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ORIGINAL ARTICLE

Groundwater resources use and management in the Amu Darya River Basin (Central Asia)

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Abstract This paper analyses groundwater resources use and management in the socio-economic context of the Amu Darya River Basin which covers a part of the following landlocked Central Asian countries: Afghanistan, Tajikistan, Turkmenistan and Uzbekistan. These agrarian nations for sustaining their vital agricultural productions started to use groundwater during the recent drought years (1998–2001) because of its relatively good quality and quantity and as an alternative to highly mineralized surface waters. Present extent of groundwater resources use is discussed with consideration to their reserves, quality, and institutional management and transboundary aspects within the basin. After the collapse of the centralized water resources management system and infrastructure of the former Soviet Union, new underdeveloped systems are being practiced over the whole Amu Darya River Basin. The critical situation of groundwater management in Afghanistan is also discussed. This work attempts to document the management and use of groundwater in the Amu Darya Basin and present time management realities, with fragmented and weak national and regional regulation on groundwater. Special attention is given to groundwater resources in irrigated agriculture, which increased use in all countries of the basin is due to quick access to underground resources and relatively good quality and quantity.

Keywords Groundwater · Aquifer · Water management · Amu Darya · Central Asia

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Introduction

In Central Asia, the Amu Darya River Basin (ADRB) which namely covers part of Afghanistan and the former soviet republics of Tajikistan, Uzbekistan, and Turkmenistan, groundwater resources are becoming an alternative source of supply for irrigated agriculture and livestock ranching especially in the events of recent droughts and in the context of highly contaminated surface waters due to high levels of salts and pesticides coming from irrigated lands. Due to their climatic characteristics, economic development strategies and geopolitical situation, ADRB countries have been experiencing everlasting competition over water resources. Mostly arid, these agrarian countries pursue their own development and integration into the global community through expanding irrigated lands, growing cash crops such as rice and wheat for meeting their domestic food security but also to export a large part of some productions like cotton.

Groundwater resources were not widely used for irrigated agriculture in Central Asian Republics (CAR) during the soviet period due to sufficient amount of surface water, reliable water supply, and irrigation infrastructure delivered to the farmers. Thus, the groundwater resources were used primarily for livestock sector and very site-specific purposes for example drinking water supply in both urban and rural areas. During the pre-independence period, water allocation and irrigation system infrastructures were well maintained and operated with massive funding coming from the central government.

Since the independence of the CAR, the situation has changed dramatically in terms of institutional, political, and technical systems. Political transition from planned economy to market has introduced "new" concepts like land tenure, water rights, and different kinds of ownership. The institutional changes are described as transition from former state collective farms *kholkhoz* and *sovkhoz* into smaller forms of present private farms. But many farmers were not in the capacity to pump and irrigate lands on an individual basis.

In a very different situation, Afghanistan has traditionally relied on surface water and groundwater springs and karezes in irrigated agriculture. According to the estimates of International Water Management Institute (IWMI), the share of groundwater irrigation of the cultivated area is 11.5% of the total in Afghanistan (Shah 2007). During the recent drought years (1998–2001), the use of deeper groundwater, abstracted via pumped dug wells and boreholes has increased rapidly. Private farmers have drilled many of these new wells and boreholes, and in some areas, groundwater abstraction rates are already exceeding, or will soon exceed, sustainable groundwater resources (Banks and Soldal 2002; Uhl 2003; Masood and Mahwash 2004).

Groundwater overdraw is not everywhere the case in ADRB but the water drought experienced in 1998–2001 has encouraged people to consider groundwater as an alternative to the declining surface water resources. Then many farmers, who could afford, started to exploit groundwater for the irrigation purposes and mainly to sustain the production during low flow periods and maintain the salinity of irrigation water compatible with agriculture. In addition, it should be stated that from the quantitative point of view shallow groundwater is a reliable source of water and people who are distant from source of surface water can obtain it easily for the watering of their fields.

The main goal of this paper is to document and analyze the new realities of the groundwater use both quantitatively and qualitatively in the basin in current settings and to overview main issues and perspectives for sustainable interstate use of groundwater resources as a strategic potential in reducing the poverty in ADRB countries.

Amu Darya River Basin characteristics

Physiography

The Endoreic Basin of Amu Darya River is located in the inner part of the Eurasian Continent (Fig. 1). The catchment area comprises 534,739 km^2 (Water Resources of USSR 1971). 61% of the catchment area lies on the territory of the former Soviet Union and flows through the territories of the new independent states of Tajikistan, Uzbekistan, and Turkmenistan and 39% on the territory of Afghanistan (Water Resources of USSR 1971; Uhl 2003).

The Amu Darya River is formed by the confluence of the Pyanj and Vash Rivers in the Pamir Mountains and

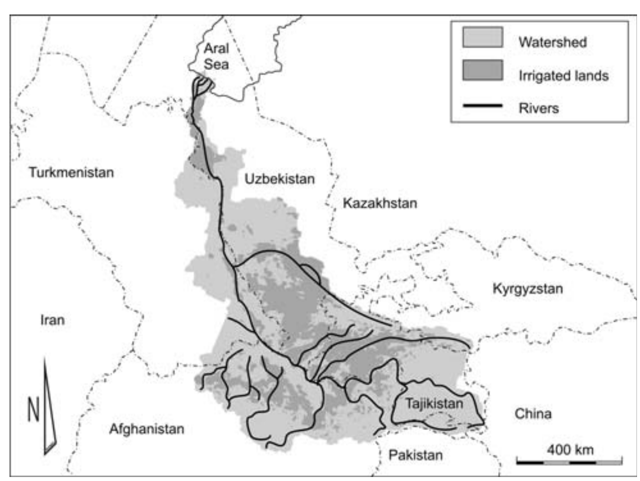

Fig. 1 Map of the Amu Darya River Basin and location of main irrigation areas

discharges into the Aral Sea after a run of 2,550 km. Two Rivers, Zaravshan and Kashkadarya, are related to Amu Darya in term of water catchment characteristics but do not discharge into the Amu Darya River (Mirzaev 1974; Masood and Mahwash 2004). The Amu Darya watershed is divided into two unequal parts, a large north-western part where plains are dominant and elevations not greater than 200 m and a smaller south-eastern part characterized by high mountain ranges of 5,000-6,000 m of Central Pamir and Tian Shan. The presence of these high mountain ranges facilitates the formation of great water courses despite the very arid conditions of the region since it can accumulate atmospheric moisture, and behave as a huge feeding reservoir. The major part of the territory of the ADRB is composed of desert–steppe areas. The juxtaposition of mountains and deserts exerts a great influence upon the hydrogeological conditions, thus favoring the formation of considerable groundwater resources in a number of arid regions. The proximity of mountains and deserts in Central Asia determines the existence of two subtypes of groundwater formation in arid conditions: autochthonous and allochthonous (Ostrovsky 2007). The autochthonous subtype is developed in regions not influenced by mountainous systems and is characterized by groundwater formation from in situ water resources, and mainly from precipitation. The allochthonous subtype is typical of deserts where groundwater is formed under the influence of mountainous systems. It is commonly held that arid zones are characterized by the presence of basins that have no runoff to the ocean and where all precipitation is used up through evapotranspiration. However, if arid zones are considered within their climatic boundaries, then the balance of precipitation and evaporation cannot be equilibrated, as the total amount of evaporation also includes evaporation of both surface runoff and groundwater discharge from mountainous humid regions (Ostrovsky 2007).

Hydroclimatology

The north-western plain of Central Asia is characterized by very hot summer (mean July temperature about 25.5°C) and cold winters (mean January temperature about 2.4°C). The ADRB is open to the dry air masses formed in Arctic and Siberia coming from the North. As they are blown towards western and southern parts of the basin these cold air masses are heated and then can encounter tropical air masses coming from the south. Unstable winters over the region are resulting from this mixing front between dry cold air masses and tropical warm air masses (Aizen et al. 2001).

The basin is characterized by uneven distribution and quantity of precipitation. The average mean annual precipitation over the basin is about 170 mm (Shultz 1949), with great contrast between north-western steppes (100 mm/year) and mountainous areas of the south-eastern (1000 mm/year). The important role of mountains and glaciers should be pointed out as these areas can store precipitation as snow and ice and deliver it through summer melting to rivers and associated alluvial aquifers during dry season (July and August). On an average 96% of the basin area receives approximately less than 300 mm/year (Shultz 1949) and most of the rainfall occurs in winter and spring from December to April.

The dominant process in this very arid region is evapotranspiration which can potentially amount to 1,500–2,000 mm/year (Létolle and Mainguet 1993; Nezlin et al. 2004) and is responsible for the loss of great volumes of water.

Hydrogeology

The region is characterized by very complicated hydrogeological conditions. At first, the complex geological history of the Pamir and Tian Shan Mountainous area is responsible for a huge diversity in term of aquifer and water bearing sediments. These regions are composed of Palaeozoic, Mesozoic, and Cenozoic formations and significant shallow groundwater resources are located in valleys, where 10–100 m thickness deposit of semi-consolidated coarse to medium Quaternary sediments have accumulated. In the piedmont area fresh confined groundwater can be found in the peripheral parts of Quaternary debris cones. Deeper aquifers in carbonate rocks (depths from 700 to 800 m up to 1,000–1,200 m) contain thermal water, widely used in Tajikistan and Uzbekistan for medicinal purposes and bottled as table mineral water (Shultz 1949).

Plains region of the ADRB are covered by alluvial sand, loam, and clay dating from the Quaternary and Pliocene and that can be interstratified, giving birth in some places to confined or semi-confined aquifers. Groundwater in these surface formations are strongly hydraulically connected to Amu Darya River and mainly recharged by losses of rivers (allochthonous river runoff), irrigation canals, and irrigated fields. A lot of shallow aquifers are salinized (1–10 g/l) or involved into salinization processes. Salinization results from agricultural practises but is also related to the sodic nature of soil like solonetz and solontchaks. It must be noted that groundwater mineralization tends to decrease with depth (Ostrovsky 2007) and that mineralization processes are strongly correlated to groundwater level rise caused by irrigation.

Confined aquifers can be found in the deep Cretaceous sandstone formations of the Aral Sea area and provide artesian waters. In some parts these deep groundwater can show high mineralization which prevent them from any use. Mineralization can even reach values around 25–50 g/l at depth close to the Aral Sea region (Water Resources of USSR 1971).

In the Soviet times, groundwater resources were explored for the purpose of irrigation. Although they proved to be abundant, the primary focus was placed on the use of surface water. In Central Asia, groundwater constitutes a resource of fresh water that is comparable or exceeds surface waters in terms of volume. In many places this renewable resource can be effectively utilized with simple wells, which may, particularly, work as artesian wells in the lower parts of mountain slopes and mountain valleys.

Groundwater reserves and extraction

Groundwater reserves and use

Groundwater resources can be classified according to their recharge processes, two main classes can be distinguished: (1) groundwater formed under natural conditions in the mountain zone and catchment areas by infiltration of rainfall (autochthonous groundwater) (2) groundwater formed from the infiltration losses from irrigated areas in the rest of the ADRB (allochthonous groundwater). The total regional groundwater reserves are estimated to be 25 km^3/year (Mirzaev 1974) which represents about 58% of the Aral Sea Basin reserves (Table 1).

Groundwater's and surface waters are strongly hydraulically connected one to another, and according to an established system in the ADRB groundwater availability is characterized by the so called "natural recharge capacity" which can be considered as the regional operational reserve (Water resources of USSR 1971). This is a potential yield of each aquifer, which under the pressure of anthropogenic factors can be reasonably tapped in order to satisfy the needs. This is based on both the existing installed pump capacity and the level of knowledge of the aquifer recharge characteristics. "Approved capacities" confer the right to design and construct new withdrawal points (Table 1).

Aquifers in Uzbekistan and Tajikistan are relatively the most intensively exploited. About 99% of approved groundwater reserves are used in Uzbekistan, whereas in Tajikistan and Turkmenistan only about 30–40% are used for various purposes (Table 1). This can be explained by both intensive groundwater abstraction infrastructure in Uzbekistan with funding from the central government in irrigated areas and by uncontrolled water extraction by local farmers and the population in more isolated areas which tend to tap the aquifers to the maximum of their possibilities.

In Turkmenistan, about 134 large groundwater bodies can be identified and used for various needs (Khatamov 2002; Orlovsky and Orlovsky 2002). The total intake of groundwater resources varies from 4.7 to 6.7 km^3/year out of which 45% is used for drinking supply, 30% for irrigation and rest for livestock ranching. Groundwater from the first water-bearing horizon serves as a major water source in the desert areas. In 1994, according to different sources, there were from 5,695 to 6,138 water wells and up to 619 boreholes, which supplied water to about 68% of pastures (Babaev and Kolodin 1995; Babaev and Kolodin 1997). In the recent years, a number of new water wells were built, but at the same time the old ones were destroyed. So the exact number of functioning wells and boreholes is now unknown.

In Tajikistan, many groundwater bodies can be identified in the very complex structural framework of the country but all limited in term of extension. According to the National Hydrometeorological Agency, the total amount withdrawn annually is about 2.372 km^3 in 2004 (Table 2) without negative impact since the approved reserved are about 6.972 km^3 (Salimov 2001). About 40% of groundwater is used for irrigation and about 49% for domestic drinking supply. In 1994, the total numbers of wells was 4,795 and out of which 511 are wellspring and 4,358 are operational wells (Orlovsky and Orlovsky 2002).

In Uzbekistan, around 94 major aquifers can be identified with a total groundwater volume of about 18.9 km^3, this includes 7.6 km^3 with mineralization of up to 1 g/l and 7.9 km^3 with mineralization from 1 to 3 g/l. 85% of the

Table 1 Groundwater reserves and their use by states in ADRB in km^3/year (UNDP 2007)

Country	Estimated regional reserve	Approved reserves for use	Factual withdrawal in 1999	Use category		
				Drinking water supply	Industry	Irrigation
Tajikistan	18.7	6.02	2.29	0.485	0.200	0.428
Turkmenistan	3.36	1.22	0.457	0.210	0.036	0.15
Uzbekistan	18.45	7.79	7.74	3.36	0.715	2.15
Total, Aral Sea Basin	43.48	16.93	11.037	4.30	1.08	4.04

Table 2 Groundwater recharge and withdrawals in the ADRB (UNDP 2007)

Country	Average annual groundwater recharge		Annual groundwater withdrawals			
	Total (km^3) years vary	Per capita (m^3) year 2000	Year	Total (km^3)	Percentage of annual recharge	Per capita (m^3)
Afghanistan	29.0	127	–	–	–	–
Tajikistan	6.0	970	1994	2.3	37.7	398.7
Turkmenistan	3.4	753	1994	0.4	11.9	100.3
Uzbekistan	19.7	809	1994	7.4	37.6	334.3

groundwater resource is recharged from surface water and only 1/3 is formed on the territory of neighboring countries and which could be called as "transboundary" groundwater resources (Mirzaev 1974; Borisov 1990). The percentage of groundwater used in irrigation amounted to 6.4% of the total irrigated land in Uzbekistan. Limits to groundwater abstraction for each aquifer in Uzbekistan have been established in order to avoid significant consequences to surface flow reduction. This quantity is estimated at 6.8 km^3/year for Uzbekistan. However, the actual groundwater abstraction is slightly superior (estimated at 7.5 km^3/year) and thus tends to lead to a surface flow reduction (Kazbekov et al. 2007).

The great aquifers or regional operational reserves of Uzbekistan have been primarily identified according to drinking water standards. For example, for the 1965–1995 period the fresh drinking groundwater resources in Uzbekistan have decreased from 471 to 294 m^3/sec and comprise only 34% of total groundwater resources compared to the 56% of total groundwater resources it represented in the past (Borisov et al. 2002). In 2001, total extraction of groundwater decreased by 4.9% and irrigation by 10.4% in the Uzbek part of the ADRB in comparison to 1995. The observed decrease in extraction is due to the reduction of operation hours of wells, worn out of pumping systems and bad condition of wells. In comparison with 1995 the total withdrawal decreased by 38.7% (Borisov et al. 2002).

On the other hand, groundwater reserves increased from 844 to 853 m^3/s in Uzbekistan from 1995 to 2001 (Borisov et al. 2002). The increase is explained by the development of irrigated lands. As a result of infiltration of water losses, the level of groundwater of unconfined aquifers began to rise also entailing the dissolution of salts contained in the upper part of soil profiles (Kitamura et al. 2006; Northey et al. 2006). This is particularly true in the lower reaches of Amu Darya River where the groundwater resources were at 15–20 m depth in 1980s and started to rise 1–1.5 m depth in early 2000 (Borisov et al. 2002).

The surface of irrigated areas with high groundwater table level has increased by 21% in ADRB (Table 3) that is to say from 1.29 million ha in 1990 to 1.56 million ha in 1999 in CAR (UNDP 2007).

Table 3 Irrigated lands with high groundwater table level in ADRB, evolution from 1990 to 1999 (FAO 2007)

Country	Areas with a water table <2 m (10^3 ha)		Increase (%) (1990–1999)
	1990	1999	
Tajikistan	92	111	21
Uzbekistan	670	801	20
Turkmenistan	528	654	24
Total	1,290	1,566	21

After the drought of 1998–2001 groundwater use has increased in lower reaches of ADRB. For instance, the Government of Uzbekistan has issued special decrees to overcome the consequences of the drought. The main purposes of the decrees were to drill 2,600 shallow wells in rural districts for population needs. The second purpose of these measures was to repair old wells that were used for both agriculture and drinking water supply (Kuchuhidze et al. 2003).

Groundwater extraction methods

Groundwater extraction methods in Central Asia are much contrasted and can go from the traditional karezes systems in Afghanistan to modern pumping plants in Uzbekistan.

Karezes are human-made underground channels common in Afghanistan. They are often very old, having been constructed several hundred years ago. They are typically located in the foothills of mountain areas, but can be constructed anywhere where the water table is relatively shallow and where there is a consistent slope of the terrain. Karezes essentially skim water off the top of the water table. This means that, in effect, it is practically impossible to overexploit an aquifer using karezes (Fuchinoue et al. 2002). On the negative side, they are extremely vulnerable to even relatively small drops in the water table caused by climatic factors or pumping of nearby wells. Karezes may be used for irrigation and drinking water. Due to decline in water table related to the current drought in Afghanistan, flows available for irrigation from karezes have become inadequate in many areas and farming viability is suffering. Thus, dug wells and boreholes are typically drilled at shallow depth (up to 20 m) in Neogene and Quaternary sediments (Banks and Soldal 2002). They may be used for drinking water or for irrigation purposes and most of the time fitted with hand pump. In some areas, artesian aquifer may exist at depth. In this case, pumps are not required in boreholes; they simply overflow under their own pressure. In the Mazrah area of Guzara District (Herat), private irrigation boreholes drilled to 60–65 m deep encounter artesian resources of fresh groundwater. Typical yields of about 5 l/s flow uncontrolled for 24 h/day from these boreholes. Such uncontrolled overflow is extremely undesirable from a water resource point of view (Banks and Soldal 2002). For irrigation, most of the lands were irrigated either by surface water or by groundwater from karezes or natural springs. This situation is rapidly changing. Lift irrigation is new technology and, although in overall terms it still accounts for a relatively modest share of total irrigated land, its use is growing explosively.

For the CAR the major share of groundwater extraction is coming from borehole and dug wells thanks to heavy equipments developed during the soviet period and still operating in many places. According to Uzbekistan Research Institute on Hydrogeology and Engineering Geology (HYDROENGEO) and Ministry of Agriculture and Water Resources of Uzbekistan, the extraction of groundwater is made mainly from borehole but at very different depth and with many kinds of design, mainly inherited from Russian technologies. Extraction of shallow groundwater up to 6.0 m is operated manually, deeper unconfined aquifer (30–150 m) from Quaternary are exploited with electrical submersible pumps of varying capacity of 10–70 l/s (Borisov 1990).

Cost of groundwater extraction

According to the HYDROENGEO Institute, the use of groundwater is not economically profitable for irrigation due to its high extraction costs and economic inefficiency in Uzbekistan (Mirzaev 1974; Borisov 1990). The global production cost per 1 m^3 of groundwater is about 0.5–1.0 US$ (UNDP 2007). Cost per 1 m^3 of surface gravity irrigation for a farmer is estimated to be 0.13–0.15 US$, and in the areas of pumped irrigation is about 0.3 US$ (UNDP 2007). Thus, production cost in the case of groundwater exploitation is clearly higher than that of surface water exploitation.

However, the use of groundwater resources for irrigation purposes is justified in water scarce conditions and in special places of the territory of Central Asia. For instance in the ADRB by 2003 approximately 27,000 boreholes were drilled to counterpoise the pernicious effects of the drought, with depth varying between 50 and 500 m with a cost of drilling for one borehole ranging within 500–2,000 US$.

Decentralized water supply of rural population, especially downstream the Amu Darya River, is provided by unconfined groundwater resources coming from shallow wells of 15–20 m. Extraction of groundwater is manually operated with hand pumps which cost’s about 100 US$ each. The drilling and equipment of the tube with steel pipes can reach about 100–150 US$ in unconsolidated sediments like sands (UNDP 2007).

In Afghanistan, according to Banks and Soldal (2002), dug wells are typically 3–4 times cheaper than boreholes. Typical drilling prices in Afghanistan are 5–6 US$/m in soft strata, 12 US$/m in hard strata. In some parts of Afghanistan, where the demand is high, prices can reach 18–20 US$/m (Banks and Soldal 2002) and are thus dedicated to a very limited number of people who can afford such prices.

Groundwater and agriculture

Massive irrigation

Irrigation in Central Asia and particularly in Uzbekistan relies on a system of pumps and canals which is among the most complex in the world. Cotton and wheat are the major crops in the ADRB followed by maize, vegetables, and fruits. As previously said with annual rainfall of 100–300 mm, the CAR’s climate is that of the dry mid-latitude desert, with a continental climate that is characterized by hot summers and cold winters. Thus, agricultural production in Central Asia is predominantly based on irrigation, which makes irrigation water supply and management the major factors limiting crop yields in the region (Ibragimov et al. 2007).

Agriculture is the dominant sector of the economy in the ADRB countries, employing from 44 up to 80% of the workforce (Table 4). This sector contributes to the basin countries Gross Domestic Product (GDP) from 16 up to 36% with an average of 26% over the basin. All of the ADRB countries are landlocked with arid climatic conditions and agricultural lands are heavily dependent on irrigation to insure acceptable production. Almost all of the agricultural lands are irrigated in Turkmenistan, while the average is around 75% in the other basin counties. Climatic conditions and recent droughts coupled with increased deteriorating quality of surface water prone water users to use more groundwater resources. The Table 4 summarizes

Table 4 Main characteristics of agricultural sector of the ADRB countries (FAO 2007)

Country	Share of employment in agriculture (%)	Share of agriculture contribution to GDP (%)	Irrigated land (million ha) Amu Darya Basin	Share of irrigated to the total cultivated land (%)
Afghanistan	80	36.1	1.16	50
Tajikistan	67.2	23.6	0.43	17
Uzbekistan	44	27.3	2.48	80
Turkmenistan	48.2	16.7	1.74	96

the main characteristics of agriculture and irrigation in the ADRB countries.

In Afghanistan, the estimated annual groundwater volume used for irrigation is minimal (1 km^3/year) in comparison with the groundwater recharge estimate (2.97 km^3/year) indicating a significant surplus of groundwater reserves in this part of the ADRB and the real potential for future development of groundwater resources for irrigation (Uhl 2003). The total withdrawal of groundwater in Uzbekistan for 2003 is about 2 km^3/year and it is used at 40% for irrigation purposes (Kazbekov et al. 2007). In Turkmenistan, agriculture is almost impossible without irrigation as shown in Table 4 and as a consequence this country is mostly impacted by pernicious effects of lift irrigation. From 1986 to 1998 strong rise in the water table was recorded with an increase from 7 to 41% in the surface of farming land with groundwater level less than 2 m.

In Tajikistan, the structure of agriculture is still heavily centralized and big collective farms are operating complex wells and irrigation systems. In 2000 there were roughly 1,000 operational boreholes and numerous wells that totaled 0.428 km^3/year discharge mainly used for irrigation purpose. According to Salimov (2001) about 30,000 ha of lands were irrigated with groundwater resources.

Livestock rearing

In the Uzbek desert and mountain zones of the ADRB, numerous small settlements can be found. These territories are part of pasturelands. The mountain pasturelands have available groundwater resources but in most cases these are in poor conditions from pollution and contamination point of view. The livestock rearing under the desert conditions is off course limited by the water supply availability even if in general, water supply of pasturelands requires very little quantity of water (from 10 to 25 m^3/day) for cattle watering ponds (Babu and Toshmatov 2000).

In Tajikistan, water supply of pasturelands for livestock ranching is supplied by both surface and groundwater resources. The vast areas of the foothills of the Central Tajikistan, plains of Pamir, and South-Tajik depression are rich winter pasturelands, the groundwater reserves can here supply millions of animals (Babu and Toshmatov 2000). At present time, just a limited part of available pasturelands is used for ranching alongside of streams and large springs.

In Turkmenistan about 5,200 wells, 50 boreholes, and 330 springs are used to water the cattle. We must also point out the use in this country of more than 600 *takyrs* as collectors of atmospheric precipitation (Orlovsky and Orlovsky 2002).

Groundwater quality

The two major land quality problems in the ADRB are the interrelated issues of salinity and waterlogging caused by high groundwater levels, only 50% of the irrigated land is classed as nonsaline (Banks and Soldal 2002). In the upper reaches of the ADRB, less than 10% of the land is saline or highly saline, while downstream (especially in Karakalpakstan) about 95% of the land is saline, highly saline or very highly saline. Salinity is closely related to drainage conditions. Moreover, a reduction in the quantity of water allocated to each farm, lower water quality, and the decay of companies responsible for maintaining the drainage network have resulted in increased salinization. Though loss of crop production due to soil salinization is important but salinized lands are generally still cultivated since no alternatives are available at present time (Heaven et al. 2002).

Less than 10% of the CAR's groundwater volume has a salinity level less than 1 g/l, equivalent to the highest quality irrigation water (FAO 2007). Overall, most groundwater has salinity levels between 1 and 3 g/l with approximately 15% showing values between 3 and 5 g/l and nearly 27% having salinities >5 g/l (Chembarisov and Bakhritdinov 1989; O'Hara 1997; Gadalia et al. 2005).

In Uzbekistan, the regional operational groundwater reserves in 2003 comprised 9.17 km^3/year out of which groundwater with mineralization lower than 1 g/l constitutes only around 30% and the rest of groundwater of 1–5 g/l.

Shallow groundwater sources have become increasingly salinized in the lower Amu Darya River in 2001. Several bore and open wells that were used as potable water supply sources have been recently abandoned because of increased salinity, thus preventing from any drinking use. Many wells were also recharging much more slowly than in the recent past and providing lower yields. As a consequence, queues at wells were increasing and the amount of water available for daily withdrawal was decreasing at many sites (Medecins Sans Frontieres 2001).

The dramatic change in the quality of groundwater resources observed in some places of the basin is linked to irrigation and melioration of lands; and reallocation and extraction of river flow (especially since 1965). Discharge of collector-drainage water into the river systems, its re-use and chemization of agriculture has led to regional pollution of unconfined groundwater resources by salts, nitrates, and pesticides (Papa et al. 2004). Such water consumption patterns are well reflected in temporal changes in groundwater depth and salinity, which both showed a rapid increase in the late 1990s. The overall spatial distribution of groundwater salinity shows also strong spatial association with the type of aquifer rock and with the distance from the river along the main irrigation canals (Ibragimov et al. 2007). Coarser sediments showed higher groundwater salinity than finer sediments. Groundwater pollution occurs progressively from upstream to downstream along the river stream. The mineralization of shallow groundwater in upstream of Amu Darya River is about 1–3 g/l and in midstream and downstream it can increase up to 5–20 g/l (Crosa et al. 2006a, b). This increase is the direct expression of the intense development of irrigation and drainage systems for the last 40 years and the consecutive mobilization of large amounts of salts already present in soils or added via agricultural practises.

In the whole ADRB man-caused influence have lead to pollution and to the decrease of groundwater resources and operational reserves of fresh groundwater resources on an average, for the last 30 years, by 0.17 km^3/year or in total by 5.1 km^3 in Uzbekistan (Borisov 1990). Contamination levels registered in both surface and groundwater are so high that it is not possible to count on any natural purification process from percolation and infiltration of groundwater through the soil (UNDP 2007). Despite this fact, farmers are forced to continue to use groundwater for agriculture, domestic, livestock, and drinking purposes since no other water resources can be exploited.

In the lower Amu Darya (part of Uzbekistan and Turkmenistan), the groundwater quality is also deteriorated in rural areas due to very poor sewage systems. Traditionally, all rural households have their toilets in close vicinity (10–30 m away) from their houses and as a consequence shallow groundwater is very often contaminated by sewage.

Due to this reduction of high-quality water resources by 30–40% compared to 1965–1970, the government of Uzbekistan undertakes extreme measures involving the creation of highly protected territories of groundwater resources with the aim of improvement of groundwater quality. With limited use of manure and pesticides and respectful development of local industry, these measures will tend to regulate and to reduce the water use in the national economy. These measures also include the renovation of the available wells which are often in very bad condition, the construction of new wells and the installation of new efficient pumps and efficient conveyance systems.

Transboundary groundwater issues

Problems coming from groundwater sharing

Groundwater regimes and quality are determined both by natural factors and by the level of abstraction; it doesn't depend on administrative boundaries (UNESCO 2001). As such, the management of internationally shared groundwater is of special importance in the ADRB (Struckmeier et al. 2006). Transboundary groundwater is assumed to include: aquifers which are located in two or more countries; and aquifers which are used in combination with surface water, and for which changes in extracted volumes may lead to changes in surface water quantity and use.

The combined use of both groundwater and surface water can be beneficial where long term sustainable groundwater extractions (not exceeding the natural recharge) replace scarce surface water resources (Zaisheng et al. 2008). However, if aquifers are not properly managed, many negative effects may occur: rise of groundwater levels and deterioration of soil conditions; local draw-down of groundwater levels around extraction points thus reducing surface water availability; pollution of aquifers because of human activities such as mining, treatment of industrial waste water, cattle-breeding; and overexploitation and long term damage to the groundwater potential.

These effects have local impacts, which may extend to the territories of neighboring states. Often, measures which provide positive effects on the territory of one country like irrigation of new areas, canal construction, and public water supply development, lead to negative effects in adjacent countries and preventive measures in the affected states may be expensive and may take several decades to become effective, essentially due to political reasons.

About 30% of the 338 aquifers of the ADRB area are international, but they represent the majority of the extracted groundwater. The main international aquifers areas include the area around the Tuyamuyn reservoir and its supply canals between Turkmenistan and Uzbekistan; the piedmont zone in the Hungry Steppe with shared aquifers between Tajikistan and Uzbekistan; and aquifers on the border between the Kashkadarya oblast of Uzbekistan and the Lebab velayat of Turkmenistan. Obviously, conflicts may arise for many reasons in these regions. The main ones are the lack of proper groundwater accounting and registration of installed pumps and the lack of proper

Table 5 The different groundwater management organizations in ADRB

Country	Surface water	Groundwater	Other relevant agency
Afghanistan	Ministry of Water and Power	Ministry of Mines and Industry	
Tajikistan	Ministry of Melioration and Water Resources	State Hydrologeological Service	Ministry of Environmental Protection, Tajikistan Public Water Supply Service
Uzbekistan	Ministry of Agriculture and Water Resources	State Committee on Geology and Mineral Resources	State Committee on Safety in Industry and Mining for Thermal and Mineral Waters
Turkmenistan	Ministry of Land Reclamation and Water Resources	Ministry of Geology	Ministry of Environmental Protection

groundwater assessments, both in the design studies and in practical operations.

Groundwater response times generally include a delay of 1–2 years, and for some areas even of 3, 5, or 10 years or even sometimes centuries or millennia for confined resources (Huneau et al. 2001; Kazbekov et al. 2007). It is then difficult to establish the direct influence of groundwater exploitation development projects without good quality pre-implementation observations. In the absence of proper management measures, special research is then needed to evaluate the consequences; it is usually carried out by the damaged party when the negative effects are already clearly showing. In the ADRB, most of the problems are arising from the absence of proper regulations (limits) of groundwater withdrawal, in particular during dry years and in situations where over-extraction affects aquifers in neighboring states or has an impact on transboundary rivers. A key problem is the lack of legal documents and international agreements to:

1. determine responsibilities when problems arise;
2. establish the rights of reimbursement of the damaged party;
3. require negative effects to be reversed;
4. require inspection of pumping installations.

Lack of institutional management of groundwater

It should be stressed out that, withdrawal and discharge of international groundwater and drainage water, which are the main source of potential conflicts, require cooperative regulation and management within the whole Aral Sea basin. The development of a set of management measures should thus be considered, to reduce the negative influence of multiple uses of groundwater and drainage water, to be submitted to the Interstate Commission for Water Coordination (ICWC) for analysis and further preparation for decision making on the evaluation of the areas and size of shared aquifers and drainage water catchments; transboundary problems should be specified and proposals prepared to share the management of international groundwater.

Apart from the ICWC, whose role is to organise international water management within the watersheds of Amu Darya and Syr Darya Rivers, almost no structure is dedicated to groundwater. Table 5 summarizes the main structures in charge of groundwater management in the different countries of the ADRB. As previously said, the extreme fragmentation and dilution of responsibilities shown in Table 5 is in clear disfavor with a proper and concerted groundwater management. The situation in Afghanistan is particularly critical since there is no regulatory framework for controlling and managing groundwater resources. In the literature, it is documented that the Ministry of Mines and Industry is the state responsible authority. But in practice, however, the ministries lack the resources and technical expertise to adequately manage the resources for which they have responsibility. There also appears to be no effective system of permits or licensing for drilling and for water abstraction in this country. In this regulatory vacuum, the United Nations and some nongovernmental organisations have accepted some responsibility for water resources.

In the CAR, there are established frameworks for both surface and groundwater resources management. However, it must be pointed out that no special regulation on groundwater has been proposed. Another major problem is the overlapping of the responsibility between different state authorities within a same country (Table 5).

Despite the various views and opinions of the parties involved, cooperation in transboundary water resource management in the ADRB has made significant steps forward over the last 10 years (UNDP 2007). A certain consensus on the principle of reasonable and equitable sharing of water in accordance with the adopted regional agreements has already been achieved. However, there is still a lack of coordination and inconsistency in water use priority that leads to losses of the limited water resource, aggravation of tension and threat of conflict (Wegerich 2007). In order to fully cooperate, the countries involved must have confidence in each other and be prepared to compromise both in the area of their own interest and in the interest of the social and environmental needs of the region.

Conclusion

Although water supply was formerly centrally organised, since independence in 1991 the CAR and Afghanistan have continued their dispute on meeting their individual and increasing water demands. Since then, the lack of water has gradually devastated the irrigation-dependent cotton, winter wheat and other major crop production. In addition, the lack of water has engendered the ecological catastrophe of the Aral Sea Basin, at the tail end of both Amu Darya and Syr Darya.

Groundwater can be a strategic resource for these landlocked countries not only for drinking but also for agricultural production and environmental issues as demonstrated by Jarsjo and Destouni (2004). The lessons learned from the 1998 to 2001 droughts have proved the feasibility of groundwater developments in lower reaches of Amu Darya and elsewhere in the basin. And even if poor situation of the Amu Darya River has been observed both in quality and quantity in recent years, groundwater can still be reasonably exploited in many places were water salinity remains acceptable.

There is a tendency for substantial unregulated groundwater withdrawal in the basin by farmers and populations for various purposes as an alternative source of water for irrigation. Historically, the agriculture sector has a very heavy weight on the basin country economies in terms of employment, financial revenues and food security. Thus, for many good reasons the development of groundwater use is inevitable and better management strategies and cooperation between the different partners involved is necessary. Unfortunately, the intricate management system of groundwater in the basin countries in terms of engineering infrastructure and institutional coordination is inadequate and, as a result, States are financially totally unable to overcome and to prevent the physical deterioration of hydraulic structures and to maintain an efficient water supply on large scale. In addition, transboundary agreements on joint utilization of groundwater resources are weak and fragmented in terms of regulation and institution levels.

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