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ABSTRACT:

As a result of the massive irrigation development during the Soviet Union era and intensive chemization of agriculture, the surface runoff quality has been degraded in this arid and endorheic region. Moreover hydraulically related groundwater has been affected too. Excessive irrigation has lead to land salinization which now threatens the soil quality of significant areas where crop yields would be at risk in the future. After the collapse of the Soviet Union, institutional changes have been undertaken for the management of the natural resources and the water infrastructure. At present, underdeveloped and inadequate systems have been practiced with respect to groundwater use and management. The aim of this paper is to analyze the present extent of groundwater resources with consideration to their reserves, quality evolution, and to technical, institutional and transboundary management aspects in Uzbekistan.

Key words: Aquifer; Irrigation; Hydrogeology; Water management; Salinization; Central Asia

1. Introduction

Groundwater resources have been widely used for various purposes around the world mainly for domestic drinking water supply and industry. In arid countries, where erratic precipitation and limited surface runoff resources prevail, groundwater has been used also for irrigation as well (Shah 2007; Giardano 2009; Siebert et al. 2010). Groundwater resources were not widely used for irrigated agriculture in Central Asian Republics during the soviet period due to sufficient amount of surface water, reliable water supply and good maintenance of irrigation infrastructure with massive funding coming from the central government. In fact, the groundwater resources were used primarily for drinking, livestock sector and very site-specific purposes.

Groundwater overexploitation is not everywhere the case in Central Asia but the drought experienced in 1998–2001 has encouraged people to consider groundwater as an alternative to the declining surface water resources. For instance, the government of Uzbekistan has issued special decrees to overcome the consequences of the drought. The main purpose of the decrees was to drill 2,600 shallow wells and to repair old wells in rural districts for population needs (Borisov et al. 2002). 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.

The percentage of groundwater used in irrigation amounted to 6.4% of the total irrigated water use in Uzbekistan at the end of the 20th century (Antonov 2000). Limits to groundwater abstraction for each aquifer per annum have been established in order to avoid significant consequences to surface flow reduction over the territory of Uzbekistan. This quantity is estimated to 6.8 km^3/year for Uzbekistan (SCS of Uzbekistan 2002; Goskompriroda of Uzbekistan 2005). However, the actual groundwater abstraction is slightly superior estimated to

7.5 km^3/year and thus tends to lead to serious surface flow reduction (Kazbekov et al. 2007; Rakhmatullaev et al. 2009; Rakhmatullaev et al. 2011).

The problems with groundwater and pressure on it over the territory of Uzbekistan are associated with the specialization and concentration of industrial conglomerates, the development of the irrigated agriculture and the inter-basin allocation of water resources. But the main impact on groundwater resources over the last four decades is from irrigated agriculture and its immense development. Extensive irrigation development caused the soil saturation issues and the subsequent construction of horizontal (open) and vertical (groundwater wells) drainage systems (Mirzaev 1974). So now Uzbekistan is facing a situation combining the inner re-allocation of natural water resources, its degradation in both quantitative and qualitative terms (due to drainage and salinity issues) and strong disturbances of natural groundwater formation processes.

So the aim of this paper is to fill gap in the literature and provide the scientific community with information on groundwater and its related issues in Uzbekistan. Therefore the paper has three specific objectives, which puts together all the parts of the puzzle: first to discuss the extent and characterization of groundwater resources; the second objective is to overview the main environmental issues related to groundwater such as land degradation and groundwater mineralization; and lastly to review the management framework with respect to technical, institutional and transboundary dimensions under the political and economic transformation after the collapse of the former Soviet Union.

2. General and Hydrogeological setting of Uzbekistan

Uzbekistan is located in the heart of Central Asia with a population over 28 million and borders with Kazakhstan in the north, Kyrgyzstan in the north-east, Tajikistan in the east, Afghanistan in the south and Turkmenistan in the south west (Figure 1). Due to its location in inner Asia, the climatic conditions of doubly land-locked Uzbekistan, i.e. continental and severe temperature and rainfall regimes and uneven water resource distribution, forced to practice irrigated agriculture for centuries in this part of the world (O'Hara 2000; Saiko and Zonn 2000; Rakhmatullaev et al. 2003; Micklin 2004). Cotton and wheat are the major crops in Uzbekistan followed by maize, vegetables and fruits. Agricultural production in Uzbekistan is predominantly based on irrigation, which makes irrigation water supply and management the major factors limiting crop yields in the region (Ximing et al. 2003; Ibragimov et al. 2007).

The total cultivated land in Uzbekistan is estimated to be 5.2 million of ha, of which 4.2 million ha are irrigated. The irrigated lands almost increased by 3 fold over the last century; about 1.3 million ha in 1900, 2.6 million ha in 1950 and 4.2 million in 2000 with massive water and land development schemes carried out by Soviet administration in order to satisfy its cotton needs (UNEP 2005). Moreover, Uzbekistan has witnessed a population boom; in fact there was an increase of 4 fold of its population growth i.e., from 6.5 million in 1940 to over 26 million in 2007. As a result, the irrigated lands per capita has reduced from 0.41 ha/person in 1940 to only 0.16 ha/person in 2008 (UNEP 2005).

In Uzbekistan, which accounts for over a half of the irrigated land in the Central Asian region, it is estimated that 70% of water is lost between the river and the crop, yet poor drainage systems further exacerbates water management problems (Nezlin et al. 2004; World Bank 2005).

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). Uzbekistan 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). In average 95% of the basin area receives approximately less than 300 mm/year (Irrigation of Uzbekistan 1975) 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 1500-2000 mm/year (Letolle and Mainguet 1993, Nezlin et al. 2004) and is responsible for the loss of great volumes of water. Lioubimtseva et al. (2005) reports that a general warming trend in Central Asia on the order of 1–2 $^{\circ}$C since the beginning of the 20th century has been observed that might have a strong potential impact on the regional temperature and precipitation regime but also on natural ecosystems and agricultural crops. In fact the evaporation increase is forecasted to be around 10-15% due to global warming effects in Uzbekistan (Hagg et al. 2007).

The presence of high mountain (5000-6000m of Central Pamir and Tien Shen) systems in the south-west and western parts facilitates the formation of great water courses in the very arid conditions of the country since it can accumulate atmospheric moisture, and behave as a huge feeding reservoir (Mirzaev 1974; Borisov 1990; Aizen et al. 2001). However the major part of the territory of Uzbekistan (about 80%) is composed of desert-steppe areas in the eastern part. 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 (Rakhmatullaev et al. 2009). 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, 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. Borisov (1990) assesses that about 5 to 22.5% of atmospheric precipitation is engaged in the formation of groundwater in Uzbekistan.

The plain regions of Uzbekistan are characterized by very complicated hydrogeological conditions and covered by alluvial sand, loam and clay dating from the Quaternary and Pliocene that can be interstratified, giving birth in some places to confined or semi-confined aquifers (Rakhmatullaev et al. 2009). Confined aquifers can also 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 salinity which prevent them from any use.

A lot of shallow aquifer are salinized (1-10 g/l) or involved into salinization processes. Salinization results from agricultural practices 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.

Groundwater resources extent

Mavlonov et al. (2003) reports that groundwater resources in Uzbekistan are estimated to be around 27 km^3/year, whereas the research Institute of Hydrogeology and Engineering Geology (HYDROENGEO) of Uzbekistan estimates this value to be around 23 km^3/year. The main recharge sources are of natural origin such as subsurface inflow, infiltration from river channels and atmospheric precipitation. 10 km^3/year or 37% of the total groundwater resources originate from subsurface inflow and precipitation whereas 63% from artificial sources (infiltration from irrigation canals and water reservoirs, and seepage from irrigated lands) (Ikramov 2006).

To assess the hydrogeological, geological and hydrological conditions, the following 13 major hydrogeological zones (Figure 2) have been established in Uzbekistan in order to estimate regional (explored) groundwater reserves (Mirzaev 1974; Irrigation of Uzbekistan 1975; Borisov 1990).

Natural and artificial groundwater recharge and discharge sources have different spatial and temporal cyclic characteristics (Akhmedov and Mavlonov 2003). The past research has shown that there are five types of water exchange for different hydrogeological structures in Uzbekistan Table 1. The duration of the groundwater resources turn-over within hydrogeologic structures and deposits is characterized by the sensitivity of these resources to impact indicators such as the natural and anthropogenic recharge and discharge factors. For example, the most rapid reaction is observed for hydrogeological massifs of fresh unconfined groundwater resources in the deltas of major rivers. These resources constitute about 12% of the total groundwater resources in Uzbekistan, whereas the duration of water turn-over for artesian aquifers (13% of the total groundwater resources) have a prolonged impact reaction varying from 95 up to 1500 years (Akhmedov and Mavlonov 2003). Average groundwater turn-over duration of 18-50 years is typical for intermountain depressions, river valleys, piedmont loops and river debris cones; these resources constitute 75% of the total groundwater resources of Uzbekistan (Akhmedov and Mavlonov 2003).

The total forecasted regional groundwater reserves are of about 19.6 km^3, including 7.3 km^3 of waters with a salinity of up to 1 g/l and about 10 km^3 with a salinity from 1 to 3 g/l (Figure 3 and Table 2) (Borisov et al. 2002; Chub 2004). In fact about 85% of the groundwater resource is recharged from surface water and irrigation canals; only a third is formed on the territory of neighboring countries and termed as ‘transboundary’ groundwater resources (UNECE 2009; Karimov et al. 2010).

Groundwater use

Although groundwater resources constitute roughly 10% of the total water resources in Uzbekistan about 60% of it is used for drinking water supply, domestic use and irrigation. In Uzbekistan, around 94 major aquifers are found mainly in the Ferghana valley (35% out of the total), Tashkent province (26%), Samarkand (18%) and the remaining 21% can be found elsewhere on the territory (Table 3) (Goskompriroda of Uzbekistan 2005).

The over-use of groundwater is observed mainly in arid southern provinces of Uzbekistan ranging almost 2 times exceeding the approved groundwater resources limits. This aspect is explained by the limited surface waters and its increasing levels of pollution from irrigated agriculture thus groundwater resources have became alternative source for local livelihoods and economic development.

Figure 4 depicts the total groundwater withdrawal and use for irrigation. 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 addition, there is an increase in groundwater use by industry which implies competition with other sectors in a foreseen future. Individual farmers do not have sufficient financial and technological capacities to implement and use boreholes for lifting groundwater for crop production.

For Uzbekistan 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. For example in 1992 there were about 45 000 boreholes in total of which 27 000 were operational (Akhmedov and Mavlonov 2003).

Reforms in water management

After the collapse of Soviet Union, the conversion from a planed centralized economy system into a market oriented one has changed dramatically the situation in water resources management in terms of institutional, political and technical systems.

Along with de-centralization in agriculture, water management system was also transformed in Uzbekistan at two levels i) river basin and ii) on-farm level (Rakhmatullaev et al. 2010). The irrigation water management was transformed from once a territorial-based management to a hydrographic principle at the river basin level. The second level is on-farm level where social complexities are observed.

The intention of the national government was to shift the operation, maintenance and management of irrigation and drainage infrastructures to non governmental institutions such as water users' associations (WUA) in the replacement of the former collective farming systems (decentralization) (Abdullaev et al. 2008). A WUA is a self-managing group of farmers working together to operate and maintain their irrigation and drainage network (only inter-farm or on-farm level) to ensure fair and equitable water distribution and increase crop yields.

The shift (decentralization) was only giving drainage facilities without proper know-how transfer programs and still many farmers believe that the central government should take care of drain systems for cleaning and rehabilitation. For example, the majorities of farmers do not understand the importance of drains and willingly or unintentionally destroy or dismantle such structures across the countries.

Constraints for groundwater use

Financial burdens

It is known that the use of groundwater is not economically profitable for irrigation due to its high extraction costs for installation of equipment (pumps) and ever increasing prices of electricity in Uzbekistan (Rakhmatullaev et al. 2009). Input per $1m^3$ of surface gravity irrigation for a farmer is estimated to be 0.13-0.15 US$, and in the areas of pumped irrigation is about 0.3 US$ (Karimov et al. 2010). 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 will be justified in water scarce conditions and in special places of the territory of Uzbekistan. For instance the Government of Uzbekistan has launched a massive program in the lower reaches of Amu Darya river basin in 2001 and by 2003 there were drilled approximately 27 000 boreholes, to counterpoise the pernicious effects of the drought, with depth varying between 50-500m with a cost of drilling for one borehole ranging within 500-2000 US$ (Kuchuhidze et al. 2003).

Low incentives for water savings

A state ordered agricultural production quota system (for cotton and wheat) guarantees farmers to access to banks credits (up to 60% of input costs) and a free access to surface water (gravity open irrigation canals or subsided lift irrigation water) with nominal memberships payments to WUA.

All of which do not leave room for incentives to use groundwater. On the other hand in order to use groundwater, a farmer should bear additional costs such as payment for receiving permission from state authorities to dig borehole and its implementation costs.

Absence of consultancy/extension service

The simple public awareness campaigns or training can substantially improve the drainage situation and can still serve its design purposes.

At the moment, the management and operation of drainage systems is carried out by the state hydrogeological melioration expedition (HGME) which is under the umbrella of national Agriculture and Water Resources Ministry. The main responsibilities of this organization are to:

i) Estimate shallow groundwater table level and its mineralization levels;
ii) Quantify total drainage water runoff;
iii) Assess irrigation and drainage water quality;
iv) Determine the extent of salt-affected irrigated lands and marginal ones;
v) Drill boreholes for monitoring groundwater table level over irrigated lands.

In order to maintain existing drainage facilities and overcome the misunderstanding of local farmers not to destroy them, the HGME organization should act as consulting body (extension service) through public private partnerships. This will enable to reinforce monitoring framework and betterment of ownership from local farmers.

3. Environmental issues related to groundwater

The dramatic change in the quality of groundwater resources observed in some place of Uzbekistan is linked to irrigation and melioration of lands, reallocation and extraction of river flow especially since 1965 (over 1 million hectares of lands were transformed into irrigation) (Talipov 1992). 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 (Green 2001; Papa et al. 2004; Gadalia et al. 2005; Tookey 2007; Törnqvist 2011). 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 (Crosa et al. 2006).

The most critical situation is when the groundwater table is less than 2 meters from the soil surface because the salt movement is observed by capillary mechanism to the root zone and thus has direct impact on crop yield and overall soil salinity.

Figure 5 depicts the change of irrigated lands area with less than 2 meters of groundwater table in the provinces of Uzbekistan from 1992 to 1998. The surface of irrigated areas with a high groundwater table level has increased by 2% in Uzbekistan that is to say from 0.90 million ha in 1992 to 0.92 million ha in 1998 (Dukhovny et al. 2005).

The irrigated lands area with a groundwater table less than 2 meters deep have increased mostly in the upstream provinces of Uzbekistan whereas the decrease of such areas is observed in downstream ones as the downstream provinces tend to practice more groundwater withdrawal for satisfying their agricultural needs because surface runoff availability both in quantity and quality opposed to upstream areas, although the groundwater extraction regulation is uniform across Uzbekistan.

As a result of infiltration of water losses, the level of groundwater of unconfined aquifer began to rise also entailing the dissolution of salts contained in the upper part of the soil profiles (Jarsjö and Destouni 2004; Kitamura et al. 2006). This is particularly true in the lower reaches of Amu

Darya River where groundwater resources were at 15-20m depth in 1980s, started to rise and in early 2000 were at 1-1.5m depth (Borisov et al. 2002).

The overall spatial distribution of groundwater salinity shows also strong spatial association with type of aquifer rock and with the distance from the river along the main irrigation canals (Figures 2 and 3). Coarser sediments showed higher groundwater salinity than finer sediments. Pollution of groundwater occurs progressively from upstream to downstream along river stream.

Man-caused influence has lead to pollution and to decrease of groundwater resources and operational reserves of fresh groundwater resources in average (Chembarisov and Bakhritdinov 1989; Crosa et al. 2006; Törnqvist 2011).

Despite of this, 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 river basin of Uzbekistan, groundwater quality is also deteoriated in rural area due to very poor sewage systems (Johansson et al. 2009). Traditionally all rural households have their toilets in close vicinity (10-30m away) from their houses and as a consequence shallow groundwater is very often contaminated by sewage (Nagevich and Chebotareva 2010).

According to the national environmental protection agency, about 35-38% of fresh explored groundwater reserves is polluted to various degrees and can not be used (Figure 6).

Figure 6 shows a general tendency of increase in groundwater resources salinity from 1992 to 1998. The most persistent situation with groundwater salinity is observed in Kashkadarya and Surkhandarya provinces where the new irrigated lands were transformed without proper drainage facilities and soils naturally of sodic type.

Moreover, the groundwater table rise has even started to threaten the famous world historical remnants (the historical buildings are mainly made of mud bricks) of heritage sites such as Samarkand, Bukhara and Khorezm. Thus the national government authorities established a network of monitoring wells. In Bukhara, 173 monitoring wells and 181 vertical drainage wells have been constructed for lifting and draining about 0.021 km^3 of groundwater that resulted in maintaining the water table around 2.15 meters below the surface (Niyazov 2000).

Melioration regime

The melioration regime in Soviet science is interpreted as a set of interrelated conditions such as artificial and natural drainage, water supply and agro-technical operations that dictate interrelationship between irrigation water and groundwater over an irrigated field (Reshetkina 1965; Dukhovny et al. 2005). The main criteria are the supply and the zone of aeration within the concerned irrigated field. When choosing melioration regimes the natural conditions of the territory should be considered under irrigation.

In order to have clear picture first lets introduce groundwater melioration classification system used in the Soviet science. There are four types of melioration regimes namely i) hydromorphic, ii) semi-hydromorphic, iii) semi-automorphic and iv) automorphic which are characterized by the groundwater regime, their engagement in the soil formation, water supply to agricultural crops, and lastly salt and nutrient content in soil aeration zone (Table 4). These melioration regime types depend on the groundwater engagement in the total water consumption by agricultural crops. Groundwater engagement depends on water-physical soil aeration zone characteristics (texture, depth, rate of capillary force, water holding capacity and etc.). In addition, abovementioned reclamation regimes depend on the type of crop growth with supplied water quantity and draining capacities plus applied irrigation techniques (Ikramov 2006).

All of these melioration regimes can be successfully established over irrigated lands with careful investigation of relationships among environmental factors (water, air, salt and nutrient availability in aeration soil rooting zone), management factors (water supply rates, drainage infrastructure, agro-technical options) and consideration of cultivated crop growth. The paramount aspect in successfully establishing such regimes is sustaining natural water-salt regimes of rooting zone and inflow of water and salts from other artificial sources such as irrigation and drainage waters with proper organizational and technical works undertaken within an irrigated field plot.

The main goal of the drainage system is to decrease and maintain groundwater table under irrigated lands, flood protection, disposal of surplus precipitation and sewage disposal purposes (Freisem and Scheumann 2001).

Transboundary groundwater

Transboundary groundwaters 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 (UNESCO 2001). The management of internationally shared groundwaters is of special importance in Central Asia (Struckmeier et al. 2006).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 Kazakhstan and Uzbekistan; in the Zarafshan River Basin between Tajikistan and Uzbekistan; in Fergana Valley between Kyrgyzstan and Uzbekistan (UNECE 2009; Gracheva et al. 2009; Rakhmatullaev et al. 2009).

Table 5 depicts the major international groundwater shared between Uzbekistan and its neighboring states in Central Asia. It is expected that groundwater resources would be more limited due to the climate change and everlasting competition of Central Asian states for their economic growth which rely mostly on irrigated agriculture. A key problem is the lack of legal framework and international agreements on joint groundwater management and monitoring systems and re-enforcement of sustainable management systems both for water abstraction and monitoring (Karimov et al. 2010). Otherwise groundwater resources would be vulnerable from depletion and pollution with heighten tensions between countries in Central Asia.

4. Institutional groundwater management

In the framework of the groundwater resources management and regulation several government agencies are involved in Uzbekistan (Figure 7). The main national agency is the State Committee of the Republic of Uzbekistan on Geology and Mineral Resources (Goskomgeologiya of Uzbekistan) that is primarily responsible for groundwater management in terms of investigating groundwater reserves, issuing groundwater withdrawal permits and strategic coordinating its management and use in Uzbekistan. The State Committee for Nature Protection of the Republic of Uzbekistan (Goskompriroda of Uzbekistan) monitors the groundwater quality and sanctions pollution fines of groundwater and surface runoff. In addition, the State Committee of the Republic of Uzbekistan on Safety in Industry and Mining deals with mineral and thermal groundwater resources. Yet, the Ministry of Agriculture and Water Resources of Uzbekistan through its HGME for monitoring of groundwater levels and salinity over irrigated lands.

Assessment of the legislation framework reveals that there is an overlapping and duplication of responsibilities among different state authorities within Uzbekistan for groundwater management and thus there is no clear management and policy regulation. The principal research on groundwater and hydrogeology is carried out by research institute HYDROENGEO which mainly collects data on groundwater.

5. Conclusion

Groundwater resources are widely used for water supply systems and to less extent for industry and irrigation in Uzbekistan. However, as the result of the massive conversions of lands for agriculture their quality and quantity has been changes in particular fresh groundwater resources with mineralization of less than 1 g/l has decreased by 40 percent in Uzbekistan and on the other hand higher mineralized groundwater resources are on the rise. This reduction will impact availability of high quality groundwater resources for irrigated agriculture and as drinking source for domestic water supply and livestock sectors. Groundwater resources should be carefully monitored by government agencies for their sustainable use in order to meet food security and human health. The assessment of the legislation framework has revealed the existence of some gaps concerning groundwater and we propose that groundwater specific legislation must be developed for outlining the great role of these resources.

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CAPTIONS OF FIGURES

Figure 1 Location of Uzbekistan

Figure 2 Hydrogeological map of Uzbekistan (adapted and modified from Goskompriroda of Uzbekistan 2005)

Figure 3 Salinity, schematic distribution and withdrawal of groundwater resources in Uzbekistan (adapted and modified from Goskompriroda of Uzbekistan 2005)

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TABLE LIST

Table 1. Main types of water cycle for different hydrogeological conditions in Uzbekistan (Mirzaev 1974; Mavlonov et al. 2003)

Type	**Hydrogeological conditions**	**Duration of water cycle (years)**	
		Epiplatform orogenic	**Turan platform**
Semi-desert	Delta of Amu Darya River, along irrigation canals, along river channels lenses of fresh water reserves	-	>1
Mountain	Hydrogeological massifs	0.95-2.6	2.1
Valley-piedmont	Inter-mountain depressions, river floodplains, piedmont loops, discharge cones	18-50	20-40
Strata	Artesian reservoirs	95-640	170-1480
Desert	Lenses of fresh groundwater resources of deserts	-	<650

Table 2. Forecasted groundwater reserves with a mineralization of less than 5 g/l in Uzbekistan (Mirzaev 1974; Borisov 1990)

Mineralization	**GW Reserves (km^3/year)**	**% to total**	**GW category**	**Description for use**
< 1 g/l	7.32	37	Fresh	All purposes
1-1.5 g/l	2.61	13	Good quality	Rural potable supply, irrigation, animals
1.5-3.0 g/l	7.42	38	Slight saline	Irrigation, rural potable supply
3-5 g/l	1.26	7	Saline	Irrigation and watering husbandry
5 g/l >	0.98	5	Moderate and high saline	Industry and irrigation of salt-tolerant crops
Total	19.6	100		

Table 3. Number of aquifers in administrative provinces of Uzbekistan as of 2004 (Goskompriroda of Uzbekistan 2005)

Province	**Number of aquifers**	**Groundwater resources (km^3/year)**			
		Total available	Approved for use	Total withdrawal	% of GW withdrawal to approved reserves
Andijan	6	2.28	0.69	0.47	68
Ferghana	6	3.08	2.48	1.76	71
Namangan	8	2.87	3.24	0.54	17
Syrdarya	4	3.08	0.24	0.39	163
Jizzak	8	0.32	0.27	0.10	37
Samarkand	14	0.36	0.78	0.66	85
Tashkent	8	2.97	3.24	0.99	31
Kashkadarya	5	0.63	0.32	0.69	216
Surkhandarya	6	0.61	0.18	0.37	206
Bukhara	3	0.98	0.15	0.29	193
Navoi	4	0.43	0.43	0.18	42
Khorezm	7	2.99	0.32	0.02	6
Karakalpakstan	9	2.49	0.24	0.03	13
Total	**88**	**23.01**	**8.59**	**5.71**	

Table 4. Melioration regime characteristics (Reshetkina 1965; Dukhovny et al. 2005; Ikramov 2006)

Melioration regime	Groundwater engagement in irrigation	Supply from groundwater and melioration share ('000 m^3/ha)	Evaporation of Groundwater ('000 m^3/ha)
Automorphic	GW is not engaged in irrigation, free downward infiltration	$-I_t<0.05-0.1x(ET-P)$ M = 0	0
Semi-automorphic	GW underlay infiltration of irrigation water and insignificant engaged in plant supply	$+I_t<0.1-0.2x(ET-P)$ M = 0.5-1.0	0-1.5
Semi-hydromorphic	GW actively engaged in plant water supply surpassing irrigation water	$+I_t>0.3x(ET-P)$ $M \geq 2.0$	1.5-3.0
Hydromorphic	Plant supply is mainly from GW	$+I_t>(ET-P)$ $M \geq 5.0$	3.0-7.0

Note: I_t – total infiltration; ET – Evapotranspiration; P – atmospheric precipitation; M – leaching share

Table 5. Major transboundary aquifers and environmental and management issues in Uzbekistan (UNECE 2009)

Aquifer	**Type***	**Shared by**	**Pressure factors**	**Transboundary Impacts**	**Environmental Issues**
Osh Aravoj	Medium	Uzbekistan Kyrgyzstan	Agriculture Industry Water disposal	Decline of GW table Pollution	Pesticides Heavy metals Hydrocarbons Radioactive elements
Almoe-Verzin	Medium	Uzbekistan Kyrgyzstan	Agriculture Ore mining Water disposal	Pollution	Nitrogen species Pesticides Heavy metals Hydrocarbons
Moiabsuv	Strong to medium	Uzbekistan Kyrgyzstan	Agriculture Industry	Pollution	Hydrocarbons Sulphates
Sokh	Strong	Uzbekistan Kyrgyzstan	Agriculture Industry	Pollution	Salinization
Pretashkent	Large deep (artesian type)	Uzbekistan Kazakhstan	Water abstraction	Decline of GW table	No significant problems
Birata-Urgench	Quaternary sand, loam	Uzbekistan Turkmenistan	Water abstraction	Moderate borehole yield reduction	Salinization (natural origin and irrigation) Wastewater and drainage water
Karotog	Moderate	Uzbekistan Tajikistan	Water abstraction	Change of water resources based on the water abstraction in Tajikistan	Nitrate contamination
Dalverzin	Moderate	Uzbekistan Tajikistan	Water abstraction	Moderate borehole yield reduction	Moderate increase on mineralization and hardness
Zaforoboi	Moderate	Uzbekistan Tajikistan	Water abstraction	Moderate borehole yield reduction	Moderate pollution
Zeravshan	Moderate	Uzbekistan Tajikistan	Moderate water abstraction	Significant effect of the industrial activities in Tajikistan	Industry
Chatkal-Kurman	Weak	Kazakhstan Uzbekistan	Water abstraction	Decline of GW table	No significant problems

* Hydraulic link with surface runoff

FIGURES

Figure 1

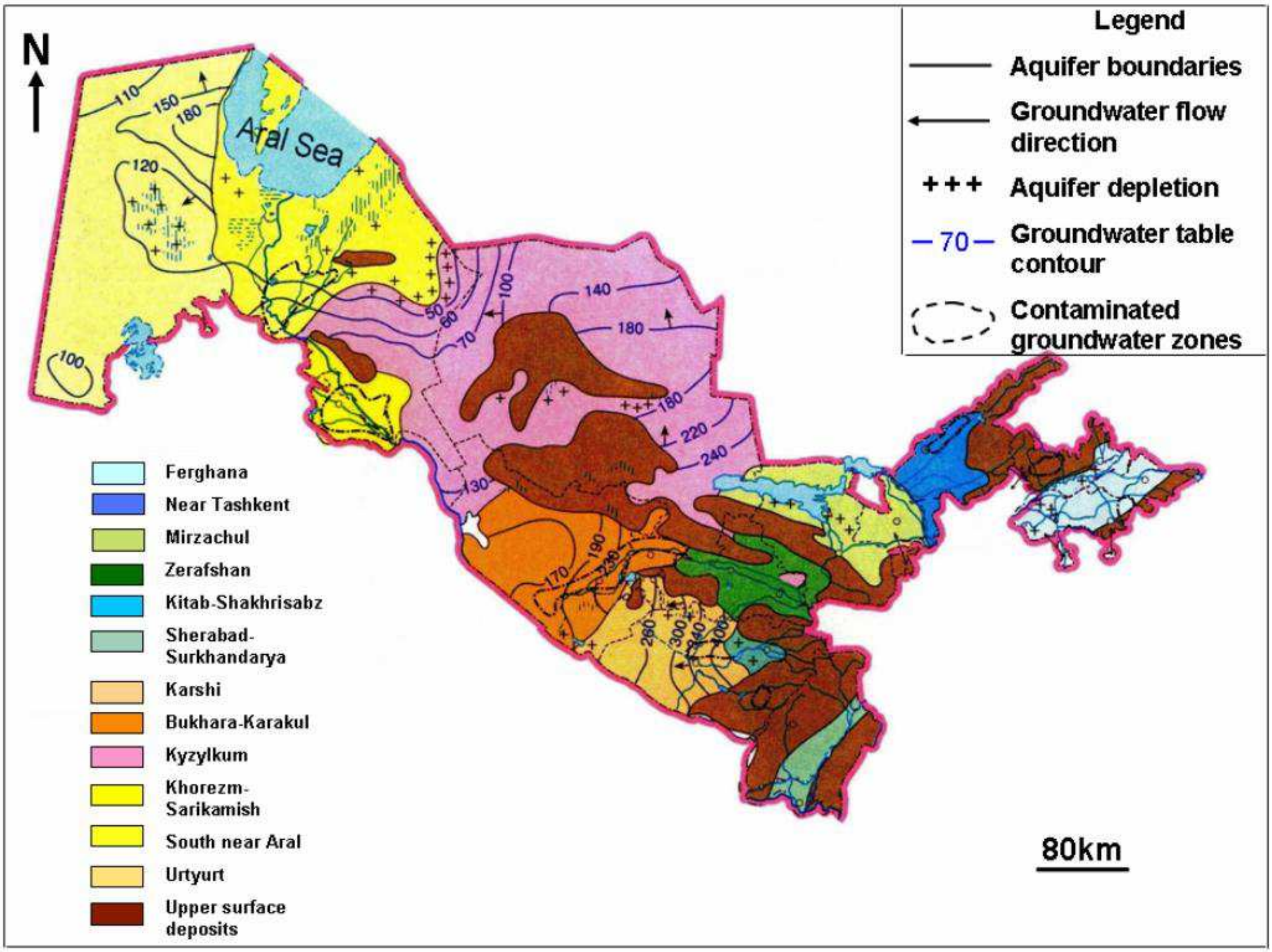

N
Aral Sea
Legend
Aquifer boundaries
Groundwater flow direction
+++ Aquifer depletion
—70— Groundwater table contour
Contaminated groundwater zones
Ferghana
Near Tashkent
Mirzachul
Zerafshan
Kitab-Shakhrisabz
Sherabad-Surkhandarya
Karshi
Bukhara-Karakul
Kyzylkum
Khorezm-Sarikamish
South near Aral
Urtyurt
Upper surface deposits
80km

Figure 2

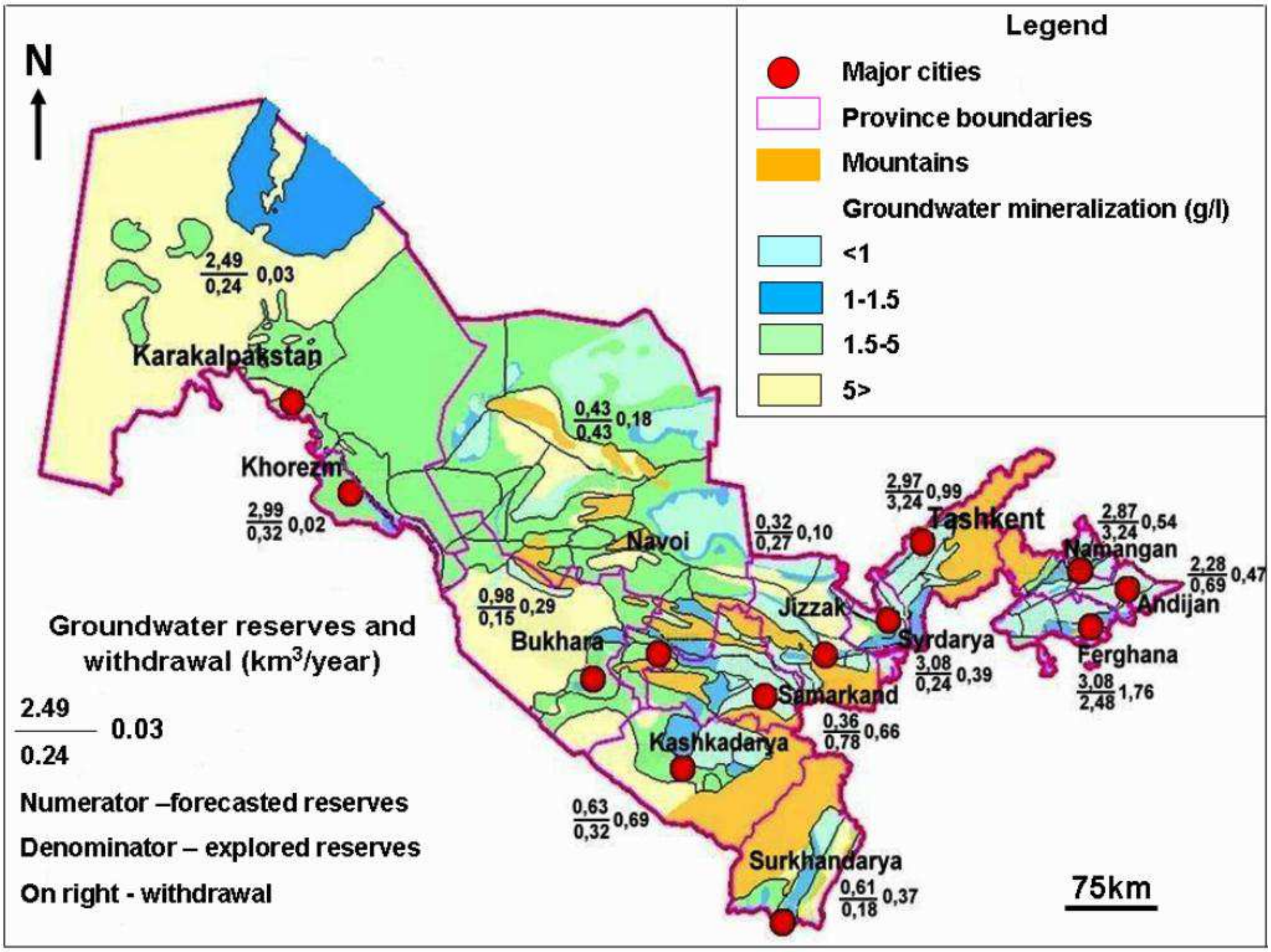

Legend
Major cities
Province boundaries
Mountains
Groundwater mineralization (g/l)
<1
1-1.5
1.5-5
5>
N
Karakalpakstan
2,49 / 0,24 0,03
0,43 / 0,43 0,18
Khorezm
2,99 / 0,32 0,02
Navoi
0,32 / 0,27 0,10
2,97 / 3,24 0,99
Tashkent
2,87 / 3,24 0,54
Namangan
2,28 / 0,69 0,47
Andijan
Jizzak
Syrdarya
3,08 / 0,24 0,39
Ferghana
3,08 / 2,48 1,76
0,98 / 0,15 0,29
Bukhara
Samarkand
0,36 / 0,78 0,66
Kashkadarya
0,63 / 0,32 0,69
Surkhandarya
0,61 / 0,18 0,37
75km
Groundwater reserves and withdrawal (km3/year)
2.49 / 0.24 0.03
Numerator –forecasted reserves
Denominator – explored reserves
On right - withdrawal

Figure 3

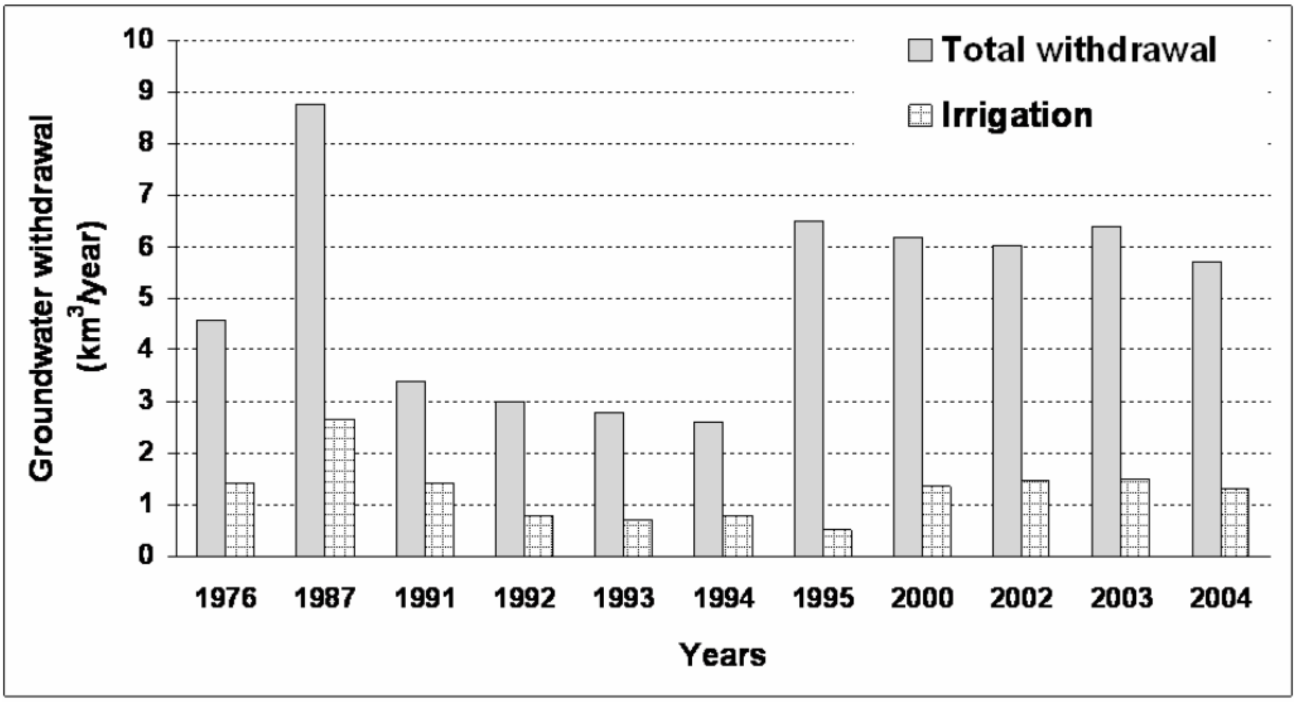
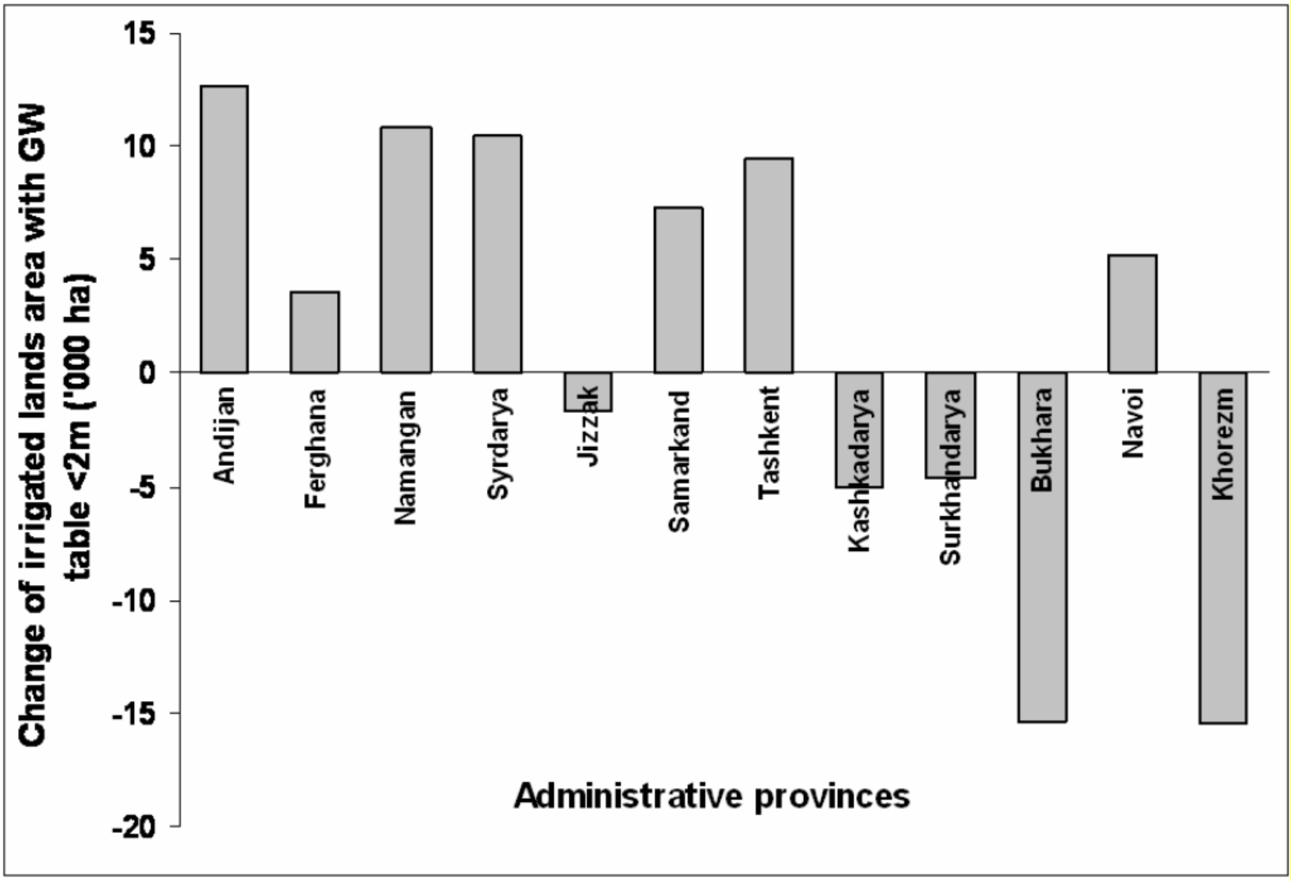
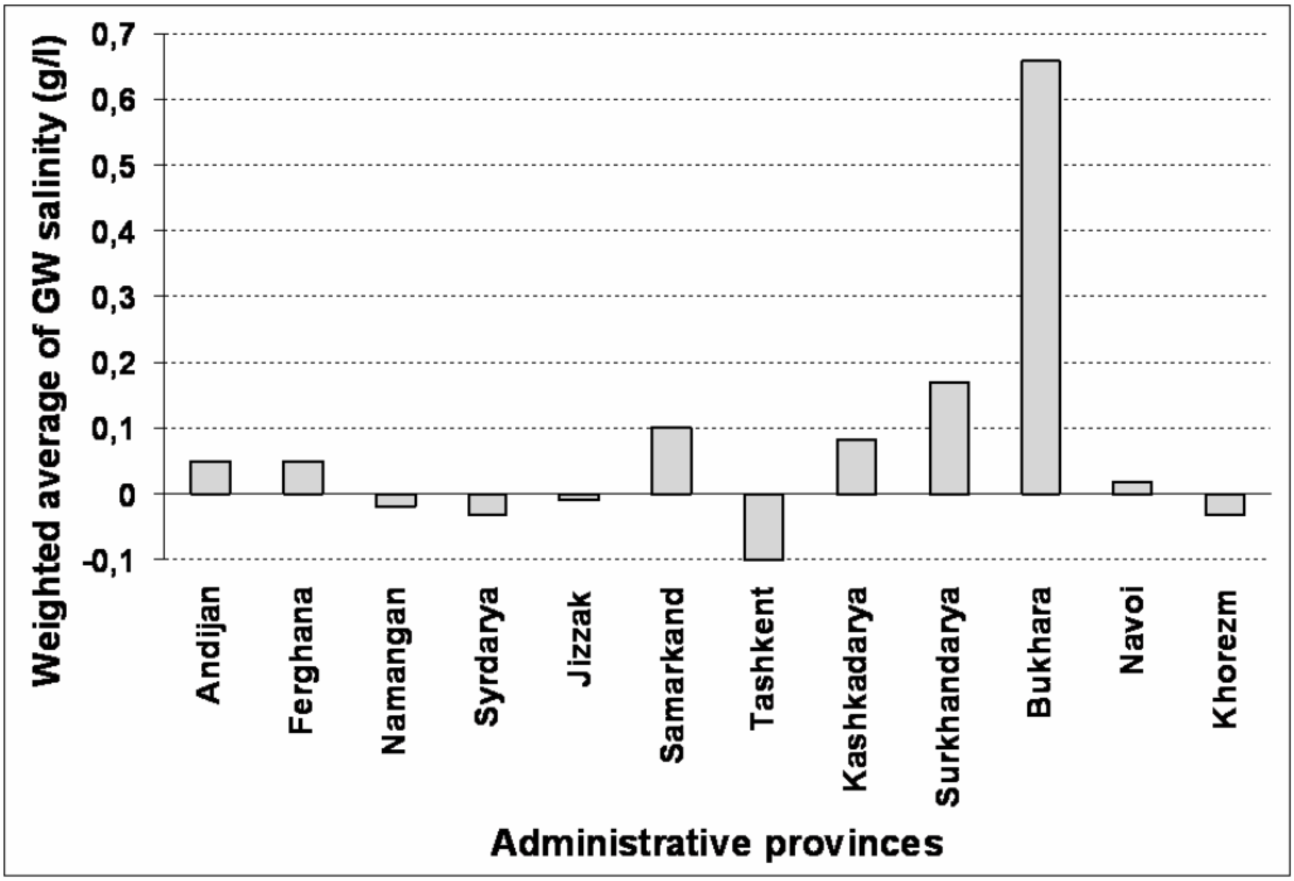

Total withdrawal
Irrigation
Groundwater withdrawal
(km^3/year)
10
9
8
7
6
5
4
3
2
1
0
1976
1987
1991
1992
1993
1994
1995
2000
2002
2003
2004
Years

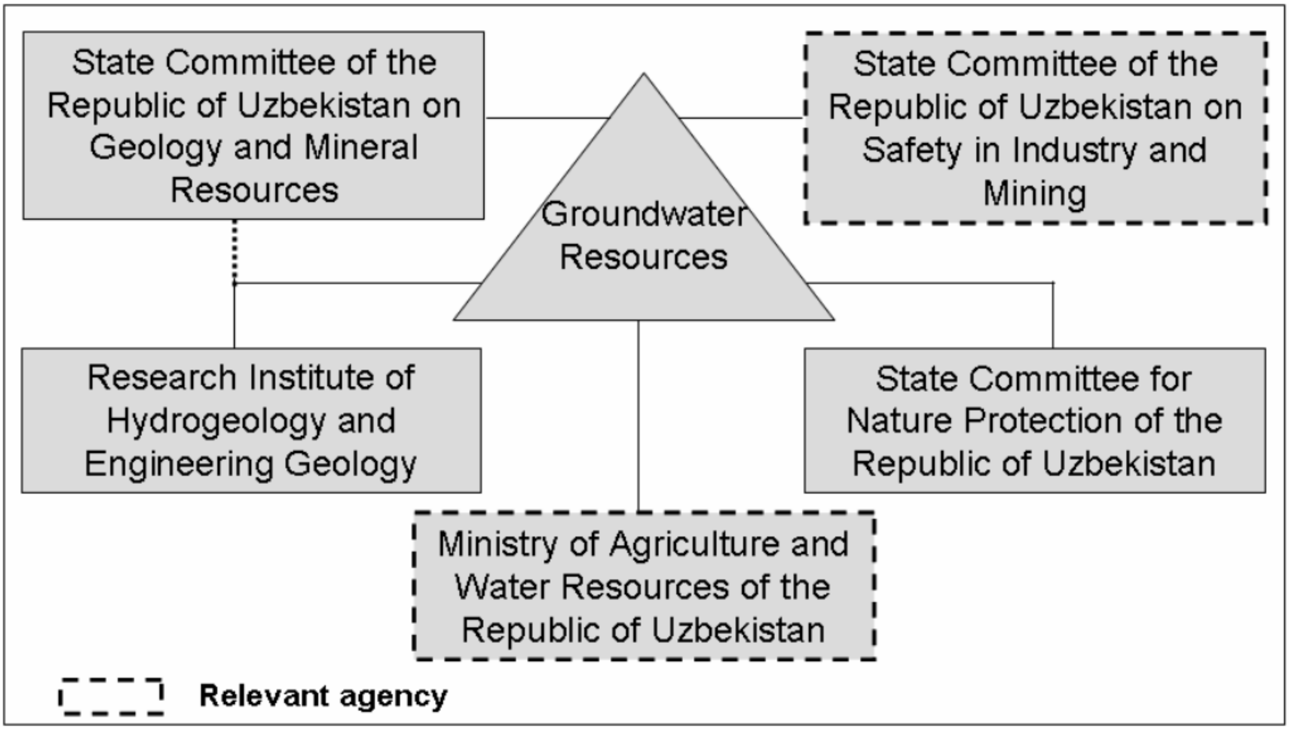
Figure 4


15
10
5
0
-5
-10
-15
-20
Change of irrigated lands area with GW table <2m ('000 ha)
Andijan
Ferghana
Namangan
Syrdarya
Jizzak
Samarkand
Tashkent
Kashkadarya
Surkhandarya
Bukhara
Navoi
Khorezm
Administrative provinces
Figure 5



Weighted average of GW salinity (g/l)
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
-0,1
Andijan
Ferghana
Namangan
Syrdarya
Jizzak
Samarkand
Tashkent
Kashkadarya
Surkhandarya
Bukhara
Navoi
Khorezm
Administrative provinces

Figure 6


State Committee of the Republic of Uzbekistan on Geology and Mineral Resources
State Committee of the Republic of Uzbekistan on Safety in Industry and Mining
Groundwater Resources
Research Institute of Hydrogeology and Engineering Geology
State Committee for Nature Protection of the Republic of Uzbekistan
Ministry of Agriculture and Water Resources of the Republic of Uzbekistan
Relevant agency
Figure 7