Groundwater resources and uses in Central Asia: case study of Amu Darya River Basin

[1]Shavkat RAKHMATULLAEV, [2]Frédéric HUNEAU, [3]Jusipbek KAZBEKOV, [2]Philippe LE COUSTUMER

[1]Tashkent Institute of Irrigation and Melioration, 39 Kary Niyazov Street, Tashkent 100000, Uzbekistan, e-mail: rakhmatullaev@rambler.ru
[2] University of Bordeaux-1, GHYMAC Géosciences Hydrosciences, Faculty of Earth Sciences, B18 avenue des Facultés, 33405 Talence, France, e-mail: f.huneau@ghymac.u-bordeaux1.fr , plc@lnet.fr
[3] International Water Management Institute, Apt.123, House 6, Murtazaeva Street Tashkent 100000 Uzbekistan, e-mail: j.kazbekov@cgiar.org

Abstract The increased share of groundwater use for irrigation is observed in the Amu Darya River Basin due to deteriorated and worn-out surface irrigation systems, recent droughts and high mineralization levels of surface water. This paper discusses the extent of groundwater resources, use and management in Amu Darya River Basin. As a consequence of increased surface irrigation and leaching, groundwater level has increased over great areas in lower reaches of the Basin and second salinization has been documented. Agriculture sector is the dominant sector of economy in the basin countries currently employing up to 40-50% of the total population, contributing to 28-50% of countries GDP. Because of that major role in the economy of Central Asian countries, it is for sure that in the futur more groundwater will be pumped out to meet the increasing demand.

Keywords: groundwater use, aquifer, Amu Darya, Central Asia

1. Introduction

The endoreic basin of Amu Darya River (ADRB) is located in the inner part of the Eurasian Continent (Fig. 1).

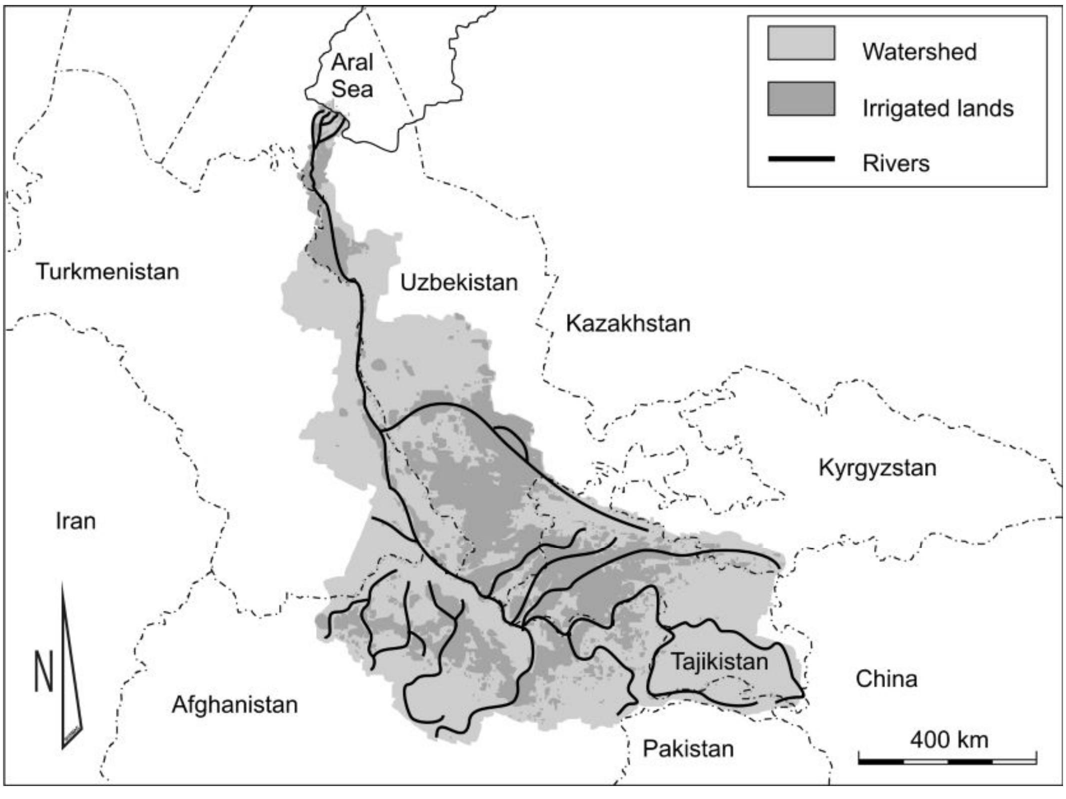

Fig. 1: Map of the Amu Darya Basin and location of irrigation areas

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 new independent states of Tajikistan, Uzbekistan, and Turkmenistan and 39% on the territory of Afghanistan (Water Resources of USSR 1971; Uhl 2003). Amu Darya River is formed by the confluence of Pyanj and Vash Rivers in the Pamir Mountains and discharges into the Aral Sea after a run of 2550km. Two Rivers, Zaravshan and Kashkadarya are related to Amu Darya in term of water catchment characteristics but do not discharge into Amu Darya River (Mirzaev 1996, Masood and Mahwash 2004).

2. Hydrogeology

The region is characterized by very complicated hydrogeological conditions. At first, the complex geological history of 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 resource is located in valleys, where 10 to 100m 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 calciferous deposits (depths from 700-800m up to 1,000-1,200m) 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 run-off), irrigation canals and irrigated fields. A lot of shallow aquifer are salinized (1-10 g/l) or engaged into salinization processes. Salinization results from agricultural practises but is also related to the sodic nature of soil like solonetz or solontchaks in the region. It must be noted that groundwater mineralization tends to decrease with the 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).

3. Groundwater reserves

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

Groundwater and surface water are strongly hydraulically connected one to another, and according to an established system in 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 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).

Country	Estimated Regional GW 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 1. Groundwater reserves and their use by states in Amu Darya River Basin (km^3/year)

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 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 been identified and used for various needs (Khatamov 2002; Orlovsky and Orlovsky 2002). The total intake of groundwater resources varies from 4.7-6.7km^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 was 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 was about 2,372 km^3 in 2004 (Table 1) without negative impact since the approved reserved are about 6,972 km^3 (Salimov 2000). About 40% of groundwater is used for irrigation and about 49% for domestic drinking supply. In 1994, the total numbers of wells was 4795 and out of which 511 are wellspring and 4358 are operational wells (Orlovsky and Orlovsky 2002).

In Uzbekistan, around 94 major aquifers can be identified with 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 groundwater resource is recharged from surface water and only 1/3 is formed on the territory of neighboring countries and which could be called "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 surface flow reduction (Kazbekov et al. 2007).

4. Groundwater and Agriculture

4.1. 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 ADRB followed by maize, vegetables and fruits. As previously said with annual rainfall of 100–300 mm, 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 2).

Country	Share of Employment in agriculture (percent)	Share of Agriculture contribution to GDP (percent)	Irrigated land (million ha) Amu Darya Basin	Share of irrigated to the total cultivated land (percent)
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

Table 2. Main characteristics of agricultural sector of the ADRB countries (FAO, 2007)

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.

In Afghanistan, the estimated annual groundwater volume used for irrigation is minimal (1,0km^3/year) in comparison with the groundwater recharge estimate (2,97km^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 2km^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 2 and as a consequence this country is one of the most 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 2m.

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 1000 operational boreholes and numerous wells that totaled 4km^3/sec discharge mainly used for irrigation purpose. According to Salimov (2001) about 30,000ha of lands were irrigated with groundwater resources.

4.2. Livestock Rearing

In Uzbek desert and mountain zones of ADRB numerous small settlements can be found. These territories are part of pasturelands. The mountain pasturelands have available groundwater resources but in most cases 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 one cattle watering pond (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, 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).

5. Transboundary groundwater issues

5.1. 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: groundwater aquifers which are located in two or more countries; and groundwater 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 combine 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 groundwater aquifers are not properly managed the many negative effects may accrue: 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 neighbouring 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 groundwater assessments, both in the design studies and in practical operations.

Groundwater response times generally include a delay of 1 to 2 years, and for some areas even of 3, 5, or 10 years or 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 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 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 neighbouring states or has an impact on transboundary rivers. A key problem is the lack of legal documents and international agreements to:

i) determine responsibilities when problems arise;
ii) establish the rights of reimbursement of the damaged party;
iii) require negative effects to be reversed;
iv) require inspection of pumping installations.

5.2. Lack of institutional management of groundwater

It should be stressed that, withdrawal and discharge of international groundwater and drainage water, which are a 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; specification of the transboundary problems and preparation of proposals 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 3 summarizes the main structures in charge of groundwater management in the different countries of the 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

Table 3. The different groundwater management organizations in ADRB

As previously said, the extreme fragmentation and dilution of responsibilities shown in Table 3 is in clear disfavour 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 literature, it is documented that Ministry of Mines and Industry is 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 drilling or water abstraction in this country. In this regulatory vacuum, the United Nations and some nongovernmental organisations have accepted some responsibility for water resources.

In Central Asian Republics, 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 3).

Despite the various views and opinions of the parties involved, cooperation in transboundary water resource management in ADRB has made significant steps forward over the last ten 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.

6. Conclusion

Although water supply was formerly centrally arranged, since independence in 1991 Central Asian Republics 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. The lessons learned from the 1998-2001 droughts have proved the feasibility of groundwater developments in lower reaches of Amu Darya and elsewhere in the basin. And even if poor quality 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 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. 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 an obstacle and States are financially totally unable to come over and prevent the physical deterioration of hydraulic structures and to maintain 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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