al. (2009a) provided an example where overall water requirement was decreased because of increased wheat area. But cultivation of secondary crops after wheat harvest was not taken into account, which also requires additional water resources. Furthermore, this also leads to water allocation conflicts between local harvesters of secondary crops and farmers who have cultivated cotton. These changes also created almost continuous water flow in irrigation and drainage network having water in both seasons (vegetation and non-vegetation) with negative consequences on irrigation and drainage cleaning which was done during non-vegetation period in post Soviet time (Abdullaev et al., 2009a).

Additionally, agricultural production under growing demand of increasing population is impossible without the use of mineral likewise organic fertilizers. However, excess use and/or improper management of fertilizer by farmers can threat the environment. According to Leith & Sutton (2011), the European Union (EU) loses about 70-320 € billion per year owing to environmental pollution caused by excess application of nitrogen. At the same time, freshwater quality both for surface and ground water is a matter of increasing concern, particularly when it is associated with irrigation water management and agronomic practices under different land uses. As it is known, anion form of nitrogen (nitrate) can easily move with water in soil profile which can reach groundwater depending on the N application rate, soil available N content, time and amount of irrigation or rainfall intensity. Hence, groundwater enriched by nitrate then consequently moves into surface water bodies naturally and artificially (subsurface horizontal drainage), where it causes euthrophication. In general, both of these movements are driven by the pressure head of water above an impermeable layer (Gooday et al., 2008), while in Fergana valley (FV) where the study sites are located, these movements are a bit complicated by the influences of lateral water movement from the adjacent sides and presence of artesian water.

In this context, eco-hydrology as a sub-discipline has a potential to provide foundation for the sustainable management of water resources (Wood et al., 2007). As Baird & Wilby (1999) stated: ‘Eco-hydrology is a study of plant-water interactions and the hydrological processes related to plant growth,’ thus, attempt in this study was given to know how these interactions and processes take place in the FV under anthropogenic (irrigation, agriculture and drainage) and climatic (precipitation and evapotranspiration) influences.

1.2 Objectives of the study

The overall goal of the research is to investigate water quantity and quality at the level of field in the Fergana Valley (Uzbekistan). The specific objectives are: (1) identification of water quality (salt and nitrogen species) under various land use practices at the selected study sites and (2) modelling relative impacts of different land use on water and matter fluxes on the selected study sites.

1.3 Significance of the study

The effect of leaching salt and nitrate on water quality, derived from agricultural activities, has been studied well else-where in the world (Davis et al., 2011; Dukhovny et al., 2005a; Lam et al., 2009; Portela et al., 2009; Ikramov, 2001; Wang et al., 2006). In most cases, these studies considered the estimation of water balance components as a pre-condition to know the behaviour of salt and nitrate pool in the system.

Previous studies in the Fergana valley have mainly focused on water and salt balances (Dukhovny et al., 2005a; Dukhovny et al., 2007), however, agricultural land use and irrigation and fertilization management influences on water, salt and nitrate movement from soil-groundwater into subsurface drainage is not studied well. Meantime, simple models to estimate soil moisture, deep percolation and upward movement of water are important to improve water balance calculation and to understand current water use efficiency in terms of water productivity.

1.4 Organization of the Thesis

Following the introduction part, Chapter 2 sheds light on literature review and describes ecological consequences of changes in water management in the FV, current state of agricultural land and water management in Fergana province, past and present studies of the water and salt balances, and their peculiarities in the region. Brief review of some field scale models used to estimate water and mutter fluxes are presented.

Chapter 3 gives an overview of geographic location, climatic conditions, soils and crops grown in the region. A conspicuous feature of geology and hydrogeology under irrigation and drainage interactions are highlighted.

Chapter 4 briefly discusses the site specific characteristics, data collection and analysis, methods and models used in the study. Furthermore, the evaluation method of model performance is presented.

Chapter 5 contains the results and general discussion of the quantitative and qualitative assessment of studied waters, physical and agrochemical properties of soils at the sites. Field level total and aeration zone water, salt and nitrogen balances were discussed. Irrigation water productivity (WP_I) and net water productivity (WP_N) for cotton and wheat were calculated. Applicability of the robust models, such as BUDGET and UPFLOW and complex DRAINMOD model were presented. The affect of irrigation water use on soil moisture regime and crop yield was assessed using the model BUDGET. Empirical equation to determine the daily crop coefficient (Kc) values for cotton, wheat and maize based on the BUDGET estimated actual crop evaporation (Ec) and transpiration (Tc) is discussed. Estimation of the deep percolation (DP) due to variations of the soil water storage in the root zone is discussed. The affect of soil moisture content to estimate the capillary rise (Cg) from the groundwater table was discussed. Field application of DRAINMOD model with modification of irrigation and rainfall input for the arid condition was discussed.

Finally, Chapter 6 summarizes the main findings and concludes with necessary future actions to improve current agricultural and water management practices in the Fergana region.

2 LITERATURE REVIEW

2.1 Ecological consequences of changes in water situation in Fergana valley

General background

First of all, the names of objects used by various researchers have to be distinguished. In some literatures Fergana is referred to as Ferghana or Fargona (in local name) and the Syrdarya as Syr Darya or Syrdaryo (in local name). In this study the names Fergana and Syrdarya are used.

The Fergana Valley (FV) is one of the most ancient world oases and differs by its most fertile lands (Irrigation of Uzbekistan, 1975). At the same time it is the most socially stressful and most conflict prone region for water allocation in Central Asia (CA) (Dukhovny & Stulina, 2012; Bichsel, 2011). High rate of population growth, interdependence of water and energy (Baker, 2011), as well as ethnic conflicts for territory delineation (Koichiev, 2003) and limited land resources are the main obstacles of population's wellbeing in the region (Dukhovny & Stulina, 2012).

Disputes about water allocation and land distribution along the international state borders that existed during the Soviet times became even more serious now. During the communist government, the management of rivers crossing the boundaries of individual Central Asian republics and conflict solutions were ordered and enforced by Moscow (Wegerich et al., 2012). However, after the collapse of the Soviet Union, water issues rapidly became a national rather than a regional concern. The problems concerning natural resources cause conflicts between provinces, states and even in the region. No doubts, that balancing inhabitants and ecosystem's water need is becoming a principal environmental issue (Petts et al., 2006), which may be linked to water governance. One of the destabilizing internal factors in water governance in CA is "Hydroegoism". It is becoming a pressure tool (Dukhovny, 2011) giving rise to wishes to use advantages of geographic position for the economic diktat. Countries within the Syrdarya River basin exhibit symptoms of water scarcity by increasing competition between hydropower in the upstream as well as environment, cities and agriculture in the downstream (Karimov et al., 2010), especially when there is increased demand for water in agricultural sector during vegetation period. Hence, misbalance of water resources in the upper and lower stream of the Amudarya and Syrdarya is becoming not only an economic issue, but also regional political problem in Central Asia.

Considering water management issues, comprehensive study of eco-hydrology may provide a foundation for sustainable management of water resources (Wood et al., 2007) with consideration of the effect of hydrological processes on the distribution, structure and function of ecosystems on the water cycle (Nuttle, 2002).

Prior to starting the description of ecological consequences of changing water situation, it is advisable to demonstrate the geo-morphological structure and complex land and water management system existing in the valley.

Geo-morphological structure and distribution of land resources in the valley

The FV is one of the water-rich upstream sub-regions of the Syrdarya River basin. According to the Irrigation of Uzbekistan (1975), length of the valley is 300 km, and width of 170 km with floor elevation of about 450 m above the sea level (asl). According to UNEP et al. (2005), the valley has an area of 22,000 km^2. 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 only narrow mouth to the west through which the Syrdarya River drains the valley (Abdullaev et al., 2010).

After demarcation of the Fergana Oblast in 1924 by the Soviet authorities, its territory ($8.95*10^6$ ha) has carved up into Uzbek (22%), Tajik (8%) and Kyrgyz (70%) Soviet Socialistic Republics (Irrigation of Uzbekistan, 1975). Randa (2002) argues that about 60% of valley's territory lies in Uzbekistan (Andijan, Fergana and Namangan provinces) which constitutes of a plain, central part of the valley. 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%) (Randa, 2002). Based on the above, the exact delineation of the valley's territory and its distribution among the provinces of the three countries are subject to further clarification.

Climate and demography

The average air temperature in the valley is 13.1◦C, ranging from −8◦C to 3◦C in winter (January) and 17◦C to 36◦C in summer (July). Annual precipitation ranges from 109 to 502 mm, whereas evaporation ranges from 1,133 to 1,294 mm throughout the valley (Abdullaev et al., 2010; Reddy et al., 2012a). The limited precipitation on the lowland plain coupled with high temperatures, low humidity and high degree of solar radiation causes high degree of potential evapotranspiration.

The valley is the most densely populated area in CA. The annual average population growth rate of 1.5-2% is common in the provinces of the FV (Dukhovny & Stulina, 2012) and this creates demographic tension (Abdullaev et al., 2010).

Given the importance of agriculture for the whole FV, natural resources, such as land and water have historically been amongst the most important factors in the development of the region (Qadir et al., 2009). Data from elsewhere depict that 44 to 45% of the irrigated lands of the

Syrdarya basin are located in the FV (Toryanikova & Kenshimov, 1999; UNEP et al., 2005). However, the amount of irrigated lands shared by three countries is already limited and demand for scarce natural resources will continue to rise with population growth. Hence, the size of the population depending upon these resources is consequently a key political security and environmental issue. High population density also increases the risk of natural resources depletion (Dukhovny & Stulina, 2012), and thus competition and even conflict for their control is obvious.

Hydrology: water resources management in Fergana Valley

The agricultural development and wellbeing of the rural population in the valley depends on water availability in transboundary small rivers (TSRs) and mainly flow regime of the Syrdarya River (*Jaxartes* in Ancient Greek or *Sayhoun* in Old Persian). The Syrdarya River is formed by the confluence of two major rivers Naryn and Karadarya which runs through the thalweg of the valley and drains out in a narrow mouth to the west (Irrigation of Uzbekistan, 1975; Abdullaev et al., 2010). The drainage area of the Syrdarya River is about 219,000 km^2 with total length of 2212 km (Toryanikova & Kenshimov, 1999). Within the valley, the Syrdarya River has a length of about 300 km (FAO IPTRID et al., 2004). According to CAWATERinfo (2012), the natural annual runoff of the Syrdarya River averages 37.9 km^3 and ranges between 18.3 and 72.5 km^3. In addition, a number of small tributaries feed its runoff (Dukhovny et al., 2012). The contribution of the TSRs within the valley to the Syrdarya River equals 7.8 km^3 (Wegerich et al., 2012). 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 (FAO IPTRID et al., 2004).

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 1960s is followed by population increase, industry development and mainly irrigation expansion (FAO IPTRID et al., 2004). The data provided by CAWATERinfo (2012) indicate the importance of water resources for agriculture as its withdrawal as much as 94% of the total water use in the valley (Table 2.1). Allocation of water resources between the sectors in the countries of CA is almost the same (Qadir et al., 2009).

Table 2.1: Actual use of available water resources (%) for agricultural, municipal and industrial sectors in provinces of Fergana valley (average for 1980-2009)

Sectors	Provinces						
	Andijan	Fergana	Namangan	Osh	Djalalabad	Batkent	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

Note: N/A - no information is available

Source: CAWATERinfo, 2012

Before the Soviet government in CA, a set of ring irrigation systems existed in the FV, mainly on removal cones of the Sokh, Isfara, Isfairam-Shakhimardan, Andijan, downstream part of the Naryn, Akbura, and Aravan, while the lands located on the desert and desert-steppe part of the Central Fergana were undeveloped (GWP CACENA, 2011). During the Soviet period, agricultural production, particularly associated with forced cotton cultivation in CA, underwent a rapid expansion of irrigated lands until reaching its peak in 1980s (Kandiyoti, 2005). The agriculture in riparian republics was specialized according to the specific agro-climatic zones (Qadir et al., 2009) and economics was interdependently based on centrally managed Soviet economy (Paroda, 2007). Development of the irrigated agriculture was followed to convert virgin lands into productive agricultural lands (Qadir et al., 2009). These expansions have led to the development of lands in Central Fergana (Laktaev & Ermenko, n.d.), promoting the construction of a number of large main canals and collector-drainage network (CDN) (Irrigation of Uzbekistan, 1975). The dense irrigation and drainage network has been developed within the command area of the Big Fergana Canal (BFC), South Fergana Canal (SFC), North Fergana Canal (NFC) as well as Akhunbabayev's Canal, Big Andijan Canal (BAC), and Big Namangan Canal (BNC). These led to the improvement of irrigation infrastructure and expansion of irrigated lands in central part of the valley and change of the Syrdarya river flow regime. Moreover, construction of dams and reservoirs has been commenced in the main rivers starting from 1960s (Karimov et al., 2010). These constructions enabled to regulate the flow of the Syrdarya River by 92% (Toryanikova & Kenshimov, 1999). Irrigation systems were developed on thousands of acreages in the lower reaches of the Syrdarya Basin, i.e. in the Uzbek and Kazakh Soviet Republics. Hence, allocation of water resources in the Syrdarya River basin among the CA states was regulated by the Protocol No. 413 enacted on 07.02.1984 (World Bank, 2004).

Currently, the demand for hydropower versus irrigation needs is becoming the main issue in operation of reservoirs and dams in the Syrdarya River basin, especially the Toktogul reservoir (Karimov et al., 2010; Rakhmatullaev et al., 2010; UNDP, 2007; World Bank, 2004). Although, the multi-year regulation of the Syrdarya River by the reservoir enables to generate the hydropower, its regime was followed as irrigation mode during the Soviet time (World Bank, 2004). Therefore, annual releases of the Toktogul reservoir (9.43 km^3) set up as 75% and 25% accordingly in summer and winter periods (World Bank, 2004). As stated by Dukhovny (2010), "'status quo' was formed in that period that was based on well-balanced, planned water resources distribution among riparian republics in line with 'The schemes of integrated water resources use' and the common market of electric power, which was regulated using the unified system of tariffs for fuel resources and electric power." However, water management strategies primarily comprised utilization and distribution matters as well as infrastructure measures (Dukhovny, 2010).

The climate change, apart from anthropogenic influences, is another driving force to change the natural hydrologic cycle of the river (Stucker et al., 2012). Its most hazardous and complex consequences are more frequent extreme floods and droughts (Dukhovny et al., 2008). The frequency of occurred drought years during 1990-2007 in Syrdarya basin is less compared to those which occurred during 1950-1990, while high water years (prob. ≤ 25%) and extremely high water years (prob. ≤ 10%) were increased by 1.4 and 2 times, respectively (Dukhovny et al., 2008). However, the competition for water resources in drought years creates higher water withdrawal from main intake points. Consequently, surface runoff from fields comes to 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^{-1} (Toryanikova & Kenshimov, 1999), the CDW in the valley is used as an additional source for irrigation. Seven years of study by Yakubov (1988) on continuous use of CDW with salinity up to 3 g l^{-1} showed a negligible impact on nutrient and humus content of soil and cotton yield in Central Fergana. Therefore, to couple with water shortage, the share of water withdrawal from CDN is increasing twofold (Dukhovny et al., 2012).

According to Dukhovny et al. (2012), the share of water withdrawal from TSRs and CDN for land irrigation in the FV for the last decade is averaged as 26 and 2.7%, respectively. The high water withdrawal from TSRs in Uzbek part of the valley is obvious and accounts about 86% (Figure 2.1a), because most irrigated lands of the valley are located in the provinces of Uzbekistan which equals 62% (Jaloobaev, 2007). While the highest share of water withdrawal from CDN comes in lower course provinces of the FV (i.e., Sogd and Fergana provinces, Figure 2.1b).

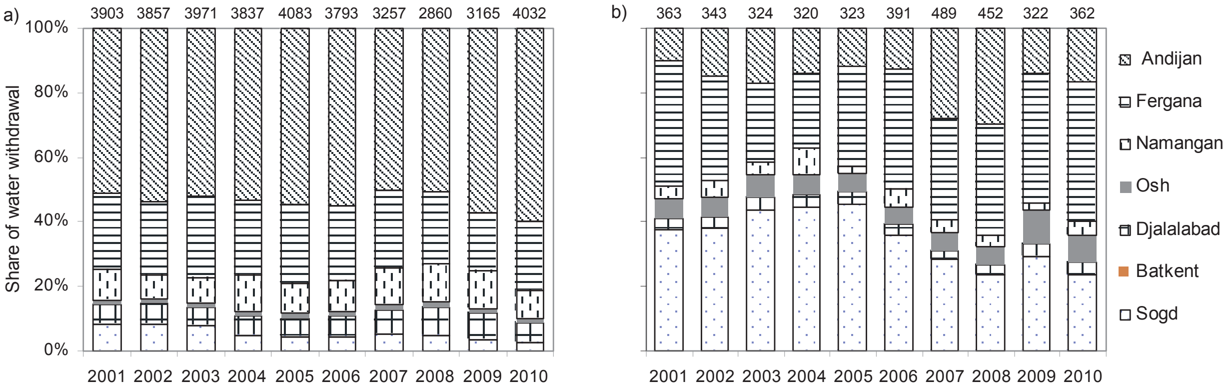

Figure 2.1: Water withdrawal for irrigation (%) from TSRs (a) and CDN (b) within the provinces in the Fergana Valley

Note: Numbers above the bars - annual water withdrawal (in 10^6 m^3) from the sources

Source: Dukhovny et al., 2012

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 (Yakubov et al., 1989). 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^3 ha^{-1} in Sogd province to 5000 m^3 ha^{-1} in Fergana province (FAO IPTRID et al., 2004). Thus, groundwater formed within the 18 aquifers of the FV (SANIIRI, 2008; Karimov et al., 2010) might be a potential source for irrigation in the future which may reduce water withdrawals from the rivers.

Supported by the materials of the Institute of Hydrogeology and Engineering Geology, Central Asian Scientific Research Institute of Irrigation SANIIRI[1] (2008) has assessed the annual groundwater resource in the valley to be 8.2 km^3, from that about 1.3 km^3 and 1.9 km^3 is annually used for drinking as well as irrigation (including pumping by the VDW during non-vegetation period) purposes. The mineralization of groundwater is fluctuating from 0.2 g l^{-1} to 3.2 g l^{-1}.

Based on the hydrogeological zones, transmissivity of the water bearing stratum, depth and salinity of the groundwater, Karimov et al. (2010) estimated the possibility of using groundwater (without mixing with canal water) for irrigation in the area of 290.000 ha in the valley. Depending on the dryness of year, the potential maximum annual groundwater extraction in the natural groundwater recharge zone including groundwater spring discharge zone could be 5.6-6.0 km^3

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[1] Since 2012 it is Scientific Research Institute of Irrigation and Water Problems under Tashkent Institute of Irrigation and Melioration (Resolution of Cabinet Ministers of the Republic of Uzbekistan, KM № 33, 07.02.2012)

(Karimov et al., 2010). However, groundwater is considered as a strategic resource for the future use and is a main reserve of drinking water (Qadir et al., 2009).

Ecology: impact of water management to the environment

Despite successful engineering construction and expansion of irrigated lands with a high rate between 1956 and 1990s (Ikramov, 2007), the fundamentals of the agriculture and water management were indeed poor. Although the achievements of irrigation expansion in ensuring food security, increasing employment opportunities, income generation and particularly improving the rural welfare have been impressive, it accompanied negative environmental implications (Qadir et al., 2009). Some of them are a secondary salinization and water-logging of irrigated croplands associated with the expansion of irrigated lands (Paroda, 2007; Ikramov, 2007). This is concerned with extensive water use and low efficiency of water use in five states of CA (irrigation systems 0.48-0.73 and irrigation techniques 0.62-0.70) causing the rise of saline ground water to the soil surface due to noncompliance with leaching water regime and mainly insufficient drainage of irrigated lands (Ikramov, 2007). The seepage from main canals and field canals caused substantial losses, when water was transported into desert lands of Central Fergana.

In contrast, salinity of the water in the Syrdarya River is also increasing by the return flow of the CDW containing salts and other pollutants from irrigated lands (Toryanikova & Kenshimov, 1999). The CDW from the irrigated lands of FV (9.4 km^3) flows into the Syrdarya river and is then used for irrigation of the lands situated in downstream.

Although FV is relatively water-rich region comparing to the lower course regions along the Syrdarya River basin, water shortage is common in some areas because of mismanagement of water resources in terms of excessive water use for irrigation and leaching of salts, and water allocation within the systems. As irrigation in arid climate is needed to create soil moisture for optimum plant growth, it significantly alters natural hydro-geological, soil and other conditions, causes salinization and water logging of soils (Dukhovny et al., 1979). Because about 52% and 82% of main canals and field canals are earthen (Table 2.2) and lack of natural drainage and deterioration of available artificial CDN leads to the GWL rise.

Table 2.2: The type and length of irrigation network in provinces of the Fergana valley (average for 2001-2010)

Provinces	Inter-farm irrigation network				On-farm irrigation network			
	Total length (km)	Earthen (%)	Concrete (%)	Specific length (m ha^{-1})	Total length (km)	Earthen (%)	Concrete (%)	Specific length (m ha^{-1})
Andijan	2200	53	47	8.4	12000	79	21	44.4
Fergana	2400	47	53	7.1	18400	89	11	52.9
Namangan	2600	61	39	9.3	8200	81	19	34.1
Osh	1212	69.6	30.4	9.6	2934	91.5	8.5	23.1
Djalalabad	656	53.9	46.1	5.2	3632	76.6	23.4	28.5
Batkent	360.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sogd	1045	28.4	71.6	5.9	8402	73	27	47.2

Note: N/A - no information is available

Source: CAWATERinfo, 2012; NWO EECCA, 2010

Although shallow GWL enables the reduction of irrigation norms due to the contribution of capillary rise, at the same time it brings salts that exist in adjacent soil layers. Under such condition, Dukhovny et al. (1979) proposed to increase the system's efficiency (canals) up to 0.8-0.9 and stop water flow in canals during non-vegetation period (October-March). However, high capital investments and regular maintenance works are required to increase the system's efficiency. Stopping the water flow in canals during non-vegetation period is impossible under current situation by the following reasons:

- Cultivation of cereals, particularly winter wheat (at the expense of reducing cotton area) is increasing since 1990s (Figure 2.2) which needs water supply during non-vegetation period as well (at least charging irrigation for seed germination). The expansion of cereal cultivation area is significant, mainly in the provinces of Uzbekistan and Tajikistan of the valley which can be explained as a favorable condition for its growth and food security being a primary concern for all CA countries on the whole (Christmann et al., 2009).
- Winter releases of water from Toktogul reservoir increases the pressure on the Syrdarya River (Abbink et al., 2005) and distribution of excessive winter flows through canals to the fallow lands and temporary storage of water (groundwater banking) in the aquifers of the FV could be a solution till reliable water-energy consensus would be made up between upstream and downstream countries (Karimov et al., 2010).
- Leaching irrigation in salt affected lands, particularly in Central Fergana, is recommended to perform in winter periods (World Bank, SIC ICWC, SPA SANIIRI, 2013) and there is a need for water supply through the canal systems.

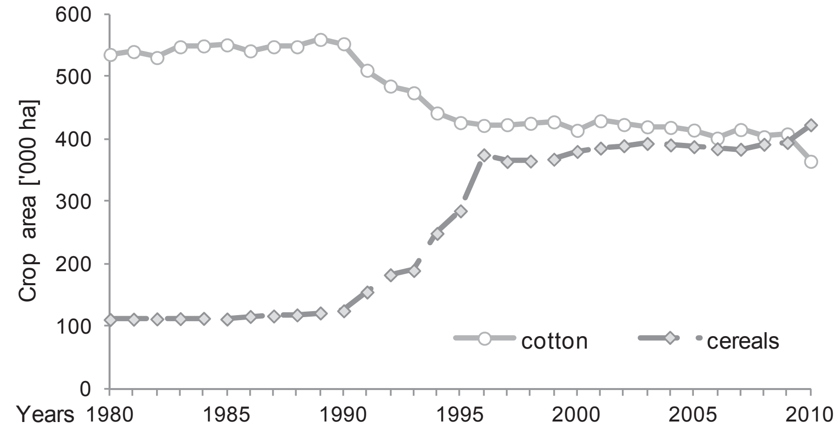

Figure 2.2: Cropping area of cotton and cereals in the Fergana valley during 1980-2010
Source: CAWATERinfo, 2012

Kijne (2005) argues that salt mobilization in the FV, especially in central plain parts, does not pose a serious problem, because the quality of pressured underground water is better than subsurface drainage water, and refreshes the soil by upward flow. Even so, these lands with very limited natural drainage capacity and improper management of available artificial drainage systems are prone to salinization (Yakubov, 1988). Therefore, land reclamation condition of the region plays a vital role in the determination and use of irrigation water and alteration of the river ecosystems.

According to SIC ICWC Report (2001), the irrigated lands of FV located along the Syrdarya River course is suffering from substantial water logging 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 decline of necessary rehabilitation and maintenance works since breakdown of the Soviet Union (FAO IPTRID et al., 2004), and absence of an adequate drainage system (Ikramov, 2007) and/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 the productivity of crops (FAO IPTRID et al., 2004). Moreover, shallow GWL with elevated mineralization has mobilized salts, damaging buildings and residential houses located near the CDN (FVWRM Project Report, 2009). As a result, the socioeconomic and ecological situations in the valley are threatened (UNEP et al., 2005).

Altering the hydrological regime of the river, its quality is also deteriorating starting from upstream up to downstream (SIC ICWC et al., 2011). The water salinity was observed to rise for the last 40 years in the Syrdarya River from 300-600 mg l^{-1} in the upper reaches to 3000 mg l^{-1} in the lower reaches within the FV, with prevailing salt composition of $MgSO_4$, $Ca(HCO_3)^2$, NaCl, and

$CaSO_4$. Moreover, there is an overall increase of concentrations of some metals including sulphates and chlorides. 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 morbidity of the local people (SIC ICWC et al., 2011).

Based on maximum allowable concentration (MAC) criteria, Toryanikova & Kenshimov (1999) have assessed the quality of water in some sections of the Syrdarya River (including right bank tributaries within FV). According to them, 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^{-1} (total hardness), 4.5-6.0 and 0.5-1.6 mgO_2 l^{-1} (COD and BOD5), 0.02-0.1, 0.002-0.013 and 0.77-1.85 mgN l^{-1} (ammonium, nitrites and nitrates), 0.003-0.012 mg l^{-1} (total phosphorus), 1.4-8.1, 0.6-4.5, 0-10.1 and 0.6-22.8 μg l^{-1} (aluminum, manganese, copper and zinc).

Moreover, it is important to note that information and data regarding water quality of the Syrdarya River (including the other rivers) is difficult to obtain; thus, extending the available information through the analysis of water quality in temporal and special scales is very important. Therefore, 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 (Table 2.3) have been used for the analysis of water chemical composition. Although analysis of available data from selected sections reveals that data were collected in 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 (Figure 2.3) may be valuable to provide some information for international scientific community about eco-hydrologic situation along the river course. The main reason of decreasing monitoring posts and sampling frequency is associated with the reduction of investments for these works mainly after break-down of the Soviet Union (Chub, 2007). Hence, from the mid 1980s till the end of 1990s the number of monitoring posts and network of meteorological stations in CA were reduced by 25-40% and 23% in average (Chub, 2007). Therefore, a hydro-chemical measurement after effluent of big collectors along the river courses has not been being performed since 1992.

Table 2.3: 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

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

Note: [ξ] coll. – collector, where water quality of Syrdarya River were measured after effluent of main collectors “Saryksuu”, “Severo-Bagdadsky collector” (SBK) and “Sokh tashlama”, accordingly in downstream of 0,2 km, 5 km and 3 km within GS1 and GS3; [ђ] numbers in the bracket - an average quantity of annual data in the period

Source: Toryanikova & Kenshimov, 1999; SANIIRI, 2010 (database for 1960-2004); UzHydromet, 2011 (Yearly bulletins for 2005-2010); Own composition